Capacitor Leakage Tester

GARY McCLELLAN

Find the leaky capacitors that many testers miss with this easy-to-build leakage checker. You can use it to test cables, appliance insulation, and high-voltage diodes, too!

THOSE NEW DIGITAL CAPACITANCE TESTers make capacitor checking quick and easy, but they have shortcomings. For instance, does the following sound familiar to you?

You are troubleshooting a piece of equipment and replace some defective capacitors with units from the junk box. After hours of additional troubleshooting you discover that those replacement capacitors are no good after all, even though they checked out OK on your tester. That's because they are leaky, and your meter is one of the many that has no leakage-test function. That "missing feature" wound up costing you much time and aggravation.

Or perhaps you just bought some electrolytic capacitors from your dealer, installed them, and watched as the power-supply fuse blew. You later find that the cause was those "new" capacitors; they had become leaky after sitting on your dealer's shelf for the better part of a decade. If you had only known, those capacitors could have been rejuvinated with a shot of current from the proper source. Instead, you have a blown fuse and some fried capacitors.

Assuming it does everything else well, don't trash your capacitance tester just because it doesn't have a leakage-test function. Instead, supplement it with the leakage tester described here. Our tester checks the all-important leakage parameter quickly and easily, weeding out defective capacitors that otherwise test good. It can also brings those elderly "new" capacitors back to life fast.

Besides checking capacitor leakage, the circuit has many other uses on the bench and in the field. For example, use it to test insulation resistances on power tools and appliances. If you find just one tool or appliance with a dangerous fault before it finds you, you'll be very glad you took the time to build and use the circuit. You can also test suspected lossy cables, as well as high-voltage diodes, rectifiers, neon lamps, and other high-voltage components that are often difficult to troubleshoot with conventional DMM's.

And in a pinch the circuit can serve as a regulated power supply. The output voltage spans 3 to 100 volts, which may make the project useful for temporarily powering devices drawing under 10 mA or so.

The circuit is easy to build and is fairly inexpensive, too. A small PC board holds the active components, including two IC's, three transistors, and some diodes, while the remaining switches and a meter mount on the cabinet. Parts costs will run about $45.00 or so, depending upon how well you can shop or scrounge for them. The PC board, and a few harder-to-get components, are available from the source mentioned in the Parts List.

How it works

The project is basically a regulated DC power supply with a metering circuit to indicate leakage current. Refer to the block diagram in Fig. 1 for details.

There are several noteworthy features of which you should be aware. First, a novel power supply design permits the unit to charge test capacitors with a constant current source. That means they charge faster, saving you testing time, particularly for large capacitors. In addition, an analog meter is used for leakage-current measurements. That allows you to see the charging action and monitor the leakage current easier than with a digital meter. And analog meters are generally much cheaper than digital ones!

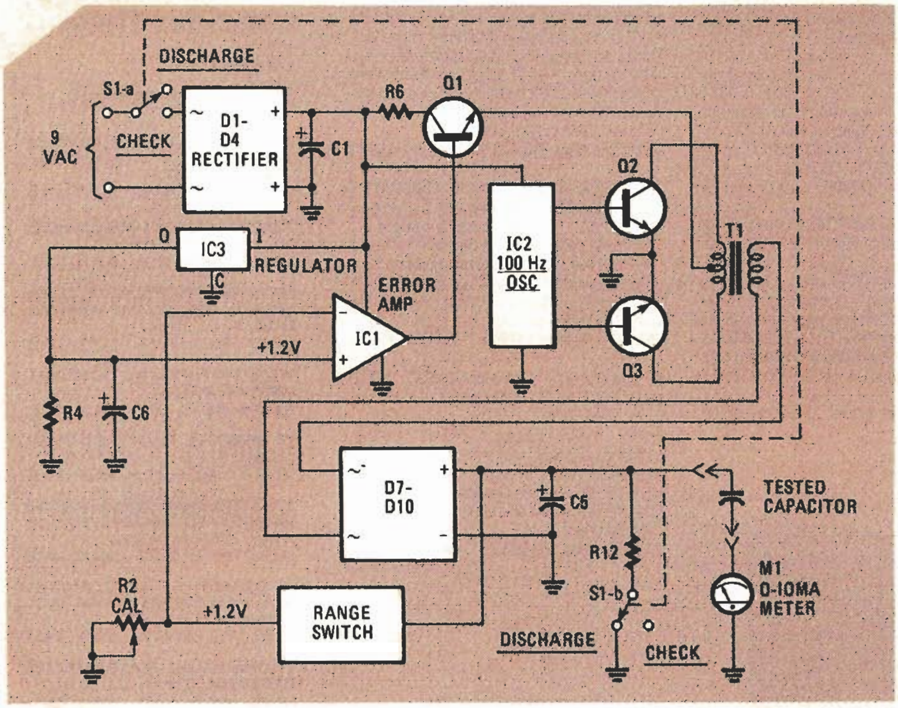


FIG. 1—THIS BLOCK DIAGRAM makes it easier to see how our little leakage tester works.

In operation, 9 volts from a plug-in transformer passes through switch S1-a and is rectified by diodes D1-D4. If field operation is required, it is possible to substitute a 12-volt battery for the plug-in transformer. The switch is a DPST unit that selects either power ON or capacitor DISCHARGE. From the rectifier, the output is filtered by capacitor C1, and is then used to power the rest of the circuitry.

Part of the power output is fed to IC3, a positive voltage regulator, which is used to provide a stable 1.2 volt reference for IC1. That ensures that the output voltage will be stable regardless of how much voltage is used to power the project.

Op-amp IC1 serves as an error amplifier. Its job is to ensure that the voltage applied to the capacitor under test is regulated. It does that by "sampling" the voltage at capacitor C5 through the range switch. The range switch is nothing more than a resistive attenuator network reducing the output voltage to about 1.2. The op-amp simply adjusts the power supply until its minus (inverting) input equals 1.2 volts. That regulates the output voltage.

Transistor Q1 serves as a control element for the rest of the power supply. Since the op-amp can't provide enough current to do the job directly, a Darlington power-transistor is used here to boost the current. Resistor R6 limits current to the rest of the circuitry, preventing transformer damage.

Moving on, the DC output from capacitor C1 powers IC2, which is a CMOS programmable one-shot wired as a 100-Hz oscillator with complimentary outputs. The outputs from IC2 alternately drive transistors Q2 and Q3, which serve as switches. They alternately switch each side of the transformer T1 winding to ground, generating current pulses.

Transformer T1 performs two purposes. First it steps up the current pulses so that they can be rectified. Second, under heavy load (as from a charging capacitor) it saturates, limiting the output current to the capacitor to about 20 mA. That forms a constant-current type power supply, which is especially effective in charging test capacitors.

The output from transformer T1 is rectified by diodes D7 to D10 and filtered by capacitor C5. From that point the DC output feeds back to the range switch, which is used along with op-amp IC1 to set the output voltage. The DC output also drives the test capacitor, which is connected to the project through binding posts.

Meter M1 is included in the minus leg of the test capacitor for monitoring the charging and discharging currents. Note that resistor R12 and switch S1-b are included to discharge the test capacitor when the power is turned off.

That takes care of the basics. Now turn to the schematic diagram of Fig. 2 for some details on the finer points of the circuitry. You should be able to identify the parts we just discussed on the schematic diagram.

First let's look at the error amplifier, IC1. Basically, that amplifier is set up as an inverting, gain-of-100 unit. Resistors R3 and R5 set the gain value. Although that practice is rather unusual for a power supply (R5 is usually not included), the reduced gain is necessary to permit stable operation when testing very large capacitors (say 15,000 μF). Diode D5 serves as

PARTS LIST

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

R1—8200 ohms
R2—5000 ohms, potentiometer, PC mount (Circuit Specialists 32JQ305 or equal)
R3—100,000 ohms
R4—270 ohms
R5—10 megohms
R6—10 ohms, 2 watts
R7—2200 ohms
R8—1 megohm
R9, R10—10,000 ohms
R11—18,200 ohms, ⅛-watt, 1%, metal-film
R12—100 ohms, 2 watts
R13—10 ohms
R14—68 ohms
R15—30,100 ohms, ⅛-watt, 1%, metal film
R16—40,200 ohms, ⅛-watt, 1%, metal film
R17—49,900 ohms, ⅛-watt, 1%, metal film
R18, R19—100,000 ohms, ⅛-watt, 1%, metal film
R20—150,000 ohms, ⅛-watt, 1%, metal film
R21, R22—249,000 ohms, ⅛-watt, 1%, metal film

Capacitors

C1—1000 μF, 16 volts, axial leads, electrolytic
C2, C6—0.1 μF, 50 volts, polyester
C3—0.001 μF, 50 volts, polyester
C4—100 μF, 16 volts, radial leads, electrolytic
C5—2μF, 450 volts, axial leads, electrolytic

Semiconductors

IC1—LF356N op-amp (National)
IC2—4047 CMOS one-shot (RCA)
IC3—LM317LE adjustable voltage regulator (National)
Q1–Q3—TIP120 NPN Darlington (Radio Shack 276-2068 or equivalent)
D1–D4, D7–D12—1N4004 rectifier diodes, 400 PIV, 1 amp
D5—1N4148 silicon signal diode
D6—not used

Other components

M1—1-mA DC meter
S1—DPST miniature toggle switch
S2—12-position, 1-pole rotary switch (Radio Shack 275-1385 or equivalent)
S3—SPST normally-closed pushbutton switch
T1—117 volts/12.6 volts, 1.2 amps, center tapped (see text)
T2—117-volts/9 volts, 300 mA, wall-plug transformer

Miscellaneous: PC board, plastic case (Radio Shack 270-627 or equivalent), knob, hookup wire, 4-40 hardware, press-on decals, etc.

An etched and drilled PC board plus all 1% resistors listed above and voltage reference IC3 are available for $17.50 postpaid from: Mendakota Products, PO Box 2296, 1001 W. Imperial Hwy., La Habra, CA 90631. When ordering request part LC1 and enclose a check or money order for the appropriate amount. California residents include 6% sales tax. Sorry no COD's or credit card purchases.

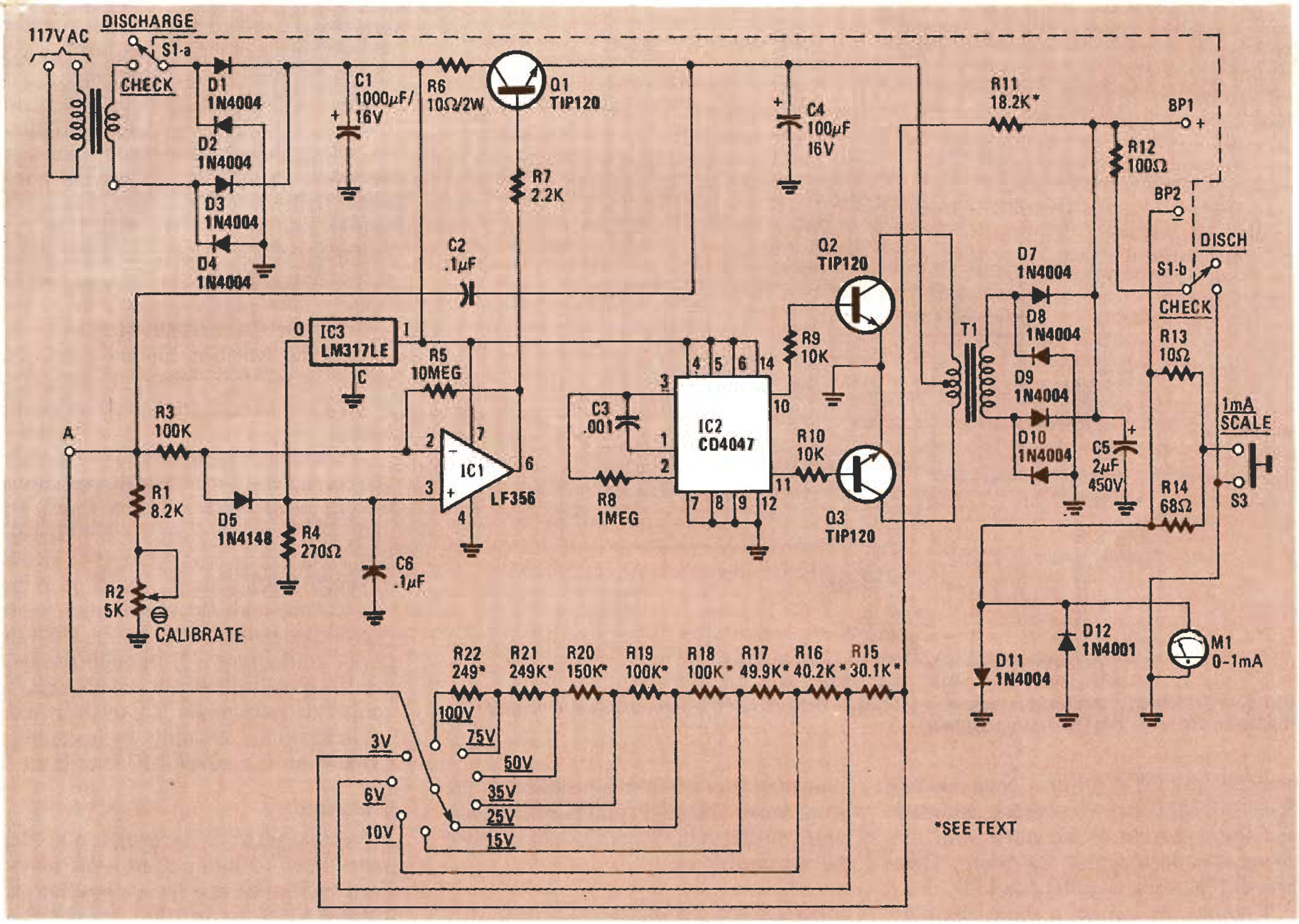


FIG. 2—THE CIRCUIT of our leakage tester is seen in greater detail in this schematic diagram.

overload protection, preventing excessive voltage from RANGE switch S2 from damaging IC1. That condition might occur if you were to switch rapidly from 100 volts to 3 volts. And finally, capacitor C2 provides some AC feedback, insuring stable operation over a wide range of capacitor loads.

Moving on, let's look at IC2. Resistor R8 and capacitor C3 set the operating frequency to 100 Hz. That frequency, while not critical, was chosen to prevent "beats" with the 60 Hz power line and permits increased output from transformer T1.

And finally, let's look at the metering circuit. Diodes D11 and D12 are included to protect the meter from harmful overloads, especially when a large capacitor is being discharged. A 10-mA current shunt consisting of resistors R13 and R14 is also included for measuring currents in non capacitor-testing applications. That shunt can be selected via pushbutton switch S3.

So much for the theory. Now why not get started building your project?

Construction

We'll describe assembly shortly, but first a few words about obtaining the parts. The circuit uses no exotic parts, and most should be available from Circuit Specialists (PO Box 3047, Scottsdale, AZ 85257), Radio-Shack, or your favorite electronics parts supplier. If you order the PC board from the supplier listed in the Parts List, you will also get the harder-to-find 1% resistors and voltage regulator. If you have trouble locating some items, try the suppliers that advertise in the back pages of this magazine. If after all of that you are still having difficulty locating a particular part, mail two first class stamps and a self addressed, stamped envelope to the PC-board supplier mentioned in the Parts List for assistance.

A word about T1: The board was designed to accommodate a transformer that was available from a parts supplier that had nationwide outlets. Since then, however, the transformer has been discontinued by that supplier. Fortunately, any 12.6-volt, 1.2-amp center-tapped transformer will do fine, although it likely will have to be mounted off the board.

Substitutions for other parts are also acceptable, providing they are equal or better in quality than the parts specified.

For the sake of both convenience and safety, you should use a PC board. If desired, you can buy one form the supplier listed in the Parts List, or else make one from the artwork provided in the PC-service section, found elsewhere in this magazine.

Once you have assembled the parts and obtained or made the PC board, you can start construction. Refer to Fig. 3 for details as we discuss assembly.

Start by placing the board in front of you with the foil side down. Then install a 100 µF capacitor at C4 along the top left-hand corner.

Continue by installing a wire jumper below C4. If you have been able to obtain a transformer that will fit on the board (see the preceding discussion), install it next. Otherwise, that transformer will have to be mounted off-the-board; in that event the wiring between the transformer and the board will be the among the last steps in the construction process.

Next, install 1N4004 diodes at D7 to D10 as shown. After that, install a 2-µF capacitor at C5, and a 100-ohm resistor at R12.

Finish up the top half of the board by installing a 18.2K (usually marked 1822F) resistor at R11, then a 10-ohm unit at R13. Also install a 68-ohm resistor at R14 and two 1N4004 diodes at D11 and D12.

Move back to the left edge of the board and continue assembly. Install TIP120

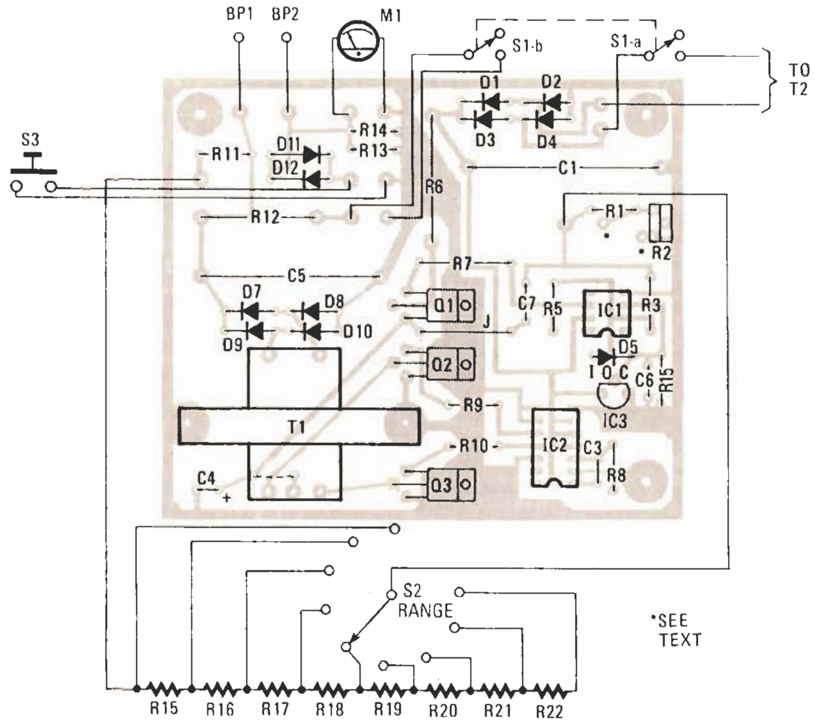


FIG. 3—FOR SAFETY, this project requires a PC board. Here we see the parts-placement diagram for the board shown in our PC Service section.

transistors at Q3 to Q1 first. Note that the leads are bent back 90 degrees, allowing the transistors to be mounted with the metal tabs flush against the board. Then install 10K resistors at R10 and R9.

Continue by cutting a short length of insulated wire and installing it between Q2 and Q1. Position the wire so it doesn't touch the transistors. Then install a 2.2K resistor at R7 and a 10-ohm unit at R6.

Install a 14-pin IC socket at IC2, then an 8-pin unit at IC1. Do not install those IC's until later. Next, install a 0.001-µF capacitor at C3 and a 1-megohm resistor at R8. After that, install a 270-ohm resistor at R4, a 0.1-µF capacitor at C6, and an LM317LE at IC3.

Finish the board by installing a 1N4148 diode at D5 and a 0.1-µF capacitor at C2. Then install a 10-megohm resistor at R5 and a 100K unit at R3. Next install a 5K potentiometer at R2. If the single-turn unit specified in the parts list is used, position the potentiometer with the adjustment screw next to the board edge. The additional pads have been provided around R2 so that a ¼-inch, multi-turn potentiometer (Radio-Shack 271-343 or equivalent) can be used if desired. After R2 is in place, install an 8.2K resistor at R1 and the 1000-µF capacitor at C1. Complete your work by installing 1N4004 diodes at D1 to D4.

Check your work carefully, especially diode and capacitor polarities before continuing. Fix any mistakes now, because they will be harder to correct later.

Refer to Fig. 4 to see the construction details for S2 and its associated resistors. Note that it is easier to wire the switch now than later when it is installed on the front panel. You might find assembly easier if you clamp the switch's shaft in a vise before starting work.

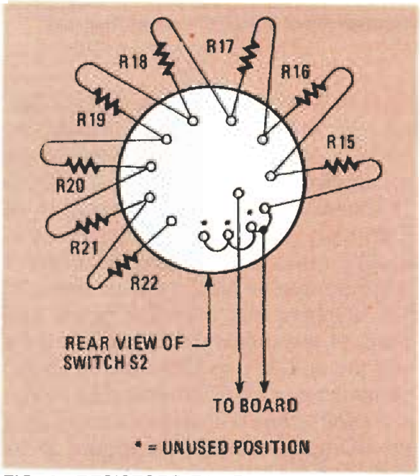


FIG. 4—RESISTORS R15–R22 are mounted on the rear of S2 as shown. Be sure to tie any unused switch positions to R15.

Wire the resistors on the back of switch S2 as shown. Note that most 1% resistors are marked in code; for instance, R15 would typically appear as "3012F."

When the resistors are wired in place, use a piece of bare wire to connect any unused terminals to R15 as shown. That prevents dangerously high voltages from appearing at the output terminals if S2 is set to an unused position. Finish the switch wiring by attaching 6-inch leads.

Set the board and switch aside for a moment and prepare the chassis. Note that the PC-board (and T1 if required) mounts inside of the chassis, while everything else goes on the front panel.

Place the board in the bottom of the box, against the top side. Drill three mounting holes for the board, plus a 1/4 inch hole in the top side for the power cord. Drill another 1/4 inch hole in the bottom side for access to pot R2. If T1 is mounted off-the-board, drill mounting holes as appropriate for the unit you are using.

Complete the mechanical work by installing the switches, binding posts, and meter on the front panel. Connect the switches to the appropriate points on the board.

When done, check your work carefully and correct any errors. Install the board in the box using 4-40 × 1-inch screws and nuts. Use a nut as a spacer between the board and box on each screw. If T1 is to be mounted off-the-board, install it in the chassis and wire the transformer to the appropriate points on the board. Feed the power cord (from T2) through the hole that has been drilled for it and connect the cord to the appropriate pads on the board.

Finish up the assembly by installing a CD4047 at IC2 and an LF356 at IC1.

Checkout

Now we get to try the project out. Plug transformer T2 into a nearby AC outlet. Then set S1 to the DISCHARGE position and likewise set S2 to the 100-VOLT position. Set your DMM to its 200-volt DC range and connect it to the binding posts (BP1 and BP2).

Flip S1 to the CHECK position and the DMM will read somewhere between 85 and 120 volts. If so, the project works and you can go to the calibration.

If you are having problems, disconnect the power and discharge capacitor C5 with a jumper wire. Then check over your wiring for errors. Remember—when troubleshooting, always discharge C5 after turning the power off; that can prevent a dangerous shock.

Calibration

Calibration is easy to perform. First set S1 to DISCHARGE, and then set S2 to the 100-VOLT range. Then set your DMM to its 200-volt DC range and connect it across the binding posts. Flip S1 to the CHECK position and adjust R2 until the DMM reads 100 volts.

To be on the safe side, you should check the output voltage for each position of S2; it should be within 2% of the panel value. If not, the 1% resistor associated with that position should be checked.

Using the project

Danger, high voltage! This project can provide a dangerous electrical shock if misused. Avoid a harmful shock by using

continued on page 94

LEAKAGE TESTER

continued from page 58

it only for the test purposes intended, and discharge tested capacitors with a screwdriver when finished. In addition, use of this project is recommended by technically qualified personnel only.

Now that that's out of the way, the unit is a cinch to use. Let's look at some typical applications for the project:

Testing capacitors is easy. If applicable, remove the suspect unit from the circuit first, as any external leakage can cause a good capacitor to test leaky. Set S1 to the DISCHARGE position. Then set S2 to the working voltage of the capacitor. If the voltage is greater than the project can provide, use the 100-volt position.

Then use insulated clips to connect the capacitor to the project.

Flip S1 to the CHECK position. The meter needle will "kick" upscale and drop to zero for a good capacitor. If desired, press S3 for more sensitivity; that will give you 0-1 mA readings instead of the nominal 0-10 mA readings.

Note that the meter needle may kick upscale many times before settling down. That indicates that the capacitor has excessive leakage at the test voltage and requires "forming." That is a common situation with capacitors that are used at a voltage far lower than the working voltage, like, say, a 50-volt part in a 12 volt circuit. That is not a fault of the project. However, if the meter doesn't stop kicking after several minutes, the capacitor isn't forming and should be replaced.

When the testing is finished, return S1 to the DISCHARGE position. The meter will read negative, indicating discharge. When the needle returns to zero, remove the capacitor.

So how much leakage should a good capacitor have? There is no simple answer, as it depends upon the capacitor type and circuit requirements. However, here are a few rules of thumb you can use.

Paper, mica, polyester, and tantalum capacitors should display no leakage. Electrolytic capacitors up to 50 μF should show less than 25 μA of leakage current. Electrolytic capacitors from 51 μF to 500 μF should show less than 50 μA leakage. Electrolytic capacitors from 501 μF to 1,000 μF should show less than 100 μA leakage. Electrolytic capacitors from 1,001 μF to 20,000 μF should show less than 500 μA leakage.

Another use for the project is forming new capacitors. Understand that electrolytic capacitors chemically deteriorate when they sit unused. The capacitor's electrolytic film, essential to capacitor operation, deteriorates, causing very high leakage currents. If you apply a voltage to the capacitor, the film can reform. But if that voltage is too high, that is, close to the device's rating, the film may not be able to form fast enough. So the capacitor will consume power, get hot, and possibly explode. Here's how to solve that problem:

Set S1 to the DISCHARGE position and S2 to the 3-VOLT position. Then use insulated clips to connect the capacitor.

Flip S1 to the CHECK position and note the meter reading. When the meter reads minimum current, change S2 to the 6-VOLT position. Continue increasing the voltage until the working voltage is reached. Discard any capacitor that takes over five minutes to form, or still has high leakage when checked at its working voltage.

Appliance safety is easy to check. Here's how: Set S1 to DISCHARGE and S2 to 100-VOLTS. Assuming the device to be tested uses a three-wire power cord, use an insulated clip lead to connect the "hot" side of the power cord to the positive binding post. After that, connect the ground lead of the power cord to the negative binding post. The return or common side of the power cord is unconnected. If the appliance does not use a three-wire power cord, connect the negative binding post to any exposed case screws or other metal surfaces on the unit to be tested.

To test, flip S1 to the CHECK position. Press S3 for more meter sensitivity. The meter must read under 50 μA. For higher readings repairs are indicated.

Cables may be easily checked for leakage problems. Simply perform the checks the same way you did for appliance leakage. Remember to always connect the positive binding post to the center conductor and the negative binding post to the shield; that prevents a shock hazard.

If you need more sensitivity when performing leakage testing, try using your DMM if it has a 200-μA DC range. Simply set it to the 200-μA range and connect it in series with the positive binding post and the cable under test. That technique works great for other applications, except testing high-value capacitors. With those, when you switch to DISCHARGE, the current from the capacitor passes through the DMM, overloading it.

Another use for the project is quickly checking those special high voltage diodes used in TV sets and microwave ovens. Usually a DMM can't check those components because it can't supply enough voltage to turn on the device.

To test the diode, set S1 to DISCHARGE and S2 to 100-VOLTS. Then remove the diode from the circuit and connect it to the project's binding posts. Flip S1 to CHECK and note the reading. Then return S1 to DISCHARGE and reverse the diode. Flip S1 to CHECK again and note the reading. With most silicon diodes we expect a full-scale reading when the diode is connected one way and zero when it is reversed. With selinium diodes, the difference should be at least 100 to 1. **R-E**

PC SERVICE

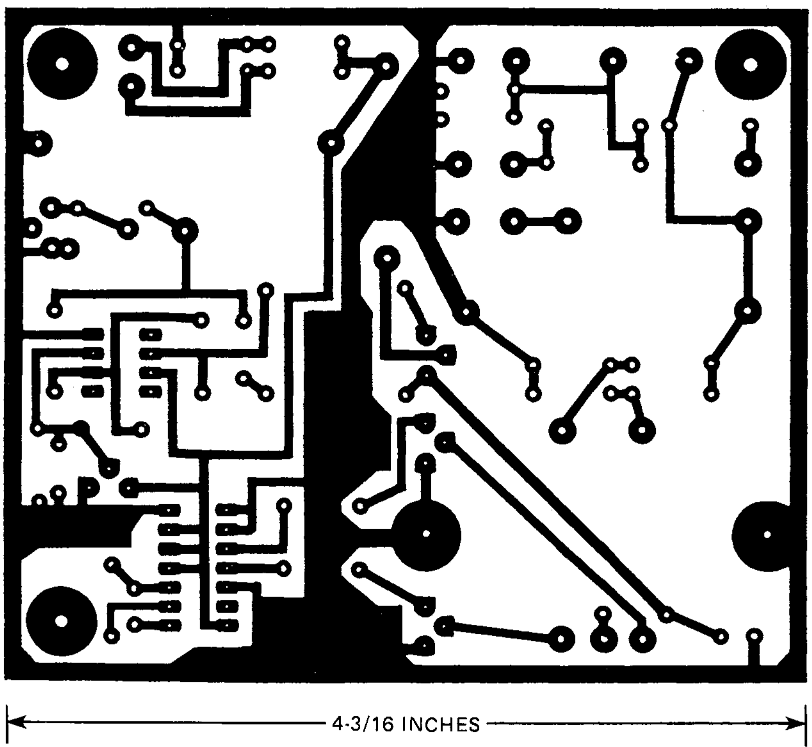
One of the most difficult tasks in building any construction project featured in **Radio-Electronics** is making the PC board using just the foil pattern provided with the article. Well, we're doing something about it.

We've moved all the foil patterns to this new section where they're printed by themselves, full sized, with nothing on the back side of the page. What that means for you is that the printed page can be used directly to produce PC boards!

Note: The patterns provided can be used directly only for *direct positive photoresist methods.*

In order to produce a board directly from the magazine page, remove the page and carefully inspect it under a strong light and/or on a light table. Look for breaks in the traces, bridges between traces, and in general, all the kinds of things you look for in the final etched board. You can clean up the published artwork the same way you clean up you own artwork. Drafting tape and graphic aids can fix incomplete traces and doughnuts, and you can use a hobby knife to get rid of bridges and dirt.

An optional step, once you're satisfied that the artwork is clean, is to take a little bit of mineral oil and carefully wipe it across the back of the artwork. That helps make the paper transluscent. Don't get any on the front side of the paper (the side with the pattern) because you'll contaminate the sensitized surface of the copper blank. After the oil has "dried" a



BUILD OUR LITTLE LEAKAGE CHECKER and find the leaky capacitors that have been eluding your capacitor tester. The pattern for the PC board is shown here; the story begins on page 51.