In-Circuit Capacitor Tester

MARVIN SMITH

I've spent a lot of time finding bad electrolytic capacitors in the TVs, VCRs, and camcorders I repaired. A few were shorted. Most had developed high *E*quivalent *S*eries *R*esistance (ESR). That's an internal resistance in series with the capacitance. Result: The capacitor has high impedance and does not function properly. A regular capacitance meter isn't helpful because it measures only capacitance, not ESR. If you did want to measure the capacitance, the meter indication could be affected by components tied to the capacitor; to get an accurate measurement, you sometimes have to use your soldering iron to lift (isolate) the capacitor. Then if the capacitance is correct, you have to re-solder it back on the board. This is a most tedious task. Some capacitance meters can't even measure above 20 µF, so you'd be stuck if you had to test a large-valued capacitor, like 470 µF. Build the *In-Circuit Capacitor Tester*, and you'll speed up your repairs by being able to test capacitors of 1 µF or above right on the circuit board.

Improving On An Old Idea. In-circuit capacitor testers are nothing new. You'll find ads for in-circuit capacitor testers—sometimes called "ESR meters"—in electronic hobby and servicing magazines; I'm sure they do a good job. However, there are advantages to the tester described here. Cost, for one—the parts cost about $60, and most are available from RadioShack. Some of the advertised meters can't detect shorted capacitors—this one can. Some can be damaged if you don't discharge the capacitor before connecting the probes. Don't worry with this tester—back-to-back diodes across the input discharge the capacitor for you and protect the tester. To prove this feature, I connected the probes across a 470-µF capacitor charged to 150 volts with no damage; I drew quite a spark, but the meter still works! A word of caution: Even though the meter won't be damaged by charged capacitors, **DO NOT** test capacitors in units with power on—you could damage the unit you're repairing (that would be a bad move).

This technician's gadget lets you test capacitors right on the circuit board and speed up your repairs.

When Good Electrolytics Go Bad. If you looked inside an aluminum electrolytic capacitor, you would see two foil strips and a paper insulator strip rolled into a cylindrical element. The paper insulator is soaked with a critical part of the capacitor—the moist electrolyte. Figure 1 shows an equivalent circuit of a capacitor. The ESR, which combines the resistance of the leads, the foils, and the electrolyte, is shown as a resistor in series with the capacitance. If the electrolyte dries out, the ESR increases and the capacitance decreases. The electrolyte can dry out because of high temperatures caused by high ripple currents, or a bad end seal may let it leak out. Loss of electrolyte results in an *open* capacitor, the most common failure. Less often, the capacitor may develop a short between the foils. The CONDITION meter will indicate 0 for open capacitors, and the SHORT LED will light for shorted ones. Some capacitors fail simply because they have reached the end of their estimated life. One manufacturer guarantees a certain line of their surface-mount capacitors for 2000 hours—that's only three months!

How The Tester Works. The tester generates a 100-mV, 100-kHz square wave with an impedance of 22 ohms across its probes. The tester doesn't measure capacitance—it displays on the CONDITION meter how well the capacitor bypasses this 100-kHz signal. Note that both the ESR *and* the capacitance must be good for the capacitor to test well. So, in effect, the tester is verifying the capacitance.

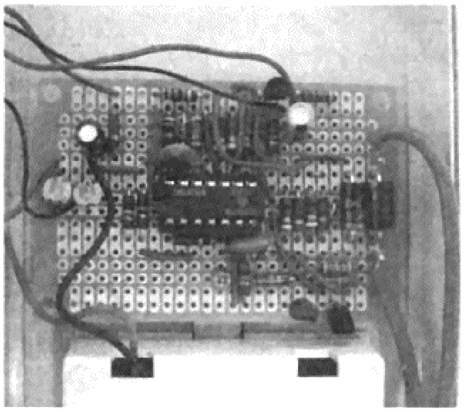
The schematic of the tester is shown in Fig. 2. The tester comprises a 14-pin quad op-amp, three transistors, three diodes, 21 resistors, six capacitors, a potentiometer, a 0–100 microammeter, a 9-volt battery, an LED, and an on/off switch.

Op-amps like to be powered by equal plus and

Fig. 1. Placing a resistor and capacitor in series demonstrates the principle of Equivalent Series Resistance. ESR is often the cause of faulty electrolytic capacitors.

minus voltages. A standard 9-volt battery powers the tester; however, we want ± 4.5 volts referenced to ground. Op-amp IC1-a generates the ± 4.5 volts for the tester. Resistors R1 and R2 are connected in series across the battery, and the midpoint is connected to pin 3 of IC1-a, the non-inverting input of IC1-a. The output at pin 1 of IC1-a is tied to the inverting input at pin 2 of IC1-a, and *connected to ground*. This does not short out the op-amp or cause high currents.

Op-amp IC1-a is connected in the negative feedback configuration, because the output is tied to the inverting input. Normally, an op-amp will adjust its output to make its input voltages equal. However, here the output is tied to ground. Therefore, the op-amp does the only thing it can—it regulates the voltage at its *power supply pins* to place the midpoint of R1 and R2 at 0 volts. Since R1=R2, half of the battery voltage is above ground and half below; thus, we have our ± 4.5 volts. Capacitors C1 and C2 suppress oscillations and provide bypassing for the ± 4.5 volts. This circuit configuration is a simple way to *split* a battery into equal plus and minus voltages, provided the difference in the plus and minus currents drawn by the circuitry doesn't exceed the output current capability of the op-amp.



This extreme close-up shows the component placement inside the In-Circuit Capacitor Tester. Following along with the schematic, readers can even use a breadboard to construct this unit.

Op-amp IC1-b is connected as an astable-multivibrator and generates a key signal—an 8-volt peak-to-peak 100-kHz squarewave. Resistor R6 couples this to the base of Q1, the driver for Q2. The waveform at Q2-C, a 0 to +4.5-volt 100-kHz squarewave, is connected to bridge resistors R9 and R11. The voltage at the junction of R9 and R10, and at the junction of R11 and R12 is a 0 to +100-mV squarewave with an average DC value of +50 millivolts. As you'll see later, this DC offset allows us to detect shorted capacitors.

Op-amp IC1-c is a differential amplifier with its input resistors, R13 and R15, connected to the 22-ohm bridge resistors. Its gain amplifies the millivolt-level 100-kHz bridge signal to drive the Condition meter and the Short LED. The non-inverting input always *sees* this reference signal. The inverting input is connected to the junction of R9 and R10. The probes are connected across R10. When the probes are open, the bridge is balanced; the inputs to the differential amplifier are equal; and the Condition meter indicates 0. When you connect the probes across a good capacitor, it kills the AC waveform at the inverting input, but leaves the average DC value of 50 mV. The bridge is now unbalanced according to AC standards; a 3.6-volt peak-to-peak waveform appears at pin 8 of IC1-c, and the meter indicates 100. If the capacitor is shorted, the bridge is not only unbalanced AC-wise, it is now unbalanced according to DC standards—the inverting input now sees 0 volts instead of the average level of 50 mV. The 50-mV average reference signal at the non-inverting input shifts the 3.6-volt peak-to-peak waveform at pin 8 of IC1-c up to an average of +2 volts; this turns on Q3 and lights the Short LED. IC1-d and D3 rectify the 100 kHz signal from IC1-c to supply the DC current for the Condition meter.

Construction. You can choose your own enclosure, but I recommend the 4- × 6-inch hand-held case and the circuit board mentioned in the parts list. The case has a compartment for the 9-volt battery, and the board has printed circuit pads for soldering the parts. Room is at a premium, but all parts will fit into the case if you carefully position the parts on the cover and on the board. Refer to the internal photo of the tester as a guide.

Refer to the photograph to see

PARTS LIST FOR THE IN-CIRCUIT CAPACITOR TESTER

SEMICONDUCTORS

IC1—TL084ACN quad op-amp, integrated circuit
Q1, Q3—2N3904 NPN transistor
Q2—2N3906 PNP transistor
D1, D2—1N5404 3-amp silicon rectifier diode
D3—1N914 general-purpose silicon diode
LED1—Light-emitting diode, 2 mA low current, red

RESISTORS

(All resistors are ¼-watt, 5% units.)
R1, R2, R3, R4—10,000-ohm
R5—1500-ohm
R6—68,000-ohm
R7, R14, R16, R17—47,000-ohm
R8—12,000-ohm
R9, R11, R13, R15—1000-ohm
R10, R12—22-ohm
R18—47-ohm
R19—7500-ohm
R20—15,000-ohm
R21—750-ohm
R22—5000-ohm panel-mount linear-taper potentiometer (Calrad 25-301 or similar)

CAPACITORS

C1, C2—10-µF, 25-WVDC, electrolytic
C3—0.001-µF, ceramic disc
C4—0.1-µF, ceramic disc
C5, C6—1-µF, 50-WVDC, electrolytic

ADDITIONAL PARTS AND MATERIALS

Plastic case, 4-× 6-inch (RadioShack 270-213 or Pac Tec K-HP-9VB or similar)
PC circuit board (RadioShack 276-150 or similar)
M1—0 to 100 microammeter (Calrad 60-166 or similar)
S1—Miniature SPST switch (GC 35-00 or similar)
9-volt battery
Knob, ¼-inch bushing

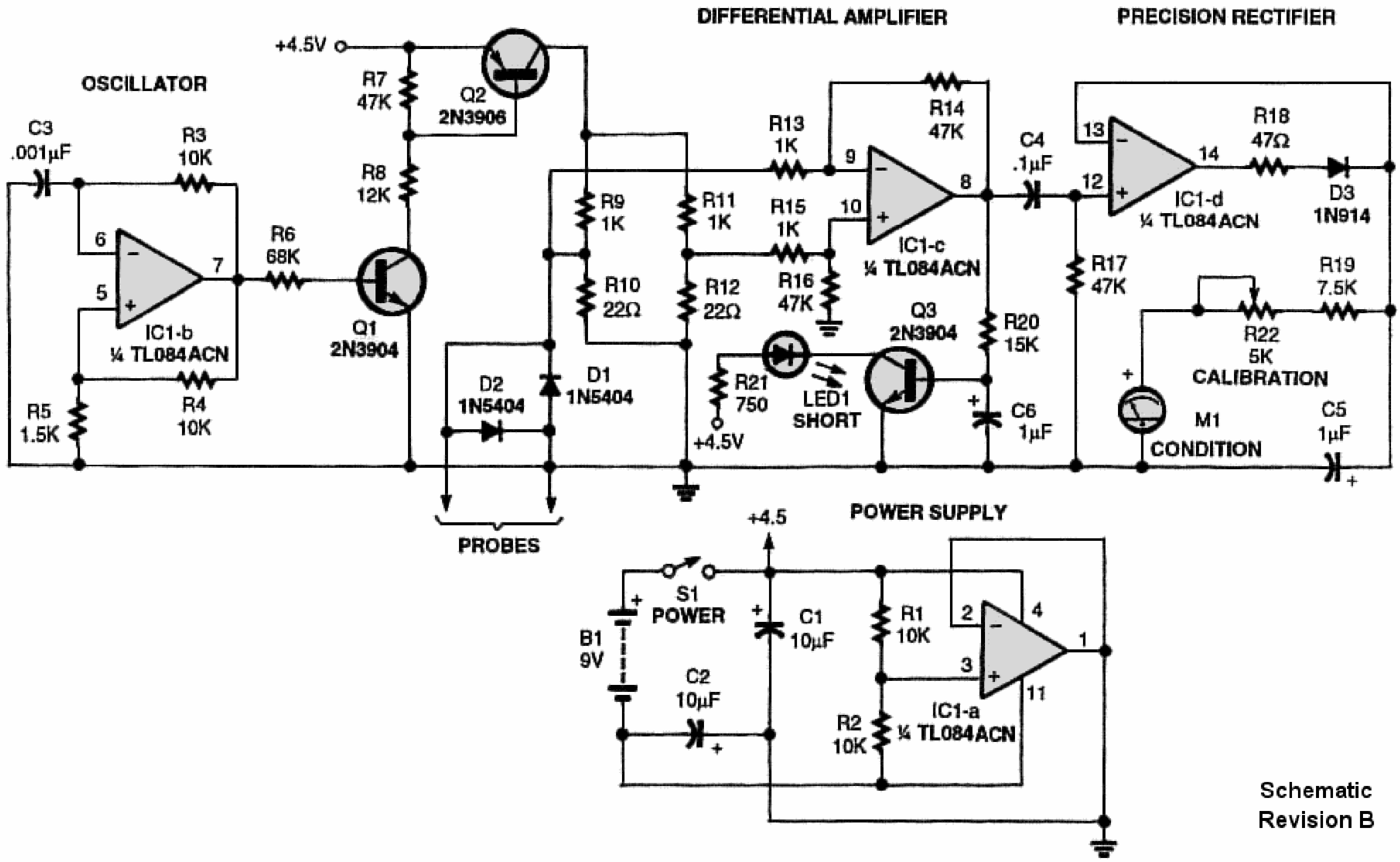
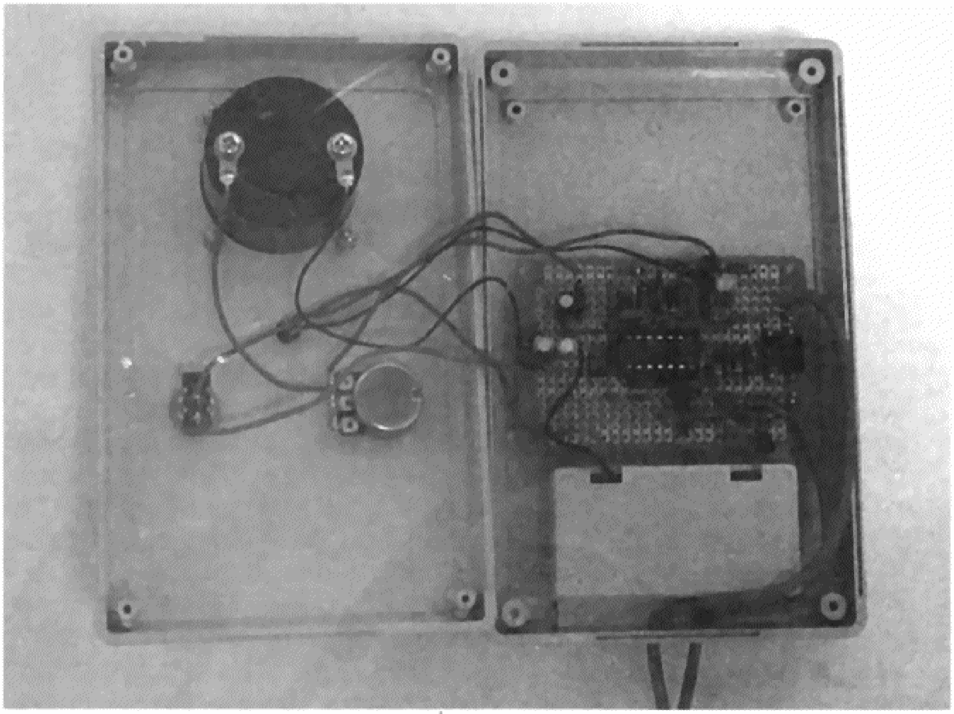


Fig. 2. The In-Circuit Capacitor Tester is simple in design and highly effective. The schematic above shows the complete circuit that is centered around a quad op-amp.

how the completed unit is assembled. The first thing to do is temporarily mount the board to the bottom of the case with a screw. You will then remove the board to mount the components. There is a pre-drilled post molded in the bottom of the case next to the battery compartment. Find a miniature screw that will self-thread the hole in the post. Center the board and position it no more than ⅛-inch from the battery compartment. This will leave room for the meter body. Mark the board hole closest to the post hole and drill out the board hole to clear the screw body. Temporarily mount the board on the bottom with the screw. With a pen or pencil, draw a circle around the head of the screw. Keep board components clear of this circle so they won't interfere with the screw when you install the completed board.

Your biggest challenge is to make the meter hole in the cover. The meter in the parts list fits in a 1½-inch diameter hole. Use a hole saw to make the cleanest hole, but be sure to use a piece of wood under the cover for support. For the SHORT LED, drill a hole slightly smaller than the diameter of the LED, and then ream or file the hole for a press fit. Use dry transfer letters for the labels on the top cover, and then spray the cover with clear acrylic to bond them. Drill two holes slightly larger than the probe leads in the bottom—½-inch apart and about 3⁄16-inch below the top edge.

When mounting the components on the board, leave the lower left area of the board free for the potentiometer. Refer to Fig. 2 for the circuit schematic. A close-up photo shows the components mounted on an experimenter's



The author's prototype has been opened to reveal its inner workings. The LED, meter, calibration knob, and power switch are all mounted on the unit's cover.

board. Drill larger holes for the oversize leads of D1 and D2. Use press-in terminals in the pads for D2 for soldering the probe leads. Connect the board pads with insulated solid wire; 26 gauge is a good size to use. The pads are close together, so watch for solder bridges. Because of the low-output impedance of the tester (22 ohms), the probe leads are soldered directly to terminals across D2; banana jacks would add noticeable contact resistance.

Testing. Set the Power switch off. Rotate the Cal control counterclockwise. Connect the 9-volt battery and insert it in the compartment. With the probes open, set the Power switch on; the Condition meter should indicate 0 and the Short LED should be off. Touch the probes together; the meter should indicate near full scale and the Short lamp should come on. With the probes touching, adjust the Cal control for a meter indication of 100. If the tester doesn't do this, set the Power switch off and check the wiring. If the wiring appears to be correct, see Table 1 and use a scope to verify the signals at these key points referenced to ground.

TABLE 1

Test Point	Signal
IC1-1	0 V_{DC}
IC1-2	0 V_{DC}
IC1-3	0 V_{DC}
IC1-4	+4.5 V_{DC}
IC1-5	1-volt peak-to-peak 100-kHz squarewave
IC1-6	1.4-volt peak-to-peak 100-kHz triangle waveform
IC1-7	8-volt peak-to-peak 100-kHz squarewave
IC1-11	-4.5 V_{DC}
Q2-C	0 to +4.5-volt 100-kHz squarewave
Junction of R9, R10	0 to +100-mV 100-kHz squarewave
Junction of R11, R12	0 to +100-mV 100-kHz squarewave

If the above signals are correct, check the voltage at IC1-8. With the probes open, the voltage should be 0 ± 0.2 volts. Touch the probes together; the signal at IC1-8 should be a 3.6-volt peak-to-peak 100-kHz-rounded squarewave at an average level of +2 volts, and the Short LED should be lit.

Application. Simple. Set the Power switch on. Touch the probes together; the Short lamp should come on. With the probes still touching, adjust the Cal control for a meter indication of 100. You're now ready to run down those bad electrolytics. Just connect the probes across a suspect capacitor and see what the meter indicates. Polarity doesn't matter; the low 100-mV output will not forward-bias capacitors or surrounding components. In fact, both probes and their leads can be red. The meter doesn't indicate the actual current through the capacitor, but shows the *condition* of the ESR and the capacitance. Think of the meter indication as a grade for the capacitor—as in school, 100 is very good, 20 is poor. For a good grade, both the capacitance *and* ESR must be good.

You'll find that a good capacitor will not always give a full-scale indication. All capacitors have *some* ESR. Most good axial or radial capacitors above 1 µF will give a meter indication of 95 or higher. Physically small capacitors have high ESR. Some new surface-mount capacitors give an indication of around 60, so it's always best to test a known-good capacitor of the same type as the one in the unit under repair and see what the indication should be. A safe rule is to replace a capacitor if the meter indication is under 50. Some capacitors are obviously bad—they don't even move the meter!

The tester circuitry draws 15 mA from the 9-volt battery. At this rate, the battery should last about 30 hours. Replace the battery when you can't set the meter to 100 with the Cal control. **P**