POCKET CALIBRATOR For Volts & Ohms

Build a multi-function calibrator for your bench for under $40.00. Your test equipment will appreciate it.

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HOW MANY TIMES HAVE YOU BEEN working on a piece of equipment or a new project and wondered, "Is the problem due to the equipment or is my test gear out of alignment?" Or perhaps you are concerned about the accuracy of a digital multimeter or VTVM that was dropped or overloaded. It seems that whenever the subject of test equipment comes up, so does the questionof accuracy. There's a good reason for that—it's because inaccurate multimeters and scopes can cause more problems than they solve. You should have a way to check them periodically.

That is where the pocket calibrator comes in. It is designed for use with low-to-moderate-cost digital multimeters, VOM's, VTVM's and scopes. Packed into a small box are three stable DC-voltage outputs for calibrating the most-used meter ranges. There are also five resistance ranges, and two AC-voltage outputs. One of them is a 10-volts p-p square wave for scope calibration, and the other a 1-volt-RMS sine wave for meter calibration. The unit is battery powered to eliminate error-causing AC hum, and for portability.

Although this construction project uses low-cost parts, it is capable of a high level of performance. A precision regulator insures that all voltages will be stable once they are set. The 10-volts-DC output can be set to within ±0.05% if the equipment is available to do so. And, thanks to increased availability of 1%-precision resistors, you can get outputs of one volt ±2% and 0.1 volts ±3%, which are more than adequate for analog meters. For the more accurate digital multimeters, you can substitute higher-precision (0.1%) resistors for more accurate output voltages, with worst-case accuracy typically an order of magnitude higher.

Many of the precision resistors are also used to calibrate resistance scales, with an accuracy greater than 1%. The values run in decades from 111.1 ohms to one megohm.

The AC voltages are derived from a 60-Hz signal source that is crystal-controlled for stability. That IC-based circuit is powered from the 10-volt regulator for maximum stability. The 10-volts p-p square wave, intended for scope calibration, is accurate to within several percent at room temperature. Finally, there's a 1-volt, 60 Hz, sine-wave output that is adjustable to within 0.1%.

You should be able to build the pocket calibrator for under $40, which is a good price considering that some *single-function* calibrators sell for over $400!

Great pains were taken to use common, readily available, components. The precision resistors may be slightly difficult to locate, but they are available from several **Radio-Electronics** advertisers, and also as a set from the supplier indicated in the Parts List. You can buy the PC board from the same supplier, or make it yourself. The IC's and remaining components are available "off the shelf."

Only two simple adjustments are needed for calibration of the device. Although a 4½-digit DMM is recommended, you can do a creditable job with an accurate 3½-digit DMM or with a good VTVM or VOM.

Circuit description

The pocket calibrator consists of four basic circuits. The first is a 10-volt precision voltage-regulator that provides the basic DC calibration-voltage. Second is a set of precision resistors used for resistance calibration, and for dividing down the DC voltage. Next is a 60-Hz crystal-controlled square-wave generator that produces a 10-volt signal for oscilloscope calibration. Finally, there's a filter circuit to smooth the square wave into a one-volt sine wave used for AC meter-calibration. The double-sided PC board on which all that is built also serves as the unit's front panel.

Refer to Figs. 1 and 2 as we discuss the calibrator's circuits.

The first area we'll consider is the 10-volt regulator, built around an LM723

IC. That IC contains a precision voltage-reference, an op-amp, and a series pass-transistor. Using just a few external components, that IC produces a highly stable source of 10-volts DC. (Precision resistors R1 and R3 set the output voltage.) Potentiometer R2 allows adjustment of that voltage over about a 10% range. The 10-volt output of the circuit drives the 60-Hz circuitry at all times, and drives the resistor voltage-divider when switch S2 is closed.

The second section is made up of a set of precision resistors, R4-R8. Next to the 10-volt regulator, they are the backbone of the project, and supply the required voltage and resistance values. Resistors R4-R6 are wired as a simple voltage divider, and provide 0.1 volt and 1 volt when switch S2 is closed. When the switch is open, they serve as resistance standards. Resistors R7 and R8 are used only for resistance checks.

The third section consists of a simple 60-Hz square-wave signal source. The output of a standard TV color-burst reference crystal is divided down from 3.58 MHz to 60 Hz by an MM5369 IC. Since it is CMOS, its output can swing between the 10-volt supply voltage and ground, providing a 10-volt p-p square wave useful for checking oscilloscopes.

The last section is a square-to-sine-wave converter. Refer to the schematic in Fig. 2 for details. The square-wave signal from IC2, the MM5369, is integrated into a rough triangle-wave by C6 and R10 for better filtering by the circuitry that follows, a low-pass filter that smooths the triangle wave into a sine wave. Darlington transistor Q1 is wired as an emitter follower buffering a two-pole filter. Capacitors C7 and C8 perform the bulk of the filtering by supplying feedback through Q1, and capacitors C9 and C10 perform additional smoothing of the signal. The sine-wave output appears on potentiometer R15, which permits adjustment over a small range. Since a DC voltage also appears at that point, and can be read by many AC meters, C11 and R17 remove that undesirable component. The result is a clean one-volt AC sine wave.

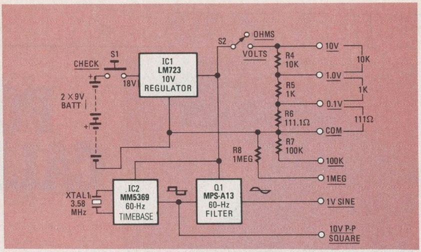

FIG. 1—POCKET CALIBRATOR has DC and AC-waveform outputs, and provides several high-precision resistances.

Component selection

The quality of the parts used in the calibrator plays an important part in how well it performs, so let's discuss the most important ones.

Of the components used, the precision resistors (R4-R8) are the most important. They should be at least 1% tolerance, deposited metal-file types. Ordinary carbon-composition resistors of the type found in radios and TV's will drift too much with age and temperature to be reliable. Fortunately, metal film resistors have become available in the past few years from R Ohm (Japan) and Siemens (Germany). They are known as type-RN-55C resistors in the industry, and you should be able to find them without too much difficulty. Using those resistors should result in a calibrator that is accurate on the 0.1 VOLT range to within 3%. However that is the worst-case error; other ranges will be better. If still greater ac-

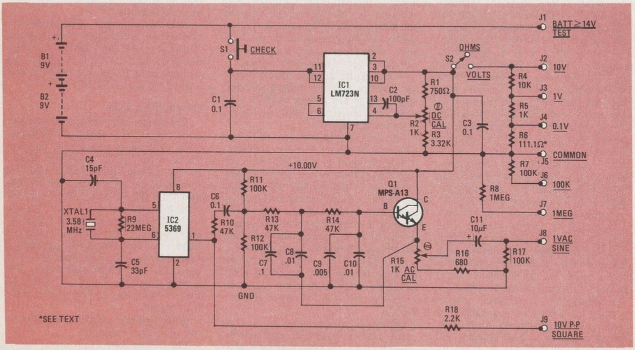

FIG. 2—60-Hz TIMEBASE uses readily available 3.579-MHz crystal and MM5369 IC.

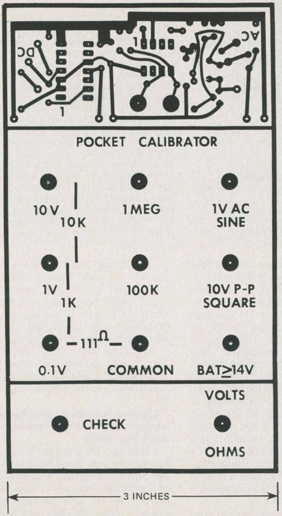

FIG. 3—TOP OF PC BOARD bears labels as well as foil pattern for circuit.

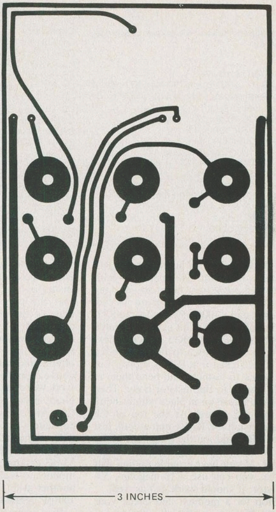

FIG. 4—BOTTOM OF BOARD shows where jacks J1-J9 are mounted.

curacy is desired, 0.1%-tolerance resistors can be used. They can be obtained from the source listed in the Parts List.

One resistor that may be hard to find is R6, which is 111.1 ohms. If necessary it can be made up by connecting a 100-ohm resistor in series with an 11-ohm one. Other combinations—in series or in parallel—will work as well, of course.

The quality of the LM723 IC is important. Since it must provide a stable 10-volts, it must be of high quality. Don't use anything but first-line quality here. Also, there are different types of LM723's on the market. The most common are the LM723C types. They'll do a good job, but if you can find an LM723N, you'll be getting a more stable part with temperature characteristics several times better than the LM723C.

To round up the list of parts of special importance, a few words about the 10-turn potentiometers. Although widely used in the industry, they may be new to you. Their multi-turn features means that they can be set quite accurately and they are very stable. They are not difficult to find; many advertisers in **Radio-Electronics** can supply them.

Construction

Foil patterns for the double-sided PC board are shown in Figs. 3 and 4. The board is also available from the supplier indicated in the Parts List.

Figure 5 shows the parts-placement diagram for the calibrator, and Fig. 6 will also help you in installing the components on the board. A good way to begin is to install the banana jacks at J1-J9. Insert each jack from the front-panel side (the side with the labels etched on it). Then place a ¼-inch toothed lockwasher over the threaded bushing of the jack, and secure it with a ¼-inch nut. The lockwashers are used to insure that the jacks don't loosen with use and cause erratic readings. After the jacks have been installed, recheck them to be sure the hardware is tight.

The switches are next. Be sure to position the board as shown in Fig. 5, with the component (non-labelled) side up. Then install the pushbutton CHECK switch at S1. Solder short pieces of wire to its terminals and then to the foil on each side of the switch as shown. Next, install S2 (VOLTS/OHMS) in the other switch position. (If you can't locate a SPST switch, use a SPDT one, but clip off one of the end lugs.) Flip the handle of the switch so that the contacts are closed. Then rotate the switch body so that the handle points to the VOLTS on the reverse side of the board. Connect S2 the same way you did for S1.

You should use IC sockets, and they can be installed next. Install a 14-pin socket at the IC1 position, and an 8-pin socket at the IC2 position, but don't insert the IC's yet.

The two potentiometers can be installed next. Insert one at the R2 location, pressing it flush against the board before soldering. Then insert the other at R15, pressing it against the board before soldering.

With the exception of R13, all the resistors mount on the component side of the board. (You will install R13 later.) Start at the top left corner of the board and install a 100K, 5% resistor at R17.

PARTS LIST

All resistors ¼ watt, 5% unless otherwise noted

R1—750 ohms, 1%
R2, R15—1000 ohms, 10-turn PC-mount potentiometer (Beckman 89PR1K or equivalent)
R3—3320 ohms, 1%
R4—10,000 ohms, 1%
R5—1000 ohms, 1%
R6—111.1 ohms, 1% (see text)
R7—100,000 ohms, 1%
R8—1 megohm, 1%
R9—22 megohms
R10, R13, R14—47,000 ohms
R11, R12, R17—100,000 ohms
R16—680 ohms
R18—2200 ohms

Capacitors
C1, C3—0.1 µF, 25 volts, ceramic disc
C2—100 pF, ceramic disc or mica
C4—15 pF, ceramic disc or mica
C5—33 pF, ceramic disc or mica
C6, C7—0.1 µF, 50 volts, Mylar
C8, C10—0.01 µF, 50 volts, Mylar
C9—0.005 µF, 50 volts, Mylar
C11—10 µF, tantalum

Semiconductors
IC1—LM723 adjustable precision voltage regulator
IC2—MM5369 60-Hz timebase
Q1—MPS-A13 NPN Darlington
XTAL1—3.579-MHz TV color-burst reference crystal
S1—SPST N.O. pushbutton switch
S2—SPST mini toggle switch
B1, B2—9-volt transistor battery
J1-J9—banana jack (Smith 101 or similar)

Miscellaneous: PC board, battery clips, IC sockets, heat-shrink tubing, enclosure (Vertox model 2000 or similar), etc.

The following are avalable from: Technico Services, P.O. Box 20HC, Orangehurst, Fullerton, CA 92633: PC board and 1% resistors (CAL-1), $13.00; PC board and 0.1% resistors (CAL-2), $16.00; 1% resistors only (RES-1), $3.00; 0.1% resistors only (RES-2), $6.00. CA residents please add sales tax. Non-USA orders please add $3.50 for shipping and handling.

The following is available from: Circuit Specialists Co., P.O. Box 3047, Scottsdale, AZ 85257: kit KT-2 (does not include PC board, precision resistors or case), $21.95 plus $0.90 for shipping and handling.

On the other side of potentiometer R15 install a 680 ohm, 5% resistor at R16. The fit is very tight here, so you may want to stand the resistor on its end. Then install a 100K, 5% resistor at R12, and another 100K unit at R11. Install a 47K, 5% resistor at R13, which is next to R11. Move down to J9 and install a 2.2K, 5% resistor at R18 as shown. Cut the leads to ¼-inch, and bend them at right angles to the resistor body. Then solder the resistor in place with its body off the PC board. At the top of the board install a 47K, 5% unit at R10, just above IC2 and, on the other side of the socket install a 22 megohm, 5% resistor at R9. If you have trouble finding that value, you can use a 10 megohm, 5% resistor; it should work just as well.

Stop for a moment and check your work. Make sure that all parts are installed correctly before going any further.

Finish up the resistors by installing the precision units. They are mounted in the same manner as R18. That is, the leads are cut to ¼-inch and bent at right angles to the body. Start by installing a one megohm resistor at R8. Solder the connection quickly to avoid overheating the part (that advice goes for *all* the precision resistors). Then install a 100K resistor at R7 in the same manner. Move to the right edge of the board and install a 10K resistor at R4 as shown and a 1K resistor at R5. Move down and install a 111.1-ohm resistor (or combination of resistors) at R6. After that, move up to the top right side of the board and install a 3.32K resistor at R3. On the other side of the potentiometer install a 750-ohm unit at R1. That completes the installation of the precision resistors.

It's a good idea to check the precision-resistor connections at this point. Make sure that they are good, and that the parts are securely mounted. That is important because any extra resistance caused by a bad solder connection will affect the performance of the calibrator.

The capacitors come next, and they are all mounted at the top of the board. Install a 10-µF tantalum at C11. Note that the plus sign points toward the edge of the board. Move to the right and install a 0.01-µF Mylar capacitor at C8, and another at C10. Those capacitors are the green rectangular units often found in transistor radios, although conventional ceramic-disc types should work well if you can't find the Mylar ones. Next, install a 0.005-µF Mylar-type at C9. After that, install 0.1-µF Mylar capacitors at C7 and C6. On the other side of the IC2 socket, install a 15-pF ceramic disc-type at C4 and next to it a 33-pF ceramic disc at C5. Continuing, mount a 0.1-µF ceramic disc at C3 and another at C1. Finish up by installing a 100-pF ceramic disc at C2.

Five wire jumpers are used to connect one side of the board to the other. Run pieces of excess resistor lead through the holes indicated by asterisks in Fig. 5 and solder them on both sides of the board. Clip off any excess lengths.

The battery connectors are installed next. Cut the positive lead of one connector to a length of about an inch, and the *negative* lead of the *other* connector to the same length. Then slip a piece of heatshrink tubing all the way onto one of the wires, and solder the two together. When the solder joint has cooled, move the tubing down over the joint and use a match or other heat source to shrink it. (Don't hold the heat source too close to the tubing—it will start to char.) Wrap the remaining leads from the connectors around switch S1's body and knot them securely around it; then connect the leads to the pads as shown in Fig. 5. The batteries themselves are attached to the bottom of the case with double-sided tape.

Finish up the component side by installing the ICs. Double-check their orientation. Turn the board over (label-side up) and install R13, a 47K, 5% resistor. Cut the leads short first, to about ¼ inch; then bend them and solder them to the pads. Note the position of the 8-pin IC socket nearby—that should make it easier to locate the pads. Once the resistor is in place, press its body tight against the board. That completes the component installation.

If you like, you can deflux the board for a more professional appearance. Use a small brush and acetone in a well-ventilated area to remove the solder flux.

Caution: Acetone is highly flammable! Always use it in a well ventilated area, away from flame.

Clean only the front panel side of the board, and keep the solvent away from the battery connectors and plastic base of the crystal—not only is acetone flammable, but it also dissolves many plastics. After the flux has been removed, and the front panel has dried, coat the panel with clear acrylic spray to preserve its appearance.

You can fashion a plate out of Formica or other material to hide the circuitry on the top of the panel. Secure it with two small blobs of silicone sealant.

Checkout and calibration

Install the batteries. Then, if you can, obtain a 4½-digit DMM to check out the calibrator. In the event you don't have—or can't borrow—one, a freshly calibrated 3½-digit instrument will work. In fact, a good time to build the calibrator is right after the purchase of a new multimeter, so you can check it on an instrument that is "known good."

A good place to start is with the resistance ranges. Set S2 to the OHMS position. Connect one of the DMM leads to the COM jack and the other to the 0.1V/111Ω jack. Set the meter for that resistance range and you should read 111.1 ohms ±1% or ±0.1%, depending upon the resistors used in the calibrator.

Note that most test leads can contribute at least 0.1 ohm of resistance themselves; be sure to allow for that error:

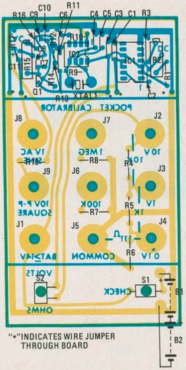

FIG. 5—COMPONENTS ARE MOUNTED on bottom of PC board with the exception of R13, which is mounted on the top.

Disconnect the leads from the calibrator, short them together, and read the lead resistance. Then subtract that value from the reading you get with the 111.1-ohm resistor.

Remove the lead from the COM jack, and plug it into the 1V/1K jack. Change the multimeter range; you should get a reading of 1000 ohms, plus or minus the resistor tolerance. Continue by removing the lead from the 0.1V/111Ω jack, and transferring it to the 10V/10K jack. You should read 10,000 ohms. Then switch your leads to the COM and 100K jacks. Change the range switch on the DMM and the reading should be 100,000 ohms. Finally, with the leads in the COM and 1 MEG jacks, the DMM should give you a reading of one megohm.

Many low-cost digital multimeters are hum-sensitive on the high resistance ranges, so your readings may change if you use long test leads. If you have that problem, simply use shorter leads (1 foot or less), and work away from 60-Hz sources.

The next check is for the correct DC-voltage output. Set S2 to the VOLTS position. Then switch the DMM to the DC VOLTS position. Press S1 and measure the voltage at the BAT ≤14V jack. The exact value you read isn't important, as long as it is 14 volts or higher—that is just a check on the condition of the calibrator's batteries to insure that the calibrator will put out accurate voltages. Transfer the test lead to the 10V/10K jack. You should read *approximately* 10 volts—the value will be set precisely in a little while.

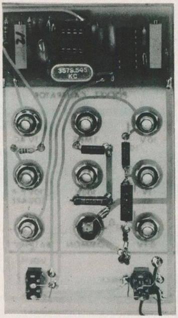

FIG. 6—NOTE HOW 1% RESISTORS are mounted ¼-inch above board.

The final checks are for the AC outputs. An oscilloscope would be handy at this point to measure the 10-volt p-p squarewave, but it isn't absolutely necessary; at this point all we are really interested in is the one-volt sine-wave output. Set your DMM to its 1 VOLT AC range, or as close to it as you can come. Plug the test lead into the 1V AC SINE jack. Press S1, and wait a few seconds. When the reading stabilizes, it should be close to one volt. That completes the performance checks. If you encounter any difficulties, correct them before going any farther.

The next step is calibration, which is quick and easy. The first thing is to adjust the 10-volt source. Connect the DMM to the COM and 10V/10K jacks and set the DMM to its 20 VOLTS DC range. If the instrument has a 10 VOLTS DC range instead, use that one. (The object is to be able to read voltages both below and above 10 volts, but accuracy is more important.) With S2 in the VOLTS position, press S1. Hold it for a few moments, and then adjust R2 for exactly 10.000 volts. That completes the DC voltage calibration.

The last step is the AC calibration. Reconnect the DMM's "hot" lead to the 1V-AC SINE jack and set the meter to its 2-VOLTS AC range. If the meter has a 1-VOLT AC range, use it instead. Press S1, and hold it for a few moments. After the reading stabilizes, adjust R15 for exactly 1.000 volt. That completes calibration of the unit.

Use

In order to get the most out of the calibrator, it pays to look at a few common applications.

As a voltmeter calibrator, it's ideal because it provides voltages that correspond to the voltmeter ranges most often used. With its 10-volt output, the unit is right at home with IC's and other devices that normally operate in the 3- to 15-volt range. There should be no problems working with instruments having input resistances of a megohm or more, which includes most FETVOM's, VTVM's, and all digital multimeters. Lower-resistance analog meters can be accurately calibrated using the 10-volt output but somewhat reduced accuracy will result using the 1-volt outputs or 0.1-volt outputs. If you are checking a known-good analog meter, make a note of the readings you get; that way you will have a way to check the meter later on.

Before checking the calibration of any voltmeter, make sure that it is zeroed properly. Generally, that step is not necessary with modern digital voltmeters (which zero themselves automatically), but older digital meters and analog meters may require zeroing.

In case of analog meters, be sure to place the instrument in the viewing position you normally use before adjusting the mechanical zero. That's because some meters (usually low-cost imported models) aren't compensated for gravity, and the needle can wander over the zero mark. Static electricity on the plastic meter-cover can cause zeroing problems too, so clean it gently with a mixture of detergent and water. Don't wipe it with a dry cloth; use a damp one to keep static generation down.

Always check the BATT ≤14V jack for at least 14 volts before using the calibrator to insure that the 10-volt regulator is being supplied enough voltage to function properly.

To calibrate a voltmeter, set S2 on the calibrator to VOLTS and connect the voltmeter across the appropriate jacks. For maximum accuracy, use the 10-volt output, if possible. Then press S1 to apply voltage to the meter. If you are checking a meter that can't be easily calibrated, make up a note showing how great the error made is, and tape it to the meter. That is usually done with analog instruments. Digital voltmeters are generally easier to calibrate, and can be readily adjusted to match the output of the calibrator.

When calibrating a digital meter that has several ranges, always calibrate on the *lowest* range. That is known as calibrating the "basic accuracy," because the error-causing attenuator built into the digital meter is out of the circuit under those circumstances. Use either the 1-volt output or the 0.1-volt output of the calibrator.

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CALIBRATOR

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Multimeters are calibrated in much the same way as straight voltmeters. Regardless of instrument, you should always calibrate it for DC volts first. Then you can set the multimeter to AC VOLTS and to the 1 VOLT range for AC calibration. Use the calibrator's 1V AC SINE jack. *Don't* use the 10-volt square-wave output—some meters react differently to a square-wave input.

The resistance ranges can be calibrated next. Switch S2 to the OHMS position, and plug in the test leads as required to get 111.1 ohms, and the decade values from 1K through 1 megohms. Remember that you get 1K by using the 1V/1K and 0.1V/111 Ω jacks and 10K by using the 10V/10K and 1V/1K jacks. The rest of the resistance connections are obvious. Generally, it is necessary only to check out a few ranges of a multimeter to get full calibration, so the entire procedure takes about five minutes on modern meters. For best results, see your meter's service manual for helpful hints.

The calibrator should also come in handy for adjusting A/D converters. Generally, all you have to do is check them on the 10-volt DC range, and adjust the converter for a corresponding output. Of course, different systems may have different input requirements, and the 1-volt or 0.1-volt dc outputs can be used if necessary. For best results, measure the exact output voltages from the calibrator and jot down the values; then you can adjust the A/D converter precisely.

If you are calibrating a 10-volt-input converter, you can get an idea of its linearity by switching to the two lower calibrator outputs. The readings from the converter should drop correspondingly. Finally, bipolar-type A/D converters, which convert either positive or negative voltages can be checked simply by reversing the leads to the calibrator. The positive and negative values should be the same, or nearly the same; otherwise the converter is suffering from excessive "rollover" error. The calibrator has been very handy in checking out A/D converters in home computers, and experimental digital voltmeters.

Oscilloscopes can benefit from the pocket calibrator. The 10-volt square-wave output was designed with them in mind. To use it, connect the scope to the COM and 10V P-P SQUARE jacks. Then press S1 and observe the scope display. Adjust the vertical gain as required to get a reading of 10 volts where you want it on the display. As a bonus, you can check ×10 probes, and adjust them with the calibrator. With the ×10 probes, the 10-volt signal should be displayed as a 1-volt peak-to-peak waveform. Anything else may indicate a defective or misadjusted probe. With the calibrator, the probe's internal compensation-trimmer can be adjusted with an insulated screwdriver for the squarest corners on the display.

Some final advice

Here are a few additional tips that can help you to get more out of your calibrator.

Perform the initial calibration using the best meter you find! Also, after the calibration, measure all the resistances and voltages. Prepare a chart, and paste it inside the lid of the calibrator. Use those values when calibrating other equipment.

Always use top-quality leads when calibrating other meters. Cheap ones, or bad ones, can introduce resistance errors.

If the pocket calibrator has been unused for a while, check the battery voltage before using it. It's embarrassing to calibrate an instrument with a calibrator that's in error due to weak batteries!

Finally, try to work in a temperature-stable environment. Calibration under unusual temperature conditions usually results in slight errors, and isn't such a good idea. **R-E**