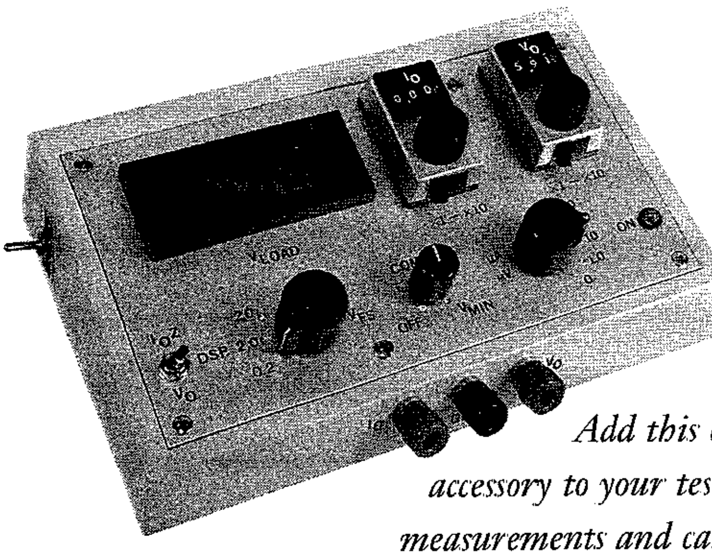

BUILD THIS PRECISION VOLTAGE/ CURRENT REFERENCE

Add this easy-to-build and inexpensive accessory to your test bench for lab-quality measurements and calibration.

SKIP CAMPISI

If you enjoy experimenting with both linear and non-linear analog-electronic circuits, you've probably gotten aggravated having to breadboard a precise reference circuit every time one is required. A standard linear power supply with variable voltage and current limiting can sometimes be used if the application is not too critical.

However, those methods leave a lot to be desired when precise, drift-free performance is required. Wouldn't it be great if you had such a piece of test equipment available on your test bench to handle such tasks?

The Precision Reference presented here has a typical stability of better than ±100-parts-per-million-per-degree Celsius when assembled with the suggested components. Even better, the cost of the entire project is less than the cost of a standard power supply! The outputs include a voltage output that can range between 1 millivolt and 10 volts, and a current output that can be set anywhere from 1 microamp to 10 milliamps. A range-select switch can set the output range to 0.1, 1, 10, 100, or 1000 millivolts or microamps. Two independent 10-turn precision potentiometers with turn counters let each range be multiplied by 1 through 10 according to the dial setting.

Using the 1% metal-film resistors specified, you can expect an accuracy of about 0.2% of the dial setting for the 10, 100, and 1000 range-switch settings. Typically, the accuracy is better than 0.1% overall. The lowest range has an accuracy of 1%, and it typically can be as good as 0.5%. A built-in 3½-digit LCD panel meter can display the load voltage present at either output. It has its own range selector switch.

Fixed current limiting is provided for the voltage-output section of the circuit. That provides a maximum of about 30 milliamps at the 10-volt-output level, increasing to about 80 milliamps at the 1-millivolt-output level. This method has the added benefit of short-circuit protection.

The current output has a variable "compliance" control in order to protect any voltage-sensitive devices being tested. The voltage at the current output is adjustable between about 1.5 volts at the minimum setting and about 11 volts at the maximum position.

Circuit Description. The Precision Voltage/Current Reference design can be divided into four basic sections: the voltage-reference inputs, the voltage-current-reference outputs, the power supply, and the panel-meter display.

The schematic diagram in Fig. 1 shows the simplicity of the circuit. A 1-volt reference is supplied by D1 to the current-reference circuit, with D2 supplying a 1-volt reference to the voltage-reference section. Both diodes are temperature-stable ICL8069 band-gap reference diodes. The 1-volt reference from D1 appears on the wiper of R3 when R3 is set to its maximum rotation. At the minimum setting of R3, 100 millivolts appears. That voltage is buffered by IC2, an LF356 JFET op-amp. The buffered reference voltage is applied to Q1. Since Q1 is a part of the feedback loop of IC2, the reference voltage is placed across the range resistor (R6–R9) as selected by S1-a.

Due to the high gain of Q1, the output current at its collector is the same as the reference voltage divided by the selected range resistor. That output current is connected to J1. The maximum output voltage at J1 is set with R13 and Q2, which is configured as an emitter follower. The bias on D3 lets the output of IC2 stay in its active-voltage range.

The 1-volt reference from D2 feeds the voltage divider composed of R17–R21. The range from that divider is selected by S1-b and is buffered by IC1, a TLC271 CMOS op-amp. It is configured as a non-inverting amplifier with a variable gain set by R24. High-current capacity for the voltage output is provided by Q3, a 2N2219 NPN transistor. It is a part of IC1's feedback loop. Current limiting and short-circuit protection for Q3 is provided by R26, a 100-ohm, 2-watt resistor.

The power-supply portion of the circuit is shown in Fig. 2. The power

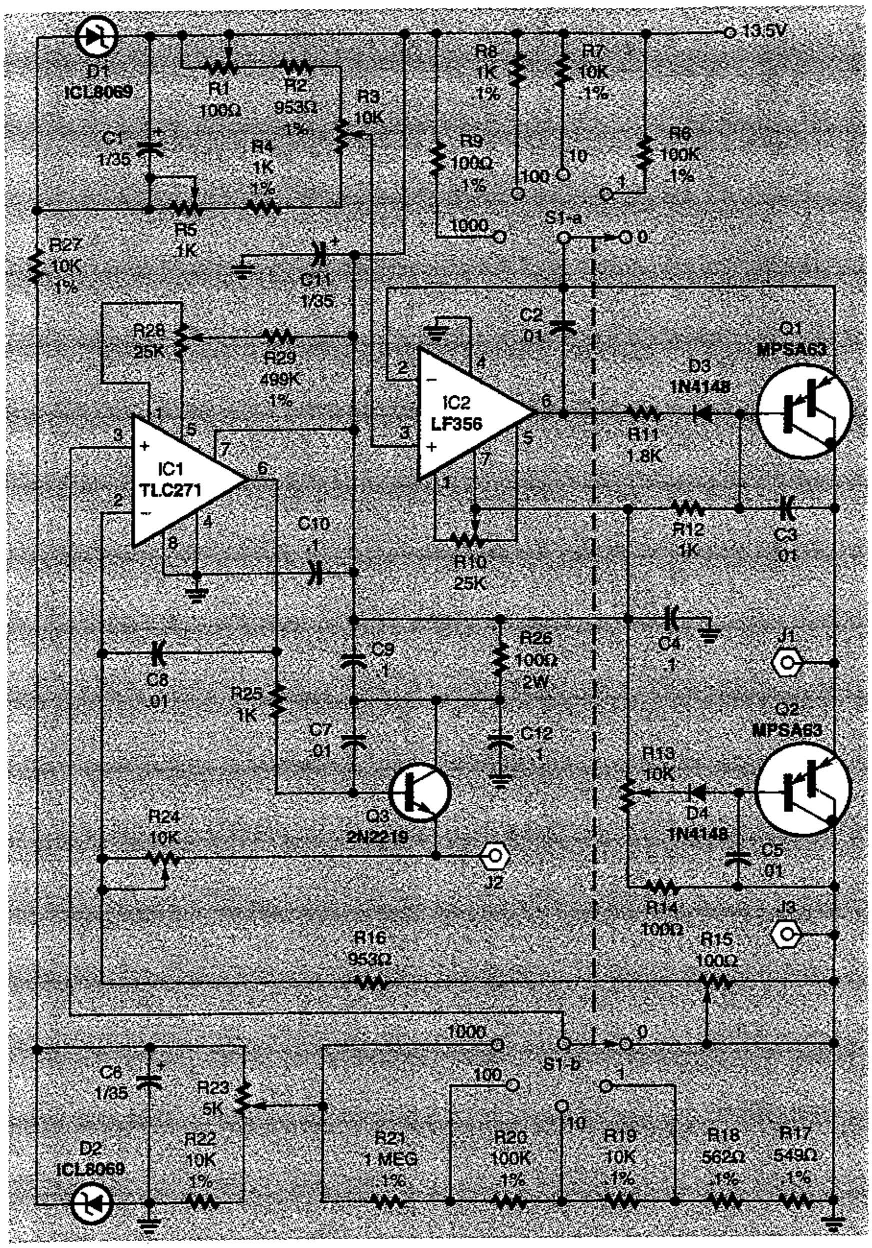

Fig 1. Although it might look complicated, the Precision Voltage/Current Reference is actually a straightforward circuit that is built around several high-precision op-amps The circuit is easy to calibrate using only an accurate digital voltmeter.

supply has some unusual design features that are needed for the circuit to work properly. There are two isolated outputs: 13.5 volts for the main circuit and 9 volts for the digital-panel meter, DISP1 Because DISP1 uses an on-board reference, its supply *must* be completely isolated from the rest of the circuit!

The isolated outputs are achieved by choosing a "split-bobbin" transformer for T1 That type of transformer has two separate 120-volt primaries and two separate 12-volt secondaries. In effect, the transformer is two separate transformers that share a common core.

The input to the display circuit is switched by S4 That lets the input measure the load voltage at J1 (the current reference) or J2 (the voltage reference). The voltage is applied to IC4, a TLC271 CMOS op-amp wired as a unity-gain buffer. The output of IC4 drives another voltage divider consisting of R34 through R37. The output of IC4 is loaded by R38 so that it can approach ground potential if needed.

The range of DISP1 is set by S3 The resistor-divider network lets DISP1 display voltages beyond its normal 200-millivolt range One half of S3 selects the range from the divider network, while the other half selects the proper decimal-point location for the display.

Construction Tips. The actual layout and construction of the Precision Current/Voltage Reference is not critical to circuit performance. However, following the guidelines mentioned here will assure success and accuracy with the project

Choose a suitably-sized cabinet that will be big enough to hold all of the circuitry and all of the controls The author's prototype was assembled in a sloping plastic cabinet about 7½-inches wide and 4¾-inches deep The cabinet's aluminum top panel on which most of the controls were installed is an excellent ground plane.

Point-to-point wiring was used on standard 0.1-inch-grid perfboard with copper-foil pads The power-supply section was mounted on a separate board supported by DISP1's mounting lugs. The power cord enters the cabinet near the supply with S2 mounted next to it. Be sure to drill several ventilation holes in the cabinet near the transformer

The references and meter driver were constructed on another board; the voltage-current-output sections are contained on a third board Both of those boards were mounted away from the power-supply board in order to avoid picking up any 60-cycle "hum". All of the connections between the components on the boards were made with 22-gauge bus wire Insulated stranded wire was used for any connections between boards or anywhere there was a possibility that the wires could come in contact with another conductor For the long runs between the boards and the panel components, the insulated wires were twisted together in pairs

Mount 0.1% metal-film resistors R17–R21 directly onto the appropriate lugs of S1-b One lead of R17 should be connected to a panel ground lug Mount R6–R9 from S1-a to the lug on R13 that will be connected to the positive power source The positive lead of R26 should be connected directly to that lug also Note that the 13.5-

volt power leads from all of the boards, including the power supply, should be run to that same lug That arrangement is called a "star" because all of the connections radiate out from one central point In that way, there is no accumulated resistance from the individual wires if they were to be run sequentially from point to point in a "daisy-chain" style.

Make a "star" connection for the ground in the same way. Connect each board's ground lead to the panel ground lug connected to R17 The common-output ground terminal, J3, should also be connected to that lug with a short piece of bus wire For best decoupling, install bypass capacitors C9 and C12 right on the body of R26 with very short leads

DISP1, a 3½-digit LCD-panel voltmeter, is available from many surplus and overstock sources for less than $10. Brand new units can be bought from several major mail-order sources, but those sources might charge $50 and up. The unit that you choose should have a maximum input range of 200 millivolts, and can be powered by an isolated supply of 9 volts, as mentioned before You have the option of using a 4½-digit digital-panel meter (DPM) at about twice the cost. If you require further information on DPMs, refer to the excellent article by Bill Stiles in the October 1996 issue of **Popular Electronics** magazine.

Install and wire DISP1 according to its instruction sheet Although a typical hookup is shown on Fig. 2, you should follow any recommendations for the actual unit that you will be using. Install R34-R37 on the appropriate lugs of S3-a One lead from R37 is connected to a panel ground lug, as with R17 and Sl-b. Wire S3-b to select the decimal point

Before connecting 10-turn precision potentiometers R3 and R24, the "dead space" at the ends of their rotations must be eliminated. Start by securely mounting R3 and R24 in their holes on the top panel. With a DMM make a note of the exact resistance between lugs 1 and 3 on R3.

Connect the DMM between lugs 1 and 2 Rotate R3's shaft until you read exactly 10% of the previous resistance. Take one of the 10-turn dial counters, set it for 2 00 (two turns clockwise from 0.00), and lock the setting Install the counter on R3 without moving the shaft Check the resistance on R3 once again to be sure that the shaft hasn't moved and lock the set screws securely.

Rotate the counter dial counterclockwise until it stops You will note that it now reads a couple of "clicks" below 1 00 That shows that the installation is correct Rotating the counter nine turns clockwise will give an indication of 0 00, which is to be taken as 10.00 Ten-turn counter dials do not have the number "10" on their dial Turning the dial an additional clockwise turn will indicate 1 00 again, which is now equal to 11 00

You can, of course, use a 15-turn counter dial for true indications However, the Precision Reference might not work correctly beyond the "10 00" setting because of the design of the circuit Using the same techniques, install the other counter dial on R24, and complete the wiring of the controls

Double check all of your wiring and interconnections before calibrating the unit Turn on the power and check the 13 5-volt supply to make sure it is within ±0.5 volt If it is over 14 volts, add an infra-red LED in parallel with LED1 If it is under 13

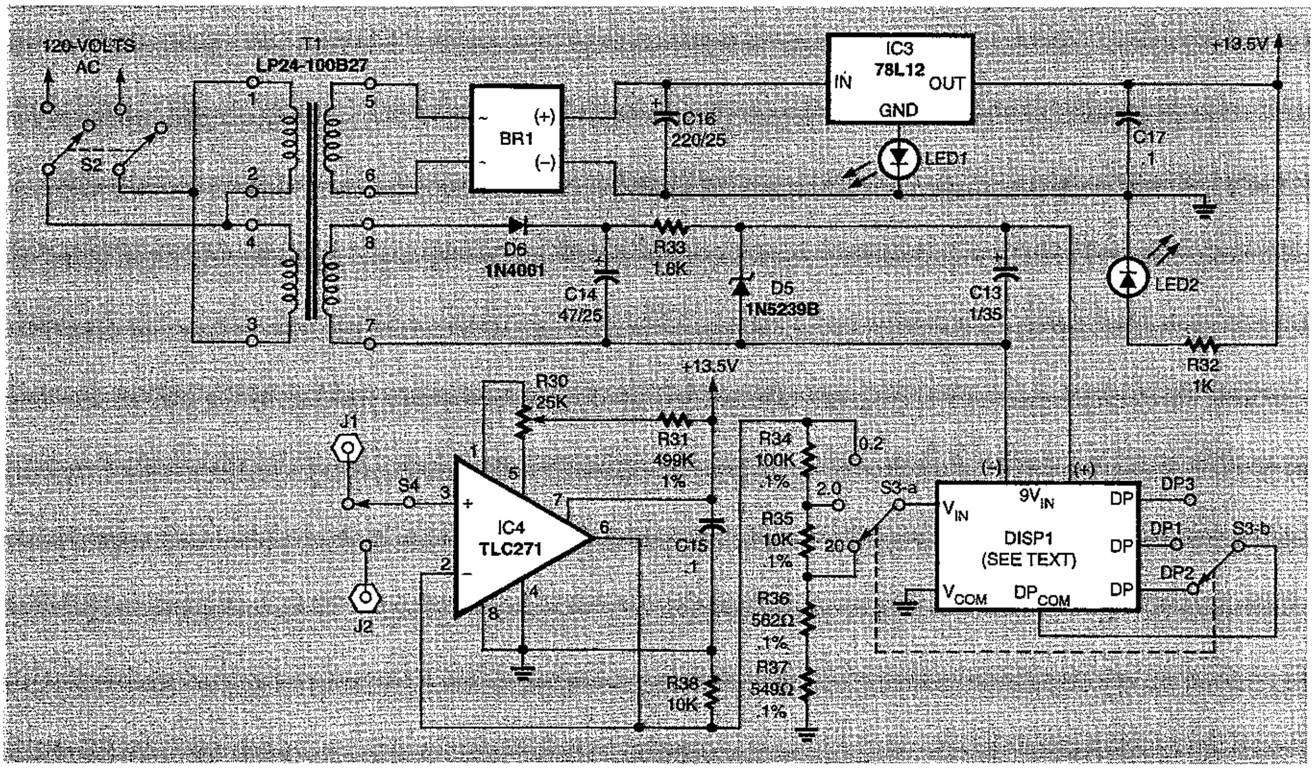

Fig. 2. The Precision Reference's power supply uses a split-secondary transformer in order to have two isolated power sources in a compact size. The digital-panel meter allows for easy monitoring of the outputs

PARTS LIST FOR THE PRECISION VOLTAGE/CURRENT REFERENCE

SEMICONDUCTORS

IC1, IC4—TLC271 or TL091 CMOS op-amp, integrated circuit
IC2—LF356 IFET-input op-amp, integrated circuit
IC3—78L12 voltage regulator, integrated circuit (TO-92 package)
Q1, Q2—MPSA63 or MPSA64, PNP Darlington transistor
Q3—2N2219, NPN transistor
BR1—1 amp, 50-volt bridge rectifier
LED1—T-1 light-emitting diode, red
LED2—T-1¾ light-emitting diode (any color)
D1, D2—ICL8069 band-gap reference diode
D3, D4—1N4148 silicon diode
D5—1N5239B Zener diode, 9.1-volts
D6—1N4001 silicon diode

RESISTORS

(All resistors are ¼-watt, 5% units unless otherwise noted.)
R1, R15—100-ohm, single-turn trimmer potentiometer
R2, R16—953-ohm, ¼-watt, 1% metal-film
R3, R24—10,000-ohm, 10-turn, panel-mount, precision potentiometer
R4—1000-ohm, ¼-watt, 1% metal-film
R5—1000-ohm multi-turn trimmer potentiometer
R6, R20, R34—100,000-ohm, ¼-watt, 0.1% metal-film
R7, R19, R35—10,000-ohm, ¼-watt, 0.1% metal-film
R8—1000-ohm, ¼-watt, 0.1% metal-film
R9—100-ohm, ¼-watt, 0.1% metal-film
R10, R28, R30—25,000-ohm multi-turn trimpot
R11, R33—1800-ohm
R12, R25, R32—1000-ohm
R13—10,000-ohm, panel-mount, single-turn potentiometer
R14—100-ohm
R17, R37—549-ohm, ¼-watt, 0.1% metal-film
R18, R36—562-ohm, ¼-watt, 0.1% metal-film
R21—1 megohm, 0.1%, ¼-watt, metal-film
R22, R27—10,000-ohm, ¼-watt, 1% metal-film
R23—5000-ohm multi-turn trimpot
R26—100-ohm, 2-watt, 5%, wire-wound
R29, R31—499,000-ohm, ¼-watt, 1% metal-film
R38—10,000-ohm

CAPACITORS

C1, C6, C11, C13—1-µF, 35-WVDC, solid tantalum
C2, C3, C5, C7, C8—0.01-µF, ceramic-disc
C4, C9, C10, C12, C15, C17—0.1-µF, ceramic-disc
C14—47-µF, 25-WVDC, aluminum electrolytic
C16—220-µF, 25-WVDC, aluminum electrolytic

ADDITIONAL PARTS AND MATERIALS

T1—Dual 12-volt, 100-mA secondary, split-bobbin transformer
DISP1—3½- or 4½-digit liquid-crystal display panel-mount voltmeter (see text)
S1, S3—2-pole, 6-position rotary switch, panel-mount, non-shorting
S2—double-pole, double-throw toggle switch
S4—single-pole, double-throw toggle switch
J1–J3—binding posts
10-turn counting dials for R3 and R24, case, line cord, wire, hardware, etc.

volts. add a 1N4148 silicon diode in series with LED1 That will assure the best operation of the Precision Reference.

Calibration Procedure. The Precision Reference needs to be calibrated properly in order to get the most benefit from the circuit. Although the calibration procedure given here is fairly straightforward. it should be followed exactly. The only tool you will need is a good-quality 4½-digit digital voltmeter. An accurate 3½-digit DVM will also work. but there will be some loss of accuracy.

Turn on the power and allow the unit to warm up for a minute or so. Set S4 to connect J2 to the panel-display circuit Range switch S3 should be set to the highest setting (20 volts). Rotate R13 to its "off" position (the wiper connected to the supply voltage) and set S1 to the 1-millivolt range Both R3 and R24 should be set to "1.00"

To calibrate the voltage-reference section. connect the DVM across pins 2 and 3 on IC1. Adjust R28 for a reading of exactly 0 00 millivolts Connect the DVM to J2 and J3 and adjust R23 for a reading of exactly 1.00 millivolt Set S1 to 10. 100. and 1000 millivolts. noting the reading each time If needed. "tweak" R23 for accuracy over the entire range With S1 set at 1000 millivolts. set R24 to "10.00" and adjust R15 for a reading of exactly 10 000 volts. Switch S1 to 1 millivolt and "tweak" R28 for a reading of exactly 10 00 millivolts Note that that adjustment is very sensitive. Return R24 to the "1 00" setting and re-check your calibration results

To calibrate the current-reference section. set S1 to 1 microamp. Connect the DVM across pins 2 and 3 of IC2 and adjust R10 for a reading of exactly 0.00 millivolts If you can't get that setting. replace IC2. Set R3 to "10 00" and connect the DVM between the 13.5-volt "star" connection and the wiper of R3. Adjust R5 for a reading of exactly 1 0000 volts Reset R3 down to "1.00" and adjust R1 for a reading of exactly 100 00 millivolts As those last two adjustments interact slightly, reset R3 back to "10.00" and note the reading. "Tweak" R5 again if necessary, and recheck the reading with R3 set at "1 00" Keep repeating the process until you are satisfied.

With S1 set to 1 microamp, connect the DVM across R6 and set R3 to "1 00" The reading should be 100 millivolts Advance R3 to "10 00" and the reading should advance linearly with the counter dial up to a 1 00-volt reading If not. replace IC2 with a unit made by a different manufacturer Some chips are known to have problems working near their positive supply rails A good chip should not have a problem working with its inputs as high as 100 millivolts above the positive rail.

Finally, connect the DVM in its current-measuring mode to J1 and J3 Set S1 to 1, 10, 100. and 1000 microamps and note the actual current readings with R3 set at "1 00". Repeat the process at "10 00" and re-calibrate. if necessary.

To calibrate the digital-panel-meter section, set R24 to "1 00". S1 to 1000 millivolts, S4 to connect to J2, and S3 to 2.0 volts Connect the DVM across pins 2 and 3 of IC4 and adjust R30 for a reading of exactly 0 00 millivolts Adjust the reference-calibration trimmer located on DISP1 as per its data sheet for a reading of exactly 1 000 volts on its LCD display. Check the readings on all other ranges and "tweak" the trimmer as needed for overall accuracy.

If the display refuses to go down low enough to indicate the lower output ranges, try swapping IC4 with IC1, or replace IC4 altogether Maximum output swings for the TLC271 can vary from unit to unit, although they will normally go down to within a few hundred microvolts above ground

Operating Hints. The Precision Voltage/Current Reference is extremely accurate and simple to operate. Aside from the obvious uses such as the calibration of analog circuitry, metering equipment and the like, the unit has many other applications. Only a few examples will be discussed here—you will surely find many others uses.

If you need to put high current into a low-impedance load, you might want to use "remote sensing" to maintain an accurate load voltage That is easily done by bringing the lead from lug 1 on R24 out to a separate binding post rather than connecting it to Q3 and J2 Likewise, connect the ground connections of R15 and R17, along with D2, C6, and R22 to another binding post rather than J3.

Run separate leads from J2 and the binding post from R24 to one side of the load, and separate leads from J3 and the other new binding post to the other side of the load. For normal operation with a "light" load, simply short J2 to its companion binding post and J3 to the other binding post with short lengths of solid bus wire That will restore the original connections and only two leads will be needed for the load

If long leads are used for "remote sensing", output instability might be a problem If that is the case, shielded cables should be used. Also increasing the value of C8 by one or two decades might be quite helpful

Of course, the Precision Reference makes an excellent oscilloscope calibrator If you have a dual-trace oscilloscope, you can even use the Precision Reference as a voltage-cursor display! Input a signal into one channel of the oscilloscope and adjust the scope to show a normal display. Set the scope's attenuators to their "calibrated" position Connect J2 and J3 from the Precision Reference to the scope's second channel Set S1 to 0.0 millivolts and set the scope to "alternate" or "chop" so that both traces will be displayed superimposed on each other

The input signal from the first channel will be shown on the scope's display with a straight horizontal line through it. That line represents the "zero"-volt cursor from the Precision Reference. By using the second channel's vertical-position control, the zero cursor can be moved to any position vertically on the trace from which you wish to begin your measurement

Note the approximate signal voltage being displayed on the first channel and set up the second channel to display a similar voltage available from the Precision Reference Set S1 on the Precision Reference to the appropriate range required and advance R24 until the cursor reaches the measurement endpoint Since you already know the approximate voltage from the CRT display, it is a simple matter to read the precise, actual voltage from the Reference controls.

The current reference can be easily used as a precision ohmmeter simply by connecting the resistance to J1 and J3. Leave R3 set at "1.00", set S4 to read current from J1, set S3 to 2.0 volts, and raise compliance control R13 so that there is no "compliance" Advance S1 from 1 to 1000 microamps and find the highest voltage reading that can be displayed on DISP1 Dividing the voltage by the current setting gives the resistance If you need to read higher or lower resistance readings than normal, set S3 to 200 millivolts or 20 volts and set R3 to "10.00", if required

The current source output can also be used to precisely forward or reverse bias a semiconductor junction, with the display measuring the resulting voltage drop. Reverse voltages of up to about 11 volts can be measured with R13 in the "off" position Zener diodes, signal diodes, LEDs, and laser diodes are easily tested Be sure not to exceed the maximum reverse voltage on the component or it will be destroyed. Light-emitting diodes and laser diodes are especially sensitive to reverse voltages Keeping the reverse voltage below 3 volts will protect most LEDs

Laser diodes will not "lase" at very low currents levels when being tested by the Precision Reference It is quite easy to identify the package leads in laser diodes, as the PIN photo-diode will have a forward drop of about 0.7 volts, while the laser diode will exhibit a forward drop of about 2.0 volts.

You can also identify the leads on bipolar transistors the same way. As most emitter–base reverse-breakdown voltages on silicon transistors are below 11 volts, the Reference should be used at a setting of about 10 to 100 microamps to locate that junction. The collector–base reverse-breakdown voltages are usually well above 20 volts Of course, the forward voltages of both junctions are about 0.7 volts.

As you can see, the Precision Reference has unlimited applications. The display is only for showing the load voltages at the current source output—the voltage-source output-control settings have much more resolution than the 3½-digit display If you're more interested in ultimate display accuracy, it's a good idea to invest in a 4½-digit digital-panel meter which will have higher resolution Ω