

## Dc differential voltmeter resolves 1 microvolt

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If you're dissatisfied with the choice of commercially available dc differential voltmeters, here's a high-performance unit that you can build yourself for about \$800. Besides functioning as a high-resolution differential voltmeter, this instrument can serve as a picoammeter or an adjustable voltage-reference source. It affords good stability, an absolute five-place accuracy of  $\pm 0.001\%$ , and a resolution of 1 microvolt. It also provides an output for a ground-referenced stripchart recorder and overload protection for its nullmeter.

The voltmeter is intended for use with standard cells, temperature-compensated zener diodes, and other precision low-voltage sources. Its input voltage range is 0 to 10 v, and its operating temperature range is  $20^{\circ}\text{C}$  to  $30^{\circ}\text{C}$ .

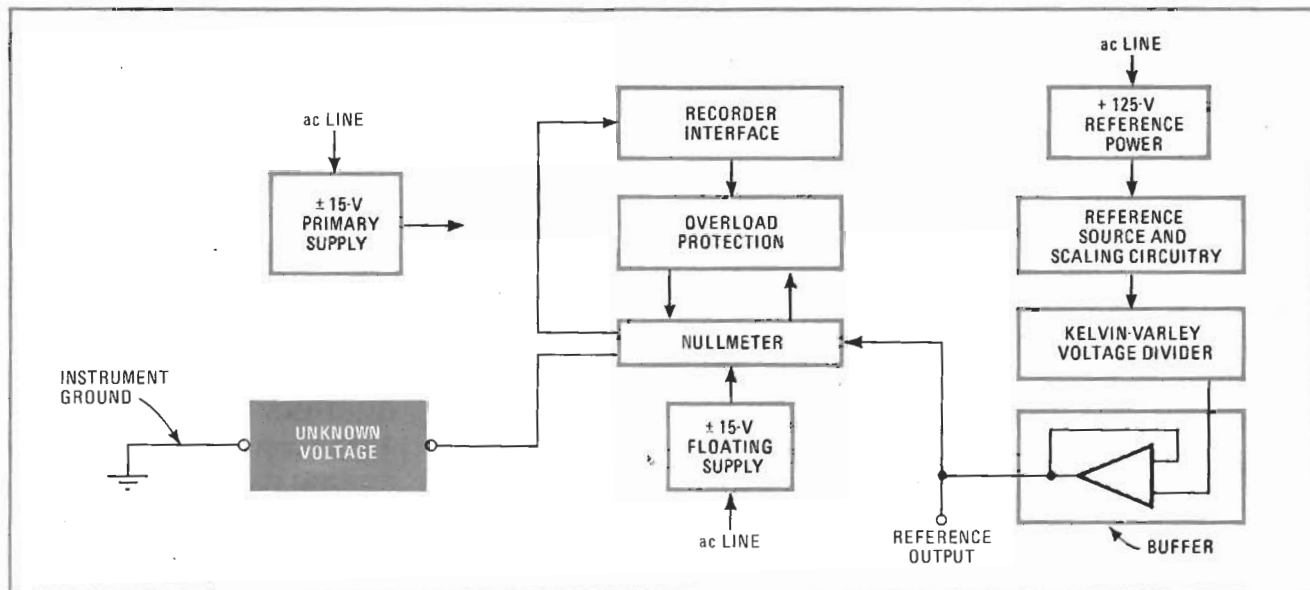
In general, a high-resolution differential voltmeter makes a measurement in a classical potentiometric way. A stable voltage reference is placed across a variable voltage divider, whose output is applied to one input of a high-sensitivity voltmeter. The voltage to be measured is applied to the other input of the voltmeter. When the divider is adjusted to the same potential as the unknown voltage, the voltmeter will read zero. Since no current flows through the voltmeter during null, the unknown voltage sees an infinite impedance.

The block diagram of the voltmeter is given in Fig. 1. The instrument includes a high-stability solid-state voltage-reference source and a nullmeter having a full-scale resolution as fine as  $5\ \mu\text{V}$ . Since the input impedance of the nullmeter is known, the unit can also function as a highly accurate picoammeter for determining low-level offset and bias currents. If the meter goes off scale, there are indicators to show which way to bring the meter back on scale.

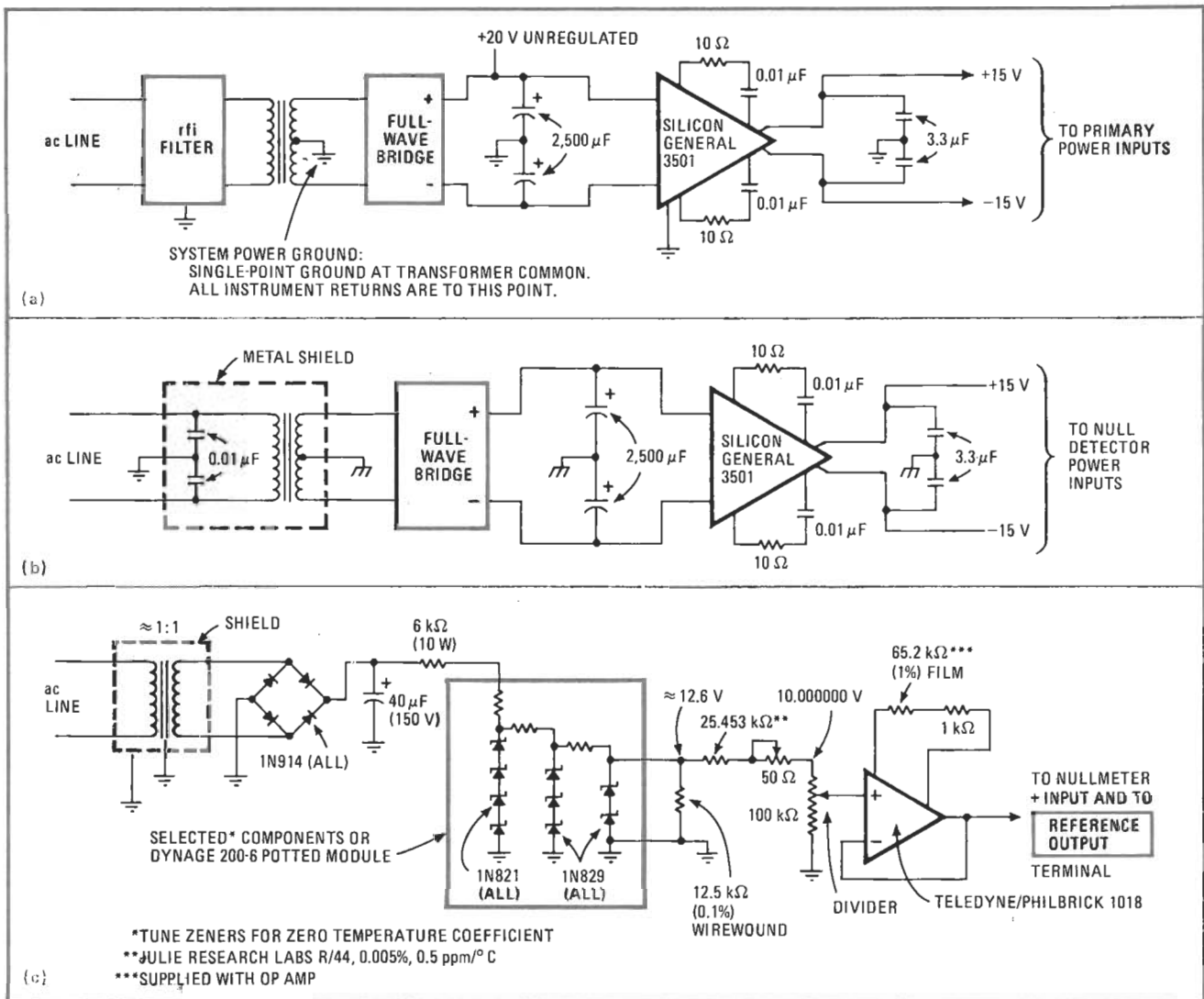
The output for the ground-referenced stripchart recorder is derived from the floating nullmeter without introducing leakage across either the voltage divider or the voltage to be measured. The buffer amplifier connected to the divider permits the voltmeter to be used as a variable voltage-reference source that can be set to within  $\pm 0.001\%$ .

Briefly, here's how the instrument works. The ac line furnishes power to both the 125-v unregulated supply and the two  $\pm 15\text{-v}$  supplies, one of which is floating. The 125-v supply acts as a pseudo-current source while driving the voltage-reference source. The output of the reference, which is approximately 12.6 v, is resistively scaled to 10.000000 v (at  $25^{\circ}\text{C}$ ) across the Kelvin-Varley voltage divider. The divider's output is buffered by an ultra-stable unity-gain amplifier that provides the REFERENCE OUTPUT terminal for the instrument. When the output from the divider equals the unknown voltage, the nullmeter will read zero so that the unknown is then equal to the divider setting.

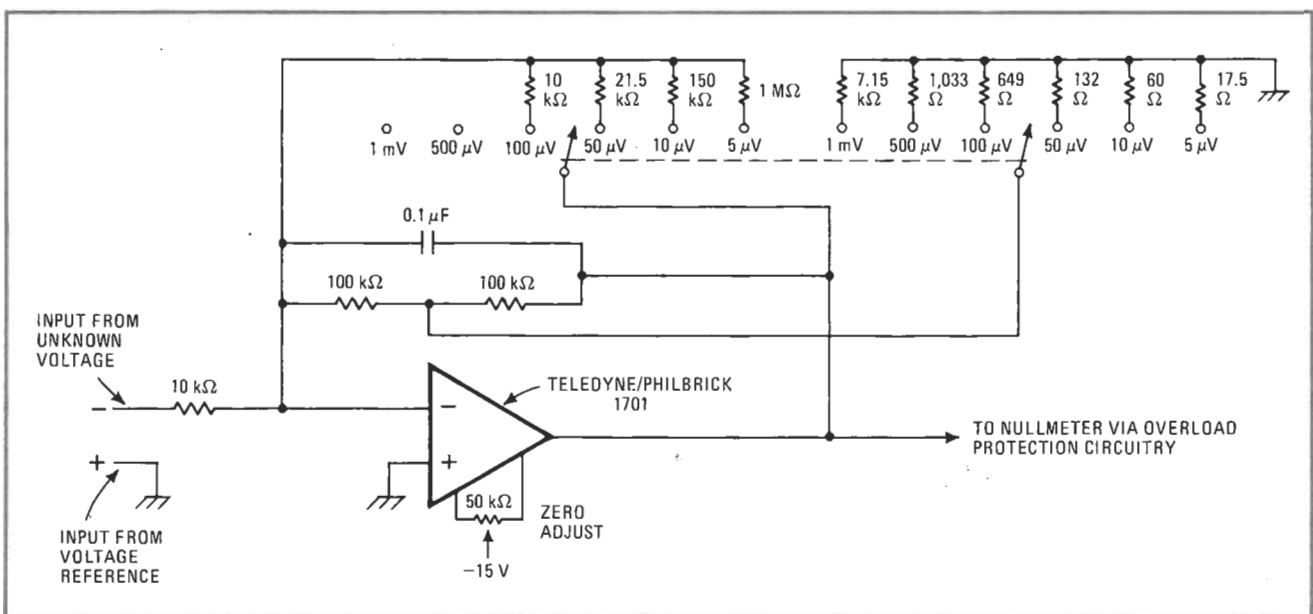
For the  $\pm 15\text{-v}$  primary power supply (Fig. 2a), a monolithic tracking voltage regulator is wired in its standard configuration. The two 10-ohm resistors provide overload sensing, and the capacitors smooth out and prevent spurious oscillations. System ground is at



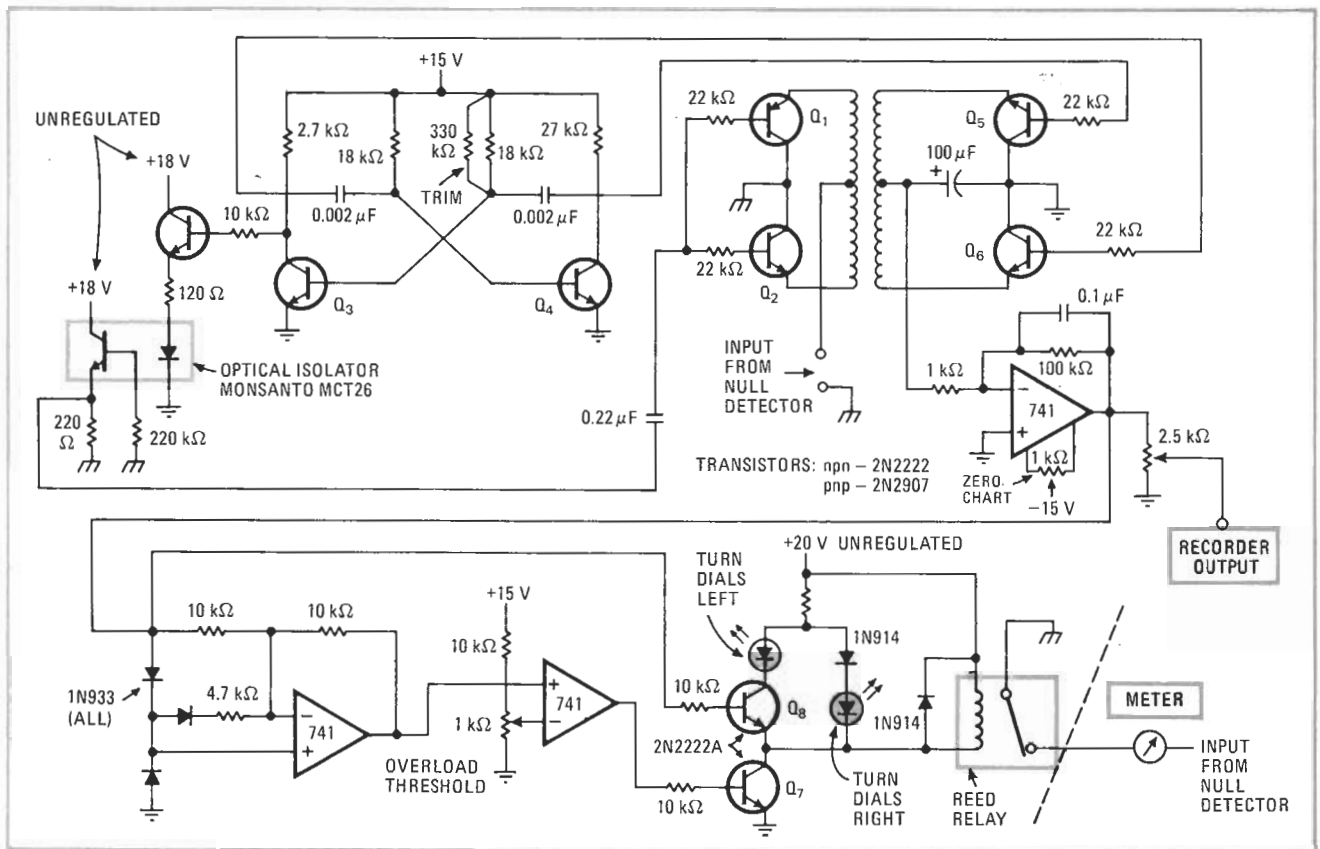
**1. Performance plus trimmings.** This high-resolution differential voltmeter takes advantage of modern solid-state technology to provide both accuracy and stability at reasonable cost. Its floating nullmeter, which is protected against overloads, assures a true differential measurement. The instrument also has a settable voltage-reference output, as well as a ground-referenced output for a stripchart recorder.



**2. The voltage sources.** The voltmeter's primary  $\pm 15\text{-V}$  supply (a) is ground-referenced, but the  $\pm 15\text{-V}$  supply (b) for its null detector is floating. The ultra-stable reference source (c), which is used to match the unknown voltage, contains an array of specially selected zeners.



**3. Precision null detector.** A chopper-stabilized amplifier is at the heart of the instrument's null detector. A T-type feedback network, which is used to set amplifier gain, minimizes leakage problems and keeps the sizes of the feedback resistances at practical levels.



4. The outputs. A ground-referenced output for a stripchart recorder is developed from the null-detector's output by isolating the floating detector with an optical coupler. LED indicators show which way to null the meter. The reed relay disconnects the meter during overloads.

the transformer common, and all common power returns are brought to this point. There are no common power bus lines in the instrument—a precaution that must be taken to avoid corrupted grounds. Moreover, an rfi filter is used to block spikes from the ac line. A similar circuit, (Fig. 2b), but one with a floating ground, is used for supplying the instrument's null detector.

The voltage-reference source (Fig. 2c) is powered by the voltage derived from the transformer and its rectification components. The cascaded temperature-compensated zener diodes are specially selected for optimum matched parameters and are aged to produce stabilities greater than those of unsaturated standard cells. But a commercially available module can be used instead, if desired.

The reference output is scaled to 10 v across the divider. An ultra-stable, low-bias-current op amp buffers the output of the divider for the instrument's nullmeter input and its REFERENCE OUTPUT terminal. The output current for the voltage reference can range from 0 to 3.5 milliamperes. Its stability is  $\pm 1$  ppm for a 10% shift in line voltage,  $\pm 2$  ppm for a 1°C change in operating temperature, and  $\pm 5$   $\mu$ V maximum over a 24-hour period.

The instrument's null detector (Fig. 3) is designed around a chopper-stabilized amplifier. Since it is powered by a floating supply, this amplifier sees a true differential signal at its inputs. The power common line is used as one of the inputs, but the power and signal common returns are separated to minimize grounding loops and noise. A T-type feedback network sets amplifier

gain, helps to hold feedback resistances to practical levels, and avoids leakage problems.

Overload protection for the meter movement and the output for a stripchart recorder are provided by the circuit of Fig. 4. The ground-referenced recorder output preserves the integrity of the nullmeter's true floating ground and simplifies the interfacing of the recording device.

The input for this circuit, which is the output from the null detector, drives the pulse-amplitude modulator formed by the transformer and transistors Q<sub>1</sub> and Q<sub>2</sub>. The signal is chopped at the frequency set by the multi-vibrator made up of transistors Q<sub>3</sub> and Q<sub>4</sub>. The chopping drive signal must be fed through an optical isolator because the multivibrator, which is the source of the chopping signal, is instrument-grounded. The signal that appears at the transformer secondary is demodulated synchronously by transistors Q<sub>5</sub> and Q<sub>6</sub>. The multi-vibrator's trim resistor is selected to give a symmetrical swing about zero at the demodulated output. This output is then amplified for the recorder hookup.

The input for the overload protection circuit is taken from the signal developed for the stripchart recorder. The first stage of this circuit takes the absolute value of the recorder output. When the meter is overloaded, transistor Q<sub>7</sub> conducts. If the base voltage of transistor Q<sub>8</sub> is high, the meter is off scale in its plus zone, and the TURN DIALS LEFT indicator will light. If Q<sub>8</sub>'s base is low, the meter is off scale in its minus zone, and the TURN DIALS RIGHT indicator will come on. In either case, the reed relay disconnects the meter during an overload. □