

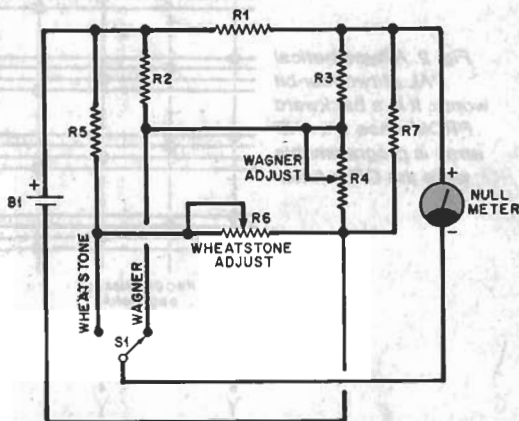
commonly employed in precision, computerized procedures that are used to measure resistance.

If the measured resistance is of low value, test-lead resistance can be a source of significant error. The standard remedy for this is to use separate current-carrying and voltage-measuring leads. This avoids measurement of the IR drop in each current-carrying lead and is known as the *Kelvin* technique.

The in-circuit measurement techniques that have been presented can also eliminate the effects of semiconductors upon the resistance reading. However, any semiconductor present in the circuit might be called upon to dissipate power if it is part of the driven shunt path. Two practices are advised if this is the case. In a constant-voltage circuit, employ a measuring voltage that is less than the conduction threshold of the pn junction. In a constant-current circuit, reverse the polarity of the meter probes. These steps will effectively turn the semiconductor junction into an open circuit for the purposes of the resistance measurement and eliminate a source of potential error.

**Practical Tips.** A number of in-circuit measurement techniques have been presented in this article. However, there are several practical effects that should be considered before these techniques

Fig. 6. A Wagner bridge circuit such as that shown here can be used to measure resistance of an in-circuit component.



are implemented. These will now be summarized.

Thermoelectric voltages can be set up at the junctions of dissimilar conductors, as well as between points on the same conductor across which a thermal gradient exists. Although they are very small for ordinary working temperatures and materials commonly fabricated into probes and leads, these voltages can cause significant error if they are amplified as part of the measuring process. They can also be troublesome if the test potential of the ohmmeter is kept low to prevent semiconductor junctions from becoming forward-biased and influencing the reading. This type of error can be reduced by certain design techniques or by determining its magnitude and then subtracting it from the overall reading. The latter technique is

In measuring circuits containing an operational amplifier, certain precautions should be observed. It is wise to install 0.01- $\mu$ F disc ceramic bypass capacitors close to the IC package from the positive and negative power-supply leads to ground. This will enhance circuit stability. Input overvoltage and output short-circuit protection must also be considered. Many contemporary op amps, such as the Motorola MC1456, provide such protection internally. In those measurement situations which call upon the op amp to source more current into the driven shunt resistance than is available from the op amp, a current booster such as the Motorola MC1438R can be employed. Details on the use of the latter chip can be found in the manufacturer's *Applications Handbook* and its *Linear Circuits Manual*.  $\diamond$

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