Technical Information

Low Voltage/Low Resistance Measurements

How to Select a Voltmeter

Many kinds of instruments can measure voltage, including digital multimeters (DMMs), electrometers, and nanovoltmeters. Making voltage measurements successfully requires a voltmeter with significantly higher input impedance than the internal impedance (source impedance) of the device under test (DUT). Without it, the voltmeter will measure less potential difference than existed before the voltmeter was connected. Electrometers have very high input impedance (typically in the order of 100TΩ [10^{14} Ω]), so they're the instrument of choice for high impedance voltage measurements. DMMs and nanovoltmeters can typically be used for measuring voltages from 10MΩ sources or lower. Nanovoltmeters are appropriate for measuring low voltages (microvolts or less) from low impedance sources.

Low Voltage Measurements

Significant errors may be introduced into low voltage measurements by offset voltage and noise sources that can normally be ignored when measuring higher signal levels. Steady offsets can generally be nulled out by shorting the ends of the test leads together, then enabling the instrument's zero (relative) feature. The following paragraphs discuss non-steady types of error sources that can affect low voltage measurement accuracy and how to minimize their impact on the measurements.

Thermoelectric EMFs

The most common sources of error in low voltage measurements are thermoelectric voltages (thermoelectric EMFs) generated by temperature differences between junctions of conductors (**Figure 1**).

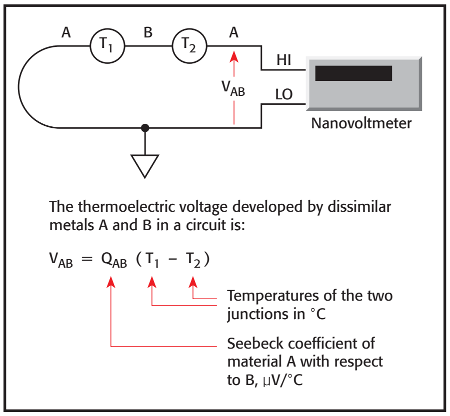

Figure 1. Thermoelectric EMFs

Constructing circuits using the same material for all conductors minimizes thermoelectric EMF generation. For example, connections made by crimping copper sleeves or lugs on copper wires results in cold-welded copper-to-copper junctions, which generate minimal thermoelectric EMFs. Also, connections must be kept clean and free of oxides.

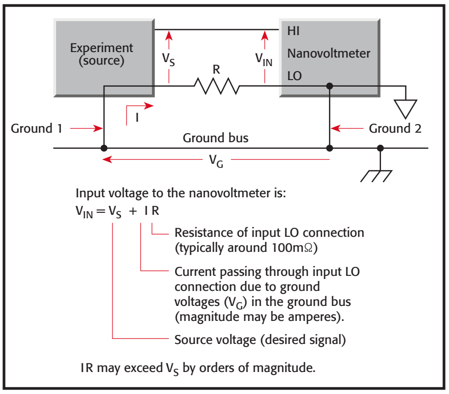

Figure 2a. Multiple grounds (ground loops)

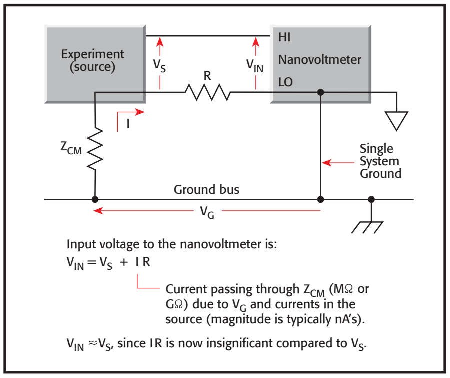

Figure 2b. Single system ground

Minimizing temperature gradients within the circuit also reduces thermoelectric EMFs. A way to minimize such gradients is to place all junctions in close proximity and provide good thermal coupling to a common, massive heat sink. If this is impractical, thermally couple each pair of corresponding junctions of dissimilar materials to minimize their temperature differentials which will also help minimize the thermoelectric EMFs.

Johnson Noise

The ultimate limit to how well the voltmeter can resolve a voltage is defined by Johnson (thermal) noise. This noise is the voltage associated with the motion of electrons due to their thermal energy. All sources of voltage have internal resistance and thus produce Johnson noise. The noise voltage developed by any resistance can be calculated from the following equation:

$$V = \sqrt{4kTBR}$$

k = Boltzmann's constant (1.38×10^{-23} J/K)
T = absolute temperature of the source in Kelvin
B = noise bandwidth in Hz
R = resistance of the source in ohms

From this equation, it can be observed that Johnson noise may be reduced by lowering the temperature and by decreasing the bandwidth of the measurement. Decreasing the bandwidth of the measurement is equivalent to increasing the response time of the instrument; thus, in addition to increasing filtering, the bandwidth can be reduced by increasing instrument integration (typically in multiples of power line cycles).

Ground Loops

When both the signal source and the measurement instrument are connected to a common ground bus, a ground loop is created (**Figure 2a**). This is the case when, for instance, a number of instruments are plugged into power strips on different instrument racks. Frequently, there is a difference in potential between the ground points. This potential difference—even though it may be small—can cause large currents to circulate and create unexpected voltage drops. The cure for ground loops is to ground the entire measurement circuit at only one point. The easiest way to accomplish this is to isolate the DUT (source) and find a single, good earth-ground point for the measuring system, as shown in **Figure 2b**. Avoid grounding sensitive measurement circuits to the same ground system used by other instruments, machinery, or other high power equipment.

Magnetic Fields

Magnetic fields generate spurious voltages in two circumstances: 1) if the field is changing with time, and 2) if there is relative motion between the circuit and the field (**Figure 3a**). Changing magnetic fields can be generated from the motion of a conductor in a magnetic field, from local AC currents caused by components in the test system, or from the deliberate ramping of the magnetic field, such as for magnetoresistance measurements.

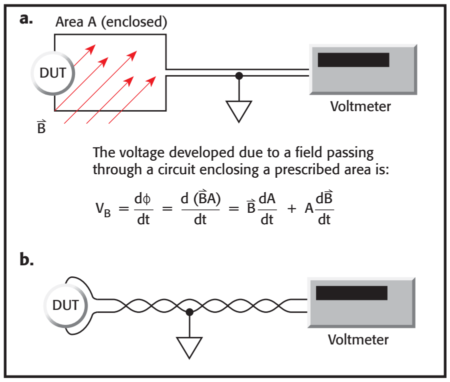

Figure 3. Minimizing interference from magnetic fields with twisted leads

To minimize induced magnetic voltages, leads must be run close together and should be tied down to minimize movement. Twisted pair cabling reduces the effects of magnetic fields in two ways: first, it reduces the loop area through which the magnetic