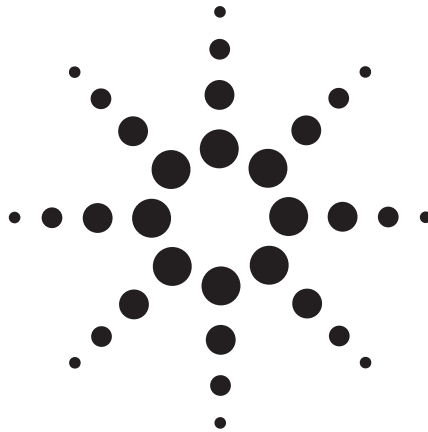


# System Cabling Errors and DC Voltage Measurement Errors in Digital Multimeters

Application Note AN 1389-1



## Introduction

When making measurements with a digital multimeter (DMM), common errors will crop up. The following discussion will help you eliminate potential measurement errors and achieve the greatest accuracy with a DMM. This paper covers system cabling errors and dc voltage measurement errors. For an overview of ac voltage measurement errors, see Application Note AN 1389-3. For a discussion of resistance; dc current; ac current; and frequency and period measurement errors, see Application Note AN 1389-2. (NOTE: The Agilent 34401A, a 6-1/2-digit, high-performance DMM with both benchtop and system features, will be used as an example throughout this article).



## System Cabling Errors

### Radio Frequency Interference —

Most voltage-measuring instruments can generate false readings in the presence of large, high-frequency signal sources such as nearby radio and television transmitters, computer monitors, and cellular telephones. High-frequency energy can also be coupled to the multimeter on the system cabling. To reduce interference, try to minimize the exposure of the system cabling to high-frequency RF sources. If the application is extremely sensitive to RFI radiating from the multimeter, use a common mode choke in the system cabling, as shown in Figure 1, to attenuate multimeter emissions.

### Thermal EMF Errors —

Thermoelectric voltages, the most common source of error in low-level voltage measurements, are generated when circuit connections are made with dissimilar metals at different temperatures. Each metal-to-metal junction forms a *thermocouple*, which generates a voltage proportional to the junction temperature. It is a good idea to take the necessary precautions to minimize thermocouple voltages and temperature variations in low-level voltage measurements. The best connections are formed using copper-to-copper crimped connections. Figure 2 shows common thermoelectric voltages for connections between dissimilar metals.

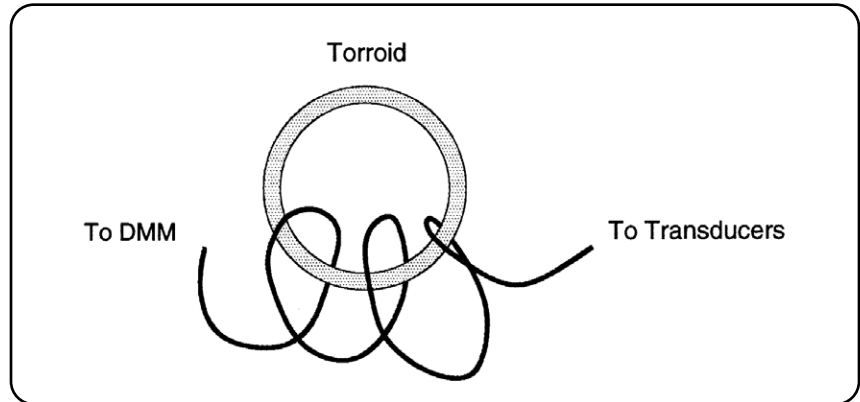


Figure 1.

### Noise Caused by Magnetic Fields —

When you make measurements near magnetic fields, take precautionary steps to avoid inducing voltages in the measurement connections. Voltage can be induced by either movement of the input connection wiring in a fixed magnetic field, or by a varying magnetic field. An unshielded, poorly dressed input wire moving in the earth's magnetic field can generate several millivolts. The varying magnetic field around the ac power line can also induce voltages up to several hundred millivolts. Be especially careful when working near conductors carrying large currents.

Where possible, route cabling away from magnetic fields, which are commonly present around electric motors, generators, televisions and computer monitors. In addition, when you are operating near magnetic fields, be certain that the input wiring has proper strain relief and is tied down securely. Use twisted-pair connections to the multimeter to reduce the noise pickup loop area, or dress the wires as closely together as possible.

Copper-to-	Approx. $\mu\text{V} / ^\circ\text{C}$
Copper	< 0.3
Gold	0.5
Silver	0.5
Brass	3
Beryllium Copper	5
Aluminum	5
Kovar or Alloy 42	40
Silicon	500
Copper-Oxide	1000
Cadmium-Tin Solder	0.2
Tin-Lead Solder	5

Figure 2.

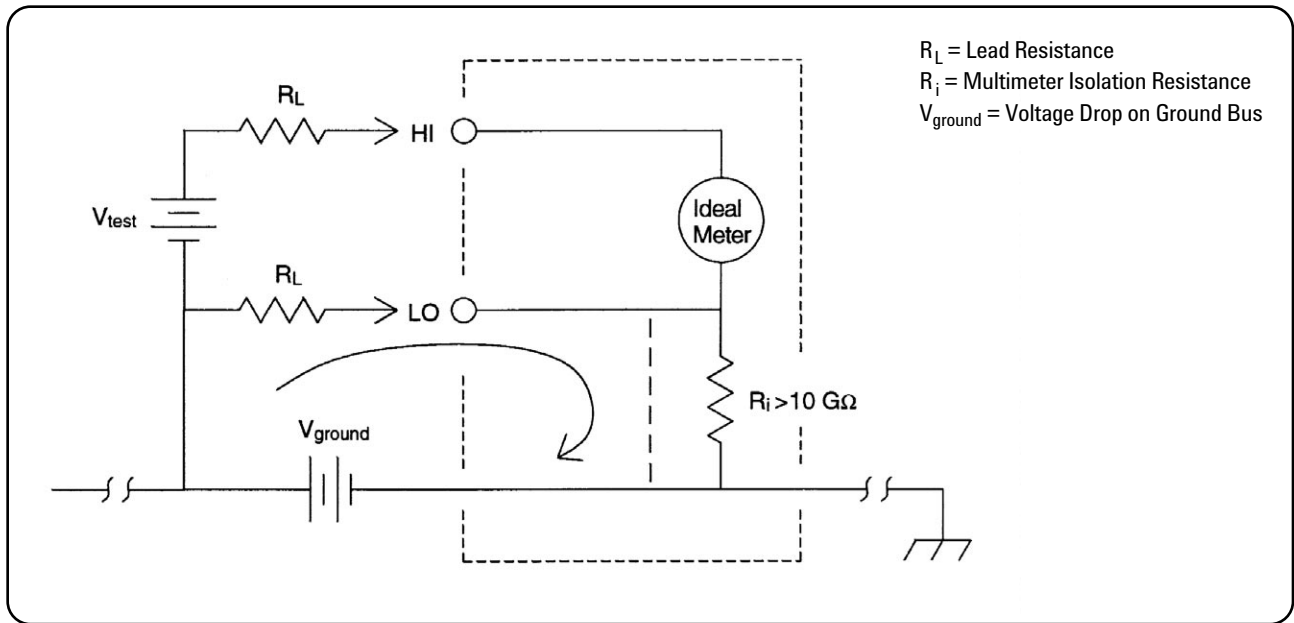


Figure 3.

**Noise Caused by Ground Loops** — When you measure voltages in circuits where the multimeter and the device-under-test (DUT) are both referenced to a common earth ground, a *ground loop* is formed. As shown in Figure 3, any voltage difference between the two ground reference points ( $V_{ground}$ ) causes a current to flow through the measurement leads. This causes errors, such as noise and offset voltage (usually power-line related), which are added to the measured voltage.

The best way to eliminate ground loops is to maintain the multimeter's isolation from earth; do not connect the input terminals to ground. If the multimeter must be earth-referenced, be sure to connect it and the DUT to the same common ground point. This will reduce or eliminate any voltage difference between the devices. Also, whenever possible, make sure the multimeter and DUT are connected to the same electrical outlet.

# DC Voltage Measurement Errors

## Common Mode Rejection –

Ideally, a multimeter is completely isolated from earth-referenced circuits. However, there is finite resistance between the multimeter’s input LO terminal and earth ground, as shown in Figure 4. This can cause errors when you measure low voltages that are floating relative to earth ground.

**Noise Caused by Injected Current.** Residual capacitances in the multimeter’s power transformer cause small currents to flow from the LO terminal to earth ground. The frequency of the *injected current* is the power line frequency or possibly harmonics of the power line frequency. The injected current is dependent upon the power line configuration and frequency. A simplified circuit is shown in Figure 5.

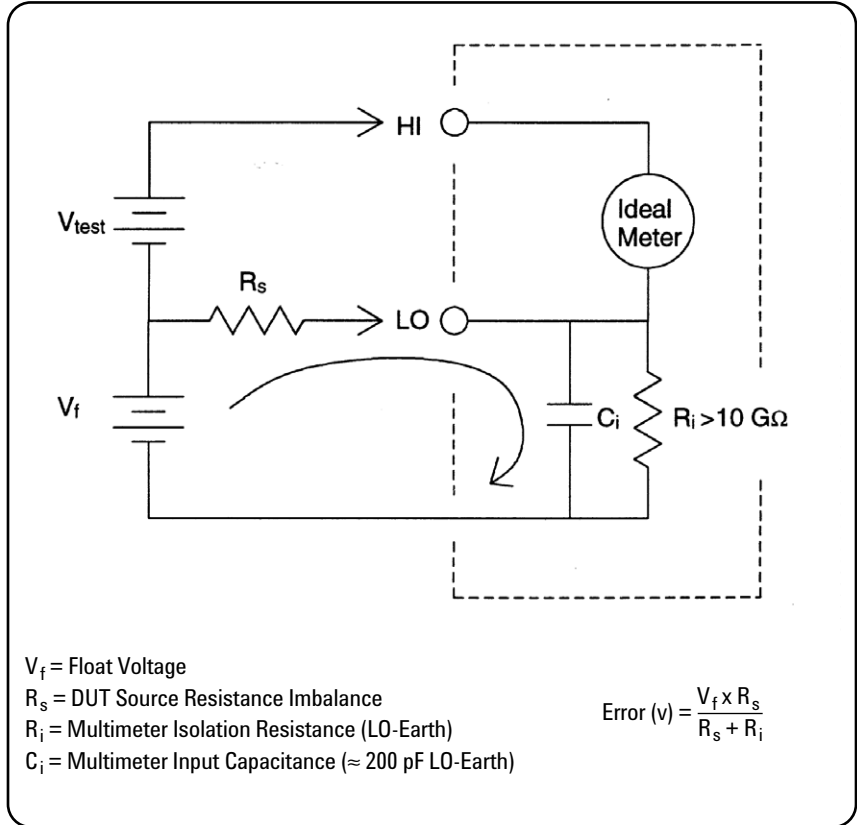


Figure 4.

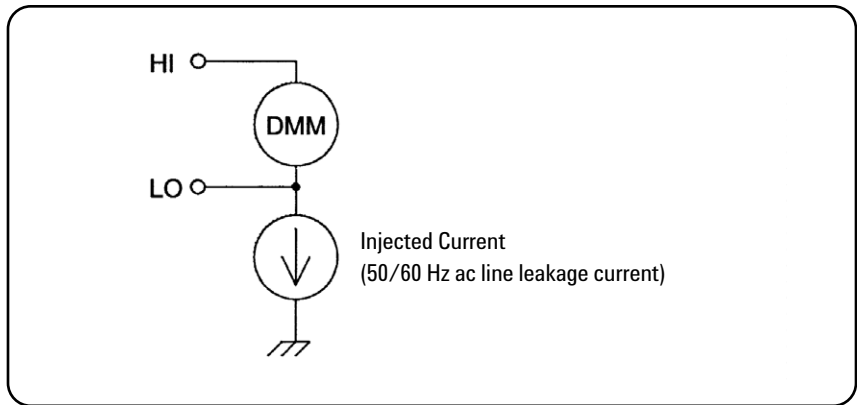


Figure 5.

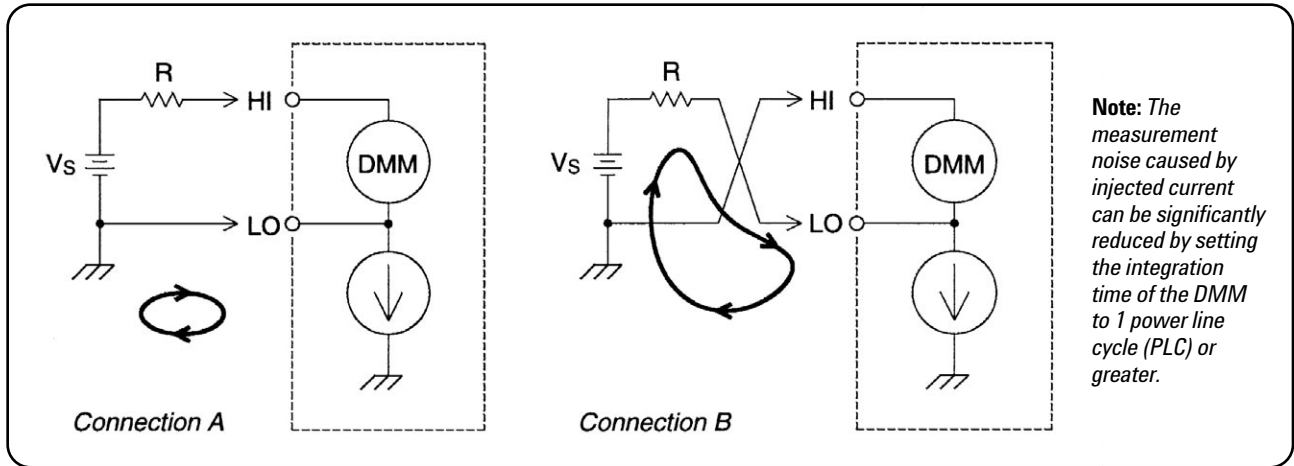


Figure 6.

With *Connection A* (see Figure 6), the injected current flows from the earth connection provided by the circuit to the LO terminal of the DMM, adding no noise to the measurement. However, with *Connection B*, the injected current flows through the resistor R, thereby adding noise to the measurement. With *Connection B*, larger values of R will worsen the problem.

**Loading Errors Due to Input Resistance** – Measurement loading errors occur when the resistance of the DUT is an appreciable percentage of the multimeter’s own input resistance. Figure 7 shows this error source.

To reduce the effects of loading errors, and to minimize noise pickup, set the Agilent 34401A’s input resistance to greater than 10 GΩ for the 100 mVdc, 1 Vdc, and 10 Vdc ranges. The input resistance is maintained at 10 MΩ for the 100 Vdc and 1000 Vdc ranges.

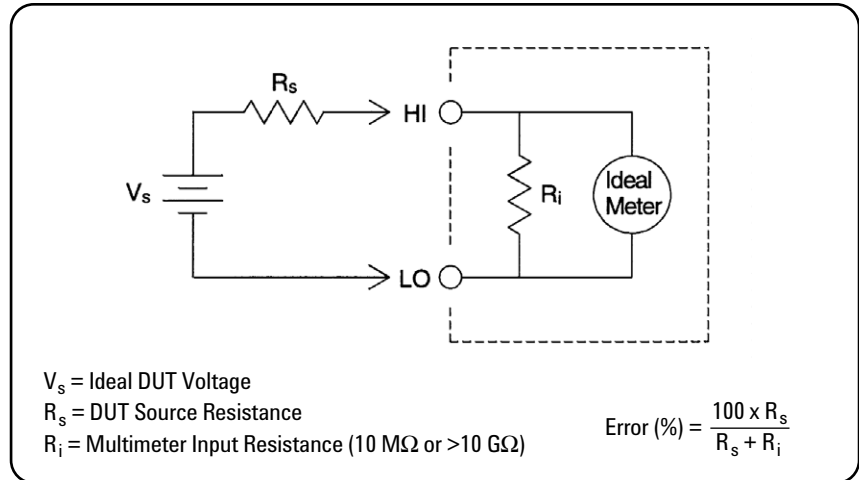


Figure 7.

**Loading Errors Due to Input Bias Current** – The multimeter’s input capacitance will "charge up" due to input bias currents when the terminals are open-circuited (if the input resistance is 10 GΩ). The multimeter’s measuring circuitry exhibits approximately 30 pA of input bias current for ambient temperatures from 0 °C to 30 °C. Bias current will double (x2) for every 8 °C change in ambient temperature above 30 °C. This current generates small voltage offsets dependent upon the source resistance of the DUT. This effect becomes evident for a source resistance of greater than 100 kΩ, or when the multimeter’s operating temperature is significantly greater than 30 °C.

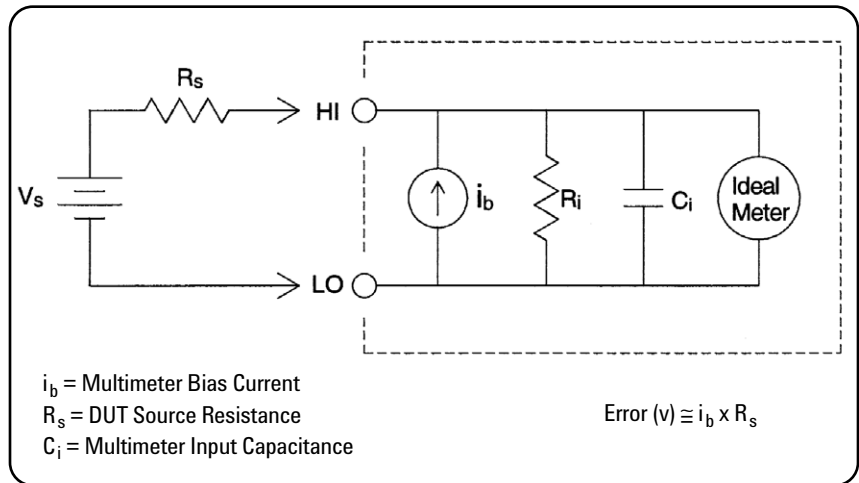


Figure 8.

## Conclusion

A modern DMM such as the 34401A has many features to help protect you from many common sources of error. However, when making low-level or precise measurements, you must be more aware of sources that contribute to measurement errors. Environmental conditions – such as changes in temperature, RF signals and electromagnetic fields – will have a significant impact on the quality of DMM measurements. Once the measurement environment has been optimized, proper cabling can significantly reduce measurement errors. The remaining sources of error can be calculated and added to the measurement uncertainty.

For more information about the Agilent 34401A, go to [www.agilent.com/find/34401a](http://www.agilent.com/find/34401a)

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