Chapter 32:

Grounding, Shielding and Guarding

This chapter discusses the grounding, shielding and guarding of instruments. It focuses on interconnecting cables and how to use them properly to prevent unwanted currents and radiated signals from affecting the accuracy of precision measurements.

This chapter discusses grounding, shielding, and guarding of interconnected instruments. While these are not measurement techniques, they can have a significant effect on a measurement. By following the basic do's and don'ts in these areas, hard-to-find measurement errors can be avoided. This is particularly true when several instruments and a number of different types of cable are used in precision measurements, as in a test system. There are other possible sources of error in instruments and their interconnections. These include leakage currents, thermal emfs, contact resistance, and transients. They are discussed in Chapter 33, "A Rogues' Gallery of Parasitics."

Measurement set-up schematics and block diagrams show components and circuits in ideal situations for interconnecting instruments and cables. In best-case conditions, connecting wires have no unwanted resistance or reactances; metal-to-metal contacts involve no contact resistance or thermal voltages. Ideally, the laboratory area is free of unwanted signals that can affect the measurement.

In the real world, wires do have unwanted resistance and reactances and there are unwanted signals present which affect the ability to make high quality measurements. Making precision measurements depends on control of these important but sometimes subtle factors.

While the concepts of grounding, shielding, and guarding are not difficult to grasp, the detail of their proper application can be rather complex. Although not all of the material in this chapter may be of interest to the reader with only a casual interest in precision measurement, information included in the subsections titled "Practical Hints" should be of value in common measurement situations. These hints simplify the choice and application of the various wires and cables that are available in the laboratory, and guide one around many of the pitfalls that may be encountered. This chapter will also explain the purpose and application of the various terminals, switches, and connectors labeled guard, shield, ground, and chassis.

Grounding

Ideal vs. Real Ground

An ideal ground has no resistance to current flow. The result is that there is no voltage drop between different points along the ground, regardless of the amount of current flowing. This is illustrated in Figure 32-1 which shows two loops, both of which use a common ground.

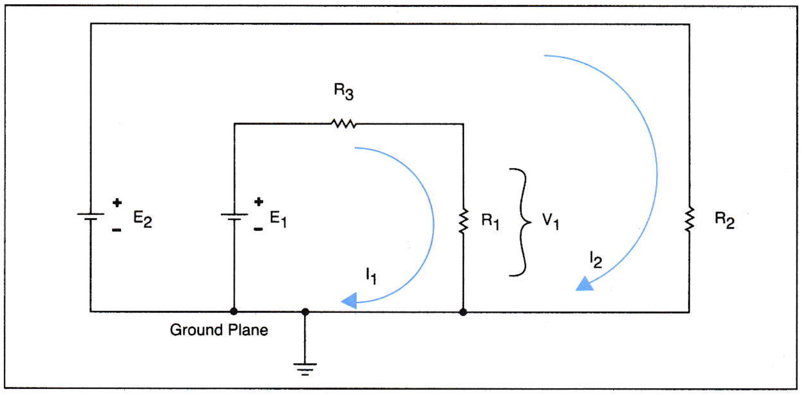

Figure 32-1. *Ideal Ground*

The loop with E_1, R_1, and R_3 is a voltage divider. The output voltage from the divider (V_1) is unaffected by the current in the other loop consisting of E_2 and R_2.

In the ideal case, the divider's output is:

$$V_1 = E_1 \frac{R_1}{R_1 + R_3}$$

In reality, ground has a finite resistance, which results in potential drop along the ground when current is flowing through it. This can cause errors in a measurement system if care is not taken to control the flow of currents. Figure 32-2 illustrates this effect.

The ideal ground is replaced with lumped equivalent resistances, r_1 and r_2. The output of the voltage divider V_1 is now affected by the current in the other loop, I_2.

In the real case, it becomes:

$$V_1 = (E_1 - I_2 r_1) \frac{R_1}{R_1 + R_3 + r_1}$$

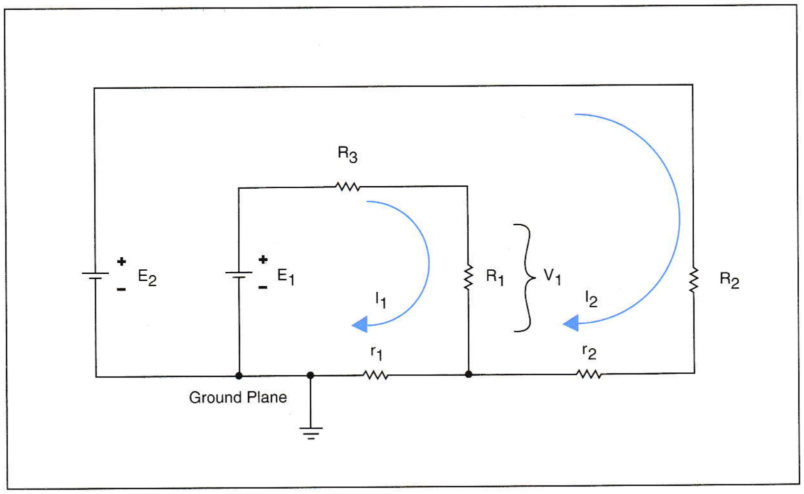

Figure 32-2. *Real Ground*

The addition of the ground resistance r_1 has changed the divider output V_1 in two ways. First, it has added resistance to the divider loop, which changes the division ratio. Secondly, current in r_1 from the second loop I_2 can now affect the value of V_1. The change in division ratio can be handled by ensuring that the value of r_1 remains constant and by changing the value of R_1 or R_3 to compensate for the addition of r_1. The error caused by I_2, which is called a ground loop error, is normally handled by changing the ground connections so that I_2 does not flow through r_1 as shown in Figure 32-3.

Instead of using a common ground for both loops, the ground return is split into two returns, one for each loop.

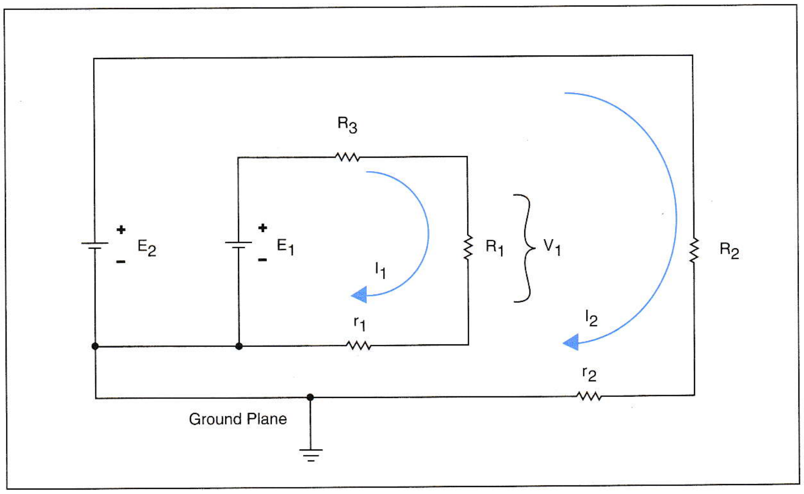

Figure 32-3. *Separate Ground Returns*

Practical Hint

- Use a separate ground return for any loop involving a precision circuit so that only the current from that loop and no other loop flows through it.

Power Line Ground Systems

A typical U.S. power mains connection to an instrument is shown in Figure 32-4.

The High and Neutral wires carry the load current, I_L, to the primary of the power transformer. A safety Ground connection is normally present. It is connected to the case or chassis of the instrument and its purpose is to carry fault current to ground through a low resistance path. Typically, the Neutral connection is grounded at the distribution point and must be isolated from the instrument case so that none of the load current flows through the safety Ground.

Safety-Ground Ground Loop Errors

In a typical laboratory environment, power mains are distributed along a bus connected to the various pieces of equipment. Figure 32-5 shows a power strip which is fed from one end and powers several instruments.

Stray leakage capacitance $c_1, c_2, \ldots, c_n$ from the High side of the line to the instrument chassis, such as the capacitance in the emi filters or the capacitance in power transformers from the primary winding to the core, causes current to flow through the safety Ground and back to the distribution point. Thus there will be a voltage drop along the Ground line, due to distributed resistance r_g, and the chassis of each piece of equipment will be at a slightly different potential.

This ground current can cause a measurement error when the signal Lo lead is not isolated from ground as shown in Figure 32-6.

The current flowing in the Safety Ground lead splits along two paths. A portion flows through the signal Lo lead, creating a voltage drop that adds to the desired source signal. This drop may be of little consequence if the measuring instrument has good rejection of power line frequencies, as would be the case with a typical dc DMM. However, it may be very significant for an ac DMM.

This problem is often solved by the use of guarding, a technique that will be covered later in this chapter. However, for equipment where the low input or output is grounded, typical of rf equipment, guarding would be ineffective. Here it is important to ensure that all instruments have a common earth return, and that good quality coax cable is used to interconnect them.

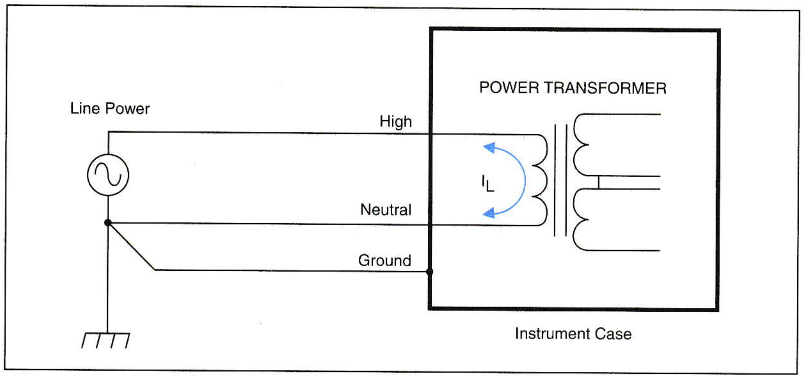

Figure 32-4. *Power Mains*

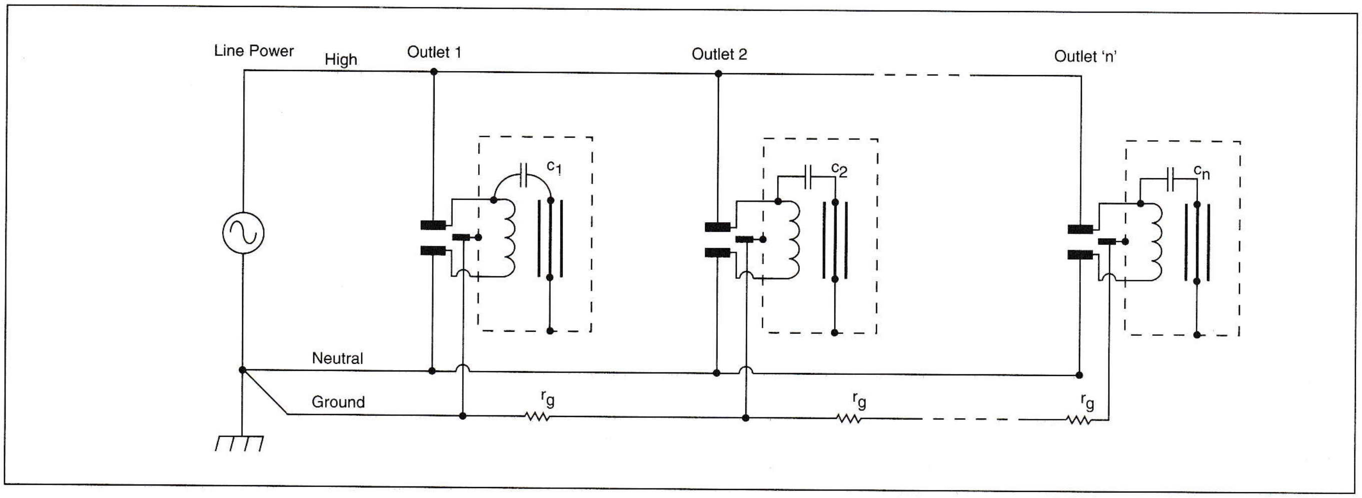

Figure 32-5. *Leakage Capacitance*

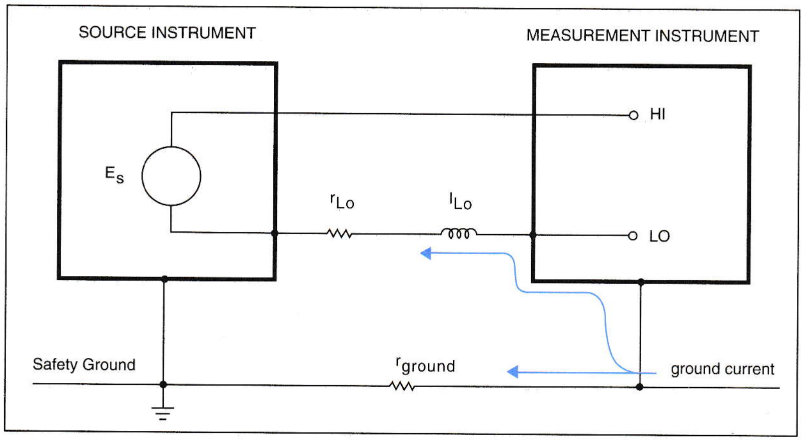

Figure 32-6. *Ground Loop*

Practical Hints

- If possible, plug the power cords of the instruments into the same receptacle. This will minimize the value of r_{ground} and thus the current through r_{Lo} and l_{Lo}.
- If possible, remove the equipment that is putting a lot of current into the Safety Ground and plug it into another branch circuit.
- Keep signal interconnections as short as possible with low resistance cable to reduce resistive and reactive impedances. Coaxial cable is often the best choice, particularly for rf signals.
- Never operate equipment with the connection between chassis ground and power-line ground unconnected. This undesirable situation occurs when using a three-to-two wire adapter (cheater plug). This defeats a prime element of protection against electric shock.
- It is possible for some of the signal current to flow through the safety ground and thus create a ground loop that causes an error in

the measurement. Figure 32-7 shows such a situation where the measurement error can be substantial.

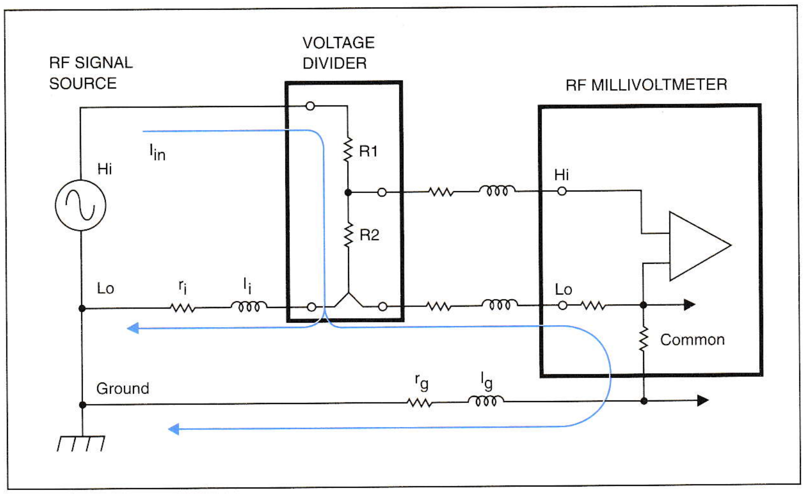

Figure 32-7. *RF Ground Loop*

Here, an rf signal source is connected to the input of a voltage divider with the output going to the input of an rf millivoltmeter. The divider input current, I_{in}, splits at the bottom of the divider and some of it returns to the source through the output cable to the meter Lo lead and the Safety Ground. This current causes a voltage drop in the Lo lead due to the resistance and inductance of the output cable and leads in the meter. This voltage drop adds to the signal from the divider, causing an error in the measurement.

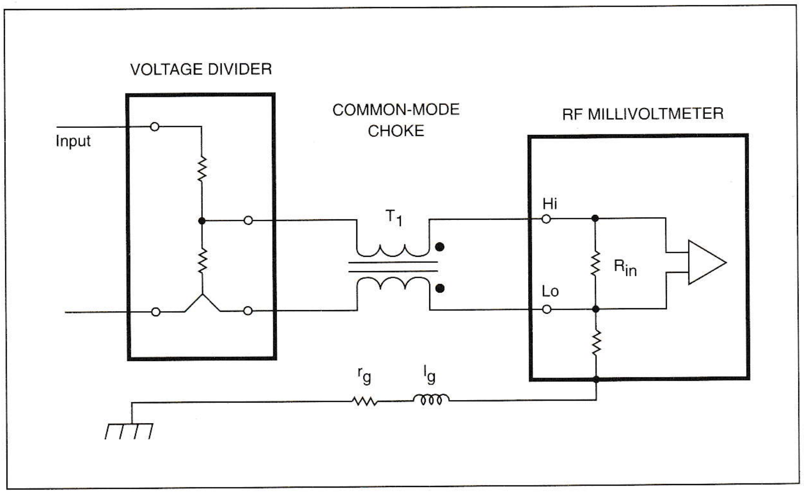

Figure 32-8. *Using Common-Mode Choke*

The solution to this problem is to reduce the magnitude and effect of the unwanted ground current by keeping cables short and adding chokes (high impedances) in the unwanted current paths.

- Decrease the value of r_i and l_i in Figure 32-7 by making the cable from the source to the divider input as short as possible.

- Place a common-mode choke, T_1, on the output of the divider. See Figure 32-8. The unlabeled components in Figure 32-7 and Figure 32-8 represent other parasitics not discussed here.

  The two windings are closely coupled so that their effect on the divider's output current is negligible; but to the ground loop current, it presents a large inductive reactance which substantially reduces the loop current (and thus the error). Such a choke is commonly built by wrapping several inches of the output cable around a ferrite core.

- Put a common-mode choke in the power cord of the meter. This will work if the ground loop current is mostly through the safety ground and not through some other ground path. Such a choke can be made by wrapping some of the power cord around a ferrite core. Another approach would be to put an inductor in just the safety lead.

Information on designing a ground system for a standards laboratory can be found in Chapter 25, "The Laboratory Environment."

Shielding

Electromagnetic radiation can adversely affect electronic equipment. It can come from many sources, such as power transmission lines, fluorescent lights, electric motors, crt's, communications equipment, cellular phones, high-speed digital logic in computers, transmitters, and many other types of electrical and electronic equipment.

Electromagnetic Radiation

Electromagnetic radiation is composed of time-varying electric and magnetic fields. These fields will occur in varied relative strengths. Higher voltage, lower current circuits tend to radiate mostly *E* (electric) fields; lower voltage, higher current circuits will tend to have the *H* (magnetic) fields dominate in lower voltage, higher current circuits.

Shielding from Electric Fields

Common sources of interfering signals, often called noise, which are predominantly *E*-field in nature are: fluorescent lights, power lines, crt's, and high-speed digital logic. The simplest model of electric field interference treats the noise generator as a voltage source capacitively coupled into the circuit of interest. Figure 32-9 shows an interfering signal coupled into the input of an ac voltmeter.

The stray capacitance, c_s, causes a current to flow through the input impedance of the meter and the output impedance of the source. This causes an error in the measurement.

In a typical situation involving fluorescent lights, the source voltage is several hundred volts at power line frequency, and the stray capacitance is on the order of picofarads. Depending on the output impedance of the source and the voltage level being measured, the error in the measurement can range from negligible to substantial. It is worst when the source impedance is high and the measurement voltage level is low.

Another common situation involves the presence of digital logic clock signals in close proximity to measurement circuitry. The source of this noise can be a computer, a cable carrying logic signals, or the logic section of another instrument not adequately shielded. Though rather small in amplitude, typically 5 volts peak-to-peak, a clock signal usually consists of a square wave with a rise time of a few nanoseconds, and an operating frequency ranging from 2 MHz to 100 MHz. This can cause large amounts of interference, and therefore errors, due to the high frequency components of the signal.

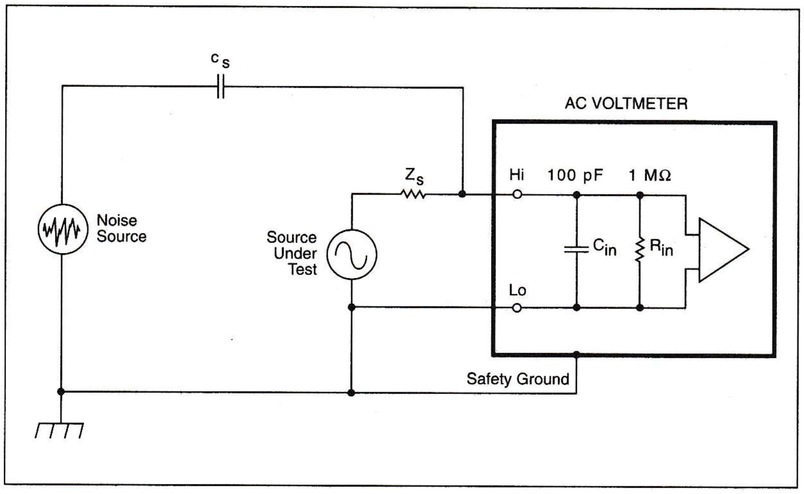

Figure 32-9. *Electric Field Interference*

Reducing the error due to capacitive coupling is best done by a Faraday shield. This shield normally consists of a piece of grounded metal placed between the noise source and the sensitive circuit. Figure 32-10 shows an equivalent circuit using such a shield.

c_{12} is the capacitance from the noise source to the shield; c_{23} is the capacitance from the shield to the sensitive circuit, meter input; and c_{13} is the capacitance through the shield (feed-through capacitance) between the noise source and the sensitive circuit. The value of c_{13} will be several orders of magnitude smaller than the original stray capacitance c_s.

A Faraday shield should completely enclose the circuit with no breaks in it anywhere. Also,

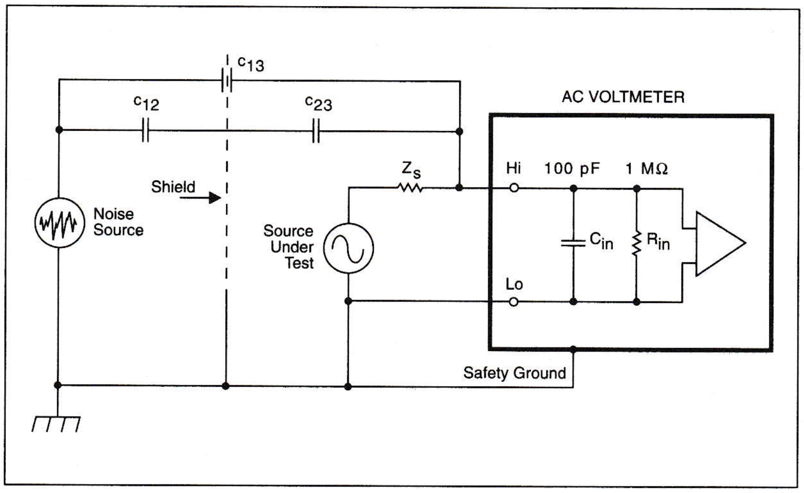

Figure 32-10. *Electric Field Shielding*

because current flows through the shield and back to the source, the shield should be constructed of low resistance material. Otherwise, the current flowing through c_{12} causes a voltage drop along the length of the shield. As a result, current flows through c_{23} into the sensitive circuit at node ①. See Figure 32-11.

Another requirement is that there not be the potential difference $E_{ground2}$ between the shield ground and the circuit ground. If there is, more current will flow through c_{23} into the sensitive circuit. The solution to this problem is to connect the shield to the measurement ground at node ② instead of node ③.

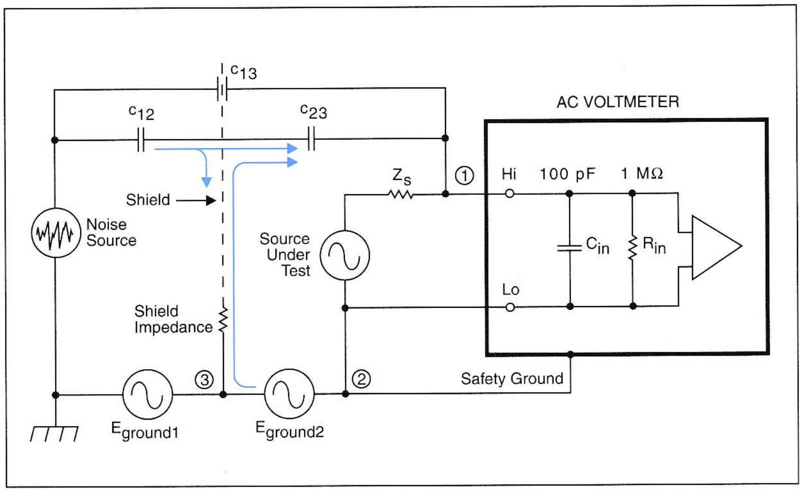

Figure 32-11. *Sources of Error*

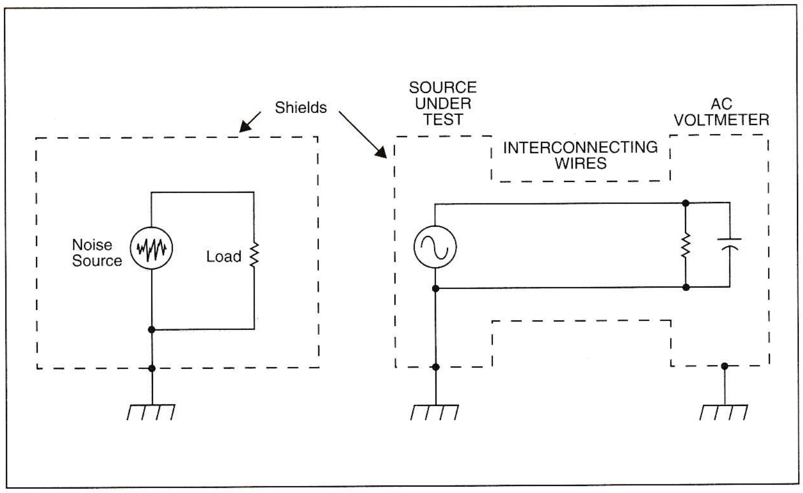

Figure 32-12. *Shielding Sensitive Circuit from Noise*

Practical Hint

- Local shielding usually produces the best results. The most complete shielding between a noise source and a sensitive circuit will be achieved if both source and circuit are separately shielded using a tight shield, and each shield is connected to its local ground. See Figure 32-12.

  This solution, when generalized, can be applied to both large systems and to instrument design. In the layout of a laboratory, it is common practice to run the power mains wiring through grounded metal conduit, and to use fluorescent fixtures with grounded metal enclosures.

  To produce a very quiet electrical environment, fine mesh shielding is used over the opening of such fixtures. In an instrument such as a precision calibrator or DMM, it is common to shield primary power circuits with chassis (power line) ground, to shield digital circuits with the digital supply common, and to use local shielding for sensitive analog circuits.

Magnetic Field Coupling

Some sources of unwanted signals radiate a predominantly magnetic field. Examples of these are motors, power transformers, crt's, and instrument displays. Whenever a sensitive circuit is near a transformer or a circuit with high peak current, there is the possibility of coupling with magnetic fields which can cause a measurement or source error.

For example, a transformer can induce unwanted ac noise into low-level circuitry, whether the circuitry is local or is in a neighboring instrument. Such noise can overload sensitive, narrow-bandwidth dc circuitry. Calibrations performed at power line frequencies may be subject to *beat signals*, where interference from line voltage sources will mix with the signal being measured. Depending on the phase of the two signals, they could effectively double or cancel the signal of interest. Effective use of magnetic shielding, and separation between the error source and the affected circuit, will reduce or eliminate such interference.

A common source of magnetic interference is a transformer with loose coupling between its primary and secondary. In most cases, the interfering signal is induced (picked up) in a loop of circuitry that intercepts a time-varying magnetic field. Figure 32-13 shows magnetic pickup by a loop formed by the wires connecting a source being measured to an ac voltmeter.

The induced current flows through the meter input to cause an error in the measurement. The magnitude of the current is proportional to the magnetic flux density and the loop inductance.

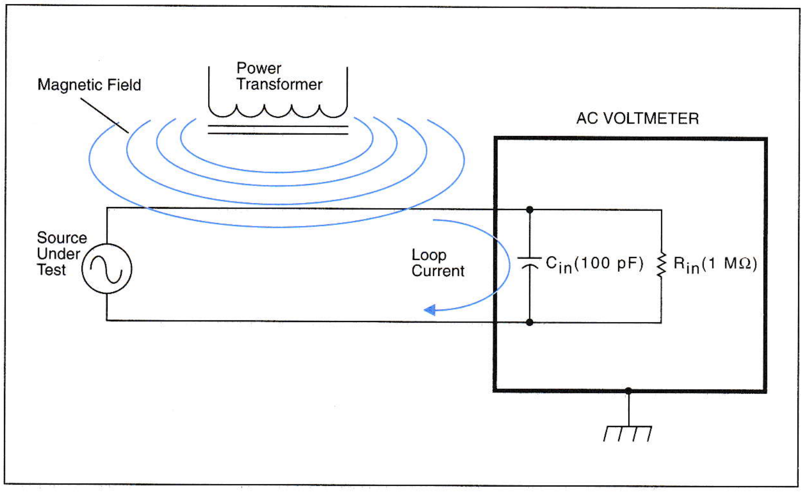

Figure 32-13. *Magnetic Field Pickup*

Minimizing Magnetic Pickup

There are two basic approaches to reducing magnetic pickup: reducing the area of the pickup loop, and reducing the magnetic field intensity.

During the design of a precision instrument, it is necessary to consider the enclosed area of low-level, sensitive loops. Careful routing of lands on a printed circuit board can significantly reduce susceptibility to magnetic coupling. Lands that run side by side, or on adjacent sides of the printed circuit board, present a small loop area. Flux density drops off very rapidly with distance from the source, so placing the power transformer and other sources of interference as far as possible from sensitive circuits can substantially reduce pickup. Sometimes the rotation of a transformer will reduce pickup, because pickup is limited to fields that are perpendicular to the loop. Care should be taken when stacking instruments so that the source of magnetic interference in one instrument is not placed close to a sensitive circuit in another instrument. Some types of electronic equipment emit so much magnetic interference that they can't be used near high accuracy meters or sources.

When using test leads, the best method of minimizing magnetic pickup is to twist the leads together. This not only minimizes the area of the loop formed between the leads; it also places the fluxes in direct opposition, and they become mutually canceling. Another way to interconnect instruments is to use coaxial cable (coax). It provides rejection of unwanted pickup from both magnetic and electric fields because the center conductor is completely enclosed by the outside shield.

Practical Hints

- Use twisted pairs rather than separate test leads where possible to reduce magnetic pickup and minimize series inductance.
- Use coaxial cables to reduce both magnetic and electrostatic pickup.

  The rejection of interfering fields by coax is related to both the frequency of the interference and the degree of coverage of the outer conductor. Most coax is constructed using a fine-wire braid as the outer conductor. Depending on how tightly this braid is woven, there can be small gaps that reduce its effectiveness at rejecting unwanted radiation or coupling. Coax available on the commercial market varies from 80% to 98% in its coverage. Some coaxial cables use foil shield instead of braid to increase coverage to 100%.

Magnetic Shielding

With properly designed shielding, it is possible to attenuate magnetic interference either at the source or at the point of interference. The primary difference is that the field strength is much higher at the source. Saturation of magnetic materials must be considered. Shielding is achieved with iron as well as iron alloys, and also through the use of high-conductivity materials such as copper or aluminum. Alternating layers of copper and high-nickel magnetic alloy are used for the best shielding.

Iron and its alloys attenuate magnetic interference by concentrating lines of magnetic flux. A common sheet metal steel box, 0.060-inch thick, will have limited effect at power-line frequencies and attenuate magnetic radiation only 3 to 6 dB. By contrast, an 80% nickel alloy, properly annealed and handled with care, can reduce magnetic field strength up to 35 dB.

Practical Hint

- The best material for magnetic shielding is an alloy of nickel and iron known as *Mu-Metal.*

Guarding

From the material covered so far, you can see that one of the biggest measurement problems in interconnecting two or more instruments is keeping extraneous signals out of the interconnecting cables. Ground loops, described previously, are a common cause of such errors.

A related case occurs when the voltage to be measured is elevated (floating) with respect to ground or some other reference point by another voltage, as illustrated in Figure 32-14.

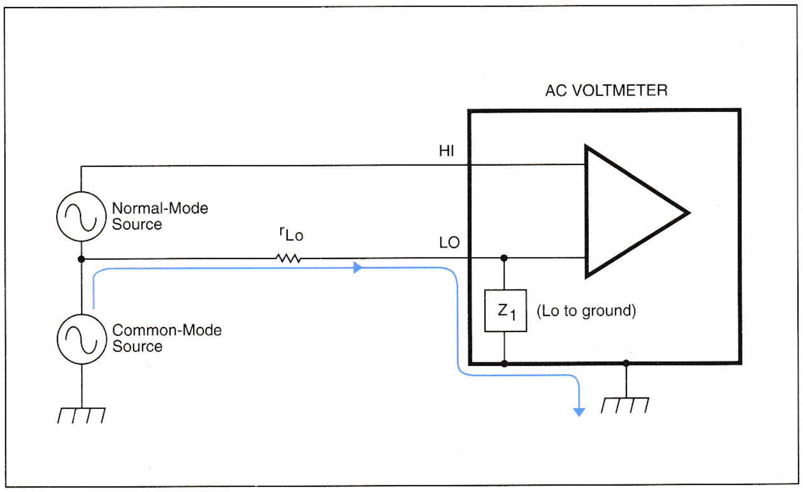

Figure 32-14. *Meter with Elevated Input*

The signal being measured is called the *normal mode* signal. The signal it is floating on is called the *common mode* signal. In fact, the situation shown in Figure 32-6 can be thought of as generating a normal mode signal, floating on a common mode signal, caused by the voltage drop in r_{Lo} due to ground current.

In either case, if the source output Lo and meter input Lo terminals are connected to ground, a current flows through the Lo lead, causing an error in the measurement. Floating the meter Lo above ground will reduce the current flow but not entirely eliminate it, because some current can still flow through the impedance between Lo and ground (z_1). This problem can be solved through the use of guarding.

Instrument Guard

An instrument guard is a Faraday or electric field shield that encloses the analog circuitry of a meter or source and is electrically isolated from the instrument case and ground. In addition to being an electric field shield, it also provides a path to ground for common-mode generated currents so they do not cause an error in the measurement (see Figure 32-15).

The ground loop current now flows through the lead to the guard and then through z_2 to ground instead of through the signal Lo lead.

Figure 32-16 shows an equivalent circuit along with typical values for the various components.

The voltage drop in the guard resistance (r_2) due to current from the 10V common-mode source appears across the Lo lead resistance r_1 and c_1. As a result, a little current does flow through the Lo lead, but its effect is insignificant: the drop is less than 1 nV at 1 kHz. The drop across the guard lead resistance r_2 will also cause some current to flow through c_3 into the meter Hi input. At 60 Hz this is insignificant; at 1 kHz the error would be a few microvolts. Using a guard in this example reduces the errors caused by the common-mode source by a factor of 10,000 (80 db), compared to that seen with a meter without a guard as shown in the preceding Figure 32-14.

Note that the guard will act as an electric field shield if it is connected to the Lo, either at the meter or at the source, but it will only reduce the error due to ground loop current if it is connected to the Lo at the source.

Practical Hint

- A measurement instrument's guard can be used to reduce common mode errors, as well as provide electric field shielding. It should be connected to Lo at the source terminals.

High-Impedance Measurements

For high-impedance measurements, an instrument guard can be used to reduce the measurement load on a sensitive node to which the Lo lead of a meter is connected. This is done by driving the guard from a low impedance source carrying the same potential as the input Lo. Driving the guard in this manner is known as *active guarding*. Consider the case of using a voltmeter as a null detector to measure the imbalance of a wheatstone bridge, as shown in Figure 32-17.

If an unguarded meter were used, any leakage resistance from the meter Lo to ground would be in parallel with a leg of the bridge, causing a measurement error. If a guarded meter is used and the guard is tied to input Lo (the normal procedure), any leakage resistance from guard to ground would cause an error.

The solution to this problem is to drive the guard with a guard amplifier. This is an amplifier whose gain is unity and whose input is connected to the circuit at the point where the meter Lo connects. Its input impedance is very high, so it doesn't load the circuit; its output connects to the instrument guard. It maintains the guard at the same potential as the Lo; thus no current flows in the Lo lead due to leakage resistance between Lo and guard. Current does flow in the guard lead due to guard-to-ground leakage, but this current is supplied by the amplifier.

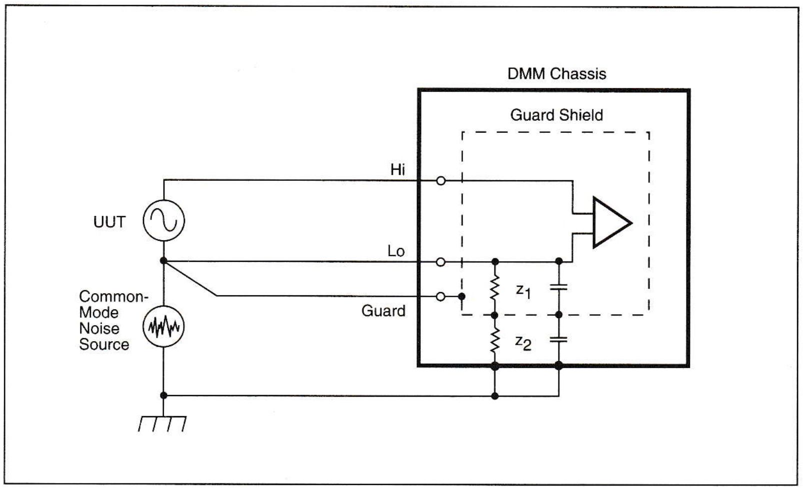

Figure 32-15. *Guarded Meter*

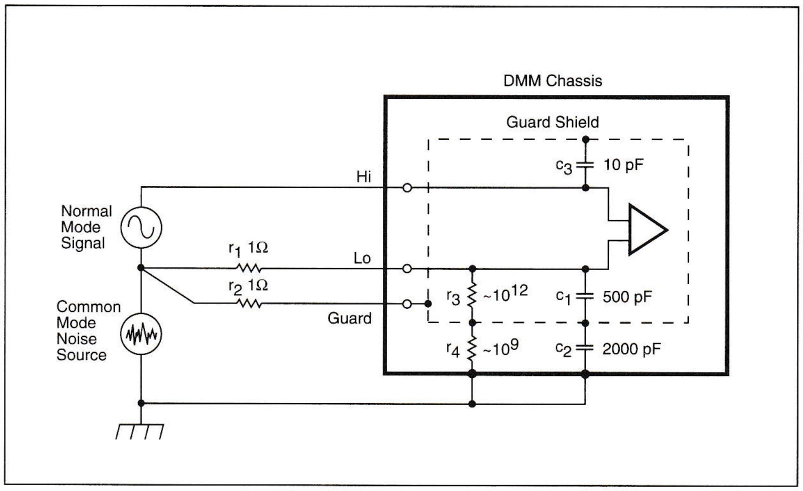

Figure 32-16. *Guarded Meter Parasitics*

An alternative to the guard amplifier is to use a low impedance divider across the bridge source. The output of the divider should be adjusted so that its voltage is equal to that of the bridge centers. This divider output should then be connected to the meter Guard terminal.

Coax Test Leads

In Figure 32-15, input Hi, input Lo, and Guard are shown schematically as separate wires. But the earlier analysis of shielding shows that this would make these inputs susceptible to both electric and magnetic field pickup. A better solution is to use the hook-up of Figure 32-18.

This hook-up uses coaxial cables for both Hi and Lo input leads, with the cable shields connected to Guard. The coax shields provide the required electric field shielding and a connection for the Guard. The hookup also provides adequate rejection of magnetic pickup, when the two pieces of coax are tied together along their length. Coax is constructed with very

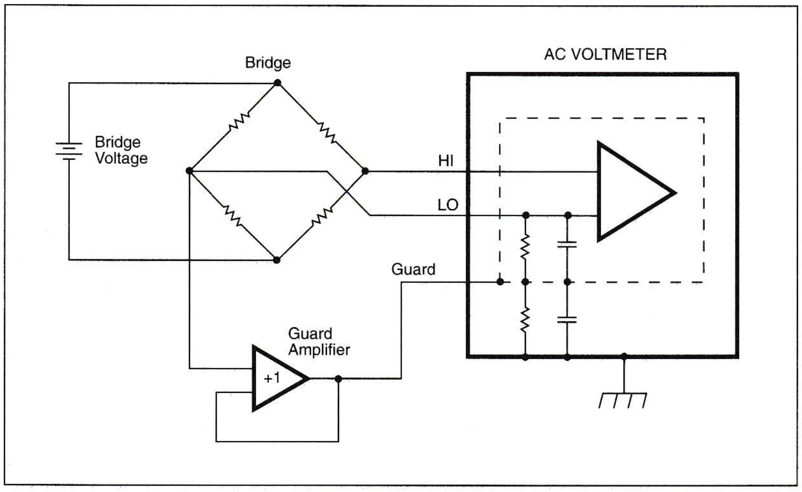

Figure 32-17. *Using Guard Amplifier*

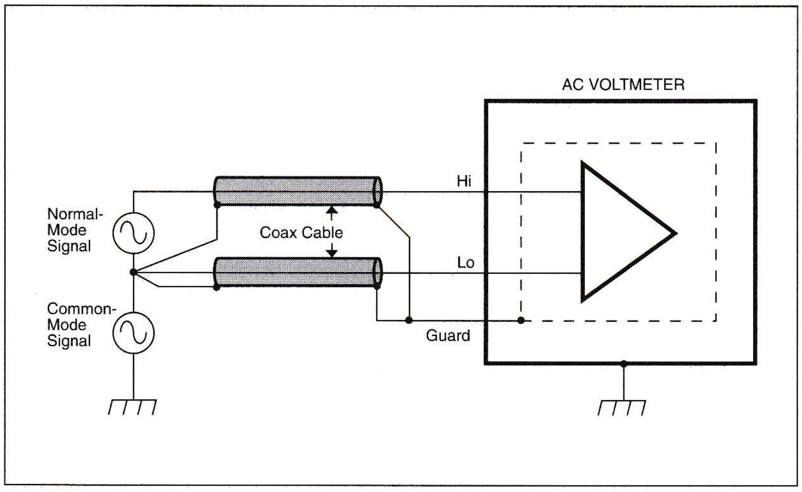

Figure 32-18. *Using Coax Cable for Interconnections*

good insulating materials and can therefore handle high voltages. There are types that have low per-foot capacitance values (capacitance between the center and outer conductors). Be sure that the coax selected uses a copper inner conductor. Some small-diameter types use copper-covered steel, which results in excessive thermal emf at their connection terminals.

Triax Test Leads

In situations where better magnetic rejection is required, triax can be used instead of parallel coax. Triaxial cable (triax) is like coax but has a second shield over, and insulated from, the first. This is not to be confused with double-shielded coax, which has two shields in contact with each other (two shields providing better coverage than one). In triax, the outer shield is connected to the Guard, the inner shield to the input Lo, and the center conductor to the input Hi. Triax has all the previously mentioned advantages of coax, but it has the disadvantages of being large in diameter and difficult to terminate the shields to the instruments, so twinax is generally used instead.

Twinax Test Leads

Twinax consists of two insulated wires which are twisted and covered with a braid or foil shield. The input Hi is connected to one wire, the input Lo to the other, and the shield to the Guard, as shown in Figure 32-19.

The twisted wires provide excellent rejection of magnetic pickup and the shield provides electric field shielding and a connection for the Guard. In situations where there is a high intensity rf field present, such as from a nearby broadcast station transmitter or cellular phone, a second shield can be used that is insulated from the first (shown as dotted lines in Figure 32-19). This shield should cover all exposed leads and have a low impedance connection to ground at both ends.

Models of twinax are available that handle high voltage and use excellent insulating materials. Most use copper conductors and a foil shield with a drain wire for easy connection. Connected as shown in Figure 32-19, twinax tends to have higher per-foot capacitance than does coax. Overall, twinax is the best type of cable to use for dc and low frequency ac measurements.

Guarding Current Sources

Under certain conditions, the connection of a precision current source to an external load may require the use of a driven guard to minimize errors. An ideal current source has an infinite output impedance. Regardless of load impedance, the current through the load will be constant. However, capacitance and leakage resistance from Hi to Lo in the interconnecting path can shunt some of the current around the load, resulting in an error in measuring or sourcing the current as shown in Figure 32-20.

The error is in proportion to the load resistance and the square of the frequency, and can reach a significant value both on the 100 µA range of ac calibrators and the highest ohmmeter MΩ or conductance nanoSiemans (nS) ranges. As a result, precision current calibrators provide a current guard, and precision ohmmeters provide an ohms guard.

To understand how such a guard works and is connected, refer to Figure 32-21.

The Current Guard is driven by an amplifier with a gain of unity and whose input is connected to the Hi Out of the current source. Its input impedance is high so that it does not load the current source, and its output connects to a shield around the Hi Out. It maintains the shield at the same potential as the Hi Out so none of the current from the Current Guard is lost due to cable capacitance or leakage resistance. The Current Guard supplies any leakage current due to either capacitance or leakage resistance from the shield to Lo Out.

When a current output is guarded in this fashion, the Lo lead is typically connected with a separate wire. (For minimum magnetic pickup, triaxial cable can be used.) Then the Hi Out is connected to the center lead, the Current Guard to the middle shield, and the Lo Out to the outer shield. This approach is limited by the relatively high shield-to-shield capacitance which loads the Current Guard output; this typically causes increased phase shift at higher frequencies and reduces its effectiveness.

A compromise that has been found to be adequate in all but the noisiest of environments is the use of conventional coax for high and guard connections. A separate insulated return wire is wrapped around the coax. This reduces the susceptibility to magnetic pickup with a smaller capacitive load on the guard amplifier.

Practical Hint

- Low level, high frequency current measurements are subject to large errors caused by leakage impedances. These errors can be reduced by the use of an active guard (provided by the meter or source) connected to a shield around the Hi lead.

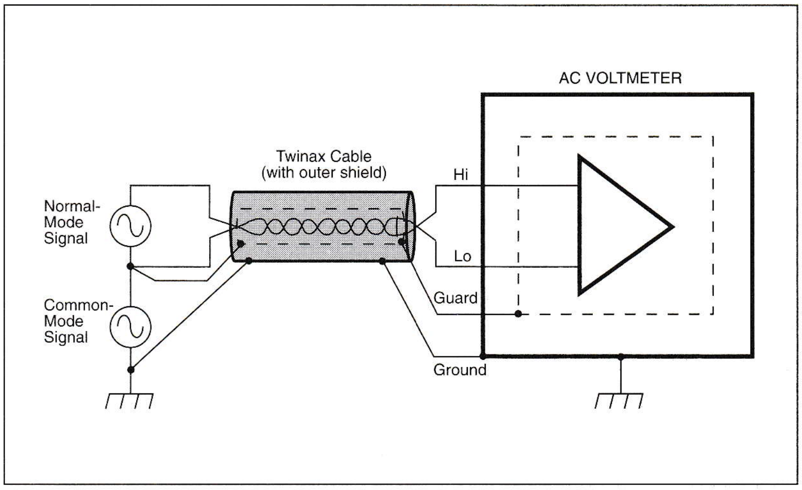

Figure 32-19. *Using Twinax for Interconnections*

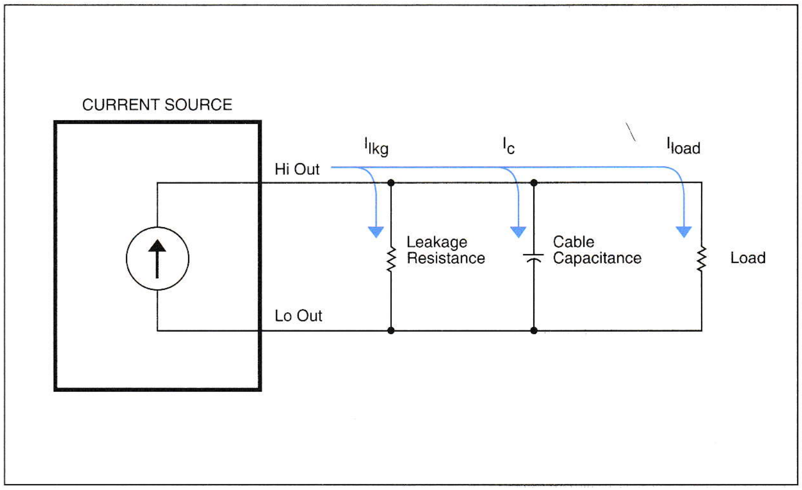

Figure 32-20. *Error in Sourcing Circuit*

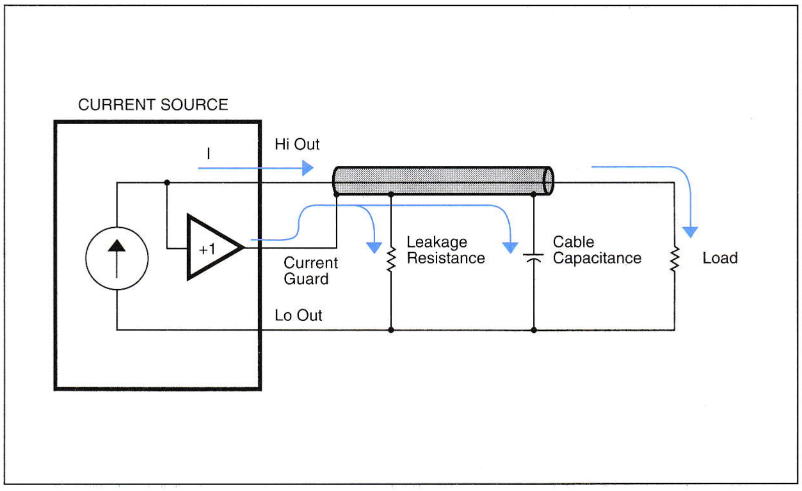

Figure 32-21. *Using Current Guard*

Interconnecting Guarded Instruments

A common operation in the calibration laboratory is the calibration of a DMM with a precision single-function or multifunction calibrator. It is common for both the calibrator and DMM to have a guard. One or both may also have a ground terminal.

The guard will sometimes be labeled V-GUARD, for voltage guard, to differentiate it from the current guard, which may be labeled I-GUARD. Also, the ground is sometimes labeled CHASSIS and may only be available on the rear panel.

Voltage Measurements

Figure 32-22 shows the proper method for interconnecting a calibrator with a DMM. The calibrator's Hi Out, Lo Out, Guard and Ground connect to the DMM's Hi In, Lo In, Guard and Ground, respectively. It is important that the Guard be connected to one of the Lo terminals, usually Lo Out, at the calibrator. Some instruments with guards have a built-in switch that makes this connection; others use a shorting link between the Lo and Guard terminals. Figure 32-2 illustrates the recommended practice of connecting the Lo to Guard at the calibrator but not at the DMM. It is also a good idea to connect the Lo and Guard to Ground. This should be done at only one point (usually at the source). Making this connection will greatly reduce any common mode signal between Lo and Ground, which could cause an error in the measurement.

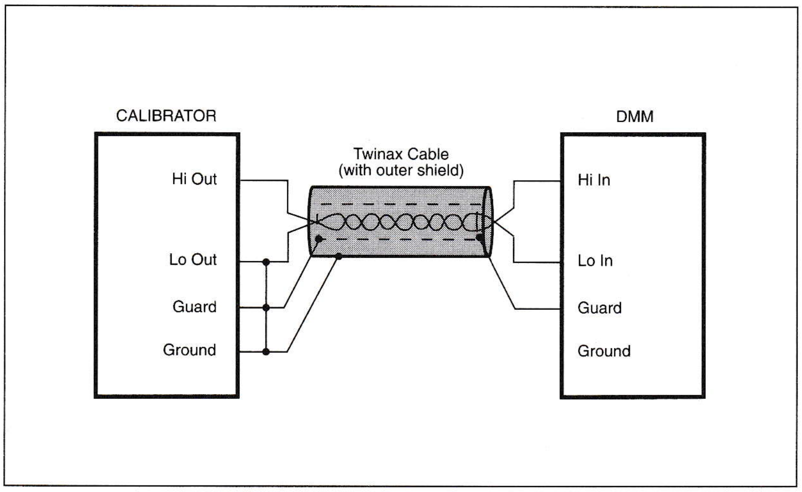

Figure 32-22. Guarded DMM-to-Calibrator Connection

Beware of confusing the label Grd with ground. Grd means guard. Chassis or Ground mean ground.

Practical Hints

- For dc and low frequency ac, use twinax to connect the source and meter. Hi and Lo are connected with the twisted pairs, and the meter Guard is connected to the shield. The source end of the shield is connected to the Lo Out. If the twinax has a separate outer shield, it should be connected to chassis Ground.
- If you need to minimize capacitance, it may be more appropriate to use two separate pieces of coax. The inner conductors will be used for the signals and the shield will be used to interconnect the meter Guard and Lo Out.
- Sometimes the use of the guard is not required for a measurement, so a simpler interconnection can be made as shown in Figure 32-23.

  Here, the Hi Out and Lo Out are connected to the Hi In and Lo In using coax. At each instrument, the Guard is connected to Lo and the connection to Ground is made only at the calibrator.
- Never leave the Guard-to-Lo connection on an instrument open; always have this connection made somewhere in the system. If the Guard is left floating (unconnected), measurement errors can occur, or the DMM may rise to a hazardous voltage potential.

Resistance Measurements

Methods of interconnecting a guarded resistance calibrator to an ohmmeter depend on whether a two-wire or four-wire connection is being made. Low accuracy meters normally have two input terminals for resistance and no Guard. This type of meter is connected to a calibrator using a two-wire connection. It is not normally required to use the Guard because of the low accuracy involved. The Guard can be connected to the Lo Out at the calibrator and the connection made with coax, like that shown in Figure 32-23. Precision ohmmeters have four input terminals for resistance measurement plus a guard. Two of the terminals are connected to an internal current Source and the other two to a voltage measuring circuit. Connecting this type of meter to a calibrator requires a four-wire connection. This can be done, as shown in Figure 32-24, by using two twinax cables, one for the current and one for the voltage.

The Guard is connected to both shields at both ends, but the Lo-to-Guard-to-Ground connection is only made at the calibrator. If the ohmmeter also has an Ohms Guard, it should be connected to a shield around the current Hi lead, as described in the earlier section "Guarding Current Sources."

Practical Hint

- Four-wire resistance measurements should be made using two twinax cables. One is used for the current source and the other for voltage measurement. Both shields will be connected to the meter's Guard and the source's Guard. The Guard should be grounded at the source.

Frequency Limitations

The application of instrument Guards is subject to some important limitations. Guarding is usually found on dc V and low-frequency ac V instruments for the intended purpose of eliminating measurement errors due to common-mode signals. Most guarding schemes work well at power line frequencies and up through audio frequencies. But above 100 kHz, using the Guard does not always lead to predictable results. The distributed reactance of the Guard shield can introduce errors that would not be present at lower frequencies. For this reason, it may be better not to use the Guard but to use coax instead, as is normally done at rf frequencies. In fact, some instruments disconnect internal Guards above a given frequency, so that the Guard acts more as a grounded shield at the higher frequencies.

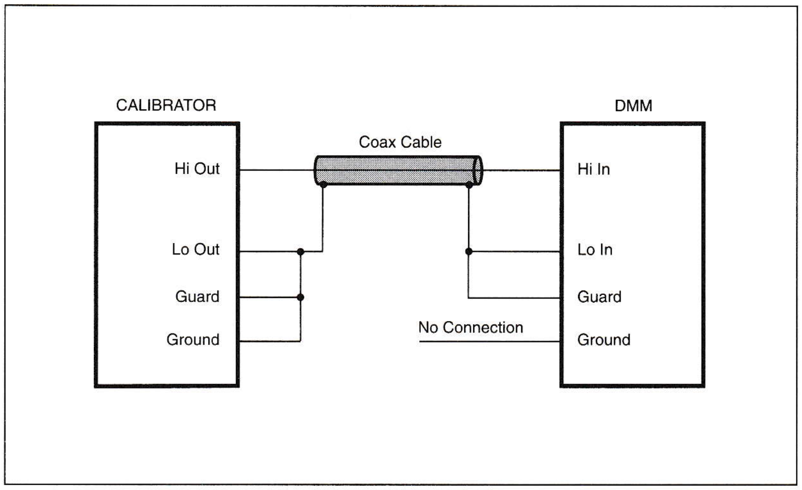

Figure 32-23. *Interconnection When Guarding is Not Required*

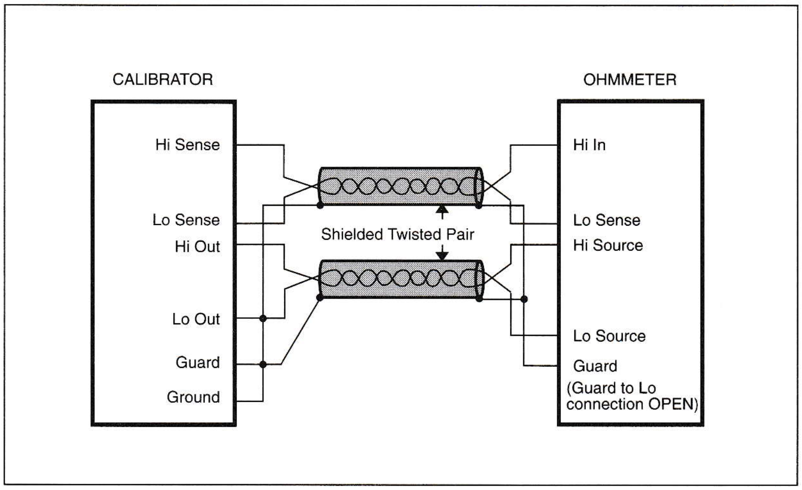

Figure 32-24. *Guarded, Shielded 4-Wire Resistance Interconnection*

Practical Hint

- In general, guarding is ineffective above 100 kHz. Above 100 kHz, one should adhere to good rf practices, such as using coax. However, for non-50Ω systems, one should be aware of the capacitive loading effects of coaxial cables.

Key References

Morrison, Ralph, *Grounding and Shielding Techniques in Instrumentation*, *2nd Edition*, John Wiley and Sons, Inc., 1977

Other references for this chapter are in the Resources Appendix.