CALIBRATION–
Philosophy in Practice

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Guarding of Digital Voltmeters, Digital Thermometers and Calibrators

INTRODUCTION

The primary purpose of this section is to show the proper use of the guard (Blue Terminal) and to clarify related specifications. Another purpose of this section is to show how the guard reduces common mode errors. If you are a DVM user, but don't have the time to completely read this section, at least read the answer to the questions, "What happens if I leave the guard disconnected; and, do I need to use a third wire for the guard for every measurement?"

GUARD USAGE

What is the proper hook-up for the guard? (See Figure 108)

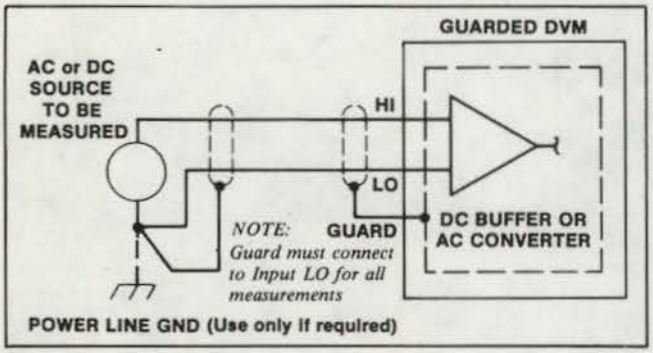

Figure 108.

Do I need to use a third wire for the guard for every measurement?

No, not all measurements need the third guard wire brought out to the source to be measured. A jumper strap between Lo and Guard at the front or rear panel will do for some measurements as the following general guidelines indicate:

Third Guard Wire Required:

1. When Common Mode voltages exist
2. When making accurate measurements
3. When making sensitive measurements with resolution below 10 μV
4. When using long signal leads
5. When using an input scanner in system applications (Guard must be switched also)

Lo to Guard Jumper Strap Okay:

1. When no Common Mode voltage exists
2. When making low accuracy measurements
3. When making insensitive measurements with resolution above 10 μV
4. When using short signal leads

Also note that the third wire for the guard can be the shield of a two conductor shielded cable.

What happens if I leave the guard disconnected?

DON'T! If you do, one of two things can happen. You will end up either calling the Fluke Sales Department complaining of incorrect readings or you will be unhappily calling a Fluke Technical Service Center to get your DVM repaired. Here's why. Leaving the guard disconnected, in the presence of a common mode current, will allow the current to flow in the signal leads through the series combination of the Lo to the Guard (C_{LG}) and Guard to Chassis (C_{GC}) capacitances and through the stray capacitance from the sensitive points in the DVM's amplifiers (the guard now being somewhere between Lo and Chassis potential), both of which will cause reading errors (almost guaranteed). The DVM can also be destroyed by leaving the guard disconnected because the voltage stored on the Lo to Guard capacitance (C_{LG}) may exceed the 100 volt maximum due to static charge accumulating or by the current supplied by an added common mode voltage.

Most Fluke DVM's and many others are rated for only 100 volts breakdown between Lo and Guard. A high

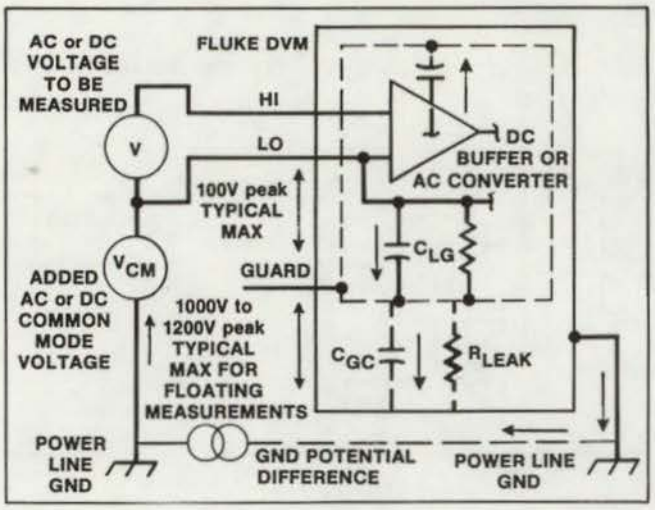

Figure 109.

common mode voltage could cause a greater than 100 volt condition from Lo to Guard due to the divider action of the Lo to Guard and Guard to Chassis capacitance and leakage resistances. All guarded Fluke DVM's can make a floating-guarded measurement to 1000 volts or 1200 volts (depending on the model used) above chassis (power line ground).

What do I do with the guard during accurate, 4-wire resistance measurements especially when the unknown resistance is at ground or at some potential? (See Figure 110)

For high value resistance measurements, a Guard Shield can be added around the unknown resistance (connect to Guard) to reduce noise pick-up.

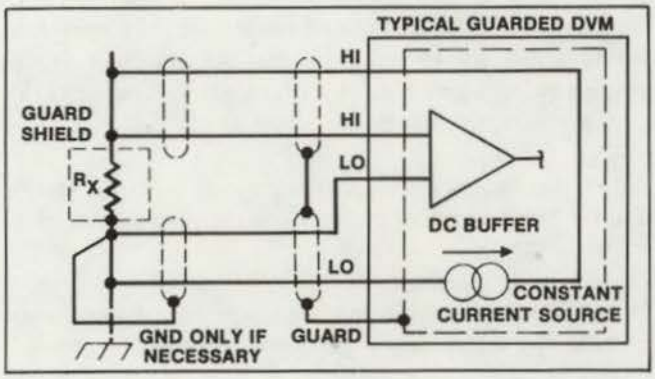

Figure 110.

What do I do with the guard during non-critical resistance measurements?

Leave the Guard strapped to Lo on the front panel.

What do I do with the guard when using a guarded source? (See Figure 111)

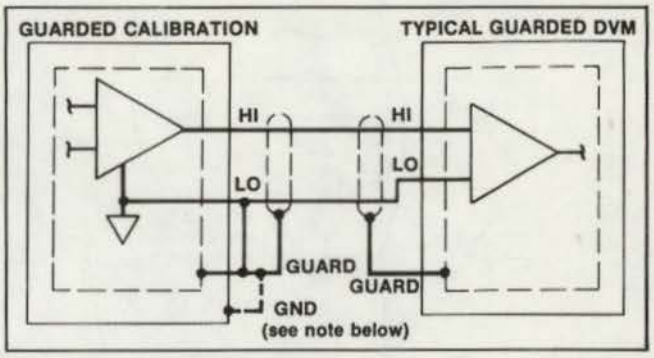

Figure 111.

NOTE

Connect only one Lo to Guard Jumper strap. For most applications, it should be placed at the calibrator end. If the calibrator has a ground terminal (white or metal), follow the hook-up instructions issued with the calibrator.

Does guarding apply to a digital thermometer? (See Figure 112)

YES, a digital thermometer is essentially a DVM that measures the voltage produced between two junctions of two dissimilar metals. The DVM also must linearize the non-linear output of a thermocouple but still needs to be properly guarded.

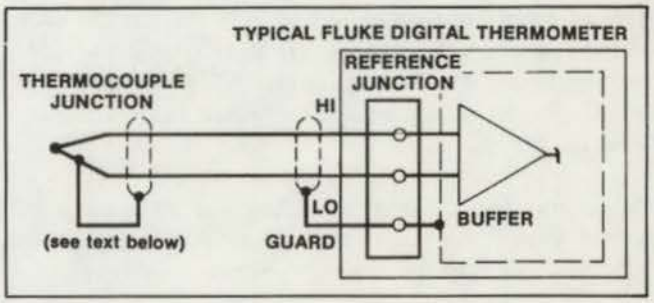

Figure 112.

For accurate measurements in application where there is a large common mode voltage present (example-thermocouple attached to a power transistor collector), the guard wire should be attached to the low thermocouple leads as close to the junction as possible without causing the temperature gradient at the couple.

What do I do with the guard for a bridge hook-up?

For a bridge, refer to the hook-up shown in Figure 113.

In this application, a guard driver amplifier is required for accurate measurements, especially for AC measurements. The function of the guard driver amplifier is to

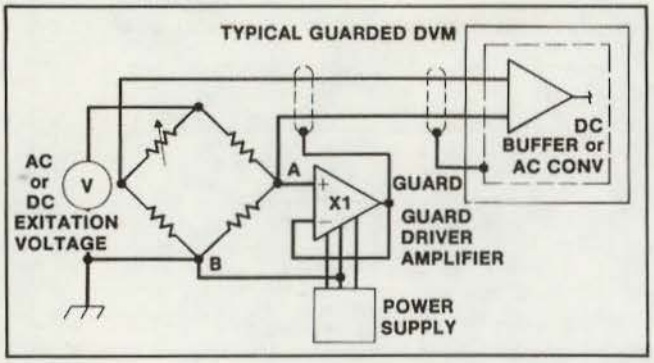

Figure 113.

minimize the loading at point A while driving the DVM guard and cable shield at the same potential as that at point A. If the guard is attached directly to point A (which can be done for lesser accurate measurements), the Guard to Chassis impedance will load point A (typical impedance is 100 MΩ/200 pF for a plastic cased DVM and 100 MΩ/5000 pF for a metal cased DVM).

The guard driver amplifier should be selected with enough output drive capability without oscillating to drive the DVM's Guard to Chassis capacitance and also to have high input resistance and low input capacitance. It should be hooked-up in the unity gain non-inverting mode. The amplifiers power supply common must be connected to point B, not to the DVM.

An intermediate solution would be to replace the Guard Driver Amplifier with a third pair of resistors to drive the guard. The ratio of these resistors should provide a voltage nearly the same as at point A. The impedance of these resistors should be low compared to the Guard to Chassis impedance.

In general, for all three hook-ups, the Lo lead of the DVM should be connected to the mid-point of the bridge which has the lowest impedance to ground.

What other applications require a guard driver amplifier?

Most off ground accurate ac measurements need a guard driver amplifier. (See Figure 114)

Note also that the difference in loading capacitance and loading resistance across each attenuator resistor must be compensated for. The typical input impedance of a DVM in the ac volts mode is 1 MΩ/100 pF.

Do all DVM's have a guard?

NO, a typical 3-1/2 digit DVM is not sensitive enough to require one. Generally, a 4-1/2 digit DVM with a plastic case doesn't require one because of its small capacitance between Input Lo and Power Line Ground.

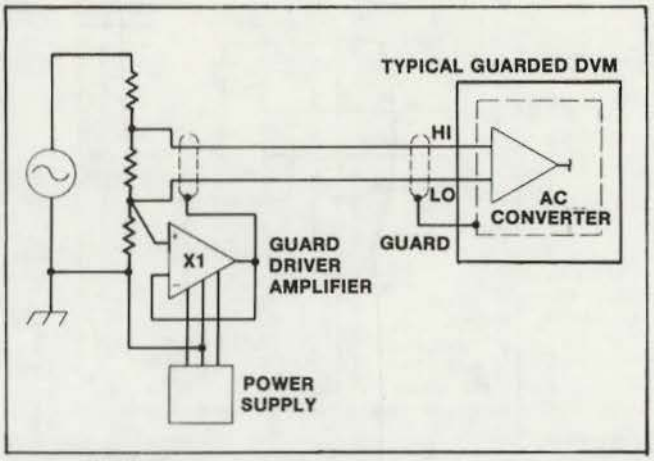

Figure 114.

What happens when I use a battery operated DVM?

Using a DVM on battery power (or using a floating source) with the power line disconnected, almost completely eliminates the common mode current and any errors it causes. How well it is eliminated will depend upon capacitance and leakage resistance (spacing) to Power Line Ground. Don't forget most electronic instruments and metal bench tops are at Power Line Ground.

COMMON MODE SPECIFICATIONS

How do I interpret the 120 dB or 140 dB CMRR specifications?

120 dB is a ratio of 1,000,000 to 1 and 140 dB is a ratio of 10,000,000 to 1. For example, if 100.000 mV is to be measured with 1 μV resolution (5-1/2 digit DVM), then a DVM with 120 dB of common mode rejection would allow up to one volt peak of common mode voltage before a one digit (1 μV) error would be seen (1V ÷ 1 μV = 1,000,000:1).

A DVM with 140 dB of common mode rejection would allow 10 volts peak of common mode voltage, etc. (See Figure 115)

Note that the common mode voltage added must also include any difference in potential between the ground lines.

What does 1 kilohm unbalance resistance mean?

It means that either the Hi or Lo lead may have up to 1 kΩ in series with it while still meeting the common mode rejection spec. Some applications require an unbalance resistance. Note that some DVM's specify the 1 kΩ resistance in the Lo lead. This is because the Lo lead is more critical to common mode currents.

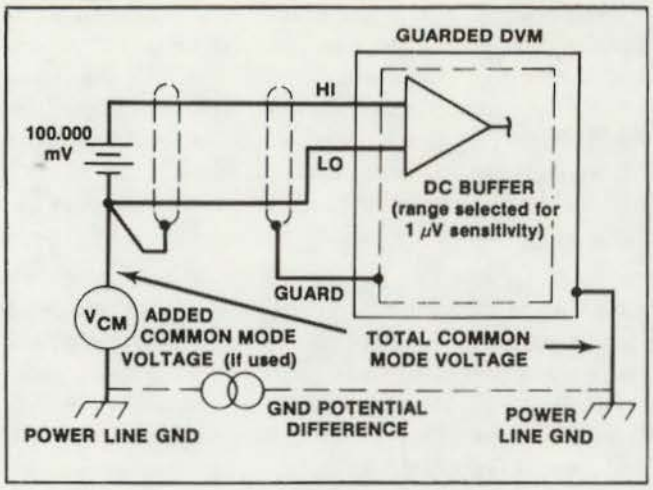

Figure 115.

Also note that for ac measurements and some other DVM's 100Ω unbalance is often specified instead of 1 kΩ. A DVM that does not specify an unbalance resistance means that it can not be used with an unbalance resistance without degrading the Common Mode Rejection Specification.

GUARD THEORY

The purpose of the guard is to reduce common mode currents which in turn will increase the Common Mode Rejection of a DVM (Reduce Common Mode Errors) for DC, AC and Resistance measurements.

What is common mode?

It is a current between a DVM and the source being measured that causes errors in the measurement being made. (See the Simplified Block Diagram, Figure 116.)

The distributed capacitance (AC) and the leakage resistance (DC) associated with the power transformer and between Input Lo and Chassis (C_{LC}) in the DVM, cause a current to flow from the AC power lines through the ground system through the similar capacitance and leakage resistances of the source to be measured. The common mode current flows through the Hi and Lo leads causing a voltage drop across the lead resistances. The DVM sees the voltage across the source plus the voltage across the lead resistances, thereby causing an error especially for sensitive measurements.

Common mode currents also cause errors that are different from instrument to instrument. The current through the capacitance and leakage resistances from critical parts of the DVM's sensitive amplifier to the chassis causes errors.

Figure 116 also shows how non-isolated analog outputs and non-isolated digital outputs can cause common mode currents via external digital and analog equipment. Besides line frequency common mode currents, non-isolated digital outputs create digital pulse type common mode currents through externally connected equipment such as a computer.

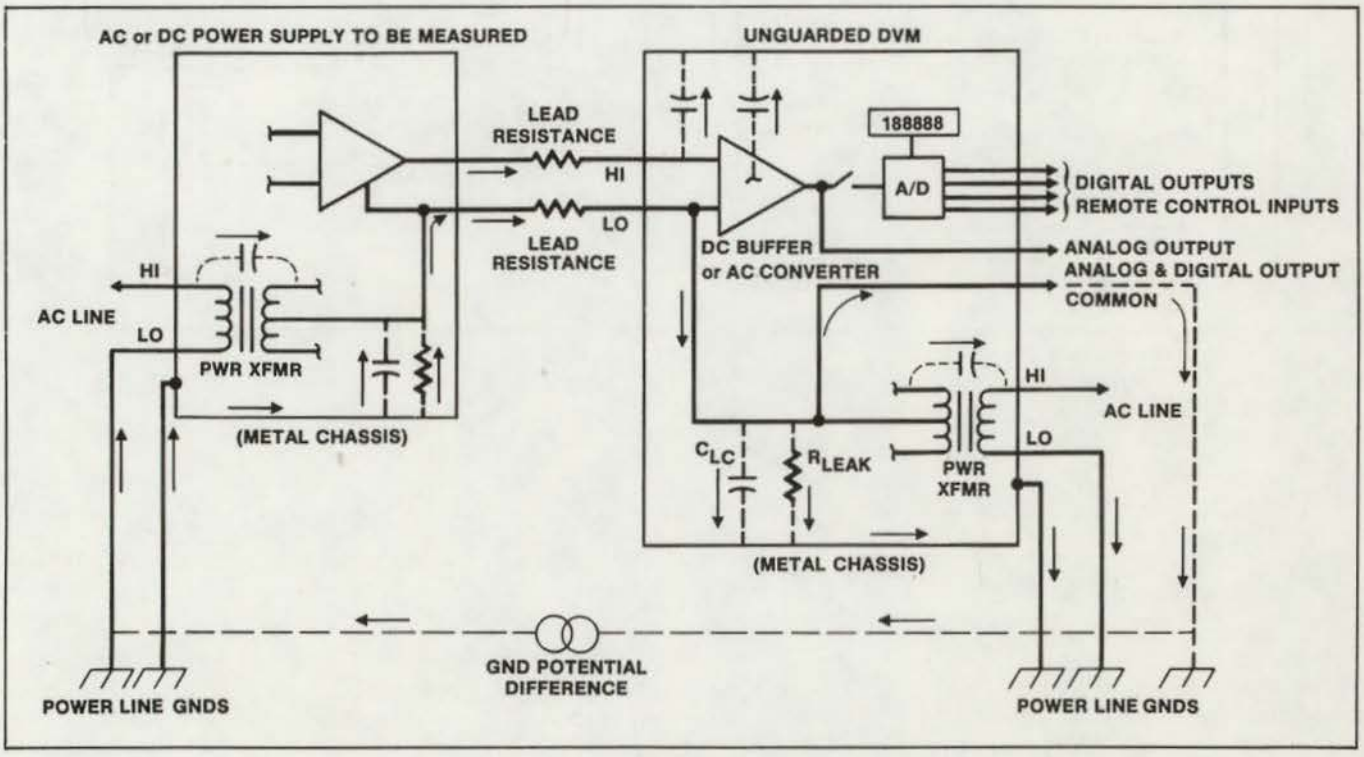

Figure 116.

How does the guard help?

By adding a guard shield (metal box within a box-type construction), the common mode current is reduced considerably but only when the guard is properly connected. (See Figure 117)

The guard shield also surrounds the secondary windings of the DVM power transformer utilizing a foil type shield with the secondary winding wound completely separately from the primary windings and other secondary windings that feed digital circuits outside of the guard. By doing this, the capacitance from the guarded secondary winding to the primary winding and the transformer core can be kept typically below one picofarad. This causes a reduction in the common mode current.

Another reduction in the common mode current effect can be made; however, it is up to the user to accomplish. By attaching a third wire to the Guard terminal and to the Lo terminal of the source to be measured, a low impedance path has been formed that will shunt the remaining common mode current out of the Lo and Hi leads. Note that the Hi lead is not as sensitive to the common mode problem because it has less capacitance and leakage resistance to guard or chassis than does the Lo lead for most DVM's.

Common mode currents caused by digital outputs and remote control inputs are minimized by using guarded pulse transformers or photo isolators. Note that a good guarded DVM actually has three commons; Chassis Ground (Power Line Ground), Input Common (Lo), and Digital Output Common. Analog outputs are more costly to provide because they require a modulator/ demodulator approach to a D to A converter approach to isolate the commons. This is why isolated analog outputs are not found on isolated (Guarded) DVM's.

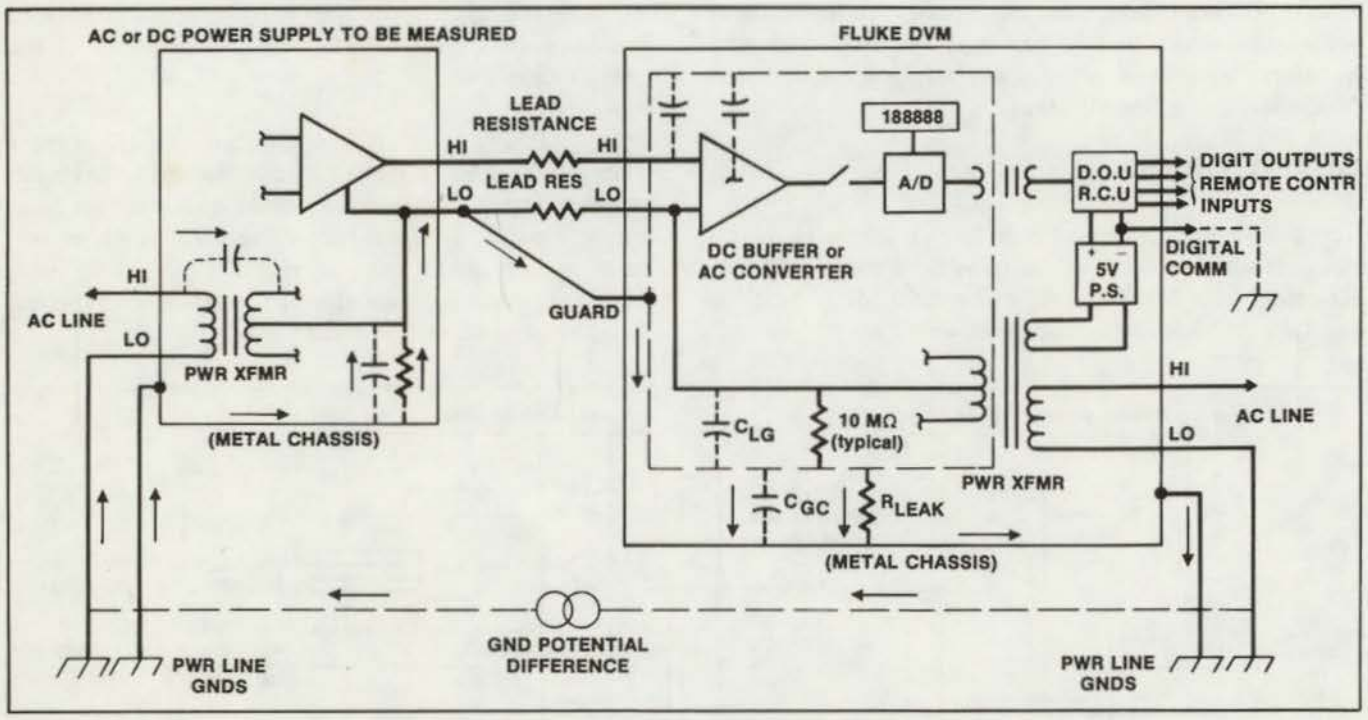

Figure 117.