Rationalizing Null Readings at Low Levels

Purpose:

This Application Guide discusses the problems encountered when comparing nulls, especially nulls made in the micro-volt and nano-volt regions, between two null meters. Frequently minor differences between two different null meters, the minor differences between instrumentation setups and other environmental issues contribute to those differences. This Application Guide is written to help a null meter user rationalize the differences and to take corrective actions, where possible, to reduce the differences between readings.

Background:

When making low-level voltage measurements, or null measurements close to zero volts, many external factors contribute to the voltmeter/null meter reading in addition to the signal coming from the desired source. As the voltage of interest approaches a few micro-volts and lower, these other contributions can become a significant part of the measurement or, in some cases, can even be greater than the measurement itself. In either case, the reading error is significant.

One way of visualizing this is shown in Figure 1, where V_s is the source voltage of interest. V_{Off} is an offset voltage (which may be generated by multiple sources) that either adds to or subtracts from the voltage you are trying to measure. The null meter reading is then the combination of the source voltage (V_s) and the un-wanted offset voltage (V_{Off}) times the instrument gain as set by the Range control.

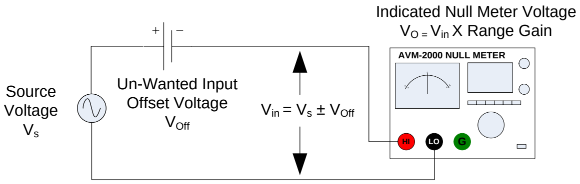

Figure 1

Two significant contributors of un-wanted voltage are input offset voltages generated by thermal and instrument amplifier conditions, and voltages generated by the flow of input offset currents in source resistances. These contributors are very common and are discussed in detail in TEGAM Null Meter Application Guides AN305 and AN309 respectively.

Other contributors to un-wanted voltage during low voltage measurements include:

Common mode voltage: AC, DC or a combination, applied between the instrument HI <u>and</u> LO terminals and a reference point (often Earth Ground). See Figure 2. The impact of common mode voltage is reduced by the instrument's CMRR (Common Mode Rejection Ratio) usually in the area of -60 to -100 dB (a factor of 1/1000th to 1/100,000th) depending on the type and frequency of the common mode voltage. Common mode voltage is often many 100s or 1,000s times greater than the source voltage of interest.

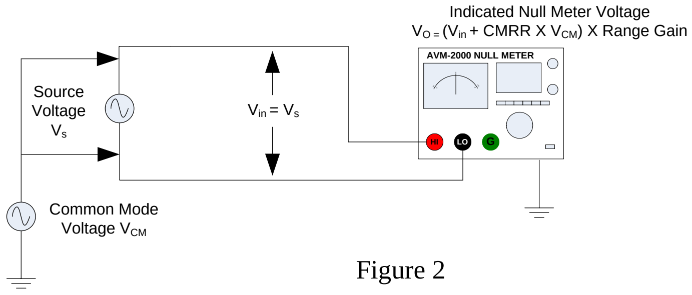

Figure 2

Common Mode (Cont.):

Certain conditions convert common mode voltages to (externally to the instrument) normal mode voltages. Some of these conditions include:

- Distortion and/or clipping of AC common mode signals (Figure 3)

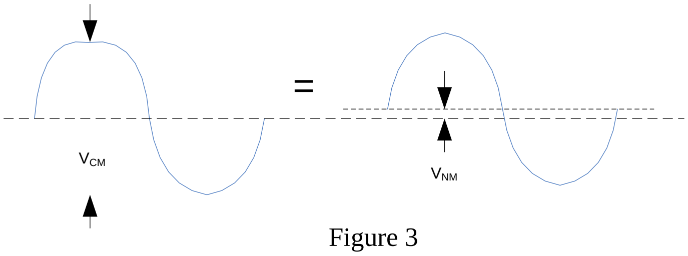

Figure 3

- Capacitively coupled common mode signals where differences in HI and LO coupling capacitance create a normal mode input (Figure 4)

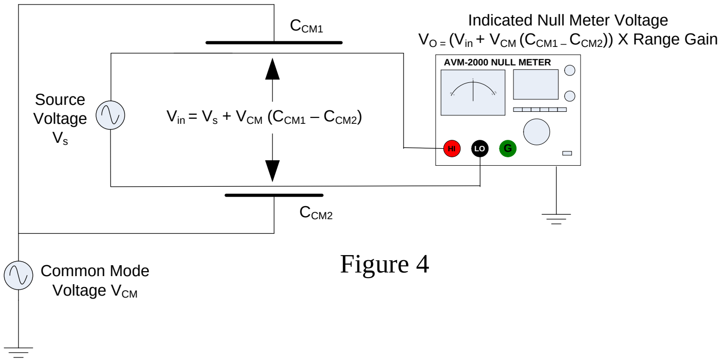

Figure 4

- Inductively coupled common mode signals where differences in HI and LO coupling inductance create a normal mode input (Figure 5)

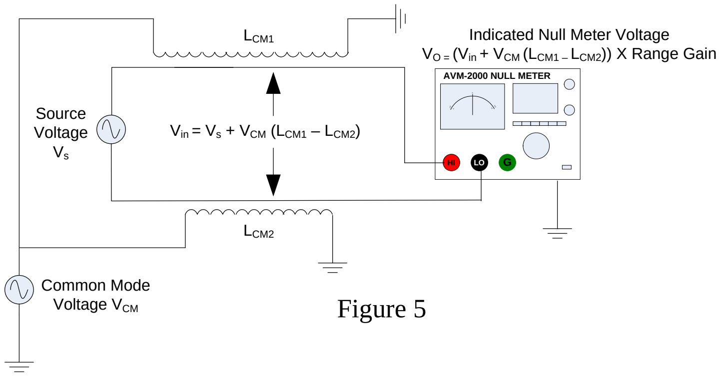

Figure 5

- Note: Both capacitively and inductively coupled common mode signals where differences in HI and LO coupling exist are often a due to (or worsened by) unequal lead lengths between connections (for example, where the source + output is connected to the null meter HI terminal by a 18” lead and the source – output is connected to the null meter LO terminal by a 36” lead).

Normal Mode Voltage: Any voltage applied between the instrument HI and LO terminals. The desired signal source is a normal mode voltage; however, externally induced voltages, for example, that also contribute to either of the input (HI or LO) signals also become (un-wanted) normal mode voltage (V_{Off} in Figure 6). Some sources of un-wanted normal mode voltage are:

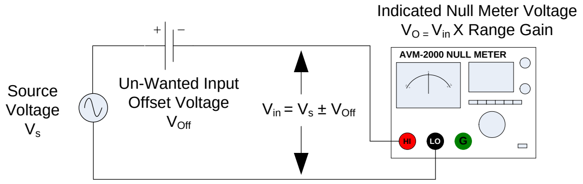

Figure 6

- Chemical emfs: Voltage generated by minute amounts of contamination (often acid from handling connections) that form micro-volt batteries
- The products of rectification in electrical connections: Electrical contacts that are not well cleaned often create a metal-oxide to metal connection. When AC (often in the form of radio frequency signals) passes through such connections, there is an unequal flow of current in the positive and negative half cycles of the signal. This results in a minute level of direct current which appears as an un-wanted signal at the instrument input.
- Unequal temperatures found at the ends of interconnecting cables or different temperatures at different points along the cable
- Noise—which can result in additional signals within the instrument bandwidth or can rectify, distort or otherwise produce a DC component which becomes an un-wanted offset voltage

The Technique:

Reducing common mode and normal mode signals involves both a disciplined approach to measurement practice as well as a situation specific approach.

The disciplined approach simply means following good measurement practices such as:

- Interconnecting cables should be shielded solid copper with shielded twisted-pair being preferable
- Connections to the source voltage and the null meter should be low-thermal-emf spade lugs or wires tightly clamped in a binding post. Banana jacks (gold plated) are a second choice as they will introduce a level of thermal offsets.
- Connections should be clean (wiped with Isopropyl Alcohol or a similar cleaner) to remove acids and other contaminants that can become electro-chemical batteries
- Interconnecting cables should be kept as short as possible and, where-ever possible should be of similar length for similar connections (for example, from the null-meter output of a bridge to the null meter HI and LO terminals)
- Cable shields should be connected to source and instrument Guard terminals
- Case connections of sources and instruments should be connected to earth grounds—normally with a spider connection (i.e. each device connected to earth ground with a separate conductor)

- Maximizing the amount of filtering used for the measurements to the greatest extent possible while still keeping reasonable response to equipment adjustments
- Adjusting null meter voltage and current offsets with as much of the experimental setup in place as possible
- Allowing an experimental setup to come to thermal equilibrium after making interconnections or otherwise introducing heating in the connections

Situational approaches involve such practices as:

- Eliminating unnecessary sources of electronic noise from the vicinity of the measurement setup (such as microprocessor/digital instruments not being used, computers, motor operated equipment, equipment with thermally controlled heaters, switching power supplies, etc.)
- Repositioning equipment, cables and the measurement setup in such a way as to reduce the coupling of interfering signals to the maximum extent
- Changing lighting from fluorescent fixtures (that tend to have a high level of electromagnetic fields at line frequency as well as generate higher-frequency electric noise) to incandescent lighting
- Moving the experimental setup into a Faraday enclosure (screen room) when very critical measurements are in process

Summary:

When making voltage or null measurements at the microvolt and sub-microvolt level many external effects can add to or subtract from the actual voltage being measured. If care is not taken, these external effects can be large enough to introduce substantial error in the measurement and in some cases can actually be significantly greater than the signal being measured.

To reduce these impacts:

- Follow good measurement interconnection practices using high quality cables and connections that are designed for low-level measurements
- Use guarding and grounding to minimize the impact of external signal sources
- Remove all possible external sources of interfering signals by either shutting the sources off or moving the measurement setup away from these sources
- Test the measurement setup for contributions from external sources and adjust the setup for minimal influence from these sources