Ready Rugged Right

PPM INSTRUMENTS

AVM 2000 Nullmeter / Nanovoltmeter

- F/S Range 100 nV to 1000V
- 21 Ranges, 1-3-10 Sequence
- 2 nV Resolution
- Wide Range of Filters
- >100 GΩ Isolation
- Floating Measurements to 1000V
- Calibration Laboratory Stability
- Battery / Line Operation
- Wide Range of Offsets
- Self-Contained Zero & Gain Set

The Model AVM-2000 is a calibration laboratory grade Nullmeter / Nanovoltmeter. It can be used as a stand-alone analog voltmeter or in conjunction with Kelvin-Varley dividers and other calibration laboratory equipment where high sensitivity ratio-metric processes are used.

The AVM-2000 has a very high sensitivity front end amplifier with extremely high common mode rejection making it ideal for comparison/ratio measurements. It is specifically designed for standards comparison and displays readings on an easy to read, dual-scale, mirror-backed meter with null (0) shown at center scale. An isolated, single ended output allows connection to other instrumentation such as chart recorders, data acquisition systems and digital voltmeters. This output also enables the AVM-2000 to be used as a high quality instrumentation amplifier with input impedances ranging from 1 MΩ to 1 GΩ, and gains from 10^{-3} to 10^{8} . Common mode rejection of 80dB, precision adjustable offset voltages and a wide selection of low pass filters ensure operation over the entire range from 100 nV to 1000V without compromising resolution or accuracy.

MAINS ISOLATION

The AVM-2000 may be operated from line power or its internal rechargeable battery (rechargeable with the internal battery charger). Battery operation allows up to 50 hours of total independence and isolation from common mode signals generated through mains and building wiring, minimizing the possibility of errors induced by ground loops and other wiring induced noise.

EASY/TRADITIONAL OPERATION

At its heart, the AVM-2000 employs modern digital technology; however to the user it functions as a traditional analog meter. The AVM-2000 incorporates a mirror-backed, high-accuracy, dual-scale, analog meter display to facilitate use as a Nullmeter. Range is selected by rotating a traditional Range selection knob. All operating modes are pushbutton selected and displayed on an easy to read LCD. Output level, and input offset level are controlled by "press-rotate-press" rotary controls. Settings are held in non volatile memory.

INDICATORS

A backlit LCD alphanumeric display assists the user in operation and setup of the instrument. It continuously displays the status of the primary selected parameters and mode of operation. The current range setting is shown in large bold numbers to eliminate range reading errors incurred when reading knob position.

The AVM-2000, utilizing the latest available technology, surpasses all of the specifications of its predecessors. It replaces, and exceeds the performance and functionality of: the PPM model AVM-100 and the discontinued Hewlett Packard HP419A, Fluke 845AB, and Keithley 155.

UNIQUE FEATURES INCLUDE:

- Scalable rear panel output (±0.5 – 1.5 Volt for Full Scale)
- Low Thermal EMF input binding posts (Gold plated Tellurium Copper)
- Input connector shield for thermal isolation of input terminals
- Wide range of filter settings (0.1 – 100 sec in 1-2-5 sequence)
- Analog sub-system in heavy metal guarded enclosure for long term thermal stability

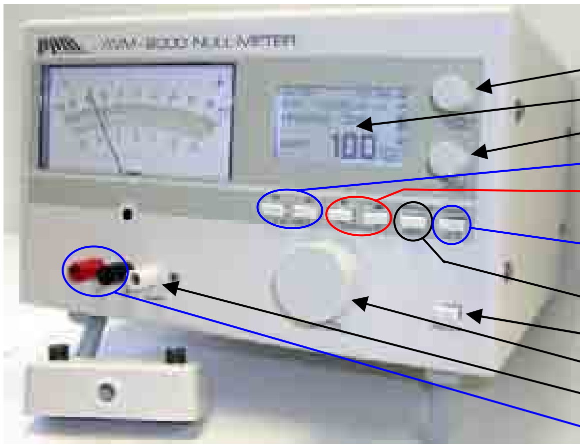
Ready Rugged Right

AVM 2000 Nullmeter / Nanovoltmeter

AVM-2000 SPECIFICATIONS

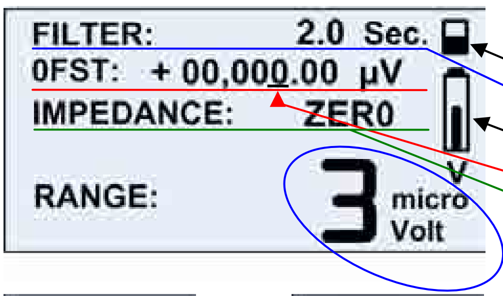
INPUTS and RANGE	• One set of input terminations for all ranges • HI LO & Guard • Low end 100nV full scale deflection with 2nV resolution • High-end range ≥1000V full scale deflection. with 5V or better resolution • 21 selectable ranges, (1-3-10 sequence)		
OUTPUTS AND INDICATORS	2 output indications • Analog meter • Isolated analog rear panel output		
Analog Output	± 0.5% of full scale of range selected (typically 0.1%)		
Resolution	Within 0.1% of full scale of selected range (after floor noise compensation)		
Linearity	Within 0.5% of full scale of selected range		
Analog Meter	± 2% of full scale of selected range		
Scaling	Mirrored zero center 10-0-10 and 3-0-3		
Resolution	≤1% of full scale of selected range (typically, 0.5% of full scale of selected range)		
Linearity	≤ ± 1% of full scale of selected range		
INPUT IMPEDANCE	100 nV to 1mV FS 1, 10, 100MΩ, or 1GΩ Selectable	3mV to 300 V FS 10MΩ, or 100MΩ Selectable	1 KV FS 1000MΩ
OFFSET CURRENT	• Adjustable (± 2.5 nA) to zero at front panel		
FILTER	10-position digital low pass filter selectable from front panel 100, 200, 500 mSec, 1, 2, 5, 10, 20, 50, 100 Sec		
OFFSET	Continuously variable (0 to ±999.9% of range) offset for all ranges		
Resolution	≤ .01% of offset full scale		
Accuracy	≤±0.5% of offset full scale		
SERIES MODE REJECTION	> 80dB at 50Hz-60 Hz		
OUTPUTS	Isolated yielding ±0.5 to ±1.5V (user adjustable) for full scale deflection		
ISOLATION	Input to case or output > 100 GΩ (typically > 500 GΩ)		
OVERLOAD PROTECTION	1100 VDC or peak on any range		
INDICATORS			
Meter	4 ½" Mirror Backed with – 3 – 0 – +3 and -10 – 0 – +10 Scales		
Status	Backlit LCD: Range, Offset, Filter Response Time, Input Impedance, ZERO/OPERATE Mode, Input Offset Mode and Isolated Output Mode		
DIMENSIONS	6.5" H X 11.5"W X 13.5" D		
WEIGHT	22.5 lbs		
CONNECTORS	• Low thermal emf input terminals plus guard • Two output Binding Posts, plus a third for case common • Input terminal cover		
POWER SUPPLY	• Internal rechargeable battery • External 12 to 30 V DC @1.25 Ampere • External "Power Cube" included		
ENVIRONMENTAL			
Operating Temperature Range	15 - 30 °C Full Specifications		
Operating Humidity Range	0 - 50% RH Full Specifications		
Storage Temperature / Humidity	-20 to + 60 °C / 0 - 80% non-condensing		

FRONT PANEL CONTROLS AND DISPLAYS ORIENTATION



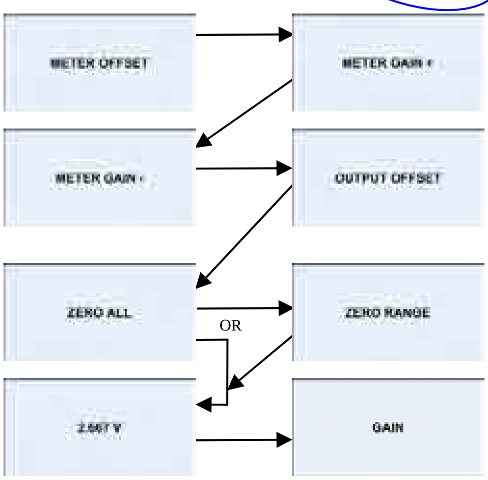
FRONT PANEL CONTROLS & TERMINALS

- OUTPUT LEVEL: Adjusts gain to Isolated Output (rear panel) ±0.5 – 1.5 V F/S
- INSTRUMENT STATUS LCD: Shows operating and setup information
- INPUT OFFSET Multifunction offset control
- FILTER: Select filtering from 0.1 S to 100 S in 1-2-5 sequence (Typically 2 S)
- OFFSET: 0 to 30 mV (maximum 10 X 3s range and 30 X 1s range) OFFSET push buttons adjust selected digit up (▲) or down (▼)
- INPUT MΩ: Selects input IMPEDANCE: 1, 10 or 100 MΩ or 1 GΩ (100 nV – 1 mV ranges); 10 or 100 MΩ (3 mV – 300 V ranges); 100 MΩ (1 kV range)
- OPERATE / ZERO; ZERO replaces impedance value in display in Zero mode
- POWER: Depressed for ON. Instrument is ON in standby mode when charging
- RANGE: Rotary selection of full scale value ± 100 nV to ± 1 kV in 1-3-10 steps
- GUARD: Internal shield for high-sensitivity circuits. Tie to LO or source shield
- HI & LO INPUT: Input terminals—maximum 1,100 volts to GUARD or chassis. Red is HI and Black is LO. Positive HI to LO moves meter upscale.



LCD – NULL METER OPERATION

- OUTPUT LEVEL LOCK: Depress control to enable (🔒) OUTPUT LEVEL
- FILTER TIME: 0.1 to 100 Sec in 1-2-5 steps
- BATTERY CHARGE: Full ~ 50 Hr., 4-bars ~ 4 Hr. 2-bars < 10 min.
- OFFSET VOLTAGE: Use INPUT OFFSET (Locked 🔒) to place cursor (▲)
- INPUT IMPEDANCE: ZERO (internal Zero reference) in ZERO mode or 1, 10 or MΩ or 1 GΩ in OPERATE mode (Mode selected by OPERATE / ZERO)
- RANGE: Full Scale range with scaling indication of **nano Volt**, **micro Volt**, **milli Volt** or **Volt** (no scaling)**.** Range uses either ± 3 or ± 10 meter scale.

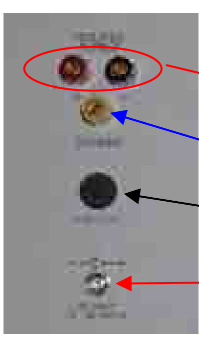


LCD – SET UP OPERATION

Press and hold RANGE until METER OFFSET is displayed on LCD. Rotate RANGE one step to sequence thru Set Up menu (Arrows show sequence for clockwise rotation). *

1. METER OFFSET: Use OUTPUT LEVEL to set meter pointer to "0"
2. METER GAIN +: Use OUTPUT LEVEL to set meter pointer to "+10"
3. METER GAIN –: Use OUTPUT LEVEL to set meter pointer to "-10"
4. OUTPUT OFFSET: Use OUTPUT LEVEL to set ISOLATED OUTPUT to 0
5. ZERO ALL / ZERO RANGE: Depress both OFFSET buttons to toggle between ZERO ALL and ZERO RANGE. Depress OUTPUT LEVEL to start Zero process. Hi quality short required between HI and LO.
6. 2.667 V: Use OUPUT LEVEL to adjust for 2.667 V ± 1 mV between HI and LO
7. GAIN: Depress OUTPUT LEVEL to start Gain Setup. HI / LO must be open

* In normal use these steps limited to confirmation of correct instrument adjustment

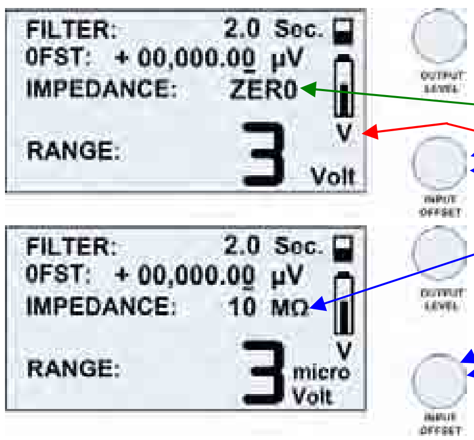


REAR PANEL

- ISOLATED OUTPUT + / - : Up to 1 kV isolation from HI & LO. Output is ± 0.5 V to ± 1.5 V for full scale on meter. Positive meter deflection causes positive output + (Red) to – (Black) -. Note: Black connected to CHASSIS when charging.
- CHASSIS: Electrical connection to instrument case/chassis
- FUSE 1 ¼ A: Charging source fuse
- DC INPUT : Charging source of 12 – 30 VDC @ 1.25 A. Do not use switching supply. Charge instrument any time not in use.

SET UP AND MEASUREMENT PROCESSES SUMMARY

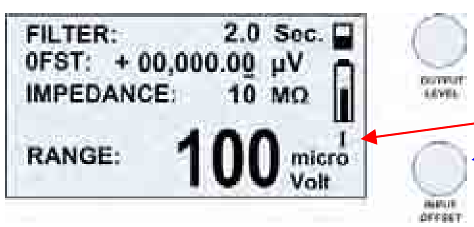
ZERO ADJUSTMENTS



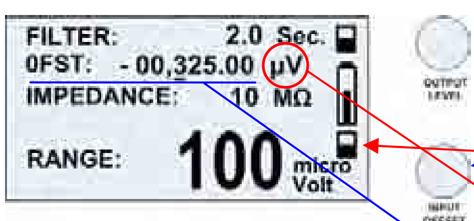
INPUT OFFSET VOLTAGE: Balance out unwanted voltage from the null measurement introduced by instrument or circuit offsets. Manual adjustment to refine ZERO ALL or ZERO RANGE.

- Select ZERO mode (use ZERO/OPERATE pushbutton)
- To Zero voltage, depress INPUT OFFSET to show V
- Adjust Zero with INPUT OFFSET (for each range of interest)
- Select OPERATE mode (use ZERO/OPERATE pushbutton)
- IMPEDANCE value shows in place of ZERO (10 MΩ)
- Connect low-resistance short between HI & LO *or* at signal source point in measurement circuit (best)
- Adjust Zero in OPERATE mode for each range of interest
- Adjust Zero for 10 MΩ and 100 MΩ Zin above 3mV range

INPUT OFFSET CURRENT: Balance out unwanted currents (that generate offset voltage in source resistance) from the null measurement introduced by instrument or measurement circuits.

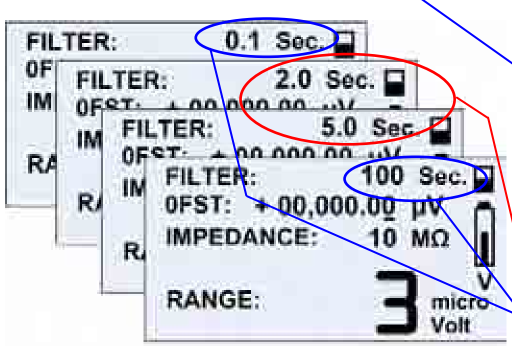


- Only adjust INPUT OFFSET CURRENT after Offset Voltage is zeroed
- Select OPERATE mode & 100 μV RANGE
- Connect 100 kΩ between HI & LO (or use high-impedance measurement circuit)
- To Zero Current, depress INPUT OFFSET to show I
- Adjust INPUT OFFSET to Zero meter (Start at 100 μV. Increase sensitivity to 10 μV Range. Ensure Zero remains with Hi Resistance and Zero Ω Resistance at between HI & LO)



OFFSET VOLTAGE: Allows the user to offset a voltage (the same on all ranges) that is, typically combined with the input signal. Offsets can be up to 30 mV within limits of ± 10 X for 3s ranges and ±30 X for 10s ranges .

- First Zero Input Offset Voltages (see above) to eliminate instrument offsets
- Use combination of INPUT OFFSET control (LOCKED) and OFFSET pushbuttons (▲ and ▼) to insert desired offset.
- Out of range Offset causes μV symbol to blink—reduce offset to correct
- Offset can be known value or experimentally derived value to create desired readings.
- Example– 325 μV offset for meter range of + 225 to + 425 μV



FILTER: Allows the user to select the time over which the input signal is averaged before being sent to the instrument display and output. Added filtering smoothes the response, removes the effects of noise, and increases the time for a measurement to settle.

- Typical null meter without filtering has 2 to 5 Second filtering. A setting of 2 Sec is a good starting point.
- The amount of noise reduction from averaging is the square-root of the time increase—100 Sec averaging reduces noise to 1/10 of its value at 1 Sec. or 1/32 the value at 0.1 Sec.

Purpose:

The PPM Null Meter Application Guides are written to assist both the new and experienced user of high-sensitivity Null Meters/Nano-Voltmeters. For the new user, the Application Guides provide a basic understanding of the fundamentals of measurement process that use Null Meters. For the experienced user, the Application Guides provide a refresher on fundamentals but more importantly help the user moving from the use an older model null meter to the PPM AVM-2000.

In the later case, the experienced user will often find small differences in results (especially when working in the micro-volt and sub-micro-volt region). In most cases these differences can be attributed to differences in measurement technology, the impact of added features, and simply different ways of making measurements. The various PPM Null Meter Application Guides address a range of different issues that may be encountered when making these transitions.

Background:

The PPM AVM-2000 is a fourth generation null meter. It was designed to replace earlier null meters such as the PPM AVM-100, the Fluke 845AB, the HP 419, the Keithley 155 and earlier models.

As a fourth generation product, the AVM-2000 offers extended features and specifications designed to allow the user to make effective null measurements in today's environment.

The user familiar with earlier generation null meters will find differences in null measurements from time-to-time. In most cases these differences are as a result of greater control now available over the measurement process and often due to the elimination of small or accounting for offsets previously inherent to measurements made using null meters with less functionality.

For example, the AVM-2000 offers a wide range of signal filtering. The displayed voltage (null) can be filtered from 0.1 second to 100 seconds in steps that are in a 1-2-5 sequence. Earlier null meters simply offered fixed filtering typically in the area of 3 seconds with filtering increasing to approximately 5 seconds for the most sensitive ranges. As noise reduction is a function of the square root of the integration time, measurements with the AVM-2000 can be made that reduce the contribution of low-frequency noise by a factor of 10 or will increase the contribution of low-frequency noise by a factor of 3.

A brief summary of the differences between the AVM-2000 and predecessor Null Meters is shown on page 2 of this Application Guide.

Solving the Problem:

A brief summary of the differences between the AVM-2000 and predecessor Null Meters is shown on page 2 of this Application Guide. Refer to the indicated PPM Null Meter User Guide for additional information on how this feature/specification contributes to measurement issues.

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APPLICATION GUIDES RELATED TO SPECIFICATION & FEATURE DIFFERENCES BETWEEN NULL METERS				
Feature/Specification	PPM AVM-2000	PPM AVM-100	Fluke 845 AB	PPM Null Meter Application Guide
Filtering	Selectable: 0.1 Second – 100 Second 1-2-5 Steps	Fixed: 5 Second 1 µV, 3 Second 3 µV, 1.5 Second all other ranges	Fixed: 5 Second 1 µV, 3 Second 3 µV, 1.5 Second all other ranges	AG – tbd
Zero Function (Voltage)	Separate Zero adjustment for ZERO and OPERATE Modes for each Range	Zero adjustment for ZERO Mode trimmed for 1 – 30 µV, 100 µV, 300 µV and 1 mV – 300 V	Zero adjustment for ZERO Mode trimmed for 1 – 30 µV, 100 µV, 300 µV and 1 mV – 300 V	AG-105
Zero Function (Input Offset Current)	User adjustable: Maximum offset ± 2.5 nA	Internal adjustment: Maximum offset ± 150 pA	No adjustment	AG-101
Input Impedance	User selectable: 1, 10, 100, 1000 MΩ to 1 mV 10 or 100 MΩ 3 mV to 300 V 1 kV fixed at 100 MΩ	1 MΩ 1 µV – 1 mV 10 MΩ 3 mV – 100 mV 100 MΩ 300 mV – 1 kV	Early models 10 MΩ 1 µV – 100 mV 100 MΩ 300 mV – 1 kV Later models 1 MΩ 1 µV – 1 mV 10 MΩ 3 mV – 100 mV 100 MΩ 300 mV – 1 kV	AG-tbd
Offset Voltage	Offsets of: ± 10 X “3s” range ± 30 X “1s” range maximum of 30 mV	None	None	AG-tbd

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Purpose:

This Application Guide describes the sources of input bias current on a high sensitivity instruments such as a null meter, the impact input bias current can have on measurements and how the user compensates for input bias current to minimize its impact on measurements.

Background:

Modern solid-state amplifiers, such as those used in null meters, use bipolar or field effect transistors (FETs). Even though the amplifier is designed for very high-gain and very low-signal operation, a small amount of current flows into or out of the amplifier's input. This is true for either bipolar transistor or FET amplifiers. This current is the amplifier's input bias current. Input bias current is usually measured in nano- or pico-amperes for high-sensitivity amplifiers. The current must have a path from the amplifier input to circuit common. Often this path is through the external measurement circuit connected to the instrument.

Amplifiers designed for instrumentation work often have differential inputs (see Figures 1a and 1b). The amplifier output signal is a function of the *difference* between the signals applied to the two inputs. In the case of differential amplifiers, each input has its own input bias current. The difference between these two currents is known as the input offset current. This is shown in Figure 1 as $I_{off} = I_{b2} + I_{b1}$. The direction of the current (in or out) depends on which current (I_{b2} or I_{b1}) is larger.

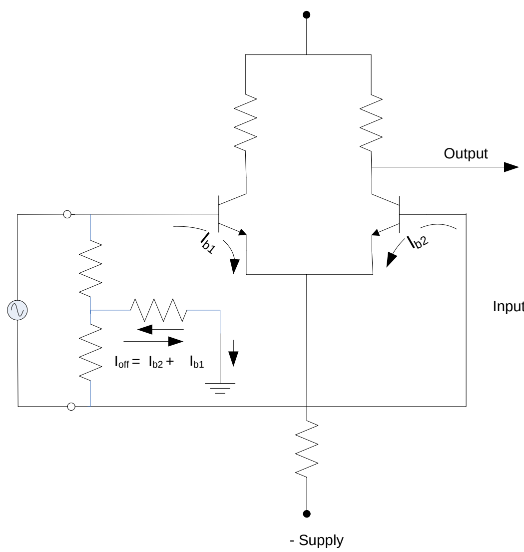

Figure 1a

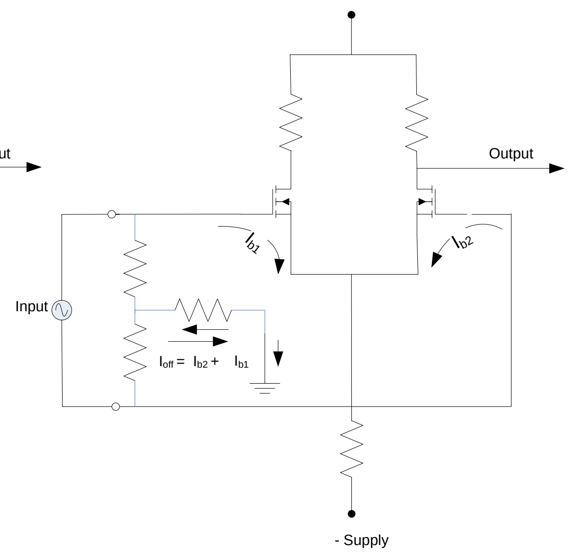

Figure 1b

In general the user does not need to know if an amplifier is single-ended or differential. What concerns the user is the small current (I_b) flowing into or out of the instrument input terminals. See Figure 2.

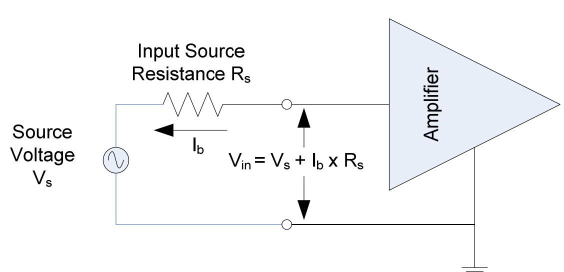

Figure 2

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This current flows through the source resistance (R_s) of the signal source driving the amplifier input. If that signal source has a high-impedance, the small current from the amplifier's input causes an additional voltage drop ($V_{Ioff} = I_b$ x R_s). That small voltage drop also appears at the amplifier's input terminals. This results in an error as it either adds to or is subtracted from (depending on the direction of the bias current flow) the signal of interest.

Solving the Problem:

A modern instrument design includes an adjustable circuit to inject a current that isequal and opposite to the amplifier bias current. In some cases, such as with the PPM AVM-2000, this is a user adjustable value. This allows the operator to balance out any amplifier bias current as well as to balance out any other unwanted current that may exist in the input circuit. Making the input offset current adjustable also allows the operator to compensate for input bias current changes that occur with changes in temperature, component aging, electromagnetic environment, etc.

The Technique:

Compensating for input bias current is a two-step process.

First, adjust the amplifier to remove the effects of any VOLTAGE offset. Voltage offset is adjusted by shorting the amplifier's input (using a very low resistance that exhibits little or no thermal voltage—see Application Guide AG-105) and adjusting the amplifier's voltage offset until the amplifier output is zero.

Second, create a source resistance that is high enough that a small input bias current flowing through the resistance generates a measurable voltage. If the measurement source resistance is not known, a suitable value for such a resistance is 100,000 Ω. The shorting strap used to adjust the voltage offset is replaced with this low-noise (carbon film or metal film) 100,000 Ω resistor. At this point any output voltage shown is the amplified version of the product (Ohm's Law) of the input bias current and the resistor value.

For example, a 1 nA input bias current flowing in a 100,000 Ω resistor produces 100 µV at the amplifier input. With the resistor in place, the instrument's input offset current control is adjusted to provide a current that is equal and opposite to the amplifier's input bias current. When the two currents are equal and opposite, no current flows through the resistor and therefore no voltage is developed across the resistor. With zero volts at the input, the amplifier output is zero. At this time, there should be no difference in the amplifier output between a shorted input (0 Ω) and a 100,000 Ω resistor at the input.

Summary:

When adjusting the Input Offset Current to compensate for Input Bias Current, keep the following in mind:

- Be sure to zero Input Offset ***Voltage*** before adjusting Input Bias Current.
- Voltages generated by the Input Offset Current should be large compared to voltages that might be generated by resistor noise, thermal emfs, electro-chemical emfs, etc. (10 µV to 100 µV are good ranges to use). See PPM AG-105 for a discussion of other potential sources of offset voltage.
- Input Offset Current will change with changes in the measurement environment and therefore should be checked from time-to-time. Large changes in the voltage levels of signals being measured may also change the measurement environment sufficiently to change the impact of Input Bias Current.

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Purpose:

This Application Guide discusses the use of filtering to improve null measurements when noise on the signal source makes measurements difficult or introduces error. This note also helps the experienced user compare a null meter with variable filtering with one that has fixed filtering.

Background:

Frequently circuits generating very low-level voltages (such as those measured by null meters) often also allow the signals (voltages) of interest to be accompanied by unwanted AC signals. The unwanted signal may be random noise or of a fixed frequency such as line frequency related signals. Signals that are either random or a fixed frequency can easily interfere with low-level DC measurements as they add to or subtract from the voltage of interest—and may add at times and subtract at other times making either absolute measurements or null indications very difficult.

Random noise can be generated by the circuits generating the signal of interest, by the connections between the signal source and the instrument as well as by the instrument itself. A contributor of truly random noise is Johnson Noise (also called thermal noise), caused by the random activity of electrons moving in a resistance. The amount of thermal noise increases with temperature. Truly random noise has equal intensity at all frequencies (often called white noise); however, noise often has varying amplitude with frequency and may be referred to as pink noise or by other similar terms.

Noise (that is, unwanted voltages interfering with the null meter measurements) may also be generated by many external sources and while appearing to be random is actually synchronized to an external event such as fluorescent or dimmed lighting circuits, heating systems, other instruments (especially those with microprocessors or other fast digital circuits), motorized equipment, radio systems and many other sources. Unfortunately, many times it is impossible to eliminate these sources (the best approach) so measurements must be made with this noise combined with the voltage of interest.

One of the measurement difficulties encountered in reducing the impact of noise on the measurements of interest is determining at what frequency to cut off unwanted measurements. All measurements normally involve some change in amplitude—if there is no change usually there is no measurement to be made. So, the user must decide what frequency of change is of interest (for example, with a null meter, the user may wish to see changes that happen over a period of one-second as the setup approaches null, and therefore signals of 1 Hz are of interest.)

Random noise and unwanted higher frequency signals can be substantially reduced by adding filtering to the measurement; however, filtering also "colors" the measurement—that is, it adds its own characteristics to the final measurement.

Filters used in instruments such as null meters typically reduce the amplitude of voltages above a particular frequency while not changing the amplitude of lower frequency signals. These are called low-pass filters and are used with null meters as the signals of interest are usually very low frequency. A filter reduces the effects of both random noise and of unwanted signals of a particular frequency such as line related signals.

Filtering techniques are simply forms of averaging. Given enough time, the average value of a random signal is zero as is the value of a pure sine wave; however, infinite time is impractical (and many interfering signals are not pure sine waves). For practical amounts of time, increasing the filtering time (or reducing the filter corner frequency) reduces the noise by the square root of the change in time. For example, changing the AVM-2000 filter time from 1 second to 100 seconds (a 100 fold increase in time) reduces the effects of noise by 10 fold while increasing the filter to 10 seconds (10 fold) reduces the noise by a factor of three.

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The Technique:

The first step in noise reduction in any measurement situation is to eliminate the source of the noise wherever possible. Some steps to aid in noise elimination are:

- Turn off noise making devices (unused instruments, computers, motorized equipment, lighting, etc.). NOTE: Switching power supplies as often used in modern electronic products (especially computers) tend to generate sufficient noise over a wide range of frequencies.
- Make all interconnections between the signal sources and the null meter with twisted pair, copper wires with a shield. The shield connections are normally connected to the instrument GUARD terminal
- Keep all connections as short as possible and where possible keep similar connections (for example the connections from a source to the HI and LO instrument terminals) of equal length
- Position (and reposition) all interconnections to minimize inductive (transformer like) and capacitive coupling of external unwanted signals into the measurement interconnections. NOTE: Not infrequently signals a local AM, FM or Television station may couple into the measurement wiring. Although the frequency of such signals is well beyond the frequency response of a null meter, it is possible that these signals may be rectified (detected) by some of the measurement circuits and thus be turned into either DC or low frequency AC interfering signals
- Connect the EARTH/CASE terminal (Yellow binding post on the rear of the AVM-2000) on signal sources and the null meter to a common high-quality earth ground
- Eliminate any un-needed resistances in the signal path (to reduce Johnson Noise)
- Use battery operation (vs. line operation) for the null meter and as many other active electronic devices connected to the system as possible
- Move the measurement setup into a location with shielding against noise such as a Faraday enclosure (Screen Room)

Reducing the noise through filtering is the second step and should be done after all measures have been taken to eliminate unwanted noise signals from the measurement. Steps to reduce noise via filtering include:

- Start with 2 or 5 second filtering if the instrument provides adjustable filtering. Increase the filtering if the measurement will allow a slower response. Remember most fixed filtering null meters have 2-second filtering for ranges of 30 µV and above and 5-second filtering for ranges below 30 µseconds.
- If strong interfering signals may be present and the signal source is a high-impedance device such as a bridge (Reference Divider, Kelvin Varley Divider, etc.) placing a low leakage (Polypropylene or Polystyrene) 2 – 5 µF capacitor across the null meter input terminals

Summary:

The first step in reducing unwanted noise from measurements is to eliminate the source of unwanted signals.

- Turn off or otherwise eliminate noise sources
- Configure wiring and the measurement layout to reduce coupling noise into the circuits
- Use the maximum level of filtering (by the instrument) possible that still allows the measurement
- Add external capacitance to the null meter input

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Purpose:

This Application Guide discusses suggested instrument interconnections and supplemental filtering to allow maximum resolution when the AVM-2000, or other very high sensitivity null meters, are used in conjunction with such instruments as Reference Dividers, Kelvin Varley Dividers and other high-impedance ratio dividers.

Background:

One of the very common uses for a null meter is the indication of balance between two voltages where one of the voltages is a reference and the other an unknown which is the product of a voltage source and a high impedance divider. For example, a common application is the Calibration Mode of a Reference Divider such as the Fluke 752A. When in the Calibration mode, a simplified schematic representation (Figure 1) of the resulting bridge circuit shows:

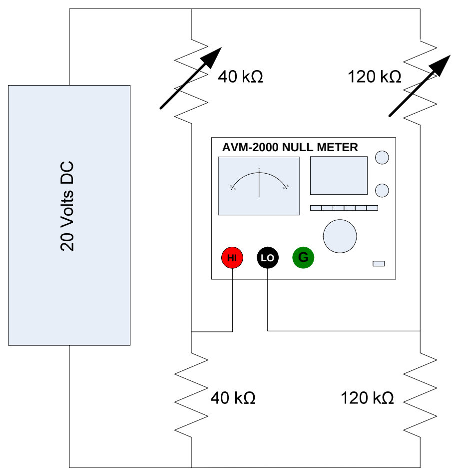

Figure 1

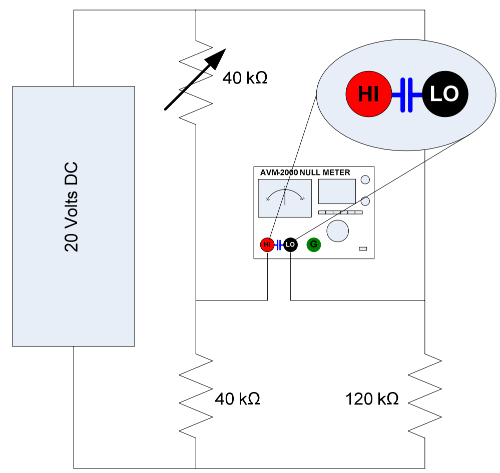

Figure 2

In this schematic we see a null meter connected to the bridge center points. Treating the 20 VDC source as having zero impedance, we find the source resistance driving the null meter to be approximately the combination of two 40 kΩ resistors in parallel (20 kΩ) plus the parallel combination of two 120 kΩ resistors for a total of 80 kΩ. As these resistors are physically quite large, they are susceptible to significant amounts of 50/60 Hz pickup when the 752A is used in a normal (i.e. non-Faraday Shielded) environment. A good balance ensures a null of 100 – 200 nV (1 part in 10^8 of the 20 V source). If external fields induce signals of 20 mV, this is 100 dB greater than the desired null voltage and may well cause erratic null meter readings.

The addition of input capacitance at the null meter terminals provides significant reduction (filtering) of the line-frequency interfering signal. This is shown in Figure 2 as a small blue capacitor between the null meter input terminals. Note: PPM provides such a 2 µF Filter Block with each AVM-2000 for this purpose.

Such a configuration is also highly susceptible to minute DC voltages generated from thermo-electric and electro-chemical effects. For example, if a copper-to-gold connection is used for the wires from the bridge to the null meter, a temperature difference of 1 °C between any two terminals, can generate DC offsets of 200 – 300 nV—an offset that is 100% the target value for a good null! Therefore, close attention must be paid to ensuring good connections as well as to reducing the impact of any external electro-magnetic fields.

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The Technique:

Calibrating a Reference Divider (such as the Fluke 752A):

The following procedure is a guide to those techniques which do the best job possible of ensuring external influences do not impact null measurements made when performing the 10:1 and 100:1 calibration steps on a Reference Divider.

a. Connect the voltage source, reference divider and null meter as in Figure 3 including a 2 µF filter block at the null meter input terminals
b. Set the voltage source to ZERO volts
c. Place a short at the reference divider NULL METER output
d. Adjust the null meter for zero on each of the µV ranges using VOFFSET
e. Remove the short from the 752A
f. Adjust the null meter for zero on the 10 µV range using IOFFSET
g. Remove the short from the 752A
h. Set the voltage source for 20 VDC
i. Perform reference divider calibration per manufacturer's directions

Using the Reference Divider:

Ensure the Reference Divider, Voltage Source to be calibrated and null meter are connected as shown in Figure 4 including the 2 µF filter block at the null meter input terminals. Follow the manufacturer's instructions for using the Reference Divider to calibrate an unknown voltage source.

Summary:

Extending these techniques to similar divider setups:

The basic concepts outlined above and in the diagrams shown in Figures 3 and 4 are applicable to both Reference Divider and Ratio Divider setups. These include:

a. Ensure the wiring between units minimizes offset voltages due to thermo-electric and electro-chemical sources as well as minimizes induced (inductively or capacitively) voltages from local electromagnetic fields
b. When using high-impedance dividers, utilize a filter block at the null meter to reduce the impact of inductively or capacitively induced line-frequency voltages
c. Zero the null meter for both offset voltage and offset current with the null meter fully connected to the measurement circuits

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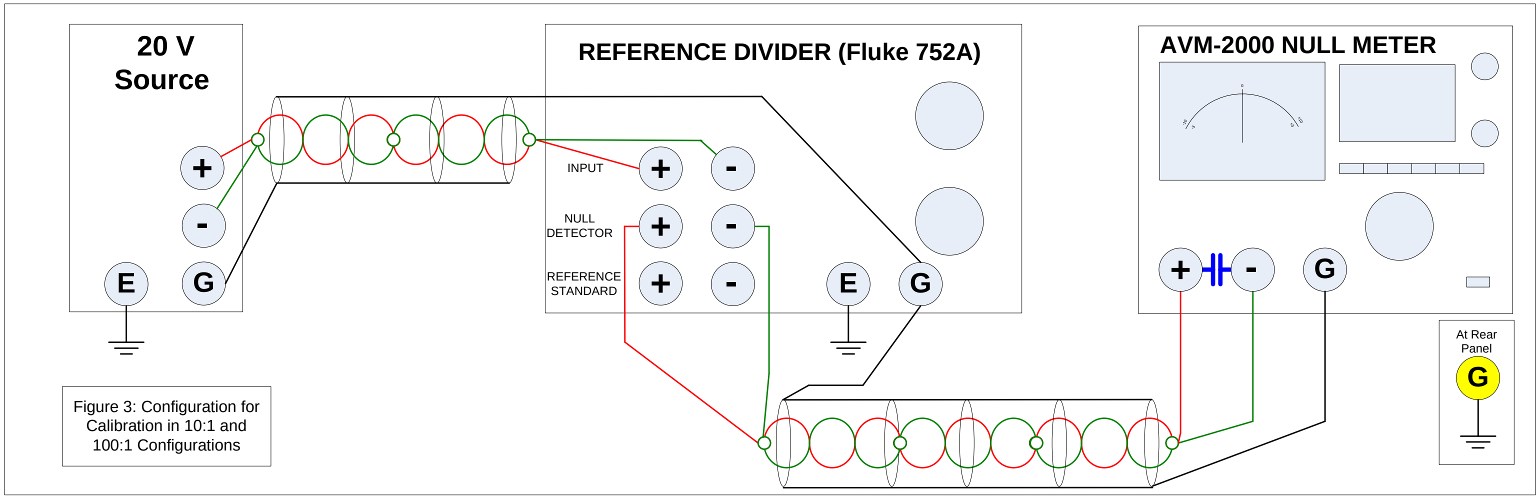


Figure 3: Configuration for Calibration in 10:1 and 100:1 Configurations

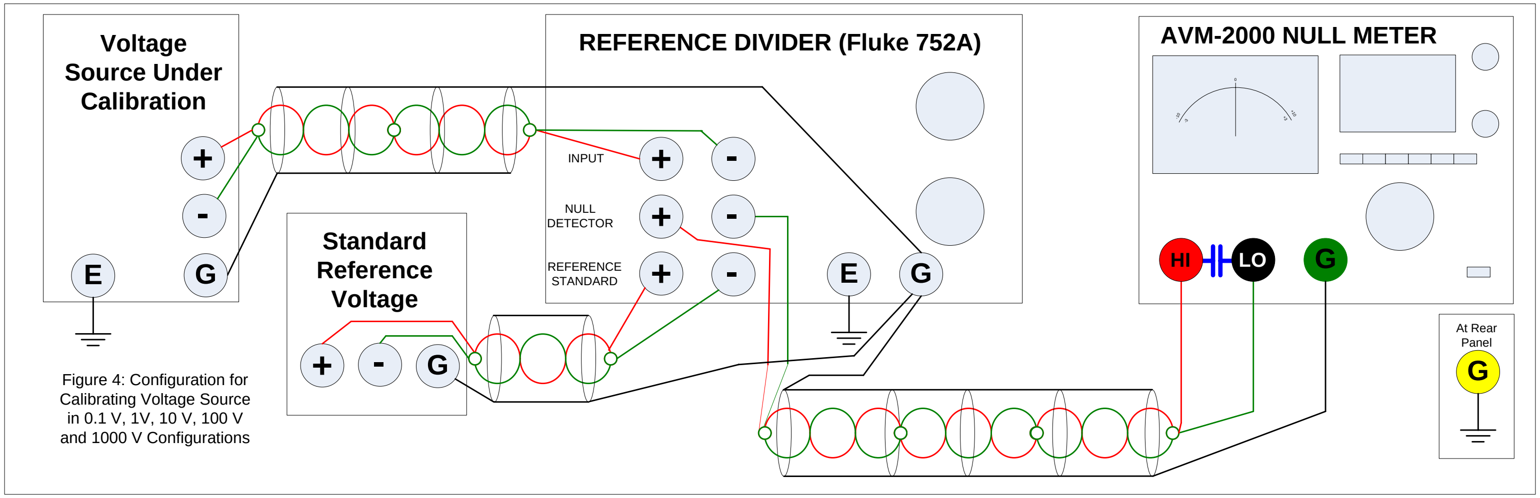
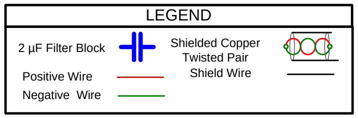


Figure 4: Configuration for Calibrating Voltage Source in 0.1 V, 1V, 10 V, 100 V and 1000 V Configurations



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Purpose:

This Application Guide describes the sources of input offset voltage on a high sensitivity instruments such as a null meter, the impact input offset voltage can have on measurements and how the user compensates for input offset voltage to minimize its impact on measurements. The experienced user will find this discussion helpful in understanding potential differences in measurements between various null meters.

Background:

Modern solid-state amplifiers, such as those used in null meters, use bipolar or field effect transistors (FETs). These amplifiers are designed for very high-gain of very low level signals, high-stability and the absolute minimum of input offset voltage. However, there is always a small difference between the input voltage needed to produce zero volts at the amplifier output (and therefore on the instrument display) and zero volts at the input. This is true for either bipolar transistor or FET amplifiers. The input voltage required to produce zero volts at the output is equal to and is the opposite polarity of the amplifier input offset voltage. Input offset voltage is usually measured in micro-volts for high-sensitivity amplifiers.

For example, if an amplifier requires an input of + 1.5 µV to cause the output to be zero, then the amplifier input offset voltage is – 1.5 µV.

One way to think of this situation is shown in Figure 1. Here the input offset voltage is shown as a tiny (µV) battery in series with the input signal. Therefore, the output signal (V_O), is equal to the sum of the signal being measured (V_S) and the input offset voltage (V_{Off}), times the gain of the amplifier (G). Remember, this is actually an offset voltage in the amplifier itself—and not an offset from external factors.

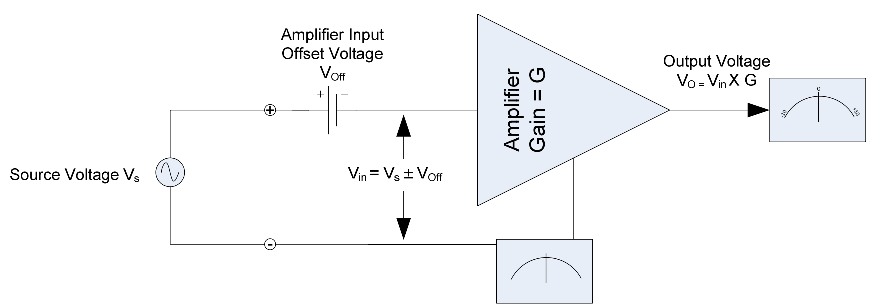

Figure 1

Again, if the “battery” is + 1.5 µV, then the source voltage must be – 1.5 µV to make the amplifier output equal to zero volts.

To add to the measurement difficulty, input offset voltage typically has a temperature coefficient. That is, the input offset voltage varies with temperature—sometimes positive (i.e. the offset voltage increases with temperature) and sometimes negative. Therefore, correction schemes must take temperature into account.

In the real world, there are other “offset” voltages that must be taken into account when making measurements at microvolt and sub-microvolt levels. One of the key factors creating additional offset voltages is those which come from the thermoelectric (Seebeck) effect. These are voltages generated by the junction of two dissimilar (or slightly dissimilar) metals—such as gold-to-copper, or even copper-to-copper or gold-to-gold. Every instrument has a number of these junctions at the input terminals where the voltage to be measured enters the instrument as well as in the external measurement circuits. Typically these voltages change from 200 – 500 nV per degree Celsius for connections found around high-sensitivity instruments.

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To show the effect of thermally generated voltages at the instrument input terminals on the amplifier output voltage, the diagram of Figure 1 is modified as shown in Figure 2.

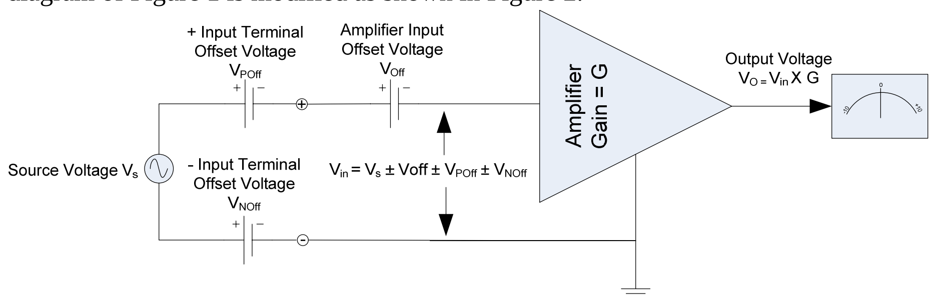

Figure 2

Figure 2 shows the amplifier output voltage now reflects A) the input signal (V_s); B) the amplifier input offset voltage (V_{Off}); and C) the DIFFERENCE between the positive input terminal offset voltage (V_{POff}) and the negative input terminal offset voltage (V_{NOff}) all times the amplifier gain (G). In this example it is presumed that both the positive and negative instrument terminals and the connections to those terminals are the same (for example, copper wire to a gold terminal). If the two terminals are exactly the same, there is no difference—that is, V_{POff} will exactly offset V_{NOff}; however this is rarely the case. Again, typically such connections show differences in thermally generated voltages of 200 – 500 nV per degree Celsius.

In null meters and other high-precision voltmeters, there are two additional places that introduce offsets. First are other connections in the external measurement circuits. These are shown in Figure 3a as V_{AOff} and V_{BOff}. Like other offset voltages these contribute to the output voltage and change with temperature. A second circuit (often just a simple switch) that must be considered is one to quickly disconnect the amplifier input from the input terminals and "short" the amplifier input thus generating a "zero" reference. Figures 3a and 3b show the two configurations of an amplifier when a Zero input switch is used.

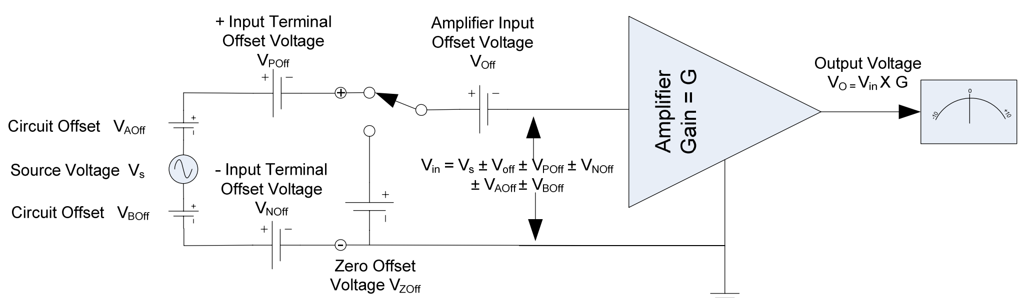

Figure 3a

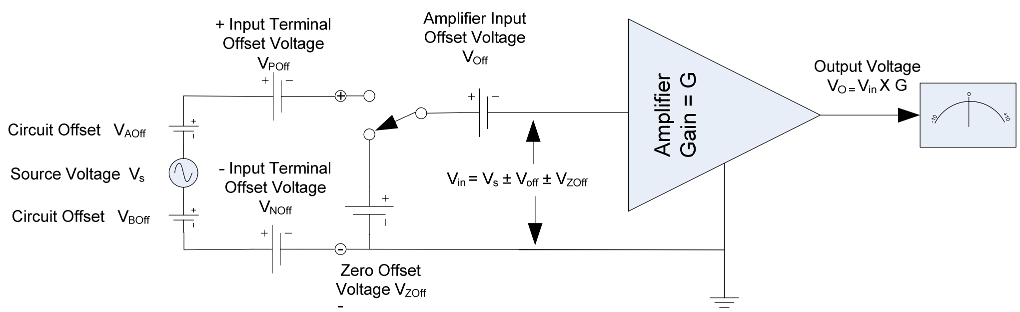

Figure 3b

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In Figure 3a, the amplifier output voltage is a function of the same input conditions shown in Figure 2 plus the contribution of any offsets from the external measurement circuits. That is, the output reflects the amplifier gain times the measurement voltage, the input terminal and external measurement circuit offset voltages and the amplifier input offset voltage. However, in Figure 3b, the amplifier output voltage no longer reflects any input offset voltages from the external measurement circuits or input terminals but does reflect the offset voltage generated by the Zero switch (V_{ZOff}).

From Figures 3a and 3b it can be seen that Zero created by a V_S of zero volts and a Zero created by placing the instrument in the ZERO mode may not be the same—especially if the ZERO switch is inside the instrument and thus removed from some of the environmental factors which influence the input terminals and external measurement circuits.

Without considerable care, these different offset voltages create a substantial difference between measurements made with two different instrument setups. This is especially true if the instrument ZERO mode is used as the absolute reference for zero for one setup vs. a zero made with all external measurement circuits included for the other setup.

Solving the Problem:

Modern instrumentation design includes an adjustable circuit to inject a voltage into the input that is equal and opposite to the sum of the input offset voltages. In some cases, such as with the PPM AVM-2000, there is a user adjustable offset voltage for each measurement configuration. This allows the operator to establish a zero for the ZERO mode, the OPERATE mode and for each range.

What is the purpose for the ZERO mode if the offset voltage in the ZERO mode is different than that of the OPERATE mode? The ZERO mode is provided for two reasons. First, many times the absolute zero is not extremely critical (for example, if a relative zero within a few µV is satisfactory then the ZERO mode and OPERATE mode zeros may be considered to be the same). Second, although each of the zeros may be set separately, the impact of amplifier offset drift and overall temperature changes are the same for both modes. Therefore, if a ZERO mode check, for example, shows a 500 nV (0.5 µV) change, it is safe to assume an overall correction of 500 nV in the measurement will eliminate the change in zero.

The Technique:

Compensating for zero offset is a two-step process.

First, place the instrument in the ZERO mode and adjust the VOffset for each range of interest.

Second, place the instrument in the OPERATE mode and establish a zero measurement voltage with as much of the external measurement circuit in place as is possible. For example, in the case of zeroing a circuit using a bridge or ratio divider, set the bridge drive or reference voltage to zero volts. With zero volts drive, adjust VOffset for each range of interest. Note, alternatively, the bridge drive or reference voltage can be replaced by a high-quality short circuit. However, this potentially A) introduces additional offset voltages from the high-quality short and B) fails to account for offset voltages that occur in the output of the voltage source.

Summary:

When adjusting the Input Offset Voltage, keep the following in mind:

- Be sure to zero as much Input Offset ***Voltage*** in the measurement circuit as possible.
- Recheck zeros from time-to-time as zero drifts with temperature and other environmental change.
- Remember handling connections introduces thermally generated offsets from body temperature.

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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.

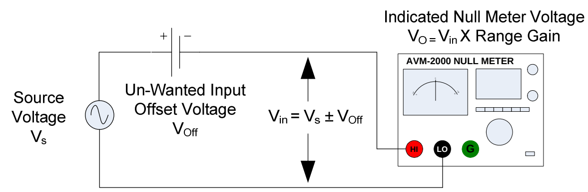

Figure 1

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 PPM Null Meter Application Guides AG-101 and AG-105 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 and 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.

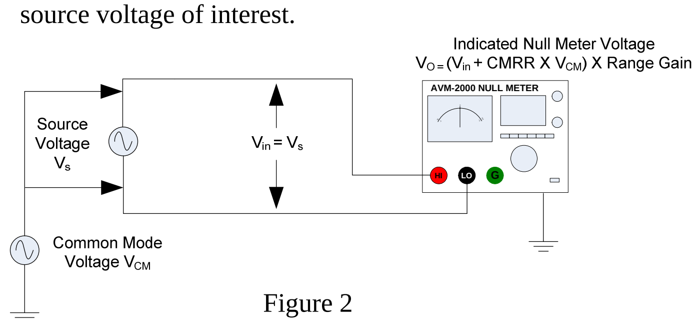

Figure 2

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)

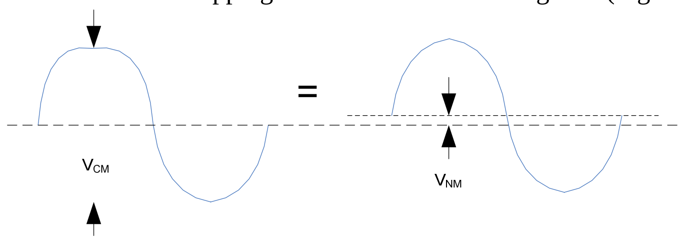

Figure 3

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

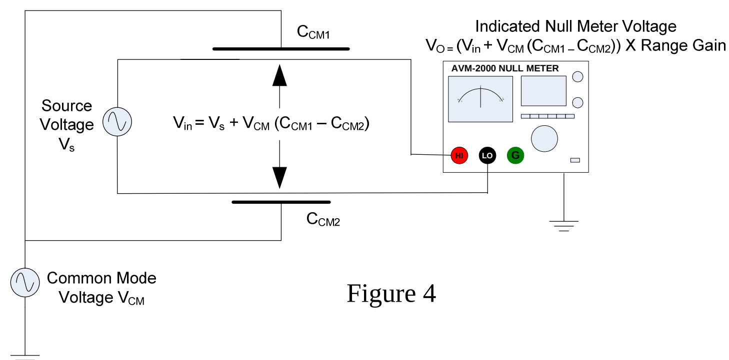

Figure 4

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

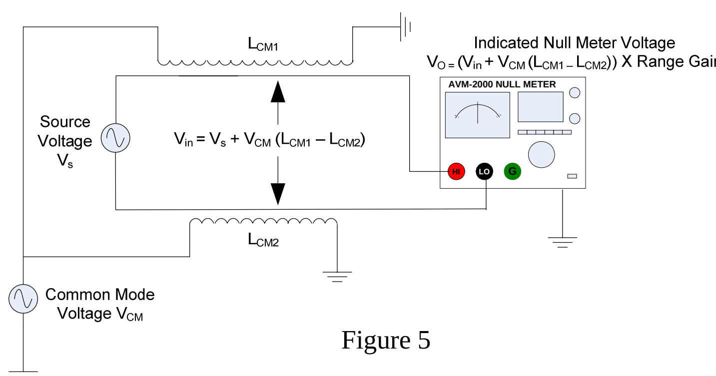

Figure 5

- 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:

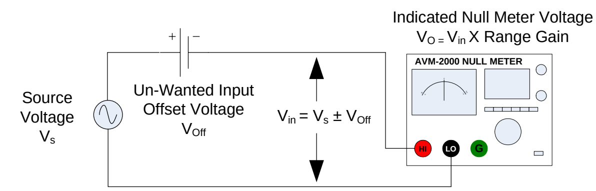

Figure 6

- 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)

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- 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

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