

Input Offset Voltage Compensation

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 $+1.5 \mu\text{V}$ to cause the output to be zero, then the amplifier input offset voltage is $-1.5 \mu\text{V}$.

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.

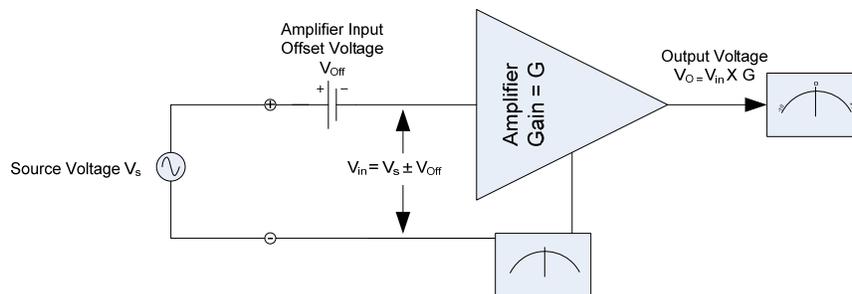


Figure 1

Again, if the “battery” is $+1.5 \mu\text{V}$, then the source voltage must be $-1.5 \mu\text{V}$ 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 $200 - 500 \text{ nV}$ per degree Celsius for connections found around high-sensitivity instruments.

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.

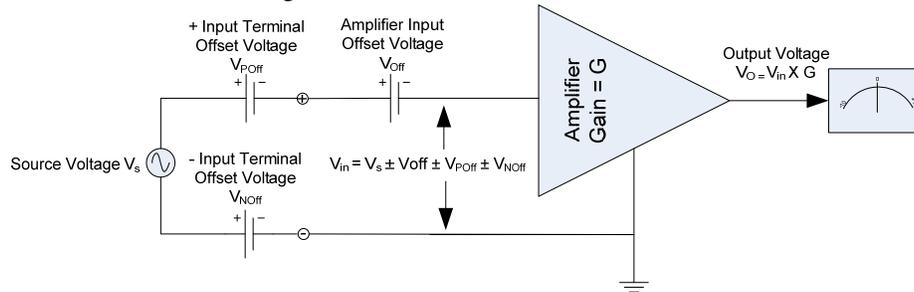


Figure 2

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.

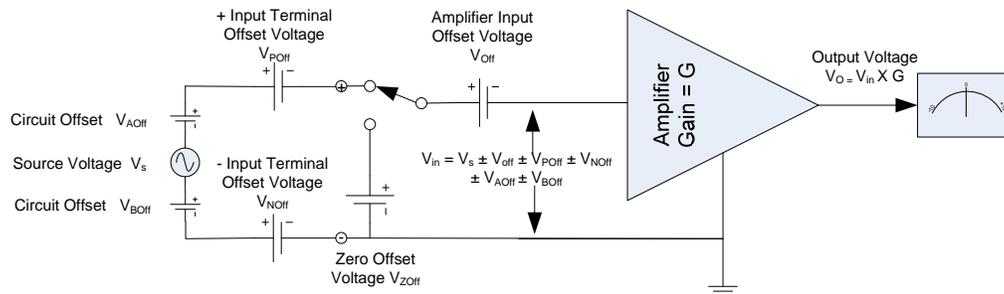


Figure 3a

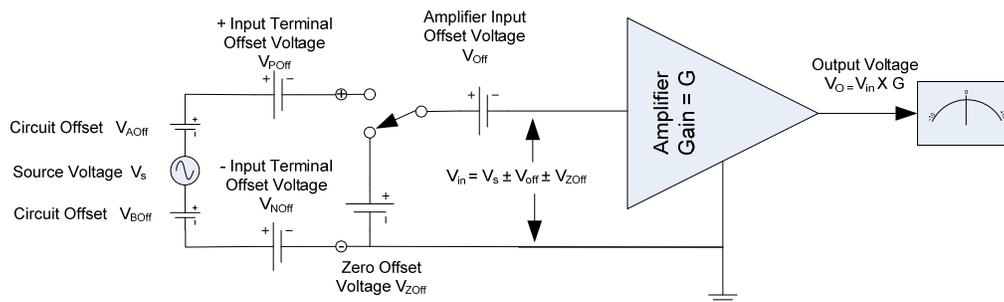


Figure 3b

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 TEGAM 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 V_{Offset} 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 V_{Offset} 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.