

# White Paper: The Essentials of Single-Ended and Differential Voltage Measurement

Learn How to Choose Which Method to Apply

*Examining important aspects of single-ended and differential voltage measurement, along with tips on why it might be better to choose one method over the other*



Acromag manufactures circuits that amplify, isolate, filter, and convert one signal form to another ([signal conditioning](#)). This is essentially what we do, but more simply stated, Acromag manufactures circuits that measure voltage, because that is exactly what we do most of the time. For example, you might have looked to Acromag for transmitters to measure temperature, resistance, current, or strain, but at the core of each of these measurements, the circuit will measure voltage.

Voltage is defined as a difference in electric potential between two points and is a measure of the potential for current flow in a conductor or circuit. You can measure voltage two ways: single-ended or differentially. Depending on your application, the integrity of your measurement system can depend greatly on which approach you choose.

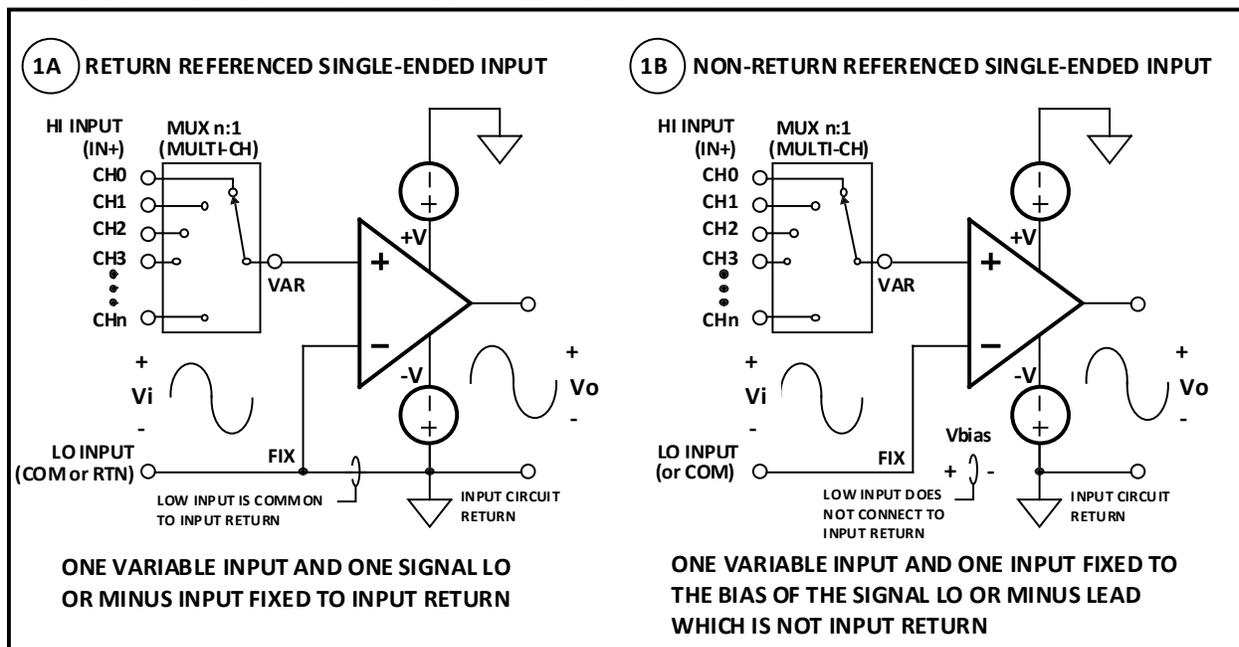
This paper looks at important aspects of single-ended and differential voltage measurement, and offers some insight on why it might be better to choose one method over the other? It will also dispel some of the myths and misconceptions of voltage measurement and show how to correctly apply earth ground to these connections.

This paper covers single-ended voltage measurement. [Part 2 \(8501-068\)](#) reviews differential voltage measurement. You can download these documents and others from <https://www.acromag.com/>.

## SINGLE-ENDED INPUT VOLTAGE MEASUREMENT

A single-ended input measures the potential of one point with respect to a fixed common reference (signal return or a reference voltage offset from signal return). Its chief differentiator is two input connections with one of variable potential and one of a fixed potential. If the single-ended input has multiple channels, then each channel measures one potential with respect to signal return (Figure 1A), or a common fixed reference (Figure 1B).

**FIGURE 1: SIMPLIFIED MULTI-CHANNEL SINGLE-ENDED INPUT**



We are being careful to discern input Return from earth ground, as Return may or may not also connect to earth ground. In Figure 1B, we see that the low input or minus lead could be fixed to a common reference point other than measurement Return. That is, the single-ended input might reference to a “pseudo-ground” or positive voltage offset from Return. This is often the case where a single-ended amplifier happens to be powered from a single positive supply, but is still able to convert negative input signals by positively biasing its fixed reference lead (some TC and RTD input circuits will do this, and some single supply bipolar A/D converters also).

Because a single-ended input measures the potential difference between one point and a common fixed reference, and because this common is a known reference generally shared with other channels, single-ended inputs save connectors and space. You can get twice as many single-ended input channels in the same space as differential. Single-ended inputs are also easier to install and analyze (only two connections are made). This measurement scheme works best applied to signals that share a common connection or return. It is however, not appropriate where one of the two points of measure is not a signal return or common reference between channel circuitry. Likewise, it cannot be applied to separate outputs that do not share a common connection in any lead (unless their respective measuring inputs are separate and isolated).

One example of a single-ended input that you may be familiar with is that of most oscilloscopes--each scope channel measure voltages relative to a shared reference point, usually earth ground. Because single-ended inputs measure one potential relative to a fixed common reference, it's also important to keep the polarity of your single-ended input straight. Get this wrong, and you might inadvertently short your signal by flipping the polarity of your input (unless the input source is isolated). Contrast this to a differential input which is more forgiving, because both of its input connections can be offset from circuit common and the measurement of one point is made relative to the other, not to a common reference point.

A weakness of single-ended inputs is that although they can support more channels in less space than differential inputs, each input is more susceptible to noise coupled into the circuit, and even noise coupled from a less than ideal common connection (single-ended inputs have little or no common mode rejection). Briefly, because a single-ended measurement is taken as the voltage difference between one variable signal and a fixed common reference, and noise in the circuit will mostly be on the variable signal lead with the opposite lead normally tied to a relatively stable reference point, there is no benefit from common mode rejection for any noise present on the positive lead of a single-ended input (only normal mode rejection applies). This means that some portion of noise will be passed through the single-ended input with the signal and possibly amplified.

## **SOME APPLICATIONS OF SINGLE-ENDED OR RETURN-REFERENCED MEASUREMENT**

- Commonly used to measure an output voltage where one connection is already tied to a fixed common reference potential or return. Not applicable in multi-channel applications where output potentials may be offset or independent of one another, do not share a common reference, or where output voltages are connected in series.
- Mostly preferred where the input signals have higher level full-scale spans greater than 1V, due to poor noise rejection.

- Most applicable for taking measurements over short distances, generally less than 3 meters.
- Often chosen where it is necessary to accommodate many channels in a small space (less wiring, simpler).
- Typically used where the emphasis is on lower cost (less connectors and wiring required) or higher channel density.
- Not recommended where the output to input coupling is made in a noisy environment with high EMI and RFI, or where the coupling cable is not shielded.

## Single-Ended Measurement Myth

There is a misconception that single-ended inputs do not handle bipolar signals or signals below 0V. This may have arose because single-ended is sometimes confused with the term unipolar, or from the condition that occurs when the output polarity of an earth grounded single-ended signal is swapped relative to the mating input polarity, which can short the output via earth ground if the input return happens to also be earth grounded. Single-Ended inputs do convert negative signals equally well as positive as long as you keep your signal polarities straight.

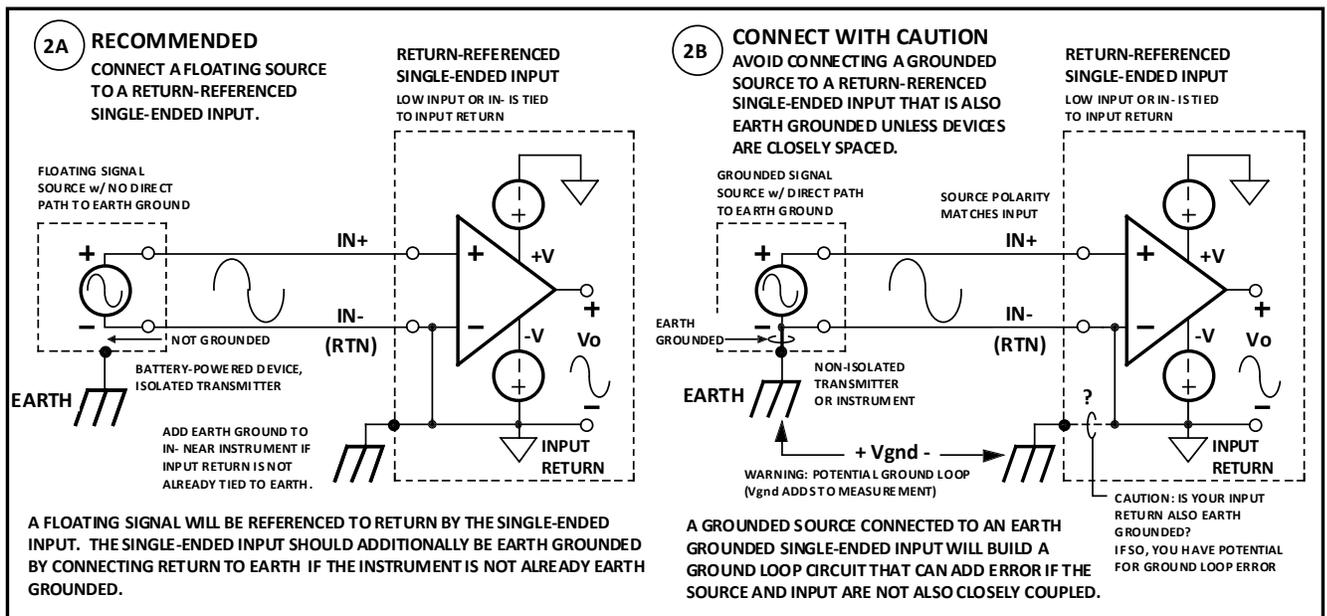
In general, it is best to use earth grounded return referenced single-ended inputs (or optionally differential inputs) to measure non-grounded or floating signal sources. Likewise, it is best to use non-earth grounded return referenced single-ended inputs (or optionally differential inputs) to measure earth grounded signal sources as illustrated in Figures 2 and 3. Note that the single-ended input can accommodate connection to an isolated output signal with no connection to earth ground, or an output signal that connects to earth ground. But in both cases, you should avoid making more than one connection to earth ground in a circuit to avoid creating a ground loop current which can offset your measurement. A single-ended input may or may not connect its return to earth ground, so you need to additionally be aware of how your measurement system is wired. A non-earth grounded or isolated output signal cannot be left to float in the case where a single-ended input is not earth ground referenced. Likewise, an earth grounded output may build a ground loop if connected to an input circuit that is already connected to earth ground elsewhere.

## DON'T FORGET TO EARTH GROUND YOUR SIGNAL

*The connection of earth ground to the I/O is sometimes a source of confusion, because a valid measurement can usually be made without connecting earth ground.*

Instrument instructions generally recommend that your input signal be additionally tied to earth ground if the signal is not otherwise earth grounded (this is usually made at IN- , GND, RTN, or COM of your circuit). But in most cases, the circuit will continue to measure properly with or without adding an earth ground connection. This leads some technicians to ignore this recommendation which could lead to measurement error or even damage the equipment. While it is true that single-ended inputs do not normally float because one input is typically signal return and most circuits will exert a weak pull on their inputs to return, inputs can still be made to float in the presence of high levels of EMI. This is why we always recommend that if a single-ended source is isolated with no path to earth ground, a connection to earth ground should be made at the input. If the instrument does not already provide a path to earth ground (often via its connection to its power supply), then it can usually be made at the signal LO or minus lead. Connecting the LO input to earth ground helps ensure the input will not float outside of its input range in the presence of high EMI. But equally important, adding earth ground gives the input circuit a low impedance path for shunting transient energy and fault voltages safely to earth ground away from the sensitive input components.

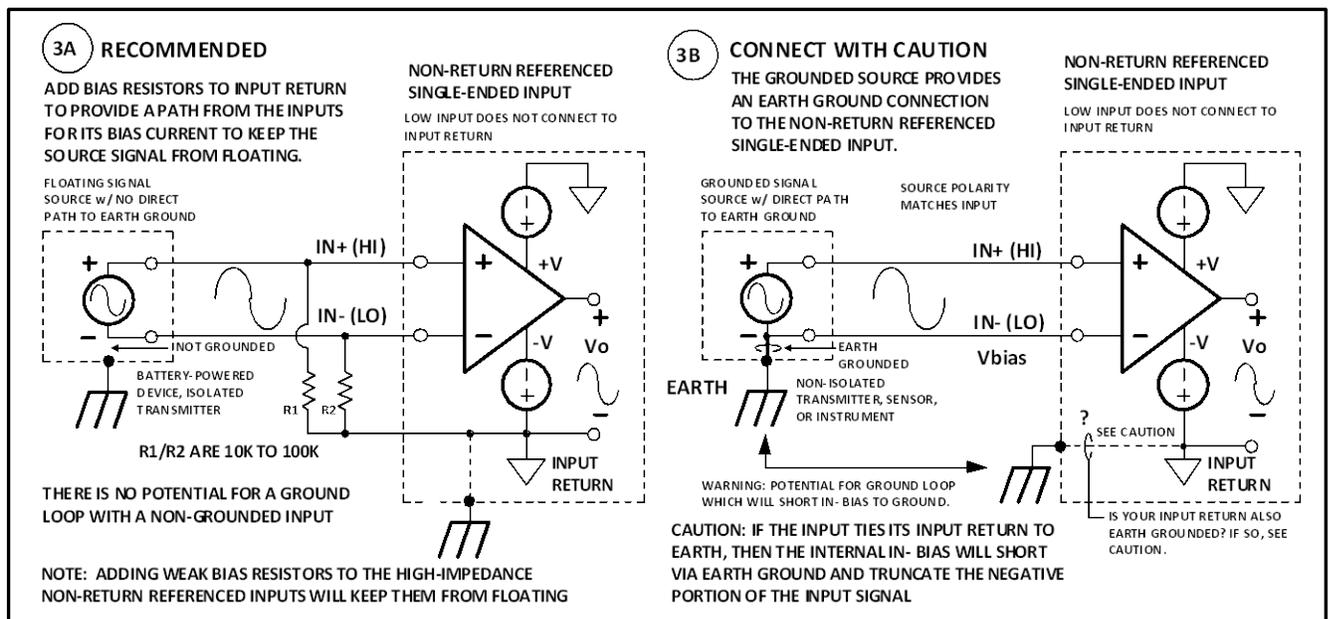
**FIGURE 2: SIMPLIFIED RETURN-REFERENCED SINGLE-ENDED INPUT CONNECTIONS**



In Figure 2A, a floating single-ended signal source is best connected to a single-ended input with an earth ground connection made at the single-ended input return. If the return-referenced single-ended input does not already connect earth ground to its negative lead as shown, then earth ground is best applied to IN- near the instrument.

A potential problem can arise when an earth-grounded signal source is connected to an earth grounded single-ended input as shown in Figure 2B, which can produce ground loop currents which may offset the measurement. While not recommended, this is primarily an issue where the coupling distance extends out to and beyond 3 meters and the earth grounding points are not the same or are spaced far apart. Having two earth ground connections will not usually be a problem if the output and input are closely spaced, where earth ground potentials are nearly identical. Figure 2B is perfectly fine to use where the coupling distance is very short.

**FIGURE 3: SIMPLIFIED NON-RETURN REFERENCED SINGLE-ENDED INPUT CONNECTIONS**



Refer to Figure 3A above which illustrates adding weak pull-downs to the input lead(s) of single-ended inputs that are not return referenced. The weak pull-downs add bias to keep the high-impedance inputs from floating. How you decide to handle this case will depend on your knowledge of the internal circuit and how the non-referenced input positively biases the signal LO or minus lead, whether you have access to input return (does the instrument earth ground its return). If you do not have knowledge of the internal circuitry, adding weak pull-downs to its inputs as shown in Figure 2A will not usually be a problem, assuming you can connect to input return. Note that in many cases, the pull-down R2 added to the signal LO or minus lead can be omitted. This is because the non-return referenced single-ended IN- lead is usually positively biased above return by a voltage reference or diode to give a single-supply input circuit the ability to convert negative input voltages. Note that the minus lead bias supply is usually sufficient to keep the minus input from floating such that R2 may not be needed to pull IN- to ground and only R1 may be required. There is no potential for creating a ground loop in Figure 3A because your signal source is isolated and not earth grounded.

In Figure 3B, the grounded signal source provides earth ground to the input device via the IN- connection if the input return does not already connect to earth. If both devices are earth grounded (the input return also connects to earth), then the IN- signal LO lead's positive bias supply will be shorted via earth ground, possibly truncating the negative portion of the input range.

## **Beware of Ground Loops**

*Because single-ended outputs and single-ended inputs may both carry their common reference or signal ground in their signal LO or minus leads (sometimes denoted COM or RTN), and that reference may also be in common with earth ground to the equipment, there is perhaps a greater chance of creating a ground loop when making single-ended connections.*

Instrument instructions will normally tell you to limit yourself to one earth ground connection in a non-isolated circuit in an effort to avoid generating a ground loop which can interfere with your measurement, but this is really only required when the earth ground connections are at different potentials which would push error current between them (not likely for closely spaced I/O). Be aware of where your output and input both connect to earth ground—if they each connect separately to earth, how far apart are their connections to earth? If the distance between the output and the input is larger than 3 meters, or the distance between the earth ground points is large, you may have to introduce an isolation barrier between the signal source and the measurement device. The presence of isolation between the circuits will “break the ground loop” by allowing the earth grounds of each circuit (on each side of the isolation barrier) to be at different potentials (within the limits of the isolation rating).

In the absence of circuit isolation, limiting yourself to a single connection to earth ground can be difficult. Wiring diagrams normally assume that the local (input) earth ground and the remote earth ground (sensor or signal source) are at the same potential. To complicate matters, your equipment will typically recommend you have a local connection to earth ground at each piece of equipment for protection purposes. This can be a source of confusion in the sense that following the letter of the law appears to introduce “more than one connection to earth ground”. But what you really need to avoid is not having more than one earth ground connection, but having more than one earth ground potential. For short distances of 3 meters or less, the remote and local earth grounds will be nearly the same potential and having two connection points to earth will not normally present a problem. If your signal source is earth grounded and the mating input is not, you should still earth ground the input and not rely only on the indirect common connection to earth ground via the output circuit. This is because of the potentially large inductance of the length of wiring for the input path to earth ground, even at distances less than 3 meters, which will impede transient energy at the input from reaching earth ground and may damage your input circuit.

## CONCLUSION

Single-ended measurement is done by measuring one potential with respect to a fixed common reference. In general, you may use single-ended measurement when there are only two output leads and one lead is connected to a known reference potential (a shared return or common for example). But single-ended measurement offers poor noise rejection compared to differential measurement making it mostly acceptable in relatively noise-free environments, when used with shielded cable over short distances (ideally less than 3 meters), and usually with higher full-scale signal range levels above 1V. It is often chosen where an emphasis is placed on greater channel density, simplicity, and low cost (less wiring). Because one lead often carries earth ground, it is more prone to earth ground loop error generation making proper wiring of signal and earth ground crucial to its success.

## ABOUT ACROMAG

Acromag has designed and manufactured measurement and control products for more than 60 years. They are an AS9100 and ISO 9001-certified international corporation with a world headquarters near Detroit, Michigan and a global network of sales representatives and distributors. Acromag offers a complete line of industrial I/O products including a variety of process instruments, signal conditioners, and distributed fieldbus I/O modules that are available with a 2-year warranty. Industries served include chemical processing, manufacturing, defense, energy, and water services.

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## The Essentials of Single-Ended and Differential Voltage Measurement

Part 2 of this paper (8501-068) will review [important aspects of differential voltage measurement](#), including wiring, earth grounding, the use of shielded cable, common-mode signal range, and common-mode rejection.

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