

Defn: A **differential** electrical source has. . .

two identical signal conductors, typically twisted or otherwise in some symmetric geometric design.

Optionally there may be a third ground reference (voltage signal) or ground return (current signal) conductor.

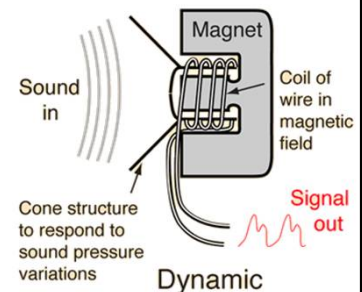
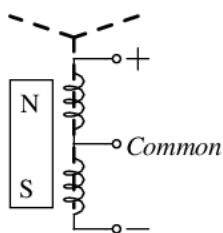
The ground conductor, if present, carries no signal. (Usually, if present, it is there as a matter of safety, not signal.)

Each of the signals is defined as the voltage difference between the two signal conductors, with no reference to ground.

Professional microphones routinely use differential signaling.

The next slides use a microphone and a mixer-board input to further explain how differential signaling works and why it is superior (by a landslide) to single-ended signaling.

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<http://hyperphysics.phy-astr.gsu.edu/hbase/Audio/mic.html>

The basic differential technique and its model.

Split the available signal into two equal halves.

Use a three-conductor cable to connect it to an amplifier.

Two conductors (+ and -) carry the signal.

Connect the third conductor to ground at the destination.

If possible, at the source sensor use 3rd cond. as an electrostatic shield.

(Magnetic shielding is impractical but shielding from electric fields works well.)



<http://royerlabs.com/ribbon-basic/>

2

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 If possible, at the source sensor use 3rd cond. as an electrostatic shield.
 (Magnetic shielding is impractical but shielding from electric fields works well.)

The chassis, or case, of the source, e.g. the handle of a hand-held microphone is symbolized as . This is distinguished from the signal reference-node .

<https://www.rane.com/note151.html>
<https://www.bhphotovideo.com/explora/audio/buying-guide/xlr-cable-just-cable-right%3F>

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Glossary of variables

v_{SIG} = The source's open circuit Thevenin equivalent voltage from + to -. This is the desired signal.

v_{sig} = The small-signal portion of the above, which is typically 100% of the above. (Thus v_{SIG} is rarely written.)

v_{CM} = The common-mode voltage at the source, measured from the amplifier's ground (ref. node) to the common terminal of the source. Ideally this is zero. In practice it is noise from electromagnetic radiation.

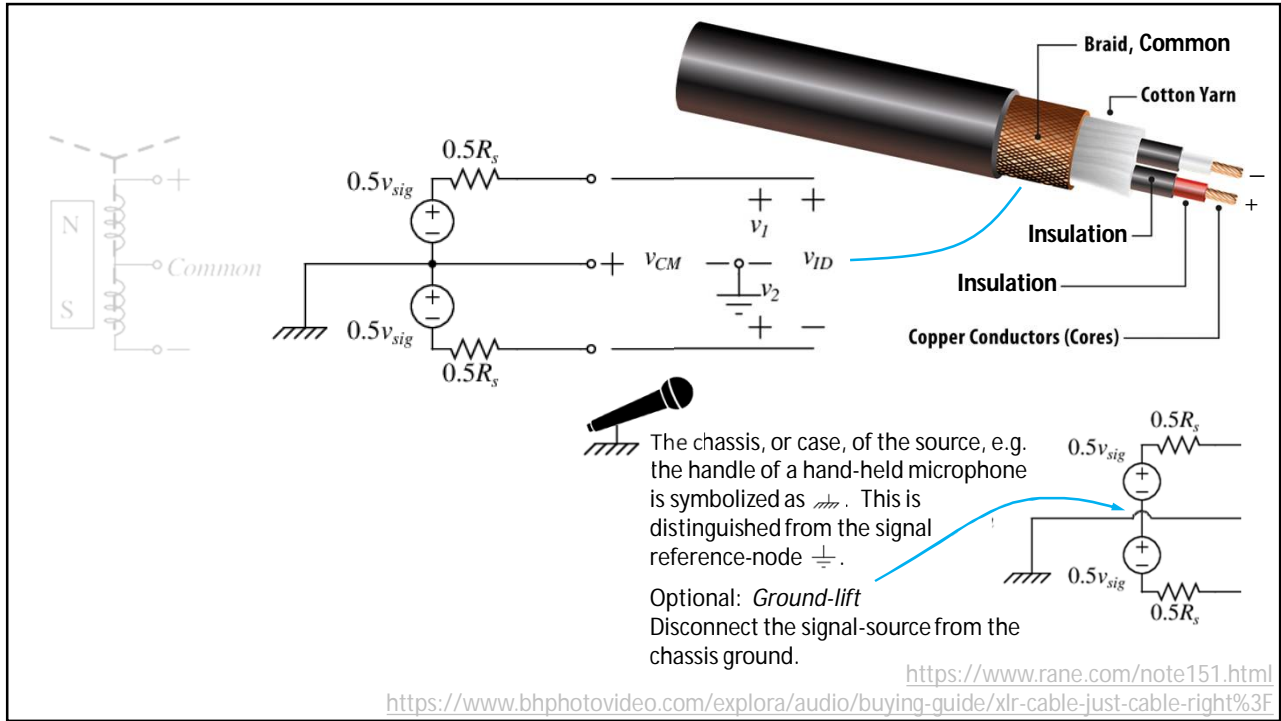
v_{ID} = The source's terminal voltage as presented to the input of the amplifier.
 This does **not include any noise** pickup relative to the common terminal. (B/c measured + to -)

v_{id} = The small signal portion of the above, which is typically 100% of the above. (Thus v_D is rarely written.)

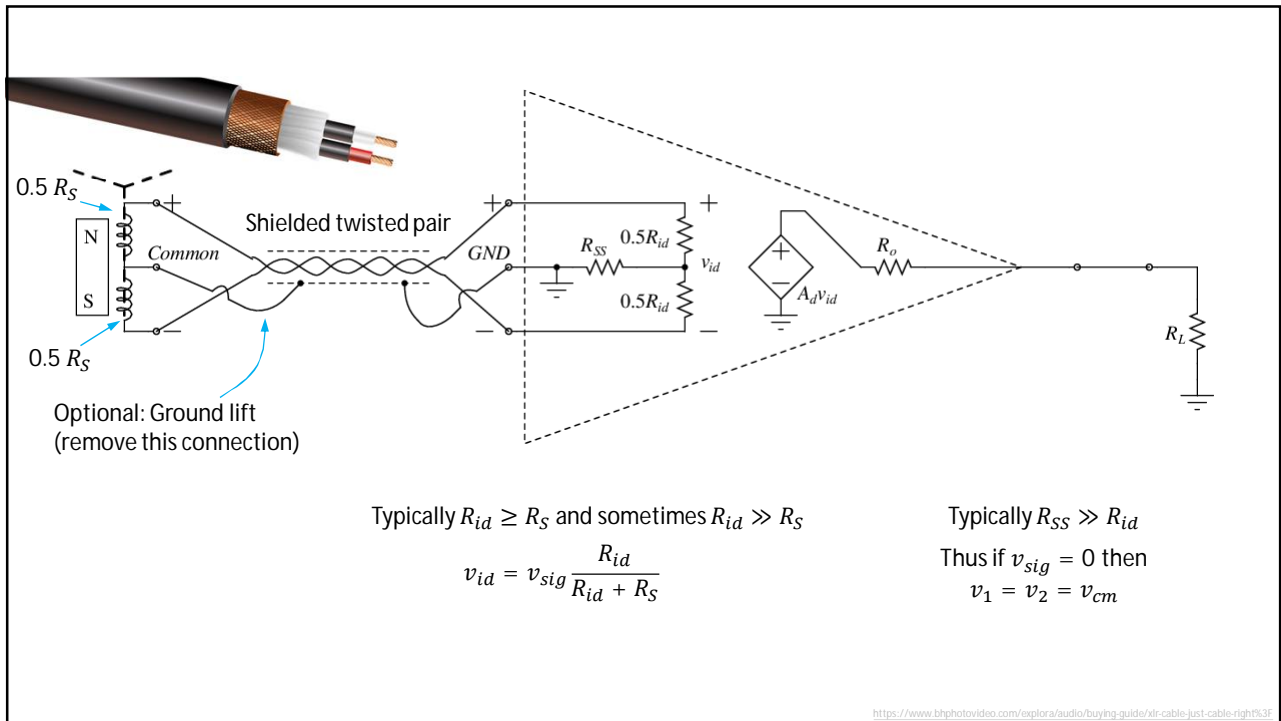
v_1, v_2 = The input voltages at the amplifier terminals relative to the amplifier's ground. Typically they **include noise**.
 These are analogous in their roles to v_i in a single-ended amplifier.

<https://www.bhphotovideo.com/explora/audio/buying-guide/xlr-cable-just-cable-right%3F>

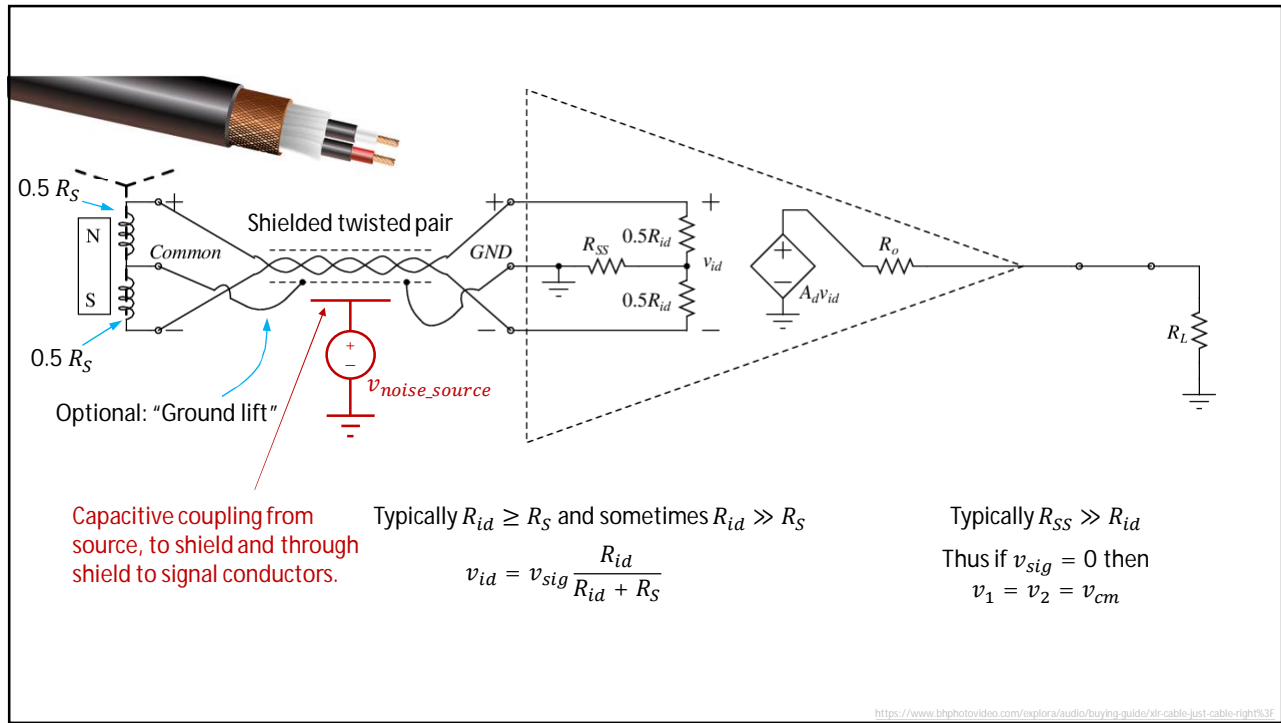
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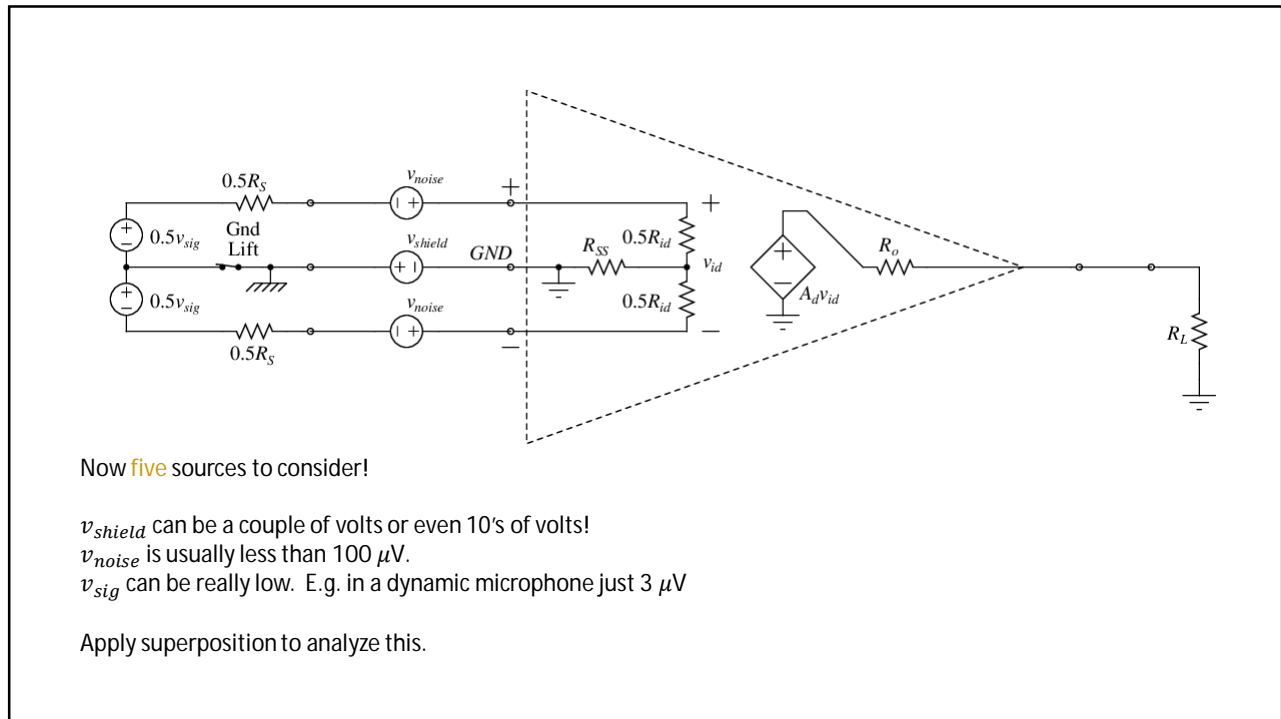
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Now **five** sources to consider! Apply superposition. **1 and 2, signals sources**

Signals only. . .
$$v_{id} = v_{sig} \frac{R_{id}}{R_{id} + R_S}$$

Typically $R_{id} \geq R_{SS}$ so this works well, better than half of the signal gets to the amp, even through a half-mile of cable.

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Now **five** sources to consider! Apply superposition. **3 and 4, electrostatically coupled noise**

v_{noise} only. . .
$$v_{id} = (v_{noise} - v_{noise}) \frac{R_{id}}{R_{id} + [2R_S || (R_{id} + R_S)]} = 0$$

Typically noise is rejected. The two conductors must pick up equal amounts of noise for this to work, thus the twisting of the pair of signal conductors.

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Mesh analysis:
 KVL, top: $0.5 R_{S_{top}} i_{top} + 0.5 R_{id_{top}} i_{top} + R_{SS} (i_{top} + i_{bot}) = v_{shield}$
 KVL, bot: $0.5 R_{S_{bot}} i_{bot} + 0.5 R_{id_{bot}} i_{bot} + R_{SS} (i_{top} + i_{bot}) = v_{shield}$

Assume $i_{top} \approx i_{bot}$, then $(i_{top} + i_{bot}) \approx 2i_{top}$ and $(i_{top} + i_{bot}) \approx 2i_{bot}$
 KVL, top: $0.5 R_{S_{top}} i_{top} + 0.5 R_{id_{top}} i_{top} + 2R_{SS} i_{top} \approx v_{shield}$
 KVL, bot: $0.5 R_{S_{bot}} i_{bot} + 0.5 R_{id_{bot}} i_{bot} + 2R_{SS} i_{bot} \approx v_{shield}$

KVL top: $i_{top} \approx v_{shield} / (0.5R_{S_{top}} + 0.5R_{id_{top}} + 2R_{SS})$
 KVL bot: $i_{bot} \approx v_{shield} / (0.5R_{S_{bot}} + 0.5R_{id_{bot}} + 2R_{SS})$

The conclusion below follows easily by multiplying the currents by their R_{id} .

Now **five** sources to consider! Apply superposition. **5, common-mode noise from the shield.**

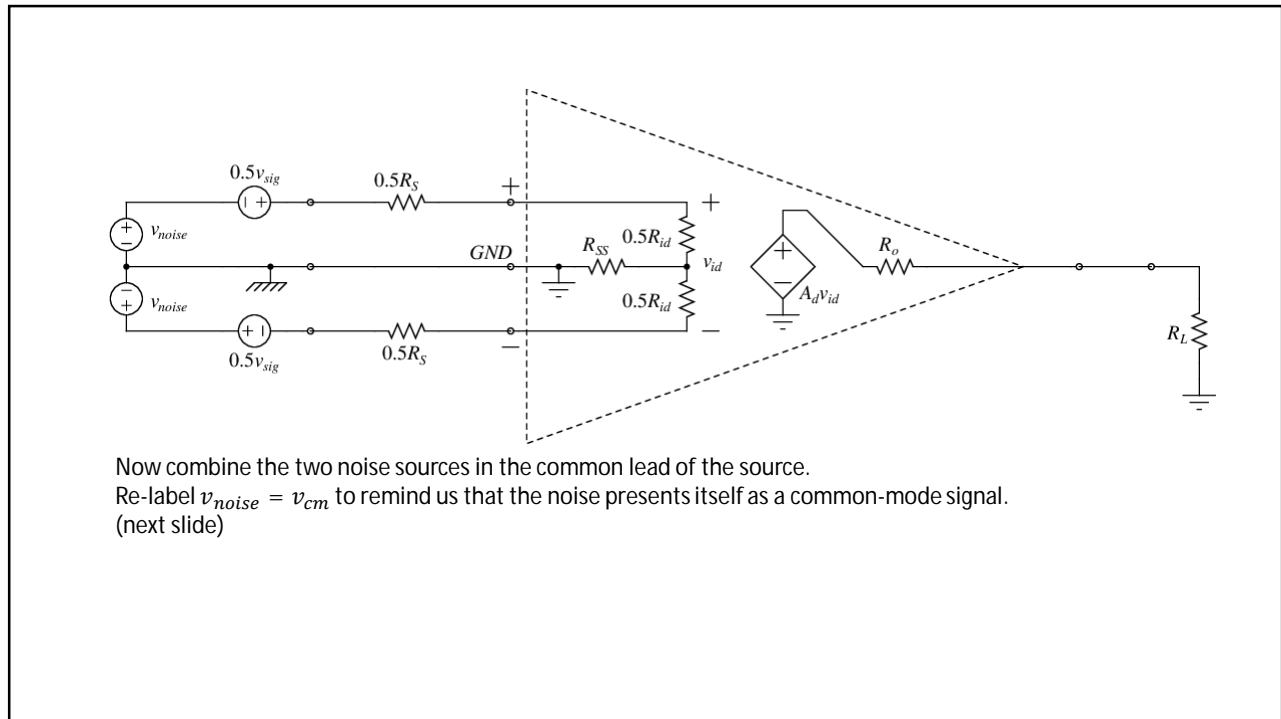
Shield noise only. . .
$$v_{id} \approx v_{shield} \left[\frac{R_{id_{top}}}{R_{S_{top}} + 4R_{SS}} \right] - \left[\frac{R_{id_{bottom}}}{R_{S_{bottom}} + 4R_{SS}} \right] = 0$$

Typically R_{SS} is very large, on the order of the Early resistance of a transistor, $R_{SS} \gg R_{id}$
 and. . . The source and input resistances are closely matched.
 Noise injected from the shield is extremely negligible—no more consideration of it.
 Note that the ground lift opens up the v_{shield} circuit, making v_{id} totally immune to it—in theory.

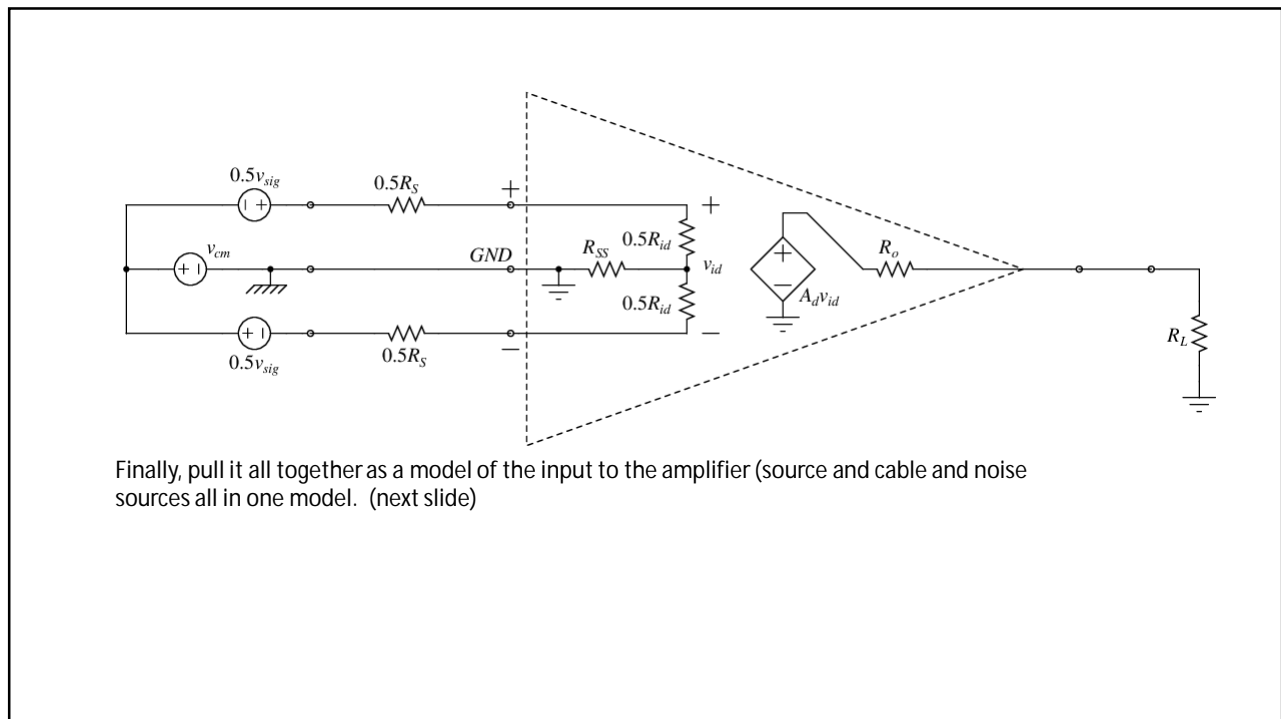
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Now eliminate the ground-lift switch and exchange the locations of the signal sources, being careful to preserve polarities. (next slide)

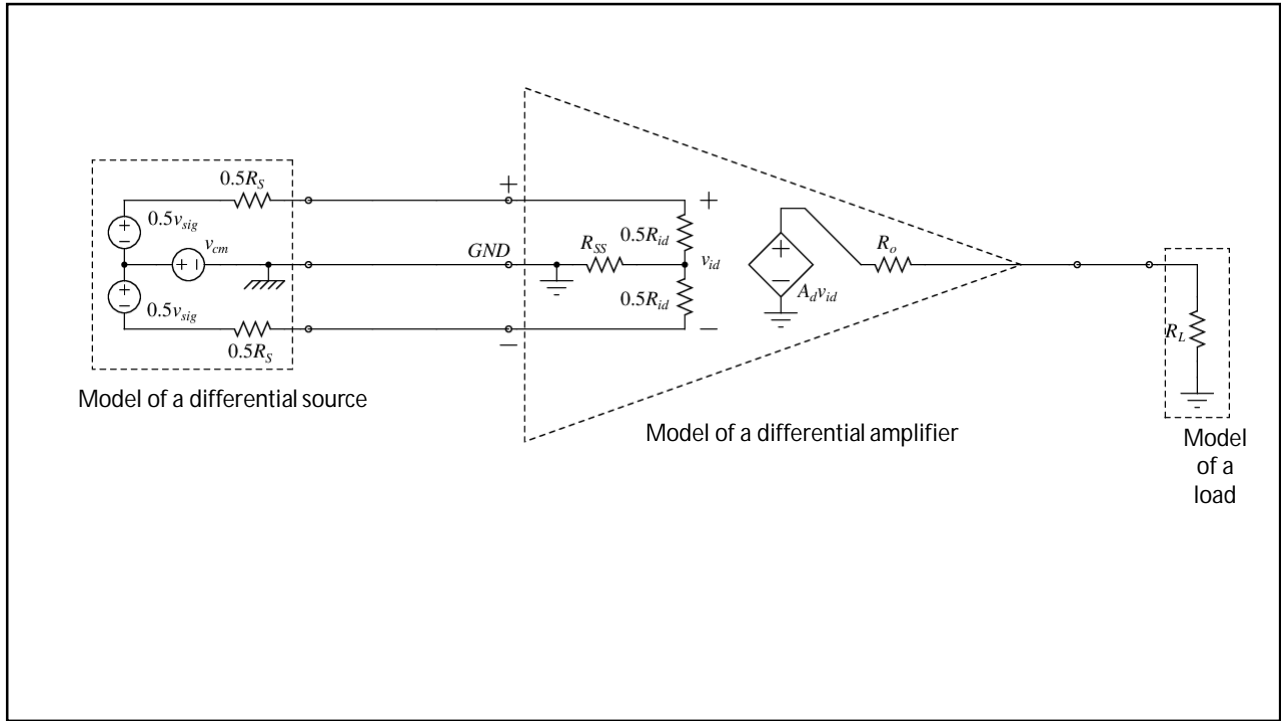
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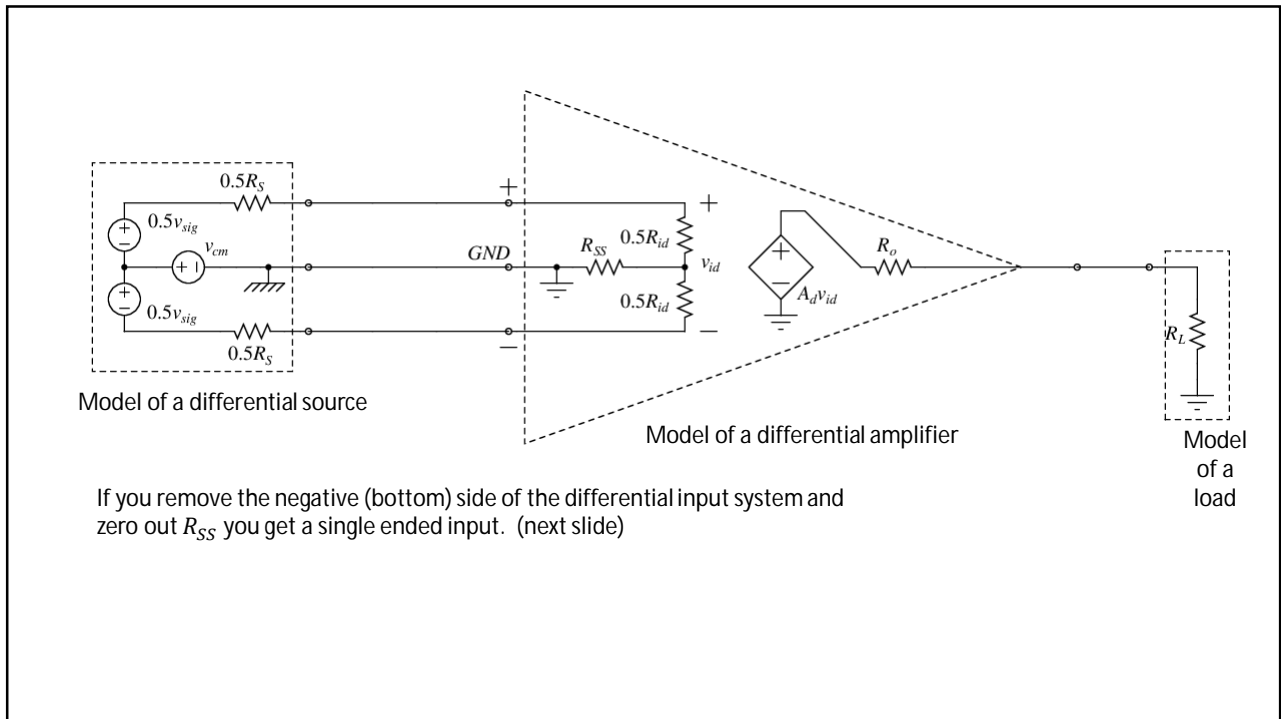
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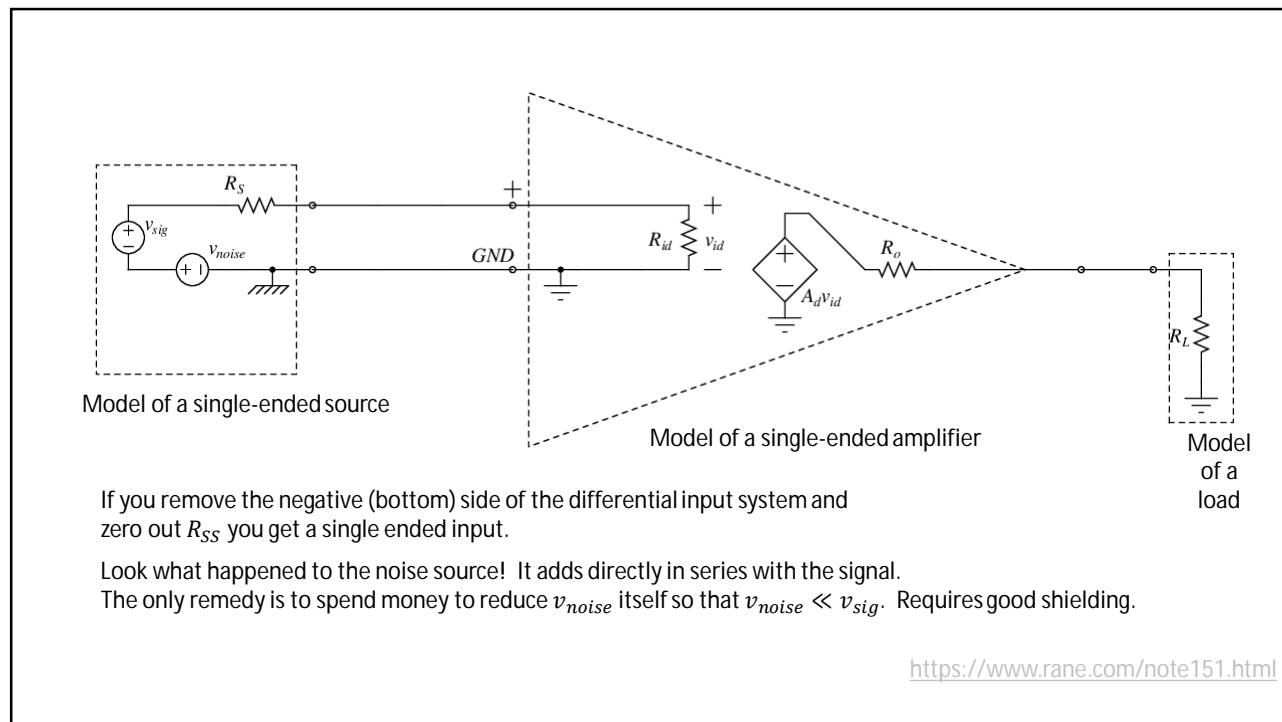
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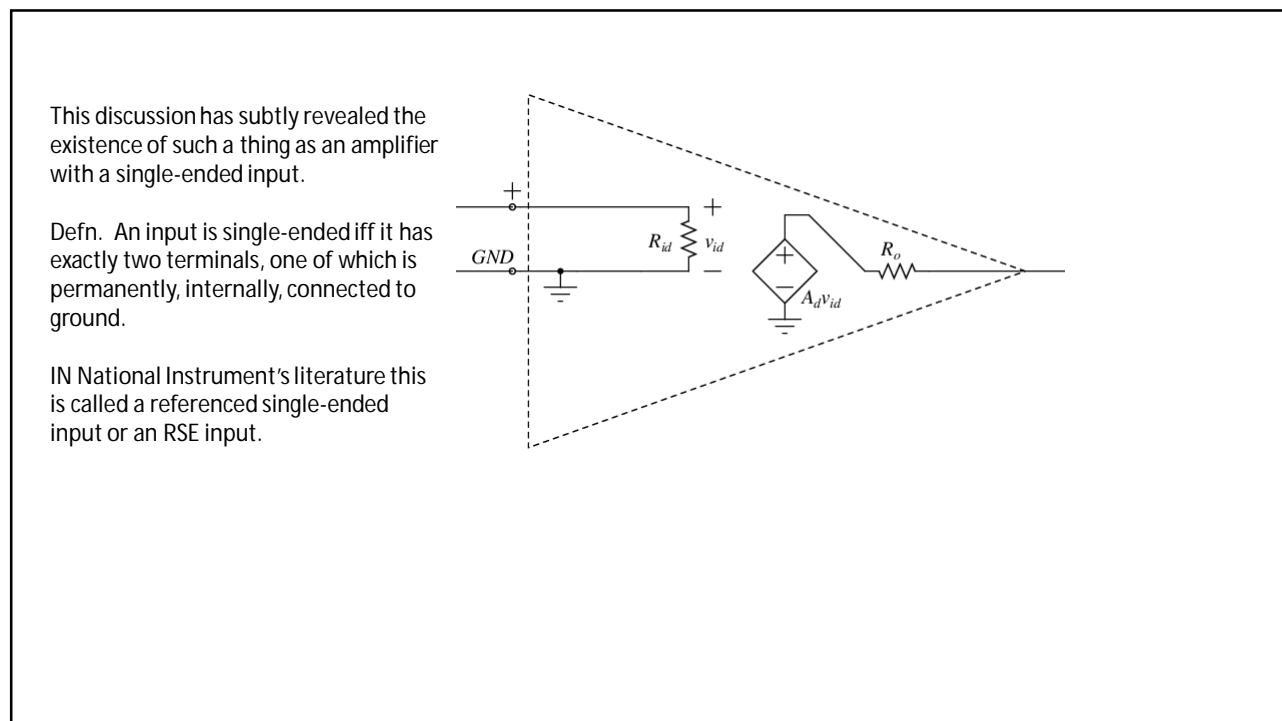
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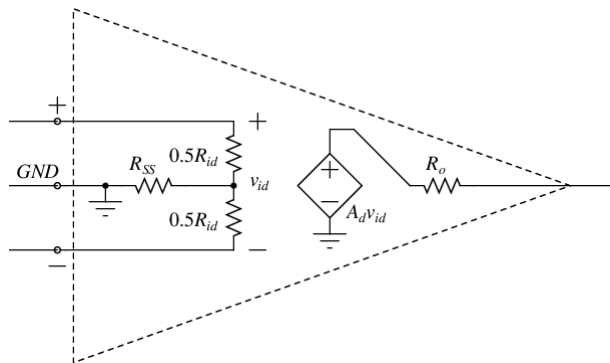


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Defn. An input is differential iff it has exactly three terminals, one of which is permanently, internally, connected to ground and the other two of which have symmetric Thevenin equivalent impedances (resistances) with respect to ground.



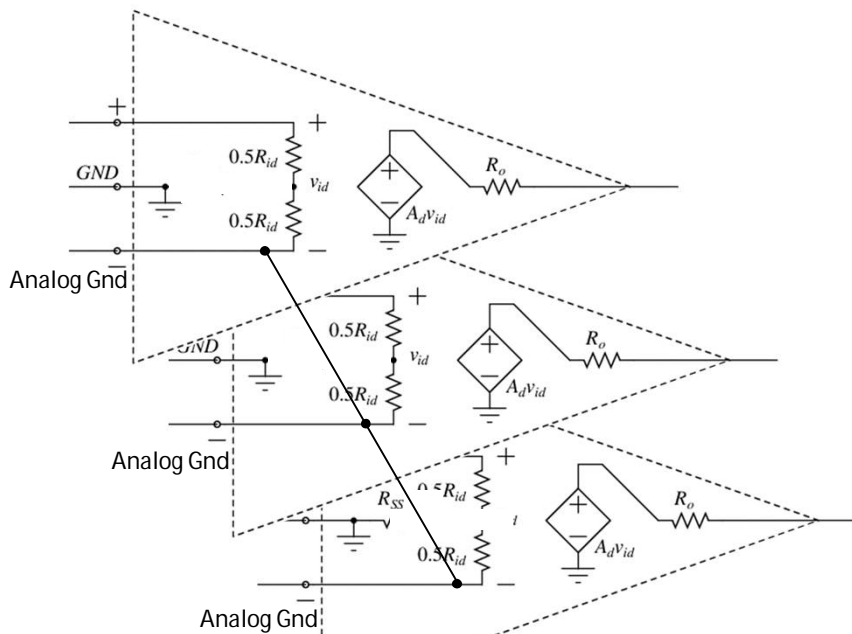
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There is a third kind of animal.
(A weasel if you please)

Defn. An input is non-referenced single-ended input iff it has exactly three terminals, one of which is permanently, internally, connected to ground another one is shared with other input.

Variation: Provide only one (or a few) chassis ground terminals for all amplifiers.

Variation: Provide only one (or a few) analog ground terminals for all amplifiers.



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A source may be single-ended or differential
 An amplifier's input may be single-ended or differential
 The way you connect things matters.

If you have a differential source you may connect it to a single-ended amplifier
 It acts single-ended. You get no advantages.

If you have a single-ended source you may connect it to a differential amplifier.
 If you are clever, this might give you practically all the advantages of a differential amplifier.
 The correct clever connection is sometimes called quasi-differential.

Unfortunately some NI products do not have truly differential amplifiers!
 (The multiplexers do not have symmetric switching.)

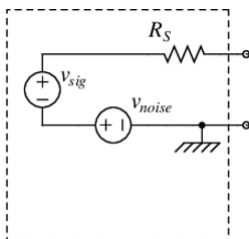
NI offers a compromised differential amplifier they call Non-Referenced Single-Ended, or NRSE.
 It better than single-ended but not as good as differential. It does not perform as a true differential input.

If you have a differential source and a differential amplifier—connect them differentially!
 Do not tie the ground return to the “-” terminal!

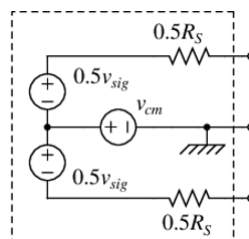
If you have a single-ended source and a single-ended amplifier (NI calls single-ended, “RSE” or “Referenced Single Ended”) be sure not to interchange the ground with the signal wires. They are not symmetric.

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A source may be single-ended or differential



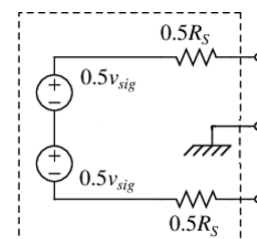
A single-ended source is characterized by unsymmetrical connections. In this case, one terminal is connected to the chassis of the source (handle of the microphone).



A differential source presents the signal on two symmetric terminals.

An optional ground connection may or may not be connected to the signal path and may or may not be connected to the chassis.

A floating differential source.



A differential source presents the signal on two symmetric terminals.

Here the optional ground is not connected to the signal source. This performs normally, probably done for safety.

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The chart at the right shows National Instrument's Recommendations for connecting their equipment. (Prof dBb added the notations that are underlined and in color.)

Three types of amplifiers ("Input Configurations") are shown

Top: True differential amplifier.

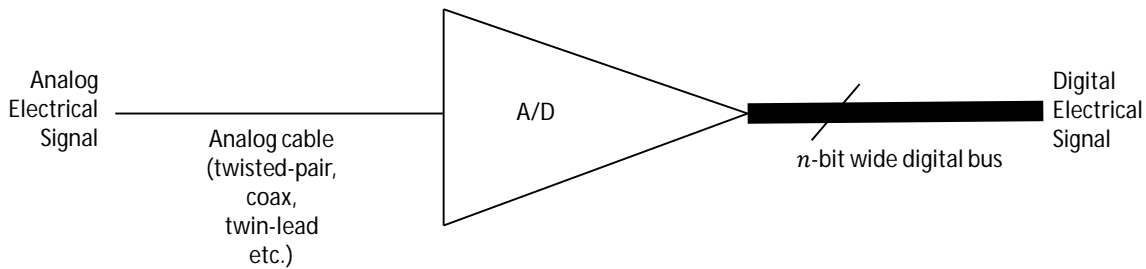
Middle: Fully single-ended amplifier. The "AI Ground" terminal is connected to the chassis and earth ground through power-main's third prong. The source must be floating or a safety issue (ground loop occurs.)

Bottom: Differential amplifier with the "inverting" or "-" input Shared in common with all channels of the conversion device, which destroys the symmetry needed for differential operation. This is NI's alternative to quasi-differential. (It is a short-cut, saves \$\$)

Input Configuration	Signal Source Type	
	Floating Signal Source (Not Connected to Building Ground)	Grounded Signal Source
	Examples • Thermocouples • Signal Conditioning with Isolated Outputs • Battery Devices	Examples • Plug-in Instruments with Nonisolated Inputs <u>single-ended source.</u>
Differential (DIFF)	<p>Two resistors ($10\text{ k}\Omega < R < 100\text{ k}\Omega$) provide return paths to ground for bias currents</p> <p><u>Best</u></p>	<p><u>Poor to midling</u> <u>Performs as single-ended</u></p>
Single-Ended - Ground Referenced (RSE)	<p><u>B- or sort of better</u></p>	<p>NOT RECOMMENDED</p> <p><u>unsafe</u></p> <p>Ground-loop losses, V_G, are added to measured signal.</p>
Single-Ended - Nonreferenced (NRSE)	<p><u>B+ or better</u></p>	<p><u>Poor to midling</u> <u>Performs as single-ended</u></p>

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Analog-to-Digital Conversion



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