

Understanding an Instrument Amplifier's Linear Operating Range

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Thu, 2017-01-12 08:00



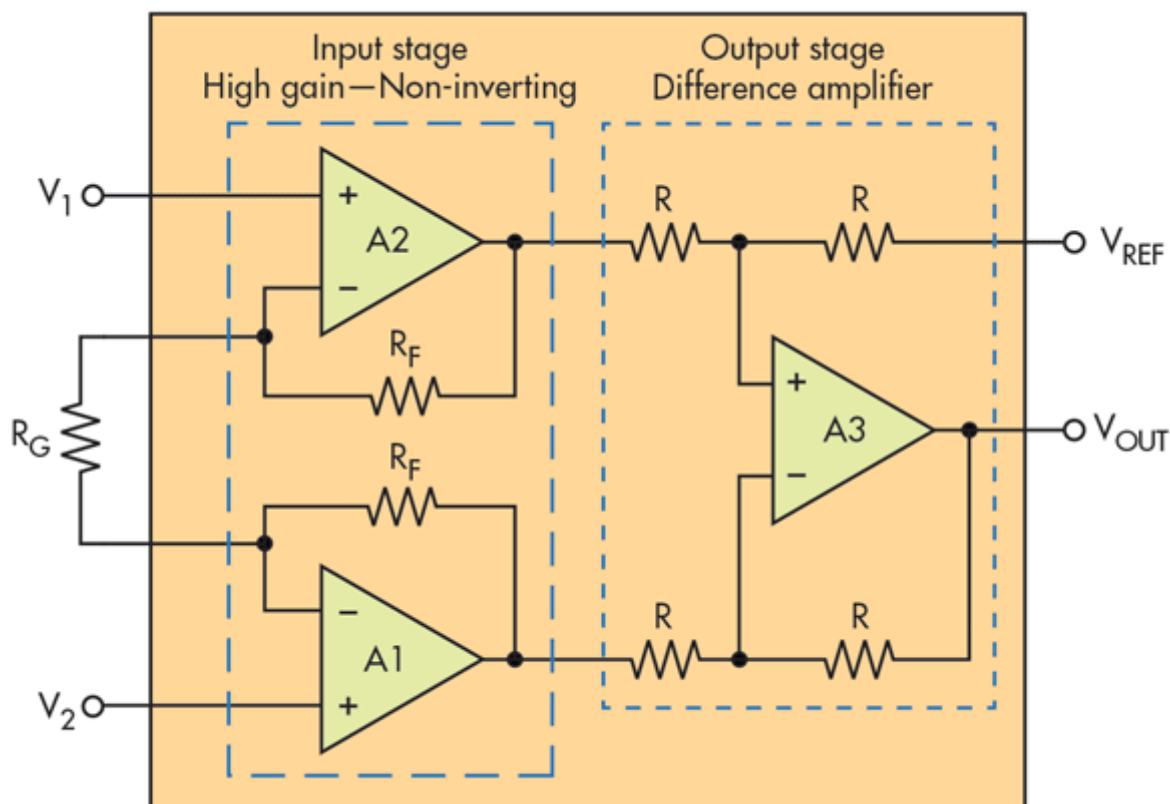
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This file type includes high-resolution graphics and schematics when applicable.

Instrument amplifiers (INAs) are widely used for signal conditioning in data-acquisition systems and telemetry. Their differential inputs, high input impedance, and high gain make them ideal candidates for boosting the output of low-amplitude sensors like thermocouples and strain gauges. This article explains the linear operating region of an INA and how it's defined by the common-mode input voltage and the output-voltage plot.

Instrument Amplifier Basics

Most instrument amplifiers consist of three op amps connected as shown in *Figure 1*. Amps 1 and 2 provide gain and high input impedance, while Amp 3 is a differential amplifier. These op amps are typically packaged along with the resistors in a single IC.



All of the differential-amp resistors are usually the same value, giving this stage a gain of 1. The input stage uses feedback resistors R_F and input resistor R_G . The gain set resistor R_G is external to the IC. The gain is determined by

expression:

$$A = (2R_F/R_G) + 1$$

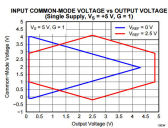
The output is computed with the expression:

$$V_{OUT} = A(V_2 - V_1) + V_{REF}$$

V_1 and V_2 are the input voltages. V_{REF} is used to center the output if there's a single supply; otherwise it's connected to V_{OUT} .

Making R_G small compared to R_F gives a very high gain, making it possible to measure microvolt and millivolt sensor signals. A gain of 1000 or more is typical.

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A key feature of an INA is its differential configuration, which is instrumental in cancelling noise or other unwanted signals that are common to the two inputs. A frequent problem involves 50-/60-Hz noise that radiates from power lines and is coupled into both input lines. This common mode signal is effectively subtracted out so that it doesn't interfere with any low level signals on the input lines.

The common-mode rejection ratio (CMRR) reveals how well common-mode signals are cancelled. CMRR is defined as the ratio of the differential gain A to the common mode gain A_{CM} :

$$CMRR = A/A_{CM}$$

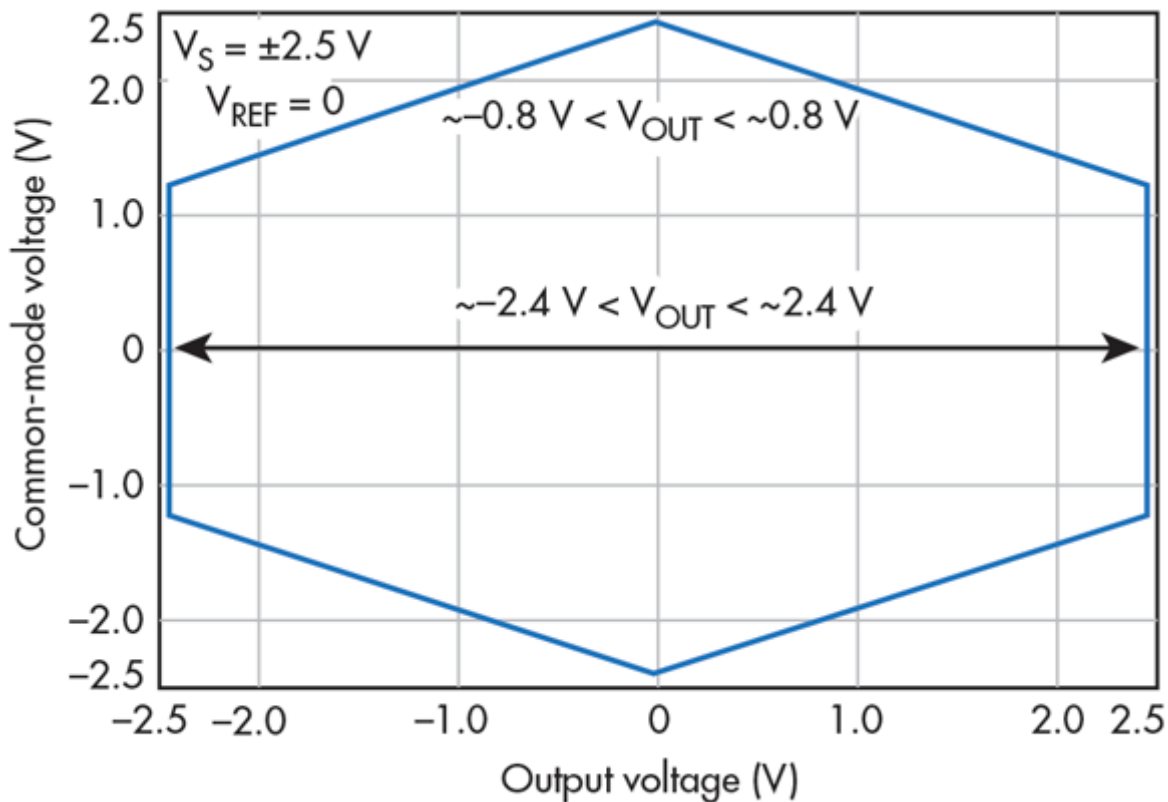
The common-mode rejection (CMR) of the amplifier is usually expressed in decibels:

$$CMRR = 20\log(CMRR)$$

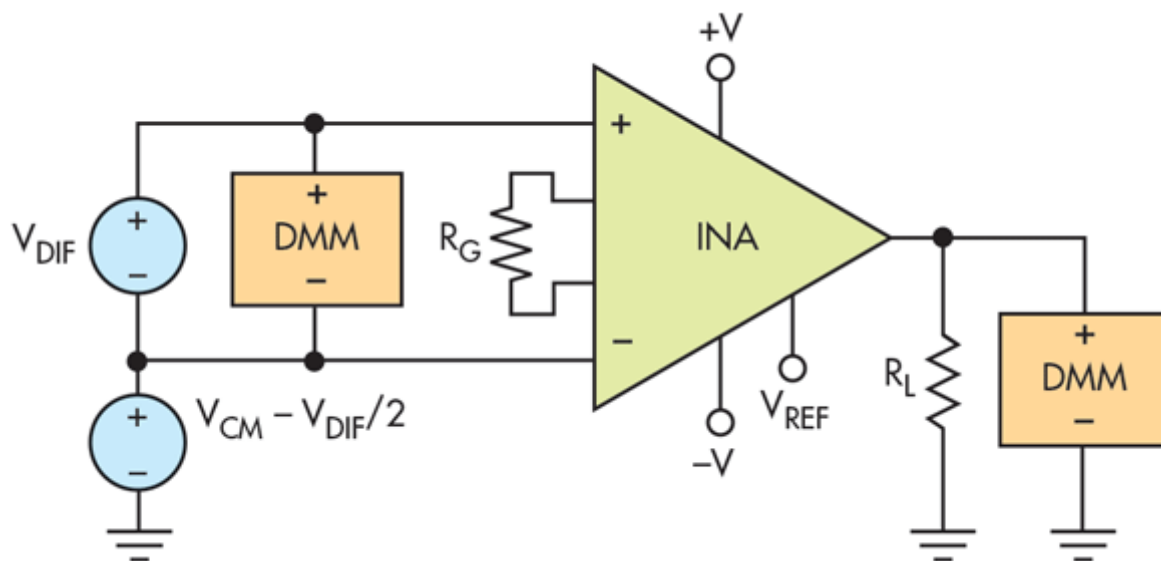
Most quality INAs have a CMR in the 80- to 130-dB range. The quality of the amplifier depends on how well the input amplifiers are matched and the precision of the internal resistors on the differential amplifier. A resistor tolerance of 0.01% or better is required for a high CMRR.

CMRR is typically stated assuming dc inputs. With ac inputs, the CMRR decreases with frequency as capacitance and other parasitics begin to affect the balances in the circuits.

Understanding V_{CM} vs. V_{OUT} Plots



The most common issue when working with instrumentation amplifiers involves the [V_{CM} vs. V_{OUT} plot](#), which defines the [linear operating region](#) of the device (*Fig. 2*).



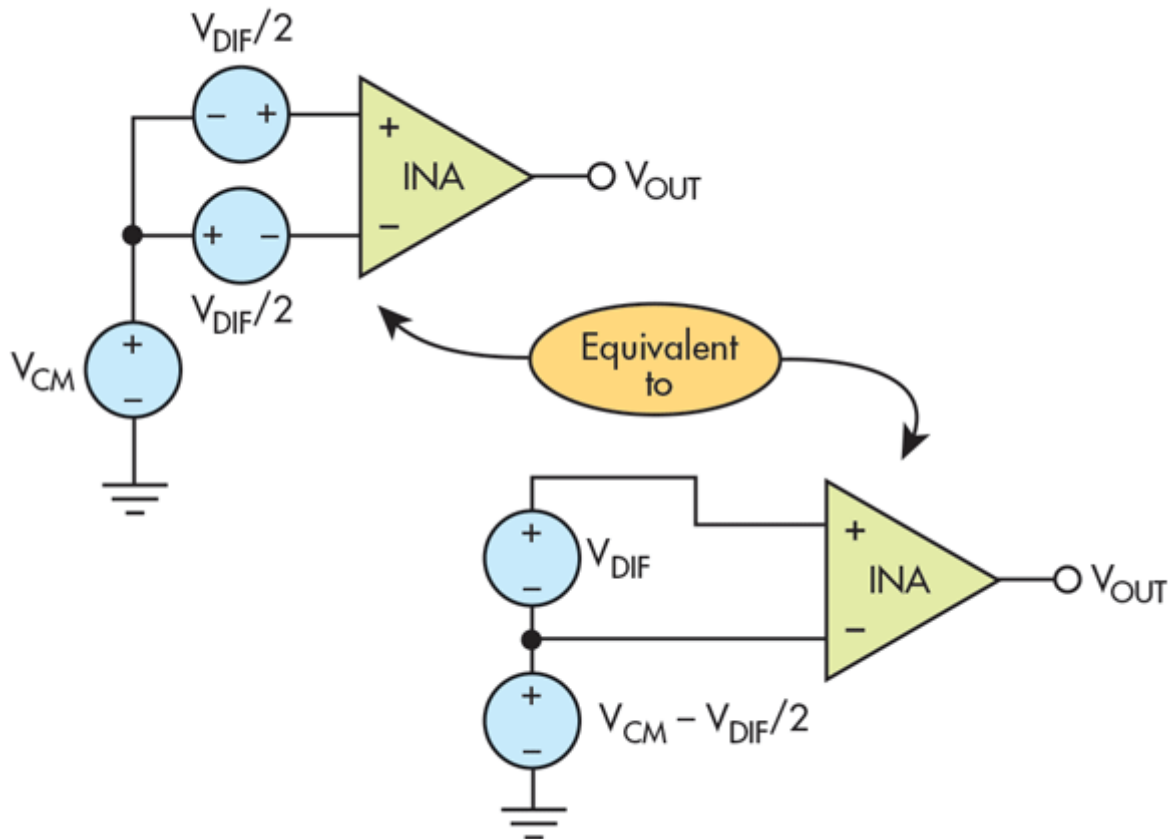
This plot is developed with the measurement arrangement shown in *Figure 3*, which requires two precision voltage sources and two accurate digital multimeters (DMMs). The differential voltage V_{dif} is defined as:

$$V_{DIF} = V_2 - V_1$$

The common-mode voltage V_{CM} is defined as:

$$I = V_{CM} - V_{DIF}/2$$

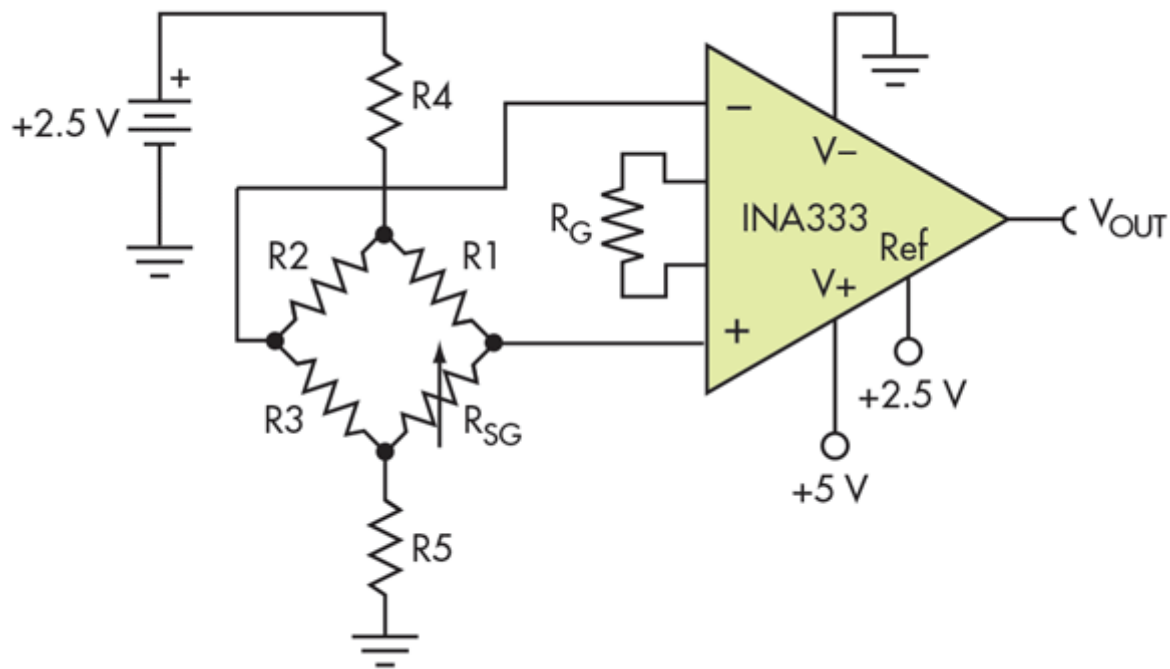
The reason for the $V_{DIF}/2$ factor in the equation is due to the difference between the mathematical analysis model and the more practical measurement arrangement in Figure 3 with V_{CM} connected to one input. The mathematical model usually represents V_{DIF} as two sources equal to $V_{DIF}/2$ (Fig. 4). The two models are equivalent.



Referring to Fig. 2 and assuming ± 2.5 -V supplies on the INA, notice that the full output swing of ± 2.4 V is only available when the common-mode voltage is zero. With a 2-V common-mode voltage, the output swing is limited to ± 0.8 V.

Reference Design

Texas Instruments offers a [reference design that uses its INA333 instrument amplifier and a strain-gauge bridge](#). The main supply is 5 V in a single-supply arrangement with a 2.5-V reference (V_{REF}) input to center the output between the rails when the input is zero (Fig. 5). The bridge supply is also 2.5 V. R_1 , R_2 , and R_3 are usually set equal to R_{SG} , the strain gauge resistance, which is typically 120 Ω . Resistors R_4 and R_5 set the bridge current and the common-mode inputs of the instrument amplifier.

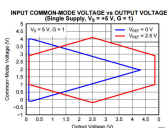


This strain-gauge reference design accurately measures the resistance of a strain gauge by being placed in a bridge configuration. The reference design includes theory, complete error analysis, component selection, simulation, PCB design, and measured data that correlates with theory, calculations, and simulation.



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