

Introduction to Different Error Sources

TI Precision Labs – Current Sense Amplifiers

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Hello, and welcome to the TI Precision Labs series on current sense amplifiers. My name is Kyle Stone, and I'm a product marketing engineer in the Current & Position Sensing product line. In this video, we will introduce the most common sources of error in current sense amplifier circuits. Each error source will be explained further in later videos in this series.

Different types of error in current sensing circuits

1. Offset error $\longrightarrow e_{Offset} (\%) \approx e_{Vos} + e_{CMRR} + e_{PSRR}$
2. Gain error $\longrightarrow e_{Gain} (\%) \approx e_{Gain_error} + e_{Linearity} + e_{Shunt_tolerance}$
3. Application error $\longrightarrow e_{Application} (\%) \approx e_{Bias_current} + e_{Other}$

Worst-case total error – more conservative

$$\zeta_{Worst}(\%) \approx e_{Vos} + e_{CMRR} + e_{PSRR} + e_{Gain_error} + e_{Linearity} + e_{Shunt_tolerance} + e_{Bias_current} + e_{Other}$$

Root-sum-square (RSS) total error – more realistic

$$\zeta_{RSS}(\%) \approx \sqrt{e_{Vos}^2 + e_{CMRR}^2 + e_{PSRR}^2 + e_{Gain_error}^2 + e_{Linearity}^2 + e_{Shunt_tolerance}^2 + e_{Bias_current}^2 + e_{Other}^2}$$

There are several error sources that can affect current sensing circuits, and they can be grouped into three main categories.

The first error type is offset error. Input offset voltage (V_{os}), common mode rejection ratio (CMRR), and power supply rejection ratio (PSRR) all create an offset voltage at the input of the device that remains mostly constant across the entire input range. In general, offset error is the dominant error type at low input levels.

The second error type is gain error. The gain error and linearity of the amplifier, coupled with the tolerance of the shunt resistor, all create errors that vary with input signal level. In general, gain error is the dominant error type at high input levels.

The third type of error is application-dependent error. This includes error induced by bias currents, temperature variations, input filters, frequency response limitations, and any other artifacts. As the name implies, the impact of this type of error can vary significantly across different applications and devices.

System designers often need to combine these error sources together to calculate the total error of the system and make sure it meets their requirements. There are two common ways to do this:

First, the worst case total error is calculated by simply summing the maximum possible errors together. This is a very conservative approach.

However, common statistical analysis tells us that these errors have distributions, and it is almost impossible to find a device with the maximum error of every type. A more realistic approximation of total error can be determined by using the root-sum-of-the-squares (RSS) method to combine the error terms. To use this method, take the square of the maximum value for each error source, add them together, then take the square root of the result.

Offset error example

Conditions

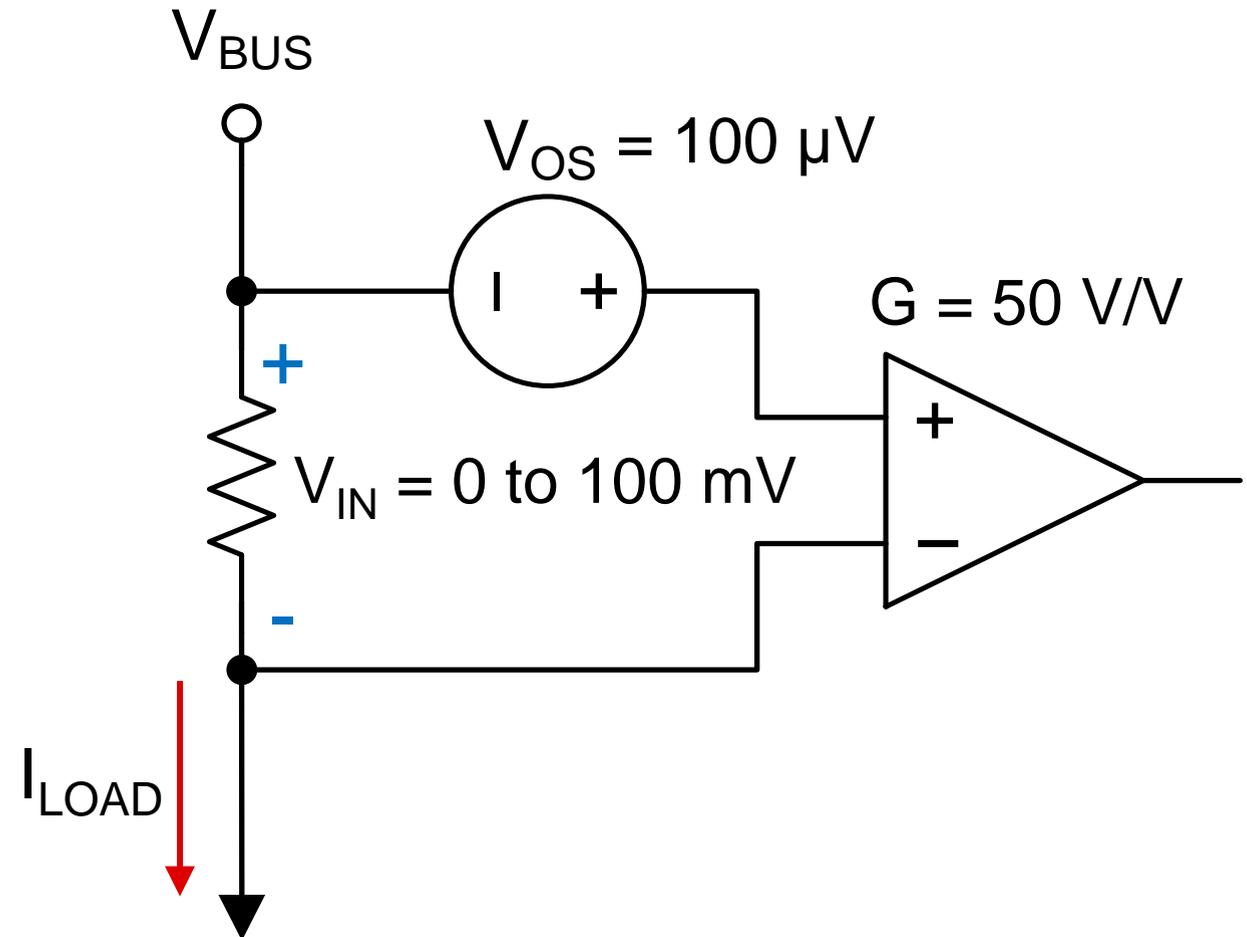
- Gain $G = 50 \text{ V/V}$
- Input offset voltage $V_{OS} = 100 \mu\text{V}$
- Input voltage $V_{IN} = 0 \text{ to } 100 \text{ mV}$

Calculations

$$V_{out_ideal} = V_{in} * G = 0 \text{ to } 5 \text{ V}$$

$$V_{out_actual} = (V_{in} + V_{os}) * G = 5 \text{ mV to } 5.005 \text{ V}$$

$$Error (\%) = \frac{|V_{out_actual} - V_{out_ideal}|}{V_{out_ideal}}$$



Let's look at an example of offset error. This is an example of a referred-to-input, or "RTI," specification – something that must be added to the input before the device gain.

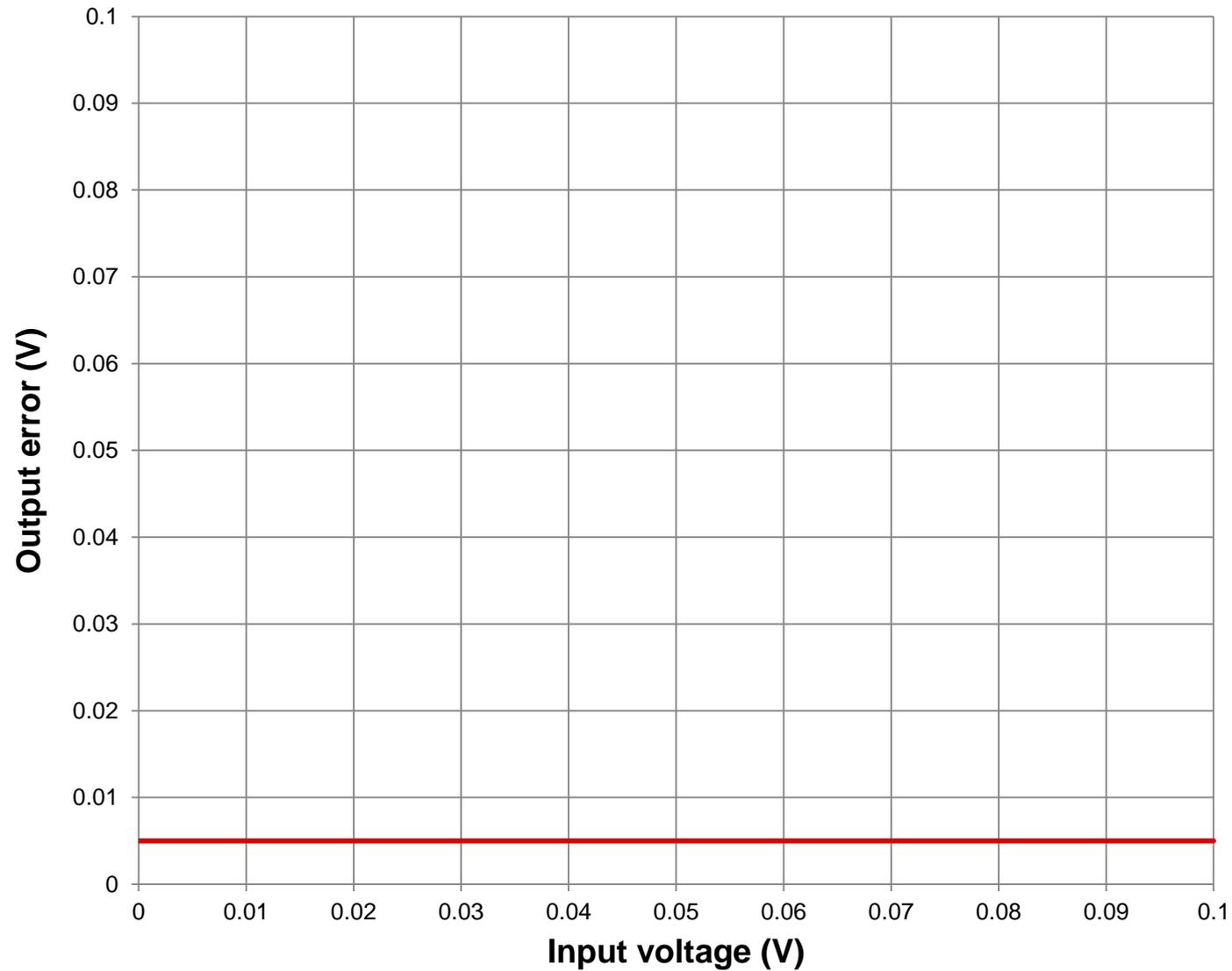
For this example, we'll consider an amplifier with gain of fifty volts-per-volt and an input offset voltage of only one hundred microvolts. The input voltage range, V_{in} , is from zero volts to one hundred millivolts.

To calculate V_{out_ideal} , the ideal output voltage of the amplifier with no errors whatsoever, we simply multiply the input voltage by the gain. This results in a range of zero to five volts.

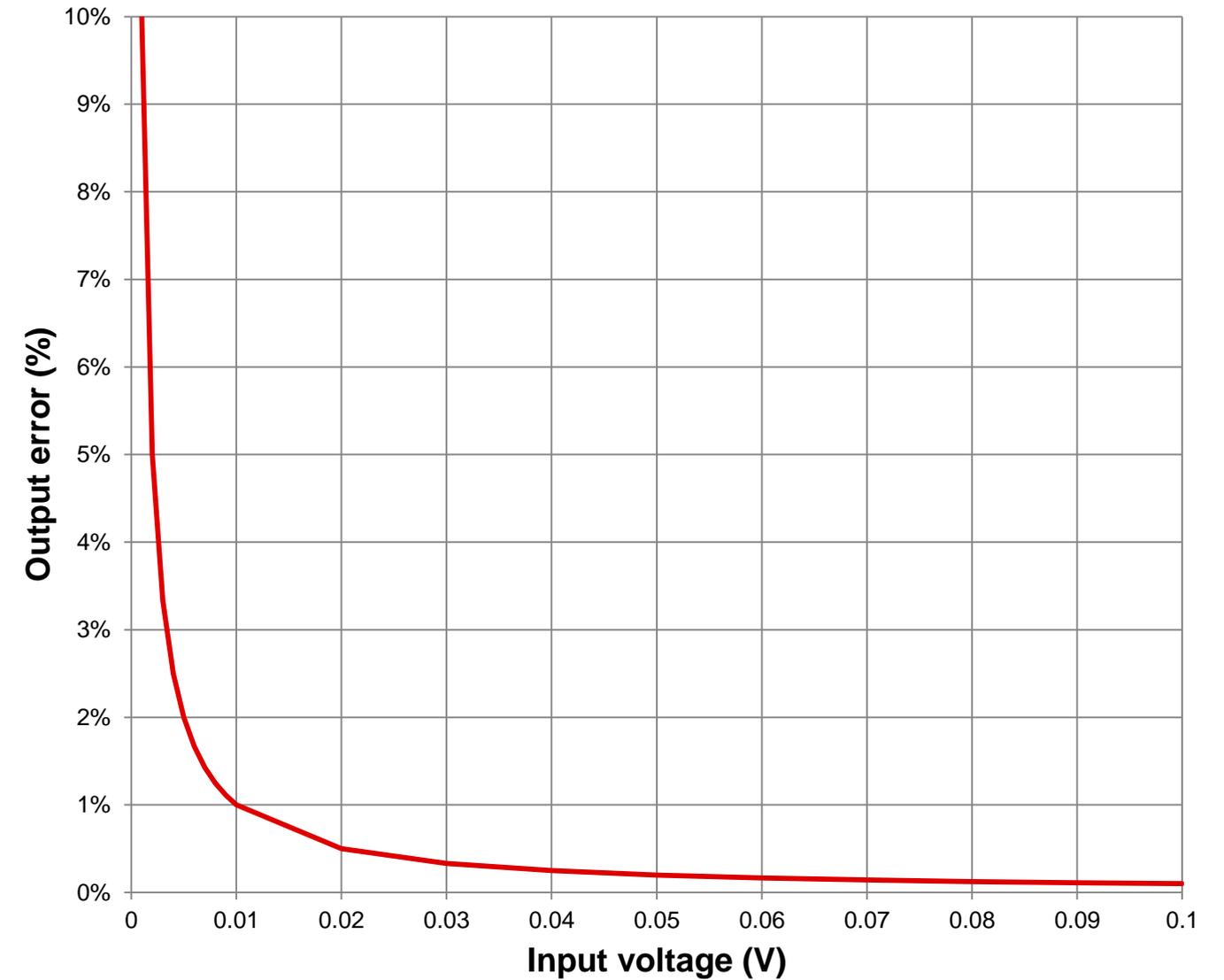
To calculate V_{out_actual} , the actual output voltage, we must add the input offset voltage to the input voltage before multiplying by the gain. This results in a range of five millivolts to 5.005 volts.

To calculate the percent error, the absolute value of V_{out_actual} minus V_{out_ideal} is divided by V_{out_ideal} . Let's look at the results of this error calculation on the next slide.

Offset error example



Error (V) = 5 mV



Error (%) = ∞ to $< 1\%$

The plot on the left shows the output error in volts between the actual and ideal outputs, which is a constant 5 millivolts across the entire input range of 0 to 100 millivolts.

Calculating the percent error gives us a much different result. The error becomes large at zero input voltage, since the error voltage of 5 millivolts is large compared to the ideal output of 0 volts. The error drops significantly with larger input levels, dropping to less than 1 percent at 10 millivolts of input signal.

Designing for a specific operating region can help mitigate these offset errors. Maintaining an input voltage which is significantly larger than the input offset voltage reduces the effect of the input offset voltage on the measurement.

Gain error example

Conditions

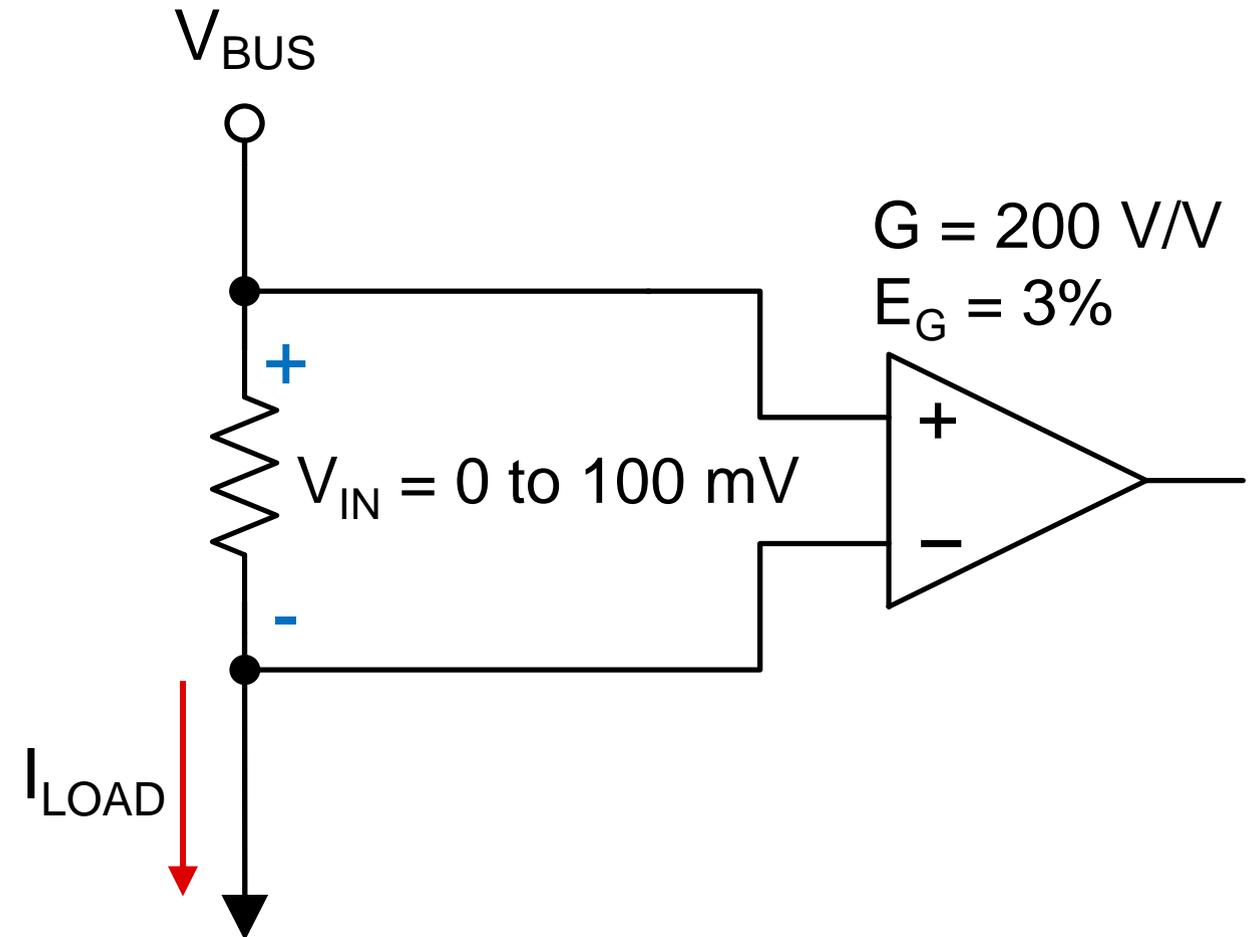
- Gain $G = 200 \text{ V/V}$
- Gain error $E_G = 3\%$
- Input voltage $V_{IN} = 0 \text{ to } 100 \text{ mV}$

Calculations

$$V_{out_ideal} = V_{in} * G = 0 \text{ to } 20 \text{ V}$$

$$V_{out_actual} = V_{in} * G * \left(1 \pm \frac{E_G}{100}\right) = 0 \text{ to } 20.6 \text{ V}$$

$$Error (\%) = \frac{|V_{out_actual} - V_{out_ideal}|}{V_{out_ideal}}$$



Let's now consider a similar example that illustrates gain error. We'll ignore any offset error for simplicity.

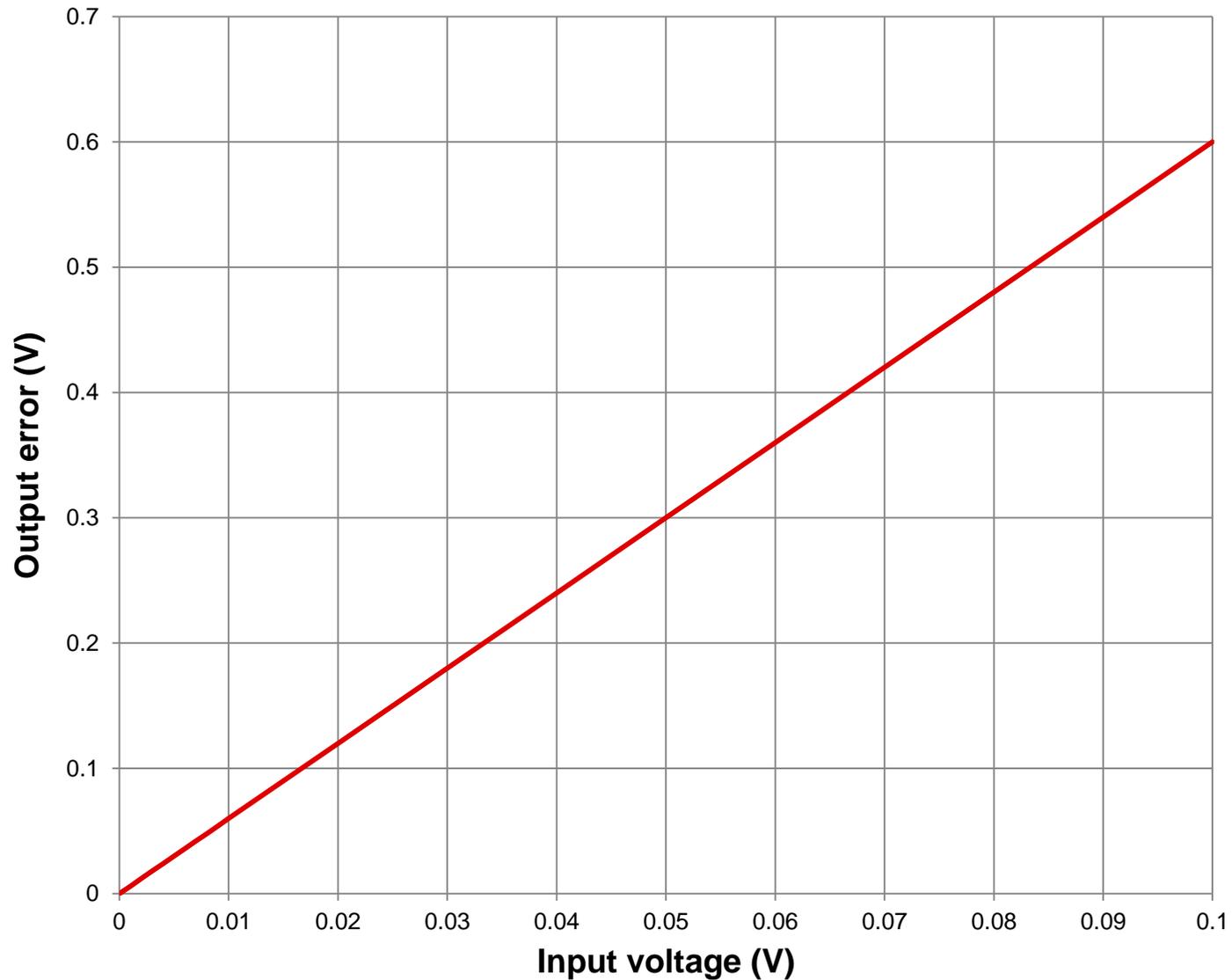
Here, we'll consider an amplifier with gain of two hundred volts-per-volt and a gain error of three percent. The input voltage range is still 0 volts to 100 millivolts.

Again, to calculate V_{out_ideal} , we simply multiply the input voltage by the gain. This results in a range of zero to twenty volts.

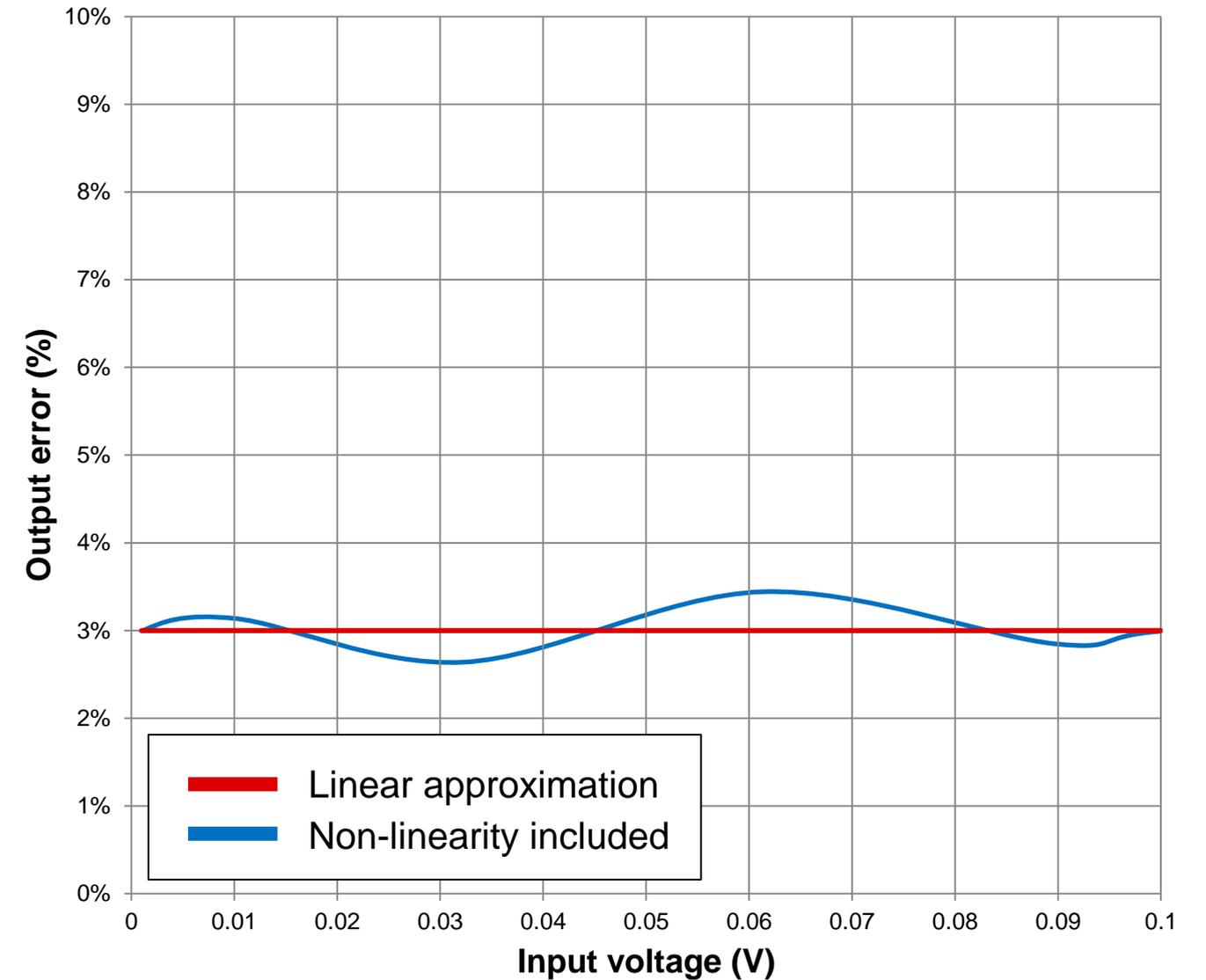
To calculate V_{out_actual} , we multiply the input by the nominal gain, plus or minus the extra percentage of error. This results in a range of zero to twenty point six volts.

Percent error is calculated the same way as before. Let's look at the results on the next slide.

Gain error example



Error (V) = 0 to 0.6 V



Error (%) = 3%

The plot on the left shows the output error in volts between the actual and ideal outputs. In this case you can see that the error voltage changes linearly with input voltage.

As you might expect, plotting the percent error gives a different result – in this case a constant 3% over the entire input range. If we considered the effect of amplifier non-linearity as well, the error line would no longer be straight. Instead, it would look more like the blue curve, depending on the internal architecture of the amplifier.

We recommend selecting an amplifier with a gain error specification that meets or exceeds your total error requirement.

Application-specific error

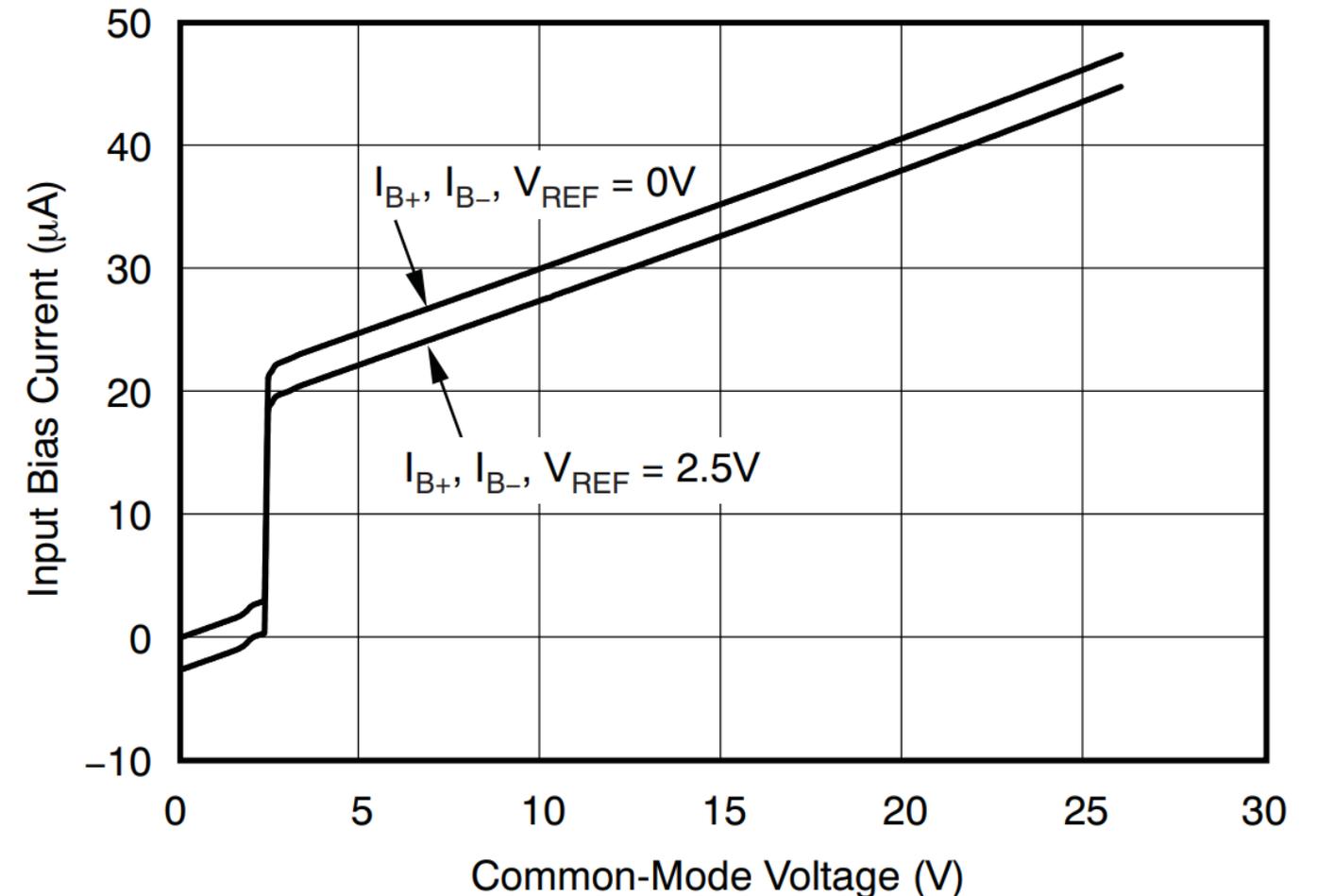
Temperature drift

- Input offset voltage V_{OS}
- Gain error E_G
- PSRR, CMRR
- Shunt resistance

Other error sources

- Printed circuit board (PCB) layout
- Input filtering
- Device-specific errors

Input bias currents – I_B



Finally, let's consider some other errors.

Changes in temperature affect the performance of a current sense amplifier, and all integrated circuits in general. Input offset voltage and gain error drift over temperature are usually specified in a product datasheet. PSRR and CMRR are not always given drift values, but min/max values are given both at room temperature and over the entire operating temperature range.

Shunt resistor value changes are specified by the resistor manufacturer, often called the “temperature coefficient” or “TEMP CO” of the resistor.

Input bias currents in a current sense amplifier are typically larger than in a traditional op-amp, diff-amp, or instrumentation amp. These bias currents are typically under 50 microamps, but depending on the system, they can cause issues at very low current levels with large resistors.

Finally, other application-specific factors like printed circuit board (PCB) layout, passive filtering at the device input, and other aspects of the device's internal architecture can contribute to measurement inaccuracies as well.

Please remember that this video is only an introduction to each of these error sources. The next videos in the series will give more details on each error source and how to manage them in your designs to achieve high performance.

To find more current sense amplifier technical resources and search products, visit ti.com/currentsense

That concludes this video - thank you for watching! Please try the quiz to check your understanding of the content.

For more information and videos on current sense amplifiers please visit [ti.com/currentsense](https://www.ti.com/currentsense).