

Gain Error

TI Precision Labs – Current Sense Amplifiers

Presented by Peter Iliya

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Hello, and welcome to the TI Precision Labs series on current sense amplifiers. My name is Peter Iliya, and I'm an applications engineer in the Current & Position Sensing product line. In this video, we will introduce gain error in current sense amplifier circuits.

Total gain error

Components of total gain error:

$$e_{Gain} (\%) \approx e_{Gain_error} + e_{gain_error_temperature_drift} + e_{Linearity}$$

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

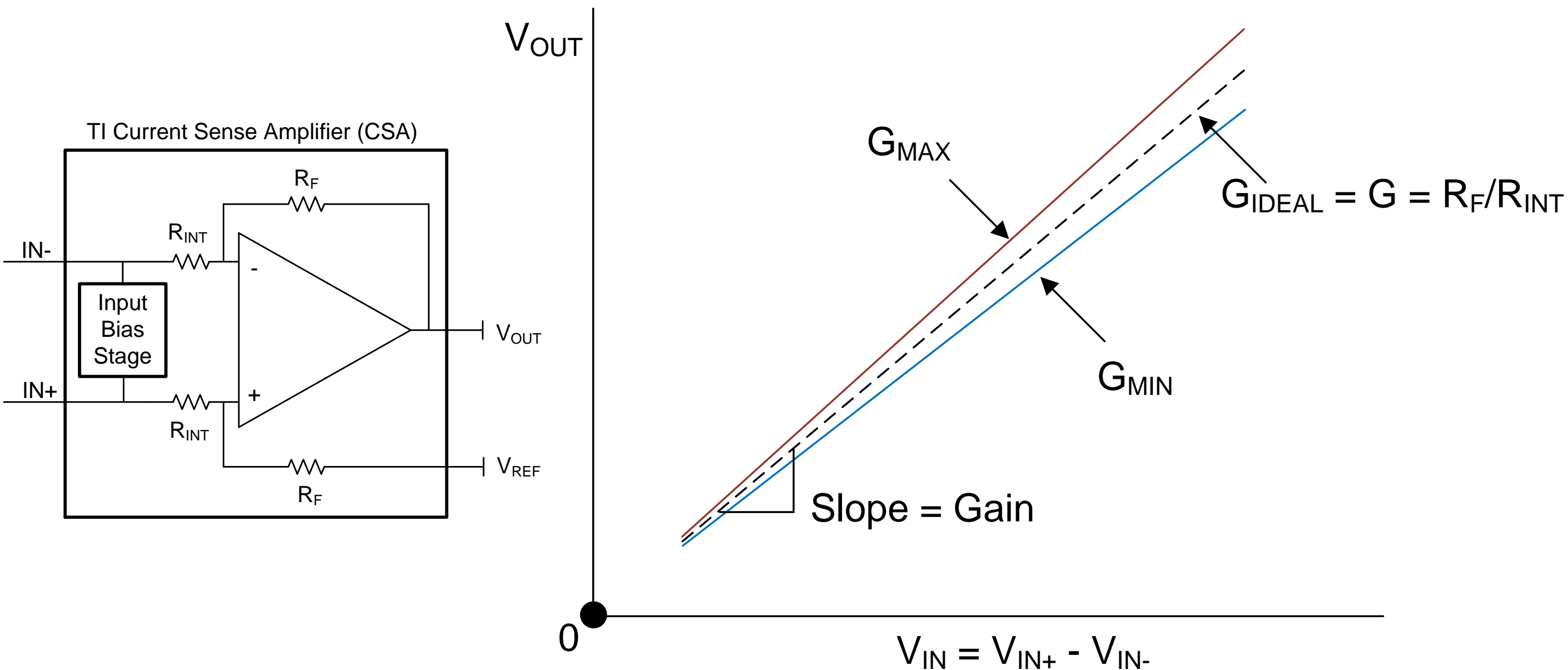
$$\zeta_{RSS}(\%) \approx \sqrt{e_{Vos}^2 + e_{CMRR}^2 + e_{PSRR}^2 + e_{Gain_error}^2 + e_{Linearity}^2 + e_{Shunt_tolerance}^2 + e_{Bias_current}^2 + e_{Other}^2}$$

Total gain error includes the device's internal gain error, the device's gain drift with temperature, and device linearity. Technically, the shunt resistor tolerance also contributes to the system gain error, but this video will only focus on the device's gain error.

Gain error differs from offset error in that it contributes the same amount of percentage error to total system error over the linear dynamic range.

In general, gain error is the dominant error type at high input signal levels.

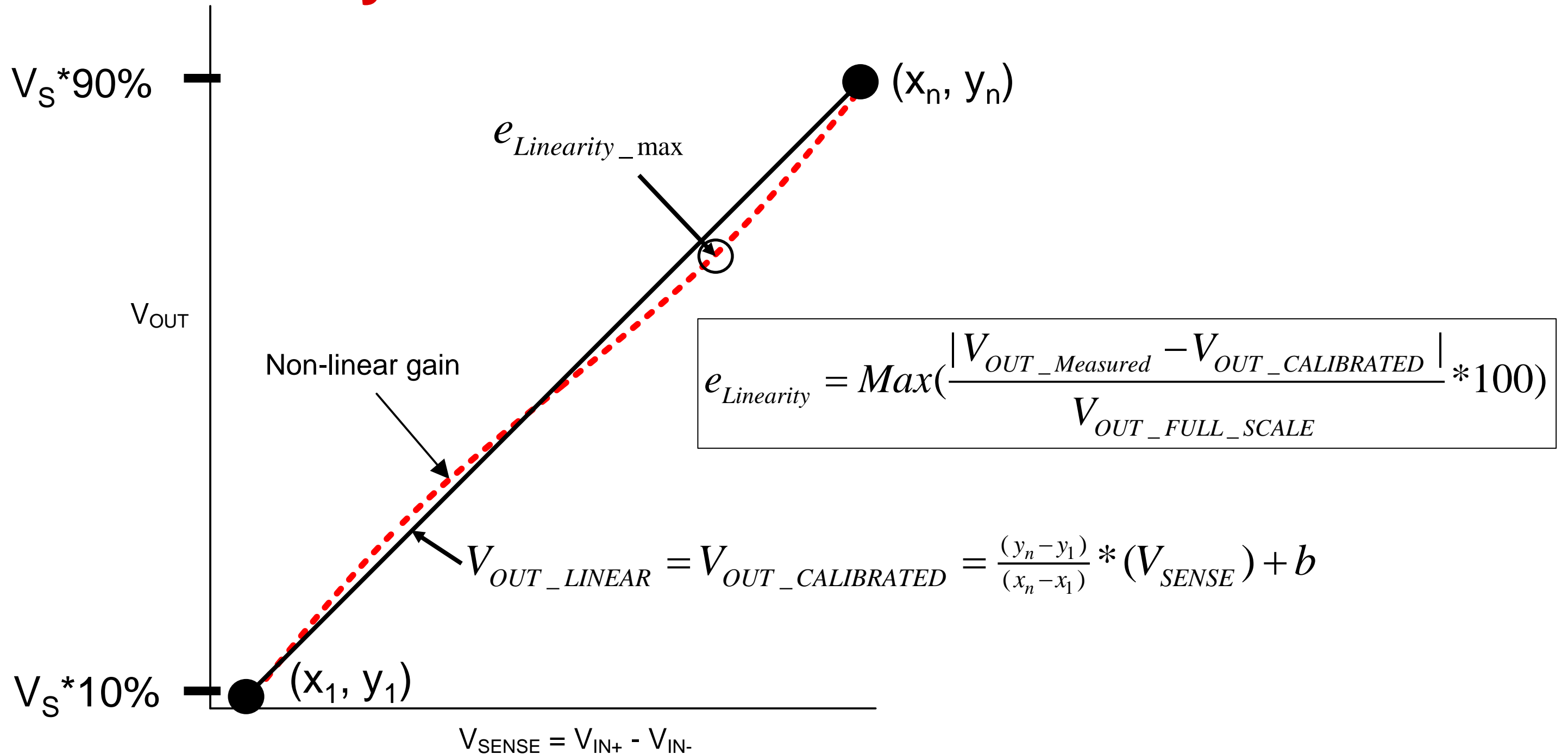
Current sense amplifier (CSA) gain error



For the typical current sense amplifier (or abbreviated as CSA), device gain is set by the ratio of the internal network resistors R_F and R_{INT} . These resistors are not trimmed to an exact resistance, rather they are manufactured to have a precise ratio, as the ratio is what sets the device gain. How much the ratio varies is what dictates device gain error.

Gain curves can be visualized with the plot on the right. Gain is simply the slope of the output vs. the input. The worst-case maximum and minimum gain curves set the bounds of possible linear gain error in a current sense amplifier. Note that this plot assumes perfect linearity.

CSA linearity error



Linearity error is a specification of how linear the gain curve is. To characterize linearity, the device's input is swept with N number of points. A calibrated gain curve is calculated by linear approximation using two data points at 10% and 90% of the full-scale output range. For example, if the supply is 5-V, then the two points considered are 0.5V and 4.5V. Determining the calibrated gain requires calculating linear slope and offset. Linearity error specified in the datasheet is set by the data point that is the furthest from the calibrated gain curve. The percentage linearity error is calculated as $V_{out_measured} - V_{out_calibrated}$ divided by the full-scale V_{out} range.

Usually, linearity error is much smaller than the maximum gain error and can be ignored. However, linearity error becomes more important if a system is to execute this two-point gain calibration. If the exact gain is determined for a CSA in a real system by measuring two data points and calculating linear gain, then the only remaining error left is the linearity error and gain drift.

Gain error vs. temperature

7.5 Electrical Characteristics

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{ V}$, $V_{\text{SENSE}} = V_{\text{IN}+} - V_{\text{IN}-}$, $V_{\text{CM}} = 12\text{ V}$, and $V_{\text{REF1}} = V_{\text{REF2}} = V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT						
G	Gain	INA240A1		20		V/V
		INA240A2		50		
		INA240A3		100		
		INA240A4		200		
	Gain error	$\text{GND} + 50\text{ mV} \leq V_{\text{OUT}} \leq V_S - 200\text{ mV}$		$\pm 0.05\%$	$\pm 0.20\%$	
		$T_A = -40^\circ\text{C to } 125^\circ\text{C}$		± 0.5	± 2.5	ppm/ $^\circ\text{C}$
	Non-linearity error	$\text{GND} + 10\text{ mV} \leq V_{\text{OUT}} \leq V_S - 200\text{ mV}$		$\pm 0.01\%$		

What is the maximum gain error when $T_A = -10^\circ\text{C}$ to $+100^\circ\text{C}$? Ignore non-linearity error.

$$Error_{max} = E_G + \frac{\Delta E_G}{\Delta^\circ\text{C}} * |\Delta T_A|$$

$$Error_{max} = 0.2\% + 2.5 \frac{\text{ppm}}{^\circ\text{C}} * 10^{-4} * (100^\circ\text{C} - 25^\circ\text{C})$$

$$Error_{max} = 0.2\% + 0.0275\% = \pm \mathbf{0.2275\%}$$

It is important to understand that the gain error specification of a CSA only applies when the device is operating within the testing conditions of the datasheet. Once the ambient temperature deviates from the gain error testing condition, the engineer must account for gain drift.

For example, what is the maximum gain error if the system ambient temperature could vary from negative 10 degrees to positive 100 degrees Celsius? Well the total gain error sums the initial gain error and the gain drift error. Initial gain error, which is tested at 25 degrees Celsius, is 0.2% max. When determining the drift component, the engineer needs to locate the drift specification and then multiply by the temperature change with respect to the initial gain error's testing temperature condition. The temperature change of importance is 100 degrees – 25° Celsius. Only the largest absolute change from 25 degrees Celsius should be considered because the gain error specification can almost always be positive or negative. Note that an easy way to convert parts per million into percentage is to multiply by ten to the negative fourth power.

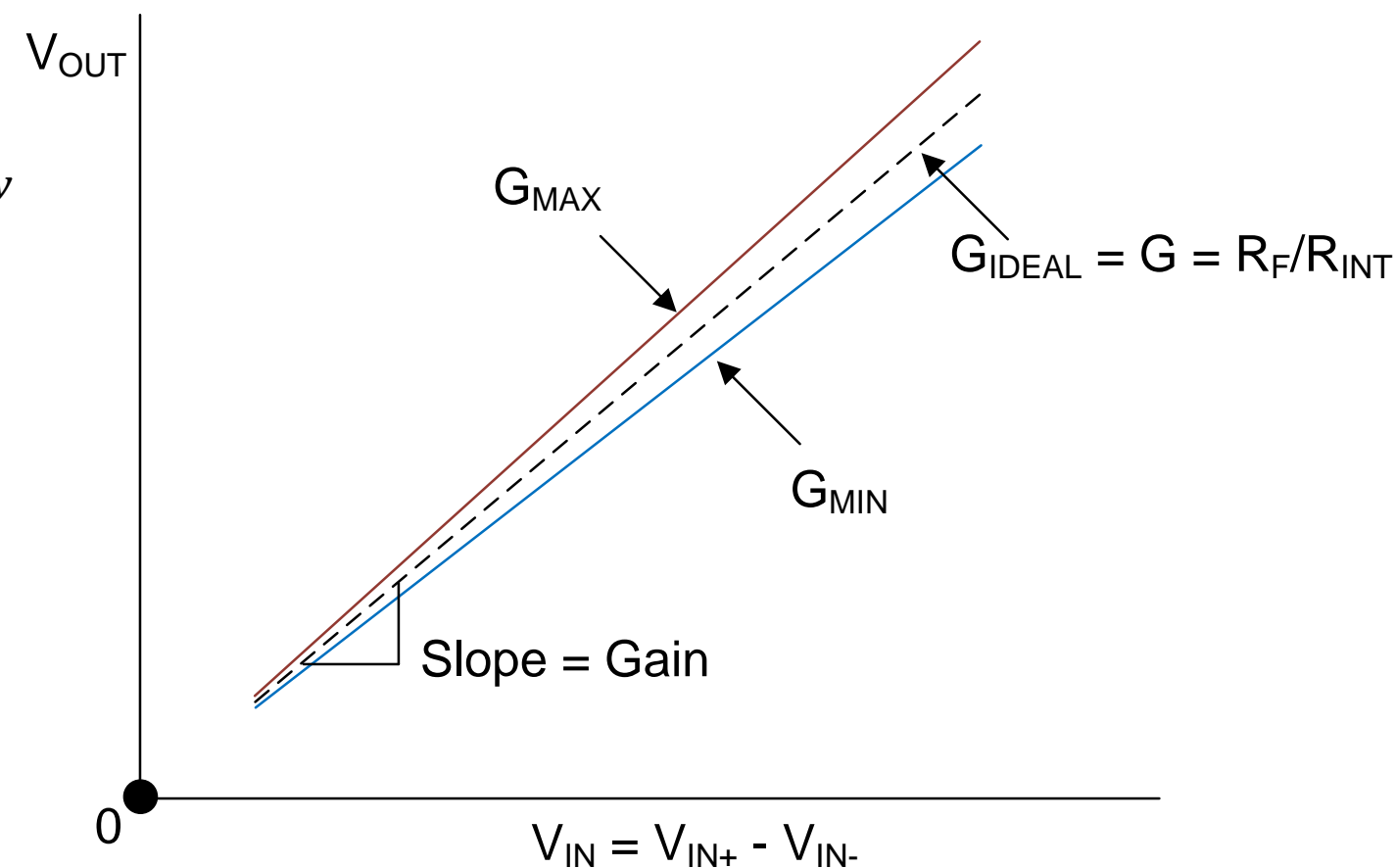
So if we continue the calculation in terms of percent, the maximum gain error is + or - 0.2275%.

CSA total gain error (E_G)

$$e_{Gain} (\%) \approx e_{Gain_error} + e_{gain_error_temperature_drift} + e_{Linearity}$$

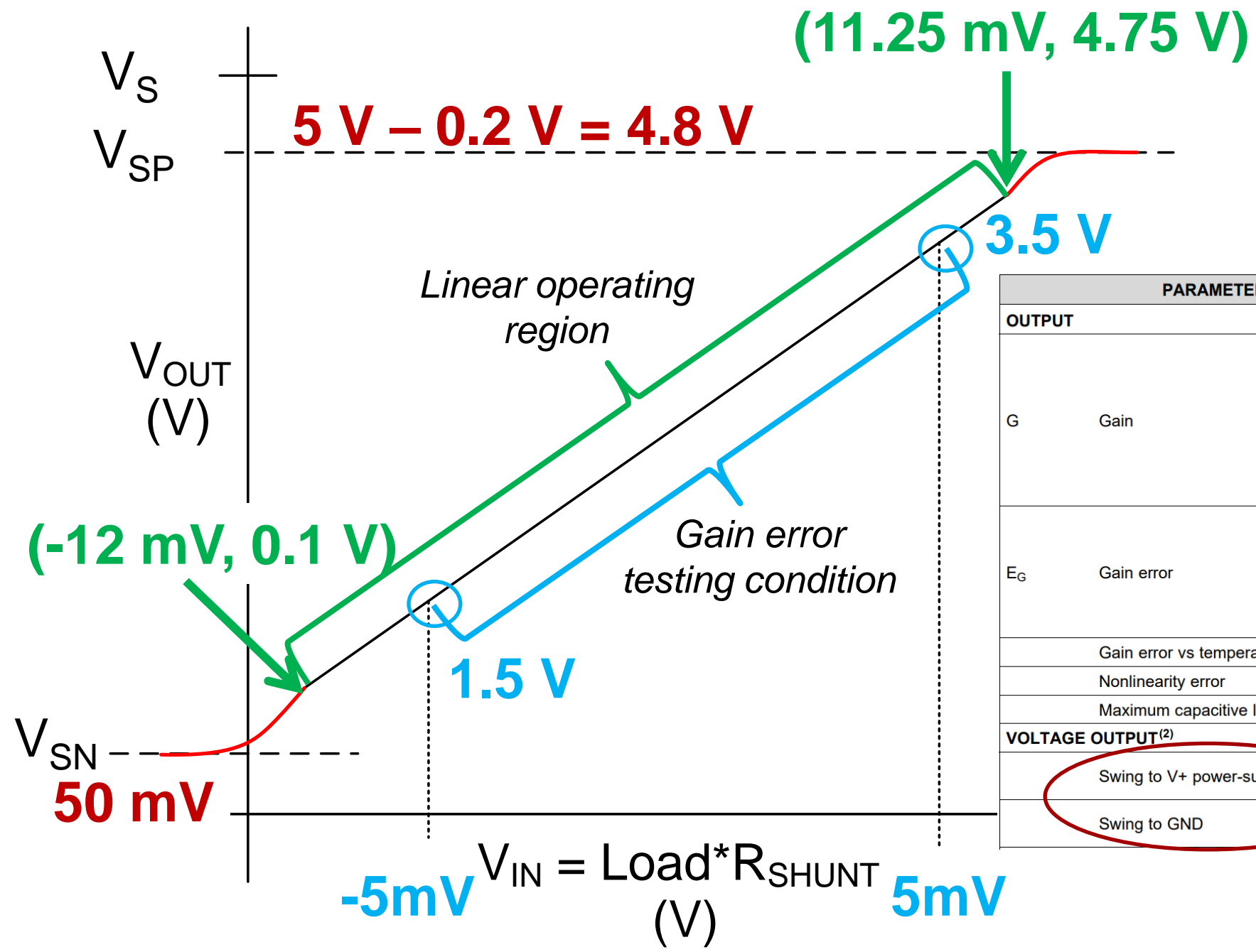
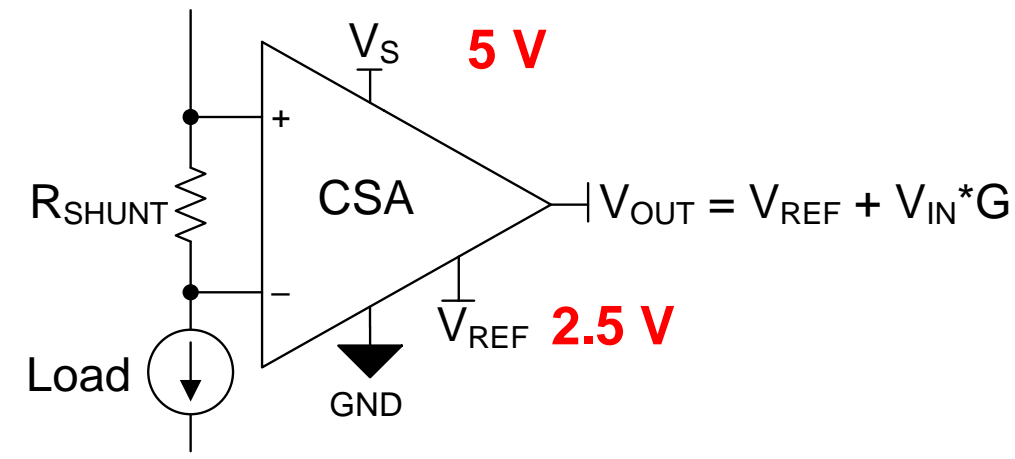
$$G_{MAX} = G * \left(1 + \frac{E_G + \frac{\Delta E_G}{\Delta^\circ C} * \Delta T_A + E_{Linearity}}{100} \right)$$

$$G_{MIN} = G * \left(1 - \frac{E_G + \frac{\Delta E_G}{\Delta^\circ C} * \Delta T_A + E_{Linearity}}{100} \right)$$



The worst-case gains of a CSA are the maximum and minimum possible gains. To calculate these worst-case gains, simply add all of the gain errors percentages together, and divide by 100 to yield a gain error factor. Finally, add or subtract this gain error factor from one. Since most all gain error specifications are symmetrical about 0, the maximum and minimum gains are symmetrical about the nominal device gain.

CSA output limitations



PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT						
G	Gain	INA210		200		V/V
		INA211		500		
		INA212		1000		
		INA213		50		
		INA214		100		
		INA215		75		
E _G	Gain error	V _{SENSE} = -5 mV to 5 mV T _A = -40°C to +125°C (Versions A and B)		±0.02%	±1%	
		V _{SENSE} = -5 mV to 5 mV T _A = -40°C to +125°C (Version C)		±0.02%	±0.5%	
	Gain error vs temperature	T _A = -40°C to +125°C		3	10	ppm/°C
	Nonlinearity error	V _{SENSE} = -5 mV to 5 mV		±0.01%		
	Maximum capacitive load	No sustained oscillation		1		nF
VOLTAGE OUTPUT⁽²⁾						
	Swing to V+ power-supply rail	R _L = 10 kΩ to GND T _A = -40°C to +125°C		(V+) - 0.05	(V+) - 0.2	V
	Swing to GND	R _L = 10 kΩ to GND T _A = -40°C to +125°C		(V _{GND}) + 0.005	(V _{GND}) + 0.05	V

It is important to know when gain error is reliable. Like most amplifiers, the output of CSAs are limited by their voltage supplies, in that they can only swing so close to the supply rails. How close the output can swing is set by the specifications called swing-to-negative (V_{SN} , otherwise known as swing-to-ground) and swing-to-positive rail (V_{SP}).

While the swing-to-rail specifications set the bounds of the output, they do not set the linear region of the amplifier. For proper amplifier gain, the output must be within the linear region. The range of the linear region depends upon several factors, but the best practice is to not violate the V_{OUT} vs. I_{OUT} curve(s) of datasheet and apportion the linear output range to be tens to hundreds of millivolts within the swing-to-rail specifications.

Gain error is always tested in a region smaller than the entire possible linear region, so it is helpful to understand how to set an appropriate output linear region and maximize an accurate dynamic range of the amplifier.

Let's examine the INA210 as an example for determining linear output region. We will assume a 5-V supply and 2.5-V reference voltage. If we examine the datasheet's Electrical Characteristics Table we can fill in the chart. For the swing-to-rail specifications, we see 50 mV for the swing-to-ground and V_s minus 200 mV for the swing to positive rail, which translates to a 4.8 V V_{OUT} limit for the 5-V supply rail.

Next we see that gain error is specified from an input range of -5 mV to +5 mV over temperature. Since the INA210 has a gain of 200 V/V and is offset with 2.5-V reference, this means gain error is tested from 1.5V to 3.5V. Remember that V_{OUT} always equals $V_{REF} + V_{IN} * G$.

Next its time to set an appropriate linear region. As long as we do not violate any output current conditions we can conservatively set the linear region to 50mV below V_{SP} and 50mV above V_{SN} . This equates to 100mV to 4.75V of V_{OUT} range, which when referred to the input is -12mV to 11.25mV of sense voltage.

Example 1 – INA210

Conditions

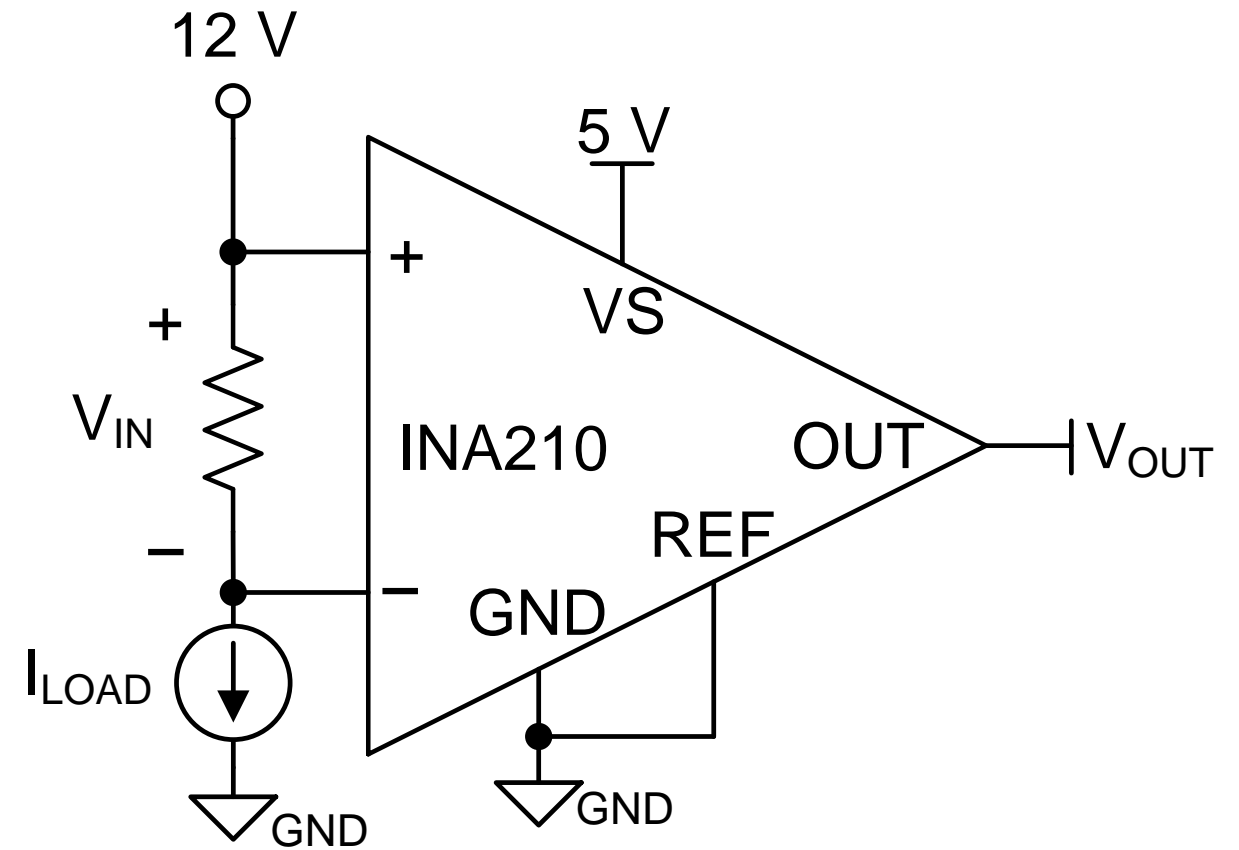
- Gain $G = 200 \text{ V/V}$
- Gain error $E_G = \pm 1\%$ ($-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$)
- Input offset $V_{OS_MAX} = \pm 35 \mu\text{V}$
- Input voltage $V_{IN} = 0.5 \text{ mV}$ to 22.5 mV

Calculations

$$V_{out_ideal} = V_{in} * G = 100 \text{ mV to } 4.5 \text{ V}$$

$$V_{out_max} = (V_{in} + V_{OS}) * G * \left(1 + \frac{E_G}{100}\right)$$

$$V_{out_min} = (V_{in} - V_{OS}) * G * \left(1 - \frac{E_G}{100}\right)$$



Note: R_{SHUNT} has perfect 0% tolerance in this example

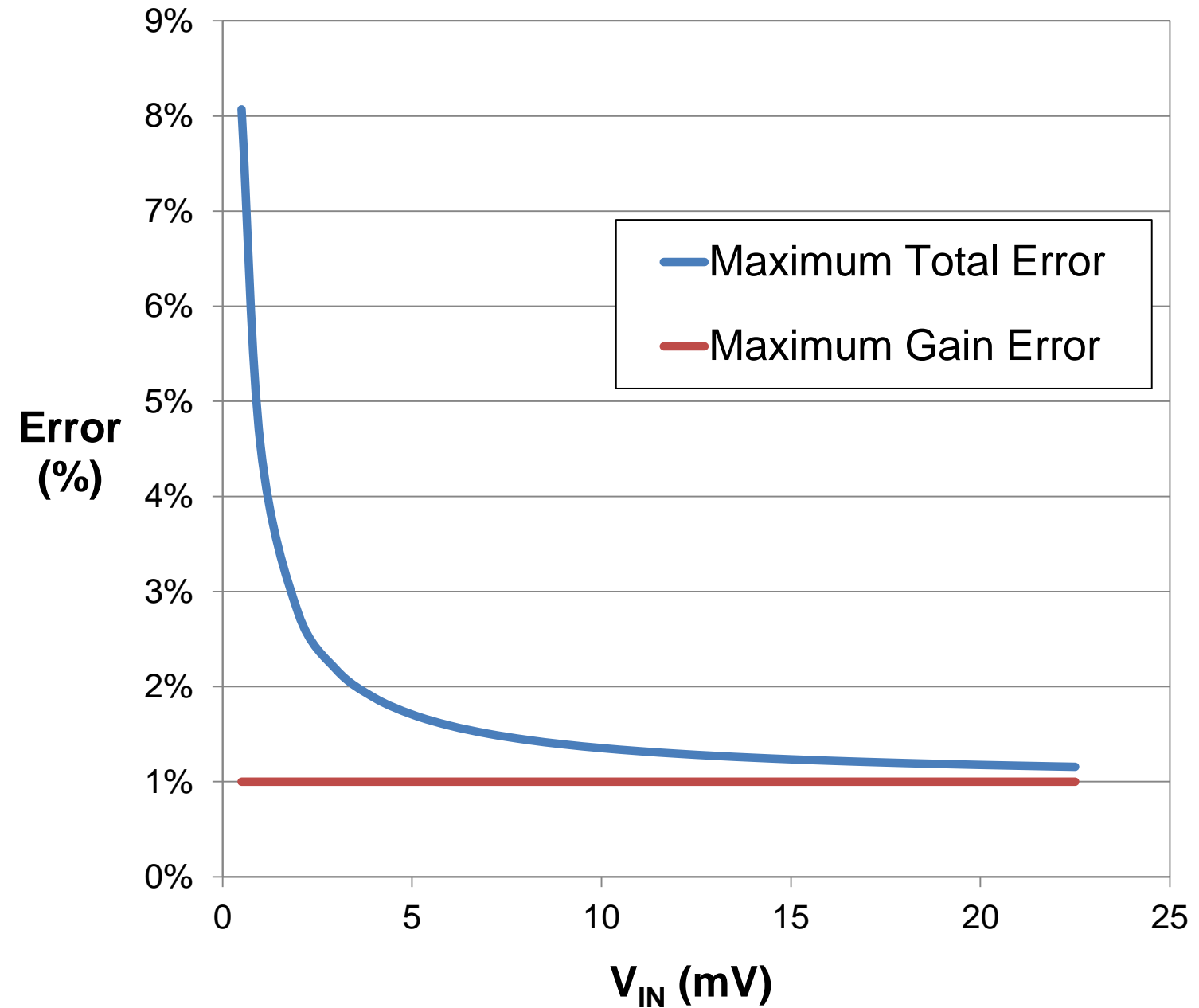
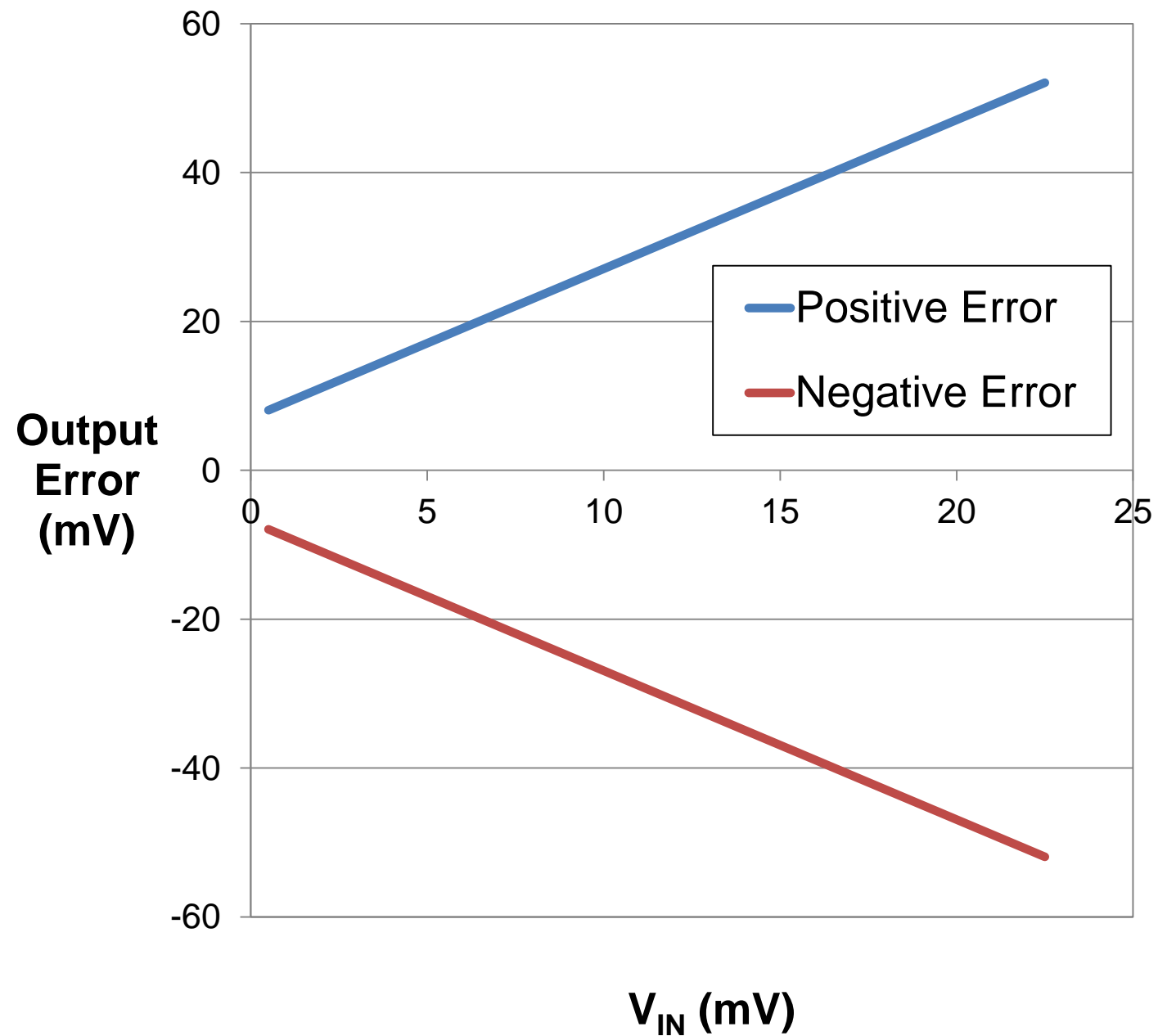
Let's now consider an example using the INA210, which is set to a gain of 200 V/V with a $\pm 1\%$ maximum gain error. The available power supply is a 5-V rail.

The input voltage range of consideration, which is set by the load current and the shunt resistor, will range from 500 μV to 22.5 mV.

To calculate $V_{\text{out_ideal}}$, we simply multiply the input voltage by the gain. This results in a range of 100 mV to 4.5 V, which is well within the normal output operating region.

The maximum and minimum possible output voltage equations are shown. When determining worst case error it is best to pair a positive gain with a positive offset and vice versa, a negative gain with a negative offset.

Example 1 – worst-case error analysis



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.

The relative errors are plotted on the right. As stated earlier, relative gain error is constant over the input range. The total error curve includes the offset error, so error increases with a $1/x$ relationship.

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

Example 2 – INA226 (digital output)

Conditions

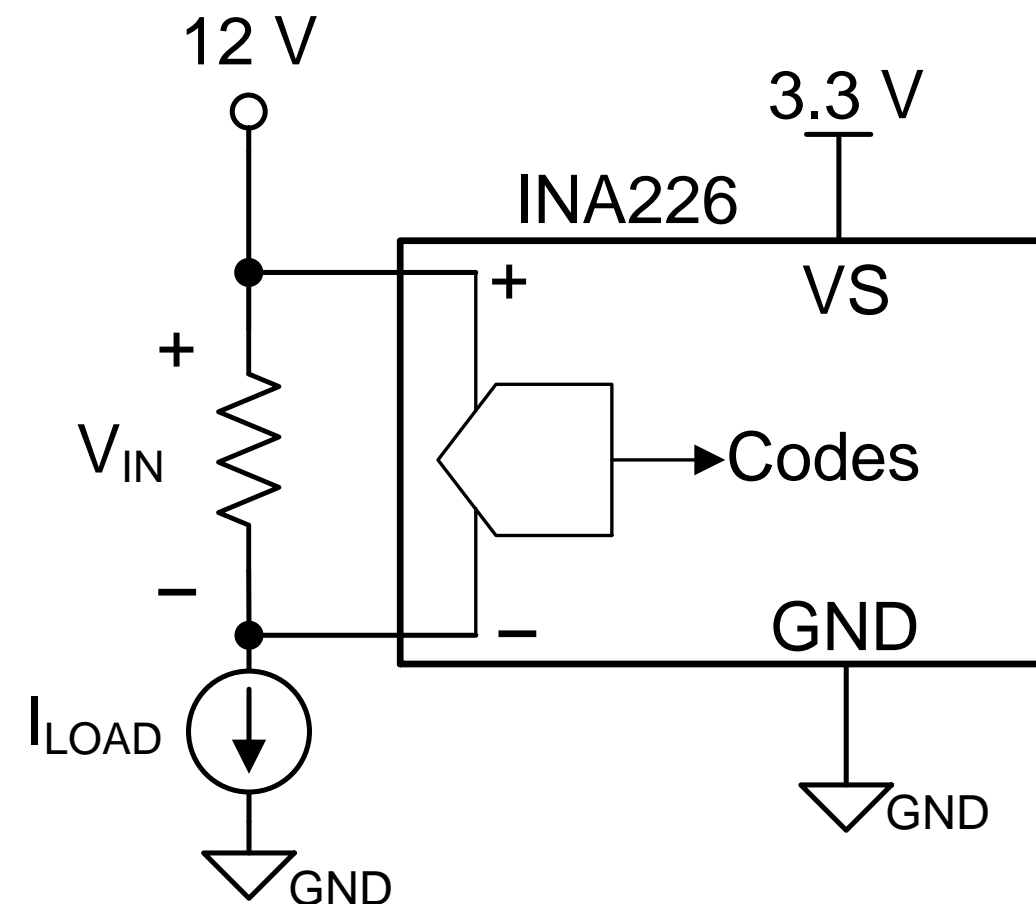
- $LSB_shunt_voltage = 2.5 \mu V$
- Shunt voltage gain error $E_G = 0.1\%$ ($T_A = 25^\circ C$)
- Input offset $V_{OS_MAX} = \pm 10 \mu V$ (4 LSB)
- Input voltage $V_{IN} = 0.5 mV$ to $80 mV$
- $T_A = 25^\circ C$ stable

Calculations

$$G_{ideal} = \frac{1}{2.5\mu V} = 40000$$

$$Codes_{IDEAL} = V_{in} * G_{IDEAL}$$

$$Codes_{MAX-MIN} = (V_{in} \pm V_{OS}) * G * \left(1 \pm \frac{E_G}{100}\right)$$

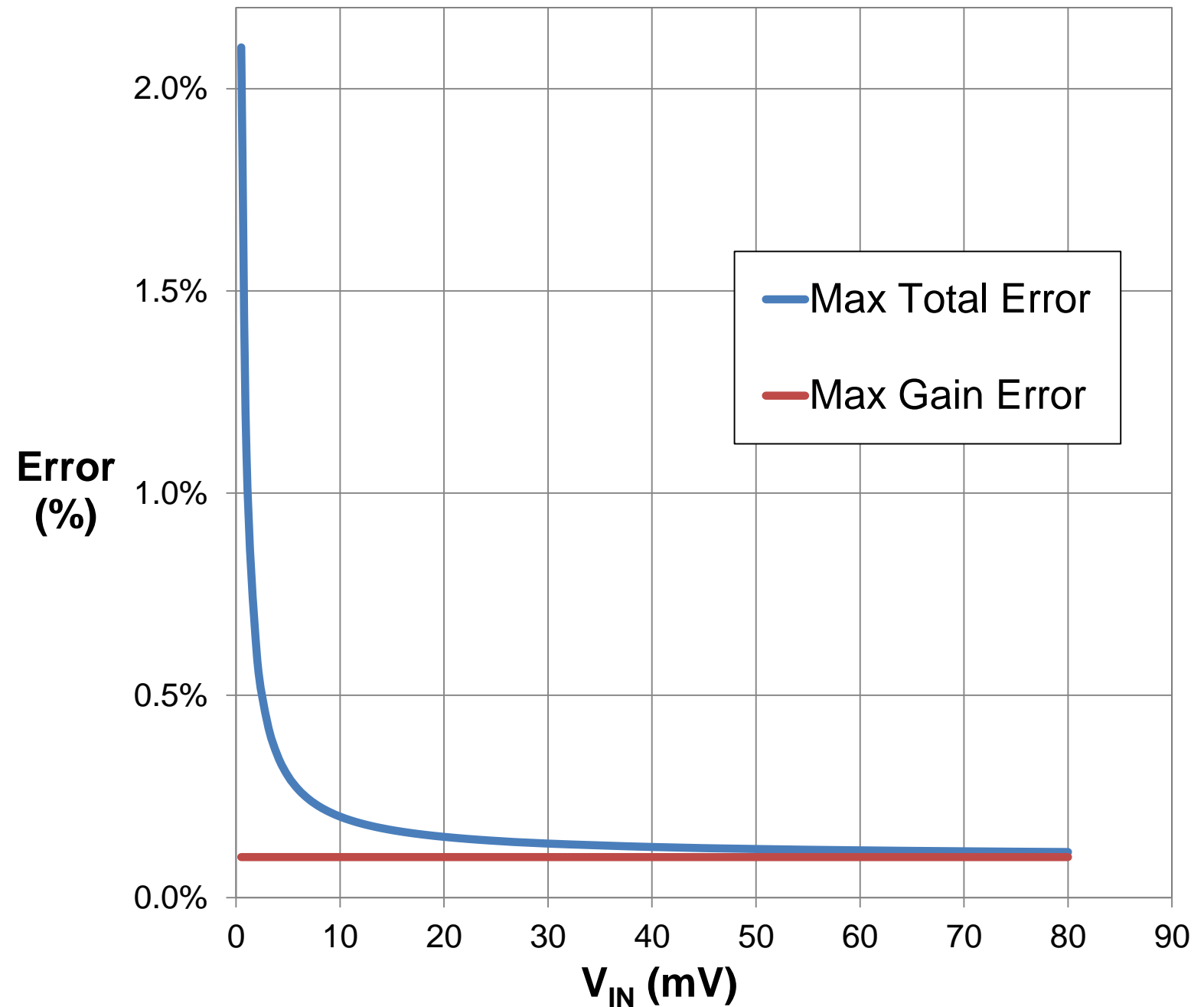
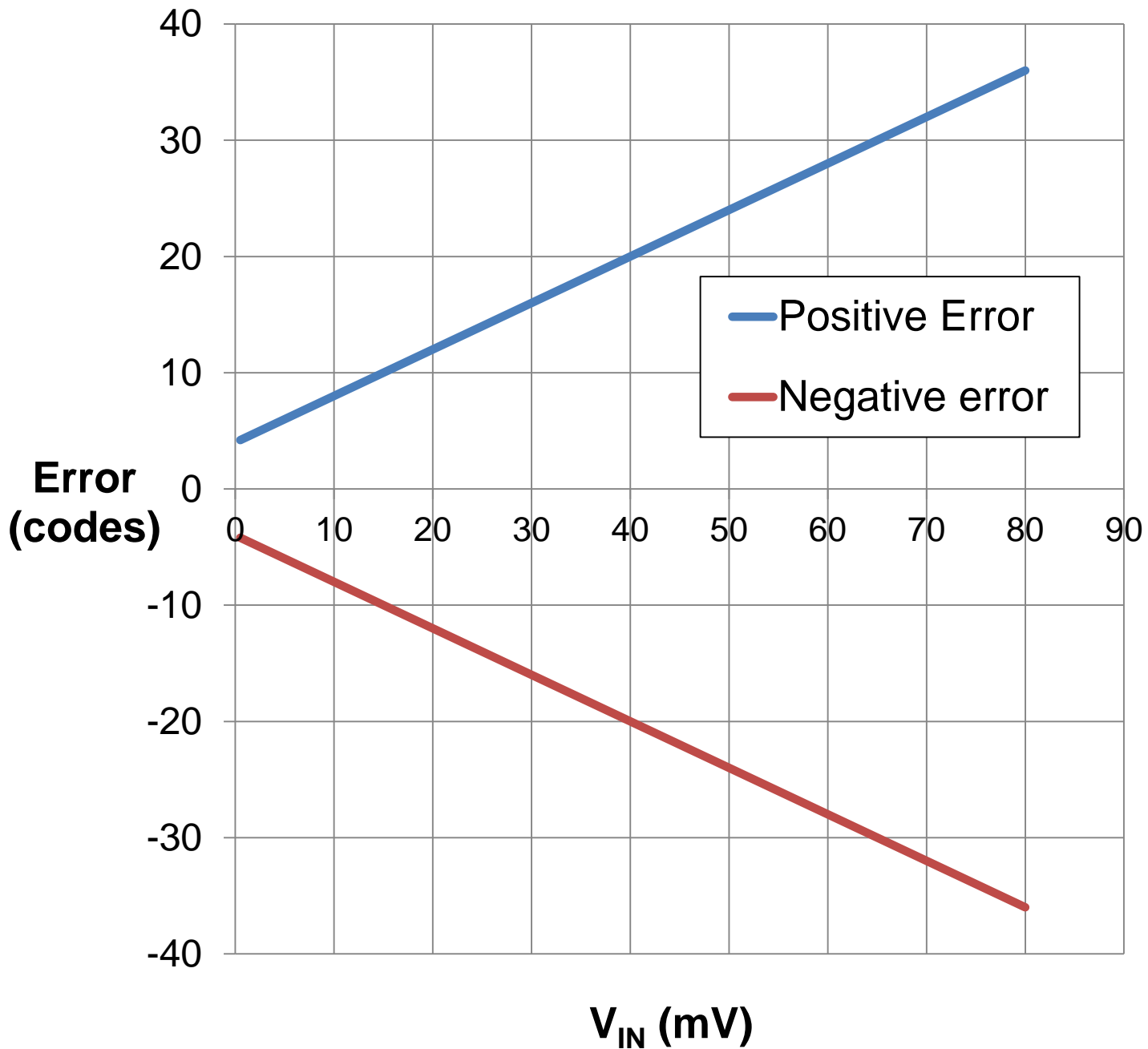


Note: R_{SHUNT} has perfect 0% tolerance in this example

Let's now consider an example using the INA226, which is digital current sense monitor that converts the shunt voltage into digital codes. Determining gain error for digital CSAs uses the same theory, but the math changes since the input voltage is not amplified, but rather converted into the digital realm.

For the calculations, the gain is simply the inverse of the shunt voltage least significant bit. Since gain error is same over the entire range, we can multiply the ideal shunt voltage by the gain and the gain error factor to determine the maximum and minimum worst case codes.

Example 2 – worst-case error analysis



As we can see, the error response for the digital device is the same as the analog. Absolute error on the left increases linearly, relative gain error is constant, and total relative error, which includes offset, has an inverse relationship where the curve approaches gain error at higher shunt voltages.

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).

Gain Error

TI Precision Labs – Current Sense Amplifiers

Quiz

Gain Error – quiz

1. Select all of the following that are true:
 - a) Total device gain error consists of gain error for a specified temperature range, gain error drift, and linearity.
 - b) Relative gain error is directly proportional to the input sense voltage.
 - c) Gain error is the dominant error source at high sense voltages.
 - d) Gain error is only valid in the linear output region.
 - e) If a CSA device's gain error is calibrated at room temperature, the only gain error left is gain error temperature drift.
 - f) Shunt resistor tolerance can be considered a gain error.

Gain Error – quiz

2. Using the following datasheet specifications for the INA302, what is the maximum total device gain error for the A2 variant if ambient temperature can vary from 0°C to 105°C?

- a) $\pm 0.215\%$
- b) $\pm 0.205\%$
- c) $\pm 0.19\%$
- d) $\pm 0.18\%$

6.5 Electrical Characteristics

at $T_A = 25^\circ\text{C}$, $V_{\text{SENSE}} = 0\text{ V}$, $V_{\text{REF}} = V_S / 2$, $V_S = 5\text{ V}$, $V_{\text{IN}+} = 12\text{ V}$, $V_{\text{LIMIT}1} = 3\text{ V}$, and $V_{\text{LIMIT}2} = 3\text{ V}$ (INA302) or 2 V (INA303) (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT						
G	Gain	A1 versions		20		V/V
		A2 versions		50		
		A3 versions		100		
	Gain error	$V_{\text{OUT}} = 0.5\text{ V to }V_S - 0.5\text{ V}$, A1 versions		$\pm 0.02\%$	$\pm 0.075\%$	
		$V_{\text{OUT}} = 0.5\text{ V to }V_S - 0.5\text{ V}$, A2 versions		$\pm 0.05\%$	$\pm 0.1\%$	
		$V_{\text{OUT}} = 0.5\text{ V to }V_S - 0.5\text{ V}$, A3 versions		$\pm 0.1\%$	$\pm 0.15\%$	
		$T_A = -40^\circ\text{C to }+125^\circ\text{C}$		3	10	
	Nonlinearity error	$V_{\text{OUT}} = 0.5\text{ V to }V_S - 0.5\text{ V}$		$\pm 0.01\%$		

Gain Error – quiz

3. A system has performed a two-point calibration at 80°C on the INA185A4 to negate offset and gain error. Using the specifications below, what is the maximum device gain error if the ambient temperature can vary from 60°C to 95°C? Assume the max gain error drift value is ± 8 ppm/°C.

6.5 Electrical Characteristics

at $T_A = 25^\circ\text{C}$, $V_{\text{SENSE}} = V_{\text{IN}+} - V_{\text{IN}-}$, $V_S = 5\text{ V}$, $V_{\text{REF}} = V_S / 2$, and $V_{\text{IN}+} = 12\text{ V}$ (unless otherwise noted)

PARAMETER		CONDITIONS		MIN	TYP	MAX	UNIT
E_G	Gain error	$V_{\text{OUT}} = 0.5\text{ V to } V_S - 0.5\text{ V}$, $T_A = -40^\circ\text{C to } +125^\circ\text{C}$	A1, A2, A3 devices		$\pm 0.05\%$	$\pm 0.2\%$	
			A4 device		$\pm 0.07\%$	$\pm 0.25\%$	
	Gain error drift	$T_A = -40^\circ\text{C to } +125^\circ\text{C}$			1.5	8	ppm/°C
	Nonlinearity error	$V_{\text{OUT}} = 0.5\text{ V to } V_S - 0.5\text{ V}$			$\pm 0.01\%$		

Gain Error- quiz

4. The INA253 is a current-sense amplifier with an integrated 2 mΩ shunt resistor so error specifications are slightly different compared to other CSAs. Given the specifications below, what are the worst-case (maximum and minimum) gain values in mV/A for the INA253A2 (200 mV/A typical) if temperature can vary from 0°C to 100°C?

7.5 Electrical Characteristics

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{ V}$, $I_{\text{SENSE}} = I_{\text{S+}} = 0\text{ A}$, $V_{\text{CM}} = 12\text{ V}$, and $V_{\text{REF1}} = V_{\text{REF2}} = V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT						
G	Gain	INA253A1		100		mV/A
		INA253A2		200		
		INA253A3		400		mV/A
	System gain error ⁽³⁾	$\text{GND} + 50\text{ mV} \leq V_{\text{OUT}} \leq V_S - 200\text{ mV}$, $T_A = 25^\circ\text{C}$		$\pm 0.05\%$	$\pm 0.4\%$	
		$T_A = -40^\circ\text{C to } +125^\circ\text{C}$			± 45	ppm/°C
	Nonlinearity error	$\text{GND} + 10\text{ mV} \leq V_{\text{OUT}} \leq V_S - 200\text{ mV}$		$\pm 0.01\%$		

Answers

Gain Error – quiz

1. Select all of the following that are true:

- a) Total device gain error consists of gain error for a specified temperature range, gain error drift, and linearity.
- b) Relative gain error is directly proportional to the input sense voltage.
- c) Gain error is the dominant error source at high sense voltages.
- d) Gain error is only valid in the linear output region.
- e) If a CSA device's gain error is calibrated at room temperature using a two-point calibration, the only gain error left is gain error temperature drift.
- f) Shunt resistor tolerance can be considered a gain error.

Gain Error – quiz

2. Using the following datasheet specifications for the INA302, what is the maximum total device gain error for the A2 version if ambient temperature can vary from 0°C to 105°C?

a) $\pm 0.215\%$

b) $\pm 0.205\%$

c) $\pm 0.19\%$

d) $\pm 0.18\%$

6.5 Electrical Characteristics

at $T_A = 25^\circ\text{C}$, $V_{\text{SENSE}} = 0\text{ V}$, $V_{\text{REF}} = V_S / 2$, $V_S = 5\text{ V}$, $V_{\text{IN}+} = 12\text{ V}$, $V_{\text{LIMIT}1} = 3\text{ V}$, and $V_{\text{LIMIT}2} = 3\text{ V}$ (INA302) or 2 V (INA303) (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
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	Gain error	$V_{\text{OUT}} = 0.5\text{ V to } V_S - 0.5\text{ V}$, A1 versions		$\pm 0.02\%$	$\pm 0.075\%$	
		$V_{\text{OUT}} = 0.5\text{ V to } V_S - 0.5\text{ V}$, A2 versions		$\pm 0.05\%$	$\pm 0.1\%$	
		$V_{\text{OUT}} = 0.5\text{ V to } V_S - 0.5\text{ V}$, A3 versions		$\pm 0.1\%$	$\pm 0.15\%$	
		$T_A = -40^\circ\text{C to } +125^\circ\text{C}$		3	10	
	Nonlinearity error	$V_{\text{OUT}} = 0.5\text{ V to } V_S - 0.5\text{ V}$		$\pm 0.01\%$		

Gain Error – quiz

2. Using the following datasheet specifications for the INA302, what is the maximum total device gain error for the A2 variant if ambient temperature can vary from 0°C to 105°C?
- a) ±0.215 %
 - b) ±0.205 %
 - c) ±0.19 %**
 - d) ±0.18 %

$$\text{Max total gain error} = E_{G_Total}$$

$$E_{G_Total} = E_{G_25C} + \frac{\Delta E_G}{\Delta^{\circ}C} * \Delta T_A + E_{Linearity}$$

$$E_{G_Total} = 0.1\% + 10 \frac{\text{ppm}}{^{\circ}C} * 10^{-4} * (105^{\circ}C - 25^{\circ}C) + 0.01\%$$

$$E_{G_Total} = 0.1\% + 0.08\% + 0.01\%$$

$$E_{G_Total} = 0.19\%$$

Gain Error – quiz

3. A system has performed a two-point calibration at 80°C on the INA185A4 to negate offset and gain error. Using the specifications below, what is the maximum device gain error if the ambient temperature can vary from 60°C to 95°C? Assume the max gain error drift value is ± 8 ppm/°C.

6.5 Electrical Characteristics

at $T_A = 25^\circ\text{C}$, $V_{\text{SENSE}} = V_{\text{IN}+} - V_{\text{IN}-}$, $V_S = 5\text{ V}$, $V_{\text{REF}} = V_S / 2$, and $V_{\text{IN}+} = 12\text{ V}$ (unless otherwise noted)

PARAMETER		CONDITIONS		MIN	TYP	MAX	UNIT
E_G	Gain error	$V_{\text{OUT}} = 0.5\text{ V to } V_S - 0.5\text{ V}$, $T_A = -40^\circ\text{C to } +125^\circ\text{C}$	A1, A2, A3 devices		$\pm 0.05\%$	$\pm 0.2\%$	
			A4 device		$\pm 0.07\%$	$\pm 0.25\%$	
	Gain error drift	$T_A = -40^\circ\text{C to } +125^\circ\text{C}$			1.5	8	ppm/°C
	Nonlinearity error	$V_{\text{OUT}} = 0.5\text{ V to } V_S - 0.5\text{ V}$			$\pm 0.01\%$		

Answer: Max gain error is $\pm 0.026\%$

Gain Error – quiz

3. A system has performed a two-point calibration at 80°C on the INA185A4 to negate offset and gain error. Using the specifications below, what is the maximum total device gain error if the ambient temperature can vary from 60°C to 95°C? Assume the max gain error drift value is ± 8 ppm/°C.

Gain error at the calibrated temperature (80°C) is now limited to just linearity ($\pm 0.01\%$). The maximum temperature change from 80°C is $|60^\circ\text{C} - 80^\circ\text{C}| = 20^\circ\text{C}$. So the maximum total gain error over the expected temperature range is calculated as:

$$\text{Max total gain error} = \frac{\Delta E_G}{\Delta^\circ\text{C}} * \Delta T_A + E_{\text{Linearity}}$$

$$\text{Max total gain error} = 8 \frac{\text{ppm}}{^\circ\text{C}} * 10^{-4} * |60^\circ\text{C} - 80^\circ\text{C}| + 0.01\%$$

$$\text{Max total gain error} = 0.016\% + 0.01\%$$

Answer: Max total gain error is $\pm 0.026\%$

Gain Error- quiz

4. The INA253 is a current-sense amplifier with an integrated 2 mΩ shunt resistor so error specifications are slightly different compared to other CSAs. Given the specifications below, what are the worst-case (maximum and minimum) gain values in mV/A for the INA253A2 (200mV/A typical) if temperature can vary from 0°C to 100°C?

7.5 Electrical Characteristics

at $T_A = 25\text{ }^\circ\text{C}$, $V_S = 5\text{ V}$, $I_{\text{SENSE}} = I_{\text{S+}} = 0\text{ A}$, $V_{\text{CM}} = 12\text{ V}$, and $V_{\text{REF1}} = V_{\text{REF2}} = V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT						
G	Gain	INA253A1		100		mV/A
		INA253A2		200		
		INA253A3		400		mV/A
	System gain error ⁽³⁾	GND + 50 mV ≤ $V_{\text{OUT}} \leq V_S - 200\text{ mV}$, $T_A = 25\text{ }^\circ\text{C}$		±0.05%	±0.4%	
		$T_A = -40\text{ }^\circ\text{C to } +125\text{ }^\circ\text{C}$			±45	ppm/°C
	Nonlinearity error	GND + 10 mV ≤ $V_{\text{OUT}} \leq V_S - 200\text{ mV}$		±0.01%		

Answer: Maximum gain is 201.495 mV/A and minimum gain is 198.505 mV/A

Gain Error- quiz

4. The INA253 is a current-sense amplifier with an integrated 2 mΩ shunt resistor so error specifications are slightly different compared to other CSAs. Given the specifications below, what are the worst-case (maximum and minimum) gain values in mV/A for the INA253A2 (200 mV/A typical) if temperature can vary from 0°C to 100°C?

$$\text{Max total gain error} = E_{G_Total} = E_{G_25C} + \frac{\Delta E_G}{\Delta^\circ C} * \Delta T_A + E_{Linearity}$$

$$E_{G_Total} = 0.4\% + 45 \frac{\text{ppm}}{^\circ C} * 10^{-4} * (100^\circ C - 25^\circ C) + 0.01\%$$

$$E_{G_Total} = 0.4\% + 0.3375\% + 0.01\%$$

$$E_{G_Total} = 0.7475\%$$

$$G_{MAX} = 200 \frac{mV}{A} * \left(1 + \frac{0.7475\%}{100} \right) = 201.495 \frac{mV}{A}$$

$$G_{MIN} = 200 \frac{mV}{A} * \left(1 - \frac{0.7475\%}{100} \right) = 198.505 \frac{mV}{A}$$

Answer: Maximum gain is 201.495 mV/A and minimum gain is 198.505 mV/A