Offset Error

TI Precision Labs – Current Sense Amplifiers

Presented by Kyle Stone

Prepared by Ian Williams and Jason Bridgmon

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 take a closer look at offset error, which is caused by an amplifier’s input offset voltage.

RSS total error equation

- The root-sum-square (RSS) total error is given by the following equation:

$$\varsigma_{RSS}(\%) \approx \sqrt{{e_{Vos}}^2 + {e_{CMRR}}^2 + {e_{PSRR}}^2 + {e_{Gain\_error}}^2 + {e_{Linearity}}^2 + {e_{Shunt\_tolerance}}^2 + {e_{Bias\_current}}^2 + {e_{Other}}^2}$$

- In the device data sheet:

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
CMRR	Common-mode rejection ratio, RTI[1]	V_{IN+} = 0 V to 26 V, V_{SENSE} = 10 mV, T_A = –40°C to +125°C	84	100		dB
V_{OS}	Offset voltage[2], RTI			±100	±500	µV
		V_{IN+} = 0 V		±25	±150	µV
dV_{OS}/dT	Offset drift, RTI	T_A = –40°C to +125°C		0.2	1	µV/°C
PSRR	Power-supply rejection ratio, RTI	V_S = 2.7 V to 5.5 V, V_{SENSE} = 10 mV		±8	±40	µV/V

In previous videos, we introduced the root-sum-of-squares, or RSS, total error equation for current sense amplifier circuits, as shown here. Note that some error terms may not be shown.

The next few topics will focus on the input-referred offset error sources:

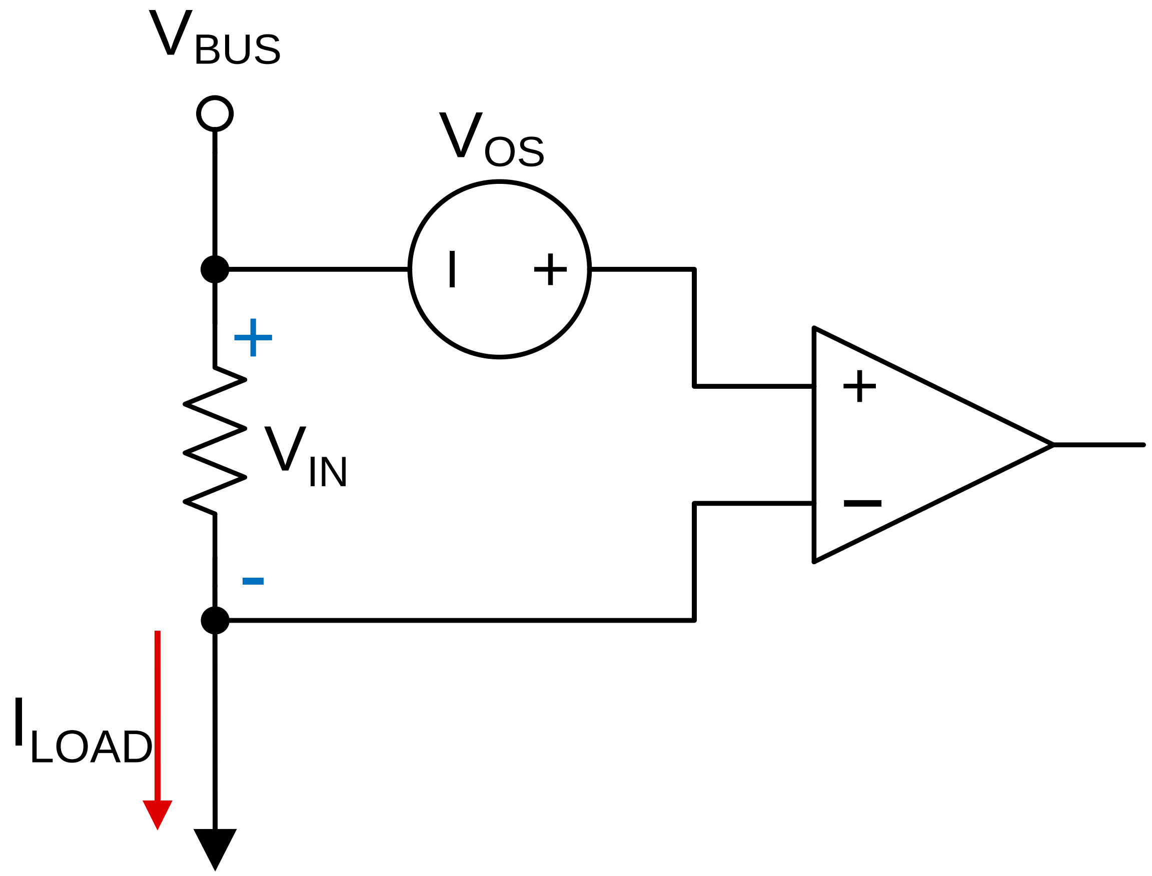
Input offset voltage, Vos, common-mode rejection ratio, CMRR, and power supply rejection ratio, PSRR. All three of these errors are given in the electrical characteristics table of a device datasheet, as shown here.

The rest of this video focuses on Vos, as well as Vos drift. Vos drift describes the change in Vos with ambient temperature.

Definition of input offset voltage – V_{OS}

Definition

The DC voltage that must be applied between the amplifier input terminals to force the DC output voltage to zero



Input offset voltage, or Vos, is defined as the DC voltage that must be applied between the amplifier input terminals to force the DC output voltage to zero.

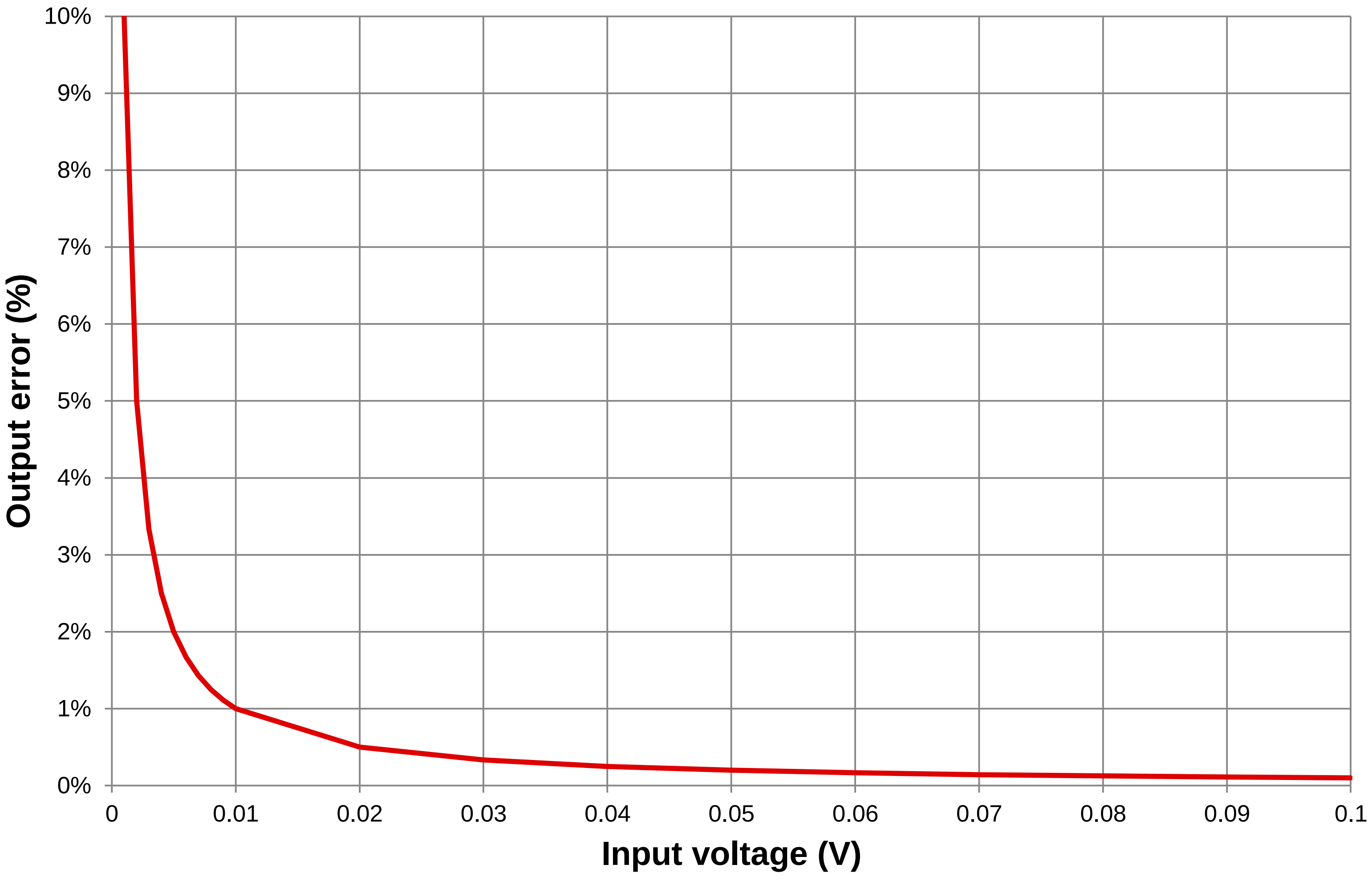
An amplifier's ideal Vos is zero volts. Process variations and device design constraints, however, cause non-zero values of Vos. Vos adds to Vin and has an impact on the accuracy of a current sense amplifier circuit, especially at low inputs as we will soon illustrate.

Offset error equation

Error equation

$$e_{Vos} = \frac{V_{OS\_max}}{V_{Shunt\_ideal}} \times 100\%$$

- Error is calculated with respect to the ***ideal*** shunt voltage
- Dominates error at low inputs as V_{Shunt_ideal} goes to zero



The equation to calculate offset error is shown here. It is simply the ratio of the maximum Vos to the ideal shunt voltage. Vshunt_ideal is the product of the load current and ideal shunt resistor value – ignoring the tolerance and temperature drift of the resistor itself, which will be discussed in later videos.

Input offset voltage is typically the largest factor affecting a solution’s accuracy at low inputs. This is because Vshunt_ideal becomes very small, to the point where Vos is very large by comparison. You can see an example of this in the error plot on the right. Minimizing this error is often the most important requirement for current sensing circuits.

Offset error example – INA195

Conditions

- V_{OS} (max) = **2 mV**
- V_{Shunt_ideal} = 5 A * 1 mΩ = 5 mV

PARAMETER		TEST CONDITIONS	TA = 25°C			UNIT
			MIN	TYP	MAX	
INPUT						
V_{OS}	Offset Voltage, RTI			±0.5	2	mV

Calculations

$$e_{V_{OS}} = \frac{V_{OS\_max}}{V_{Shunt\_ideal}} \times 100\%$$

→

$$e_{V_{OS}} = \frac{2\ mV}{5\ mV} \times 100\% = \mathbf{40\%}$$

How to minimize

- Increase the shunt voltage drop – increase R_{SHUNT}
- Decrease the offset voltage – select a different device

Let’s calculate the offset error in an example system with a minimum load current of five amps and ideal shunt resistance of one milliohms. We’ll pick the INA195 as our amplifier, which has a maximum Vos of two millivolts. The ideal shunt voltage is equal to our load current times our shunt resistor, which results in five millivolts.

Using our offset error equation from before, we calculate that the error is a whopping forty percent! This is not a very useful measurement. The first thing most engineers will ask is, how do we make it better and minimize the offset error? There are two possible ways to approach this.

First, you can increase the shunt voltage, which means increasing the shunt resistance.
Second, you can decrease the offset voltage, which requires selecting a different device.

Increasing the shunt resistance may or may not be feasible due to cost, board space, or power dissipation concerns. Let’s consider option two, selecting a different device with lower Vos.

Offset error example – INA190

Conditions

- V_{OS} (max) = **15 µV** = 0.015 mV
- V_{Shunt_ideal} = 5 A * 1 mΩ = 5 mV

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{OS}	Offset voltage, RTI[1]	V_S = 1.8 V, V_{SENSE} = 0 mV		–3	±15	µV
dV_{OS}/dT	Offset drift, RTI	V_{SENSE} = 0 mV, T_A = –40°C to +125°C		10	80	nV/°C

Calculations

$$e_{V_{OS}} = \frac{V_{OS\_max}}{V_{Shunt\_ideal}} \times 100\% \quad \rightarrow \quad e_{V_{OS}} = \frac{15\ \mu V}{5\ mV} \times 100\% = \mathbf{0.3\%}$$

Note: offset error should be calculated at ***minimum*** input current

We’ll now consider the INA190, which has a max Vos of only fifteen microvolts, or 0.015 millivolts. The application conditions for load current and shunt resistance are the same as before.

Re-calculating offset error gives a new result of only 0.3 percent! As you can see, the INA190 is a much better choice for this application. It’s important to note that offset error should be calculated at minimum input current, since that is the worst-case condition when Vshunt_ideal is the smallest.

Temperature effects

- V_{OS} typically specified at T_A = 25°C
- V_{OS} changes with temperature according to the offset drift specification

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{OS}	Offset voltage, RTI[1]	V_S = 1.8 V, V_{SENSE} = 0 mV		–3	±15	μV
dV_{OS}/dT	Offset drift, RTI	V_{SENSE} = 0 mV, T_A = –40°C to +125°C		10	80	nV/°C

Example – INA190 at T_A = 125°C

$$V_{OS} = V_{OS\_max} + V_{OS\_drift\_max} = V_{OS\_max} + \frac{dV_{OS}}{dT} * (T_A - 25°C)$$

$$V_{OS} = 15\mu V + \frac{80nV}{°C} * (125°C - 25C) = 15\mu V + 8\mu V = 23\mu V$$

$$e_{Vos} = \mathbf{0.46\%}$$

Finally, let’s consider the effects that temperature has on input offset voltage and offset error. In most amplifier data sheets, Vos is specified at room temperature, or twenty-five degrees C. If we want to analyze Vos over temperature, we must consider Vos drift as well. Drift is shown in the electrical characteristics table as dVos/dT, or a change in Vos proportional to a change in temperature.

Let’s calculate the total Vos of the INA190 at an ambient temperature of one hundred twenty-five degrees C, using the equations shown here. We first add the room temperature Vos as before, but now add an extra term which multiplies the drift value by the change in temperature relative to twenty-five degrees C. Plugging in our one-hundred degrees C difference and eighty nanovolts per degrees C drift, we get an additional offset of eight microvolts, and a total Vos of twenty-three microvolts.

Calculating offset error as we did before gives a new result of 0.46 percent. Compared to our previous result at room temperature of 0.3 percent, this is a small increase. That is because the INA190 is designed with a zero-drift architecture that preserves its excellent offset performance over temperature. Other devices may have different results.

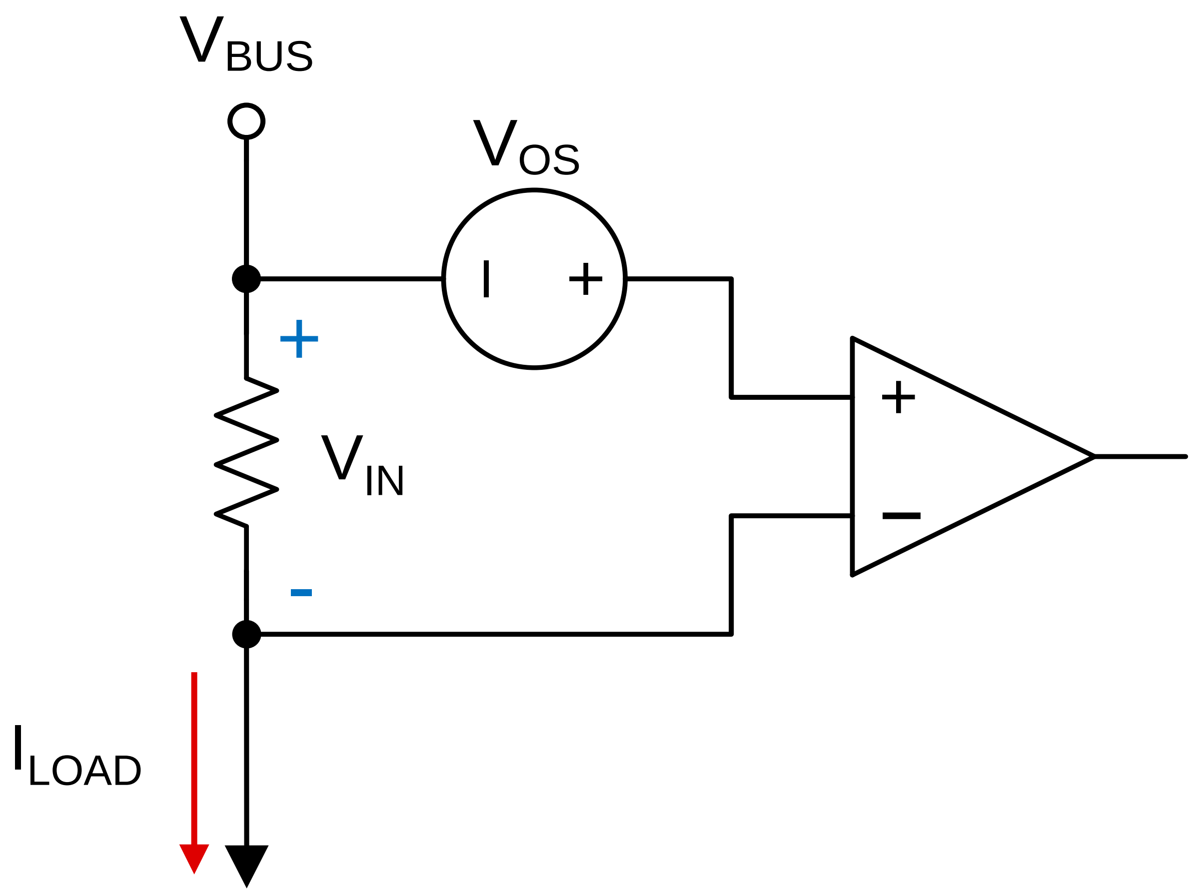
Offset error summary

- Offset error equation:

$$e_{Vos} = \frac{V_{OS\_max}}{V_{Shunt\_ideal}} \times 100\%$$

- To minimize offset error:
  - Increase V_{SHUNT} – increase R_{SHUNT}
  - Decrease V_{OS} – select a different device

- Offset error usually dominates total RSS error at low input signals
- For T_A other than 25°C, offset drift (dV_{OS}/dT) must be considered



Let’s take a minute to summarize what we learned in this video.

1. Input offset voltage, or Vos, is defined as the DC voltage that must be applied between the amplifier input terminals to force the DC output voltage to zero.

2. To calculate offset error, take the ratio of Vos_max to the ideal shunt voltage.

3. To minimize offset error, you can either increase Vshunt by increasing Rshunt, or decrease Vos by selecting a different device.

4. Offset error usually dominates total RSS error at low input signals, since Vos can become large compared to low input voltages.

5. For ambient temperatures other than twenty five degrees C, offset drift must be considered.

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.

Offset Error

TI Precision Labs – Current Sense Amplifiers

Quiz

Offset error – quiz

1. Input offset voltage (Vos) drift describes the ______________________.
   a) Change in Vos with change in power supply voltage
   b) Change in Vos with change in input common-mode voltage
   c) Change in Vos with change in ambient temperature
   d) Change in Vos with change with output current

2. Vos is defined as:
   a) The DC voltage needed between the amp inputs to force the output to 0 V
   b) The DC voltage needed between the amp inputs to force the output to Vs
   c) An error voltage that only becomes noticeable in transient measurements
   d) The difference in input bias current from the IN+ pin to the IN- pin

Offset error – quiz

3. What Vos is needed relative to a 10 mV shunt voltage to result in 25% error?
   a) 25 µV
   b) 250 µV
   c) 2.5 mV
   d) 25 mV

4. Which of the following is **not** a way to minimize offset error?
   a) Design the system with a higher minimum input current
   b) Decrease Vos by selecting a different device
   c) Increase the shunt voltage drop by increasing R_{SHUNT}
   d) Increase the input filter resistance

Offset error – quiz

5. Offset error should be calculated at minimum input current.
   a) True
   b) False

6. Calculate the **additional** offset voltage due to drift at T_A = 80°C relative to T_A = 25°C, if drift = 5 µV°/C.
   a) 0 µV
   b) 125 µC
   c) 275 µV
   d) 400 µV

Answers

Offset error – quiz

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Offset error – quiz

5. Offset error should be calculated at minimum input current.
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