Output Swing

TI Precision Labs – Current Sense Amplifiers

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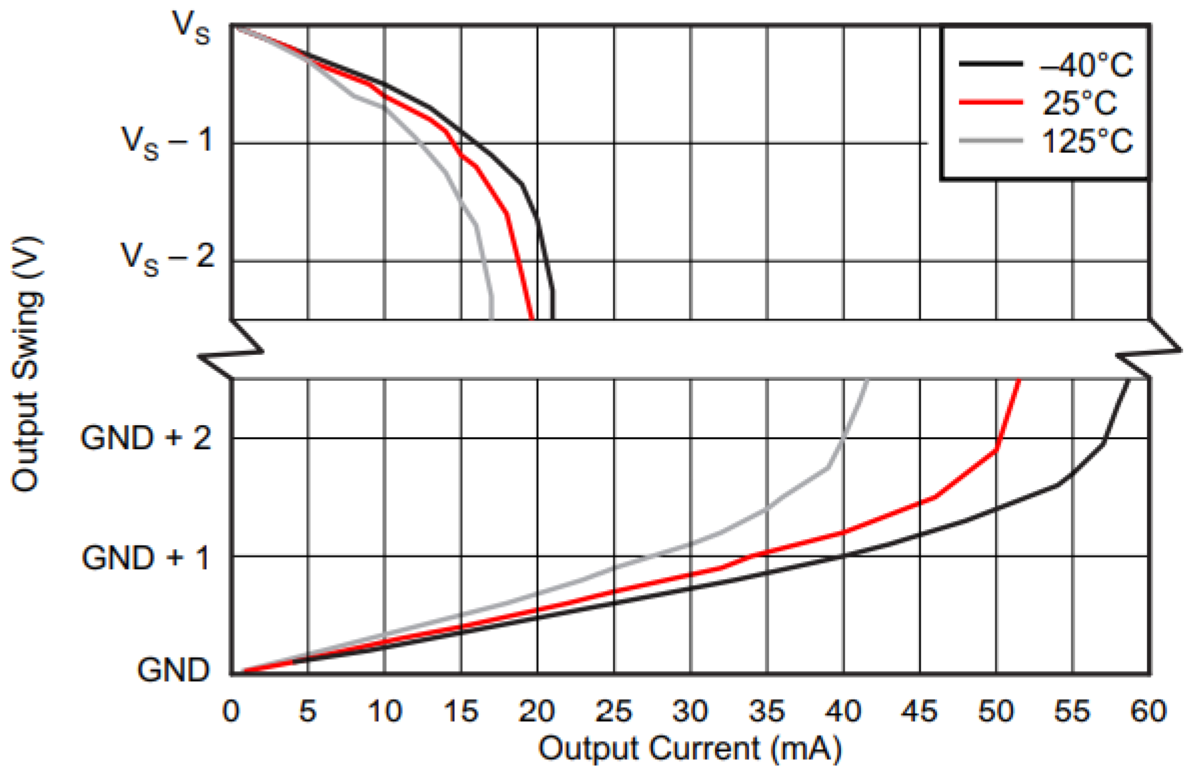
Hello, and welcome to the TI precision labs series on current sense amplifiers. My name is Kyle Stone, and I’m a Product Marketing engineer in the Current & Position Sensing product line. In this video, we will take a closer look at output swing limitations.

Output swing datasheet specifications

- In **Electrical Characteristics** table:

VOLTAGE OUTPUT(3)					
V_{SP}	Swing to V_S power-supply rail(4)	R_L = 10 kΩ to GND, T_A = –40°C to +125°C	$(V_S) – 0.02$	$(V_S) – 0.03$	V
V_{SN}	Swing to GND(4)	R_L = 10 kΩ to GND, T_A = –40°C to +125°C	(V_{GND}) + 0.0005	(V_{GND}) + 0.005	V

- In **Typical Characteristics** curves:



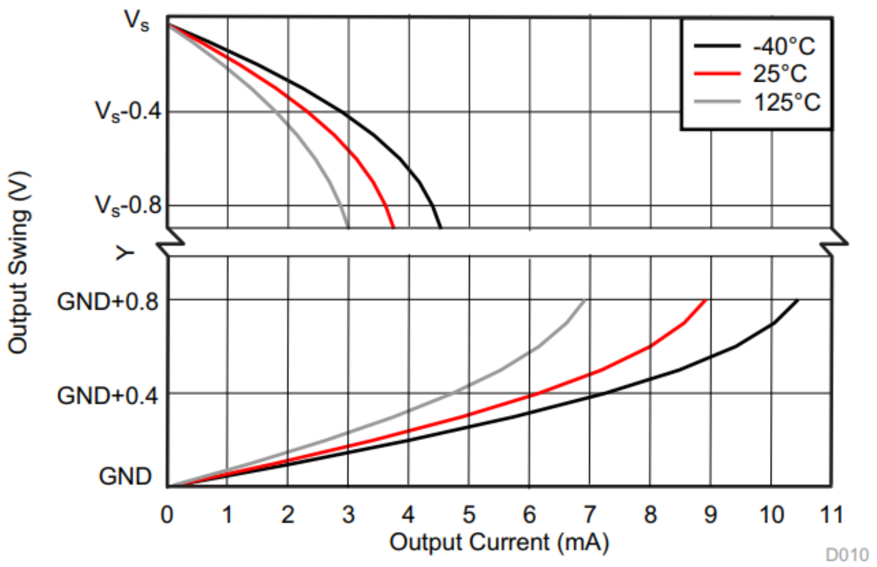
Output swing is a set of common electrical specifications found in the datasheet of a typical Current Sense Amplifier, or CSA for short.

There are usually two separate parameters listed to describe a device’s swing to rails characteristics, the first is Swing to power supply or Swing to VS, and the second is Swing to ground. These specifications are found in the Electrical Characteristics table. Often Output Swing versus Output Current is provided in the form of a set of curves in the Typical Characteristics section of the datasheet. More information can be derived from this graph. Such as the current capability of the output stage and its behavior over temperature.

Output swing datasheet specifications

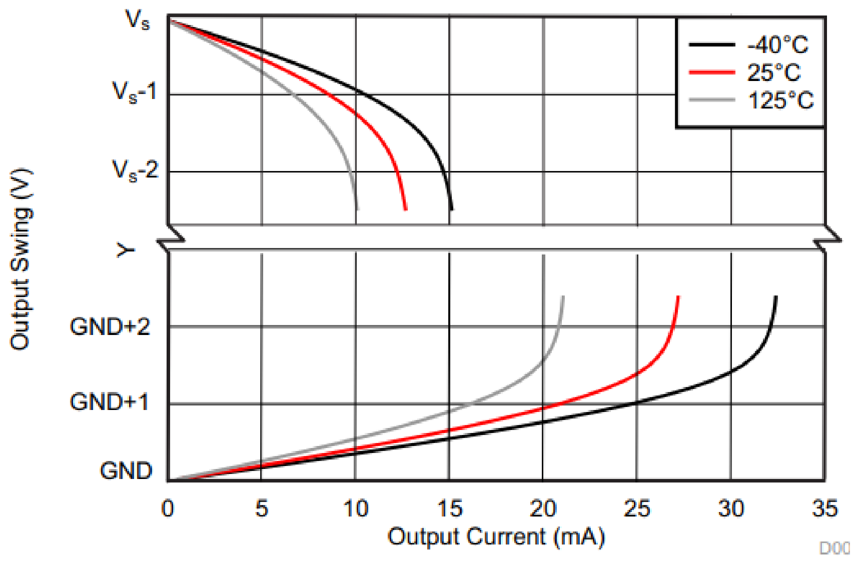
- INA190 datasheet:

VOLTAGE OUTPUT						
V_{SP}	Swing to V_S power-supply rail	V_S = 1.8 V, R_L = 10 kΩ to GND, T_A = –40°C to +125°C		(V_S) – 20	(V_S) – 40	mV
V_{SN}	Swing to GND	V_S = 1.8 V, R_L = 10 kΩ to GND, T_A = –40°C to +125°C, V_{SENSE} = –10 mV, V_{REF} = 0 V		(V_{GND}) + 0.05	(V_{GND}) + 1	mV
V_{ZL}	Zero current output voltage	V_S = 1.8 V, R_L = 10 kΩ to GND, T_A = –40°C to +125°C, V_{SENSE} = 0 mV, V_{REF} = 0 V	A1, A2, A3 devices	(V_{GND}) + 1	(V_{GND}) + 3	mV
			A4 devices	(V_{GND}) + 2	(V_{GND}) + 4	mV
			A5 devices	(V_{GND}) + 3	(V_{GND}) + 9	mV



V_S = 1.8 V

Figure 12. Output Voltage Swing vs Output Current



V_S = 5.0 V

Figure 13. Output Voltage Swing vs Output Current

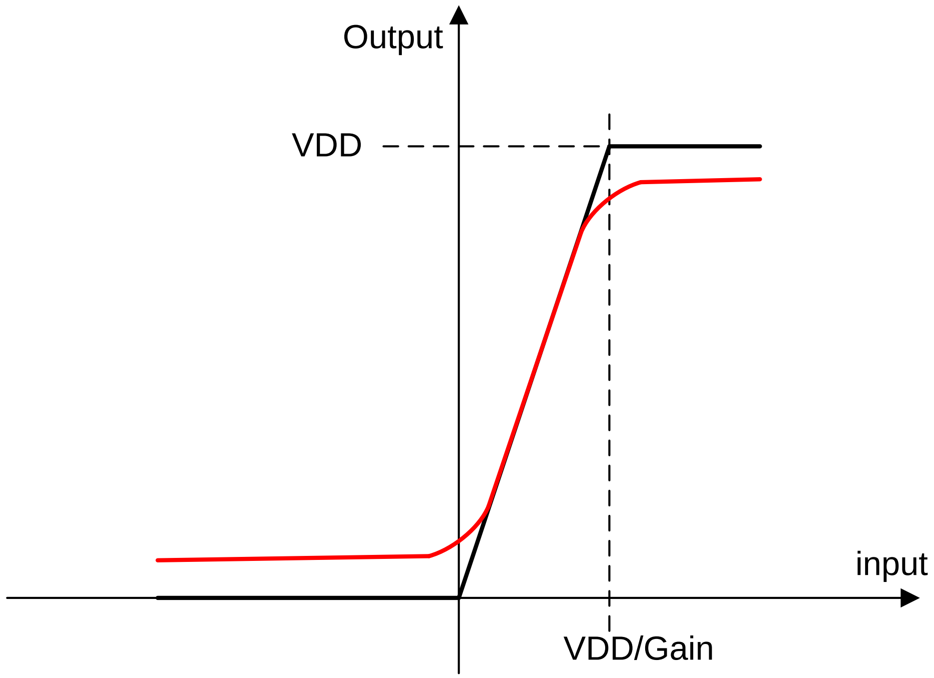
In addition to the common output swing parameters shown in the previous slide, the INA190 data sheet also provides a parameter called “Zero Current Output Voltage” in its spec table. This parameter is identical to Swing to Ground, except that the input differential over drive is set to 0mV, in other words there is no input over drive.

The INA190 datasheet also provides two plots of “Output Swing versus Output Current”. These are for two different supply voltages respectively. Sometimes all these curves can be combined into a single plot, if it is practical to do so. These are some of the different formats in presenting a device’s output swing specification.

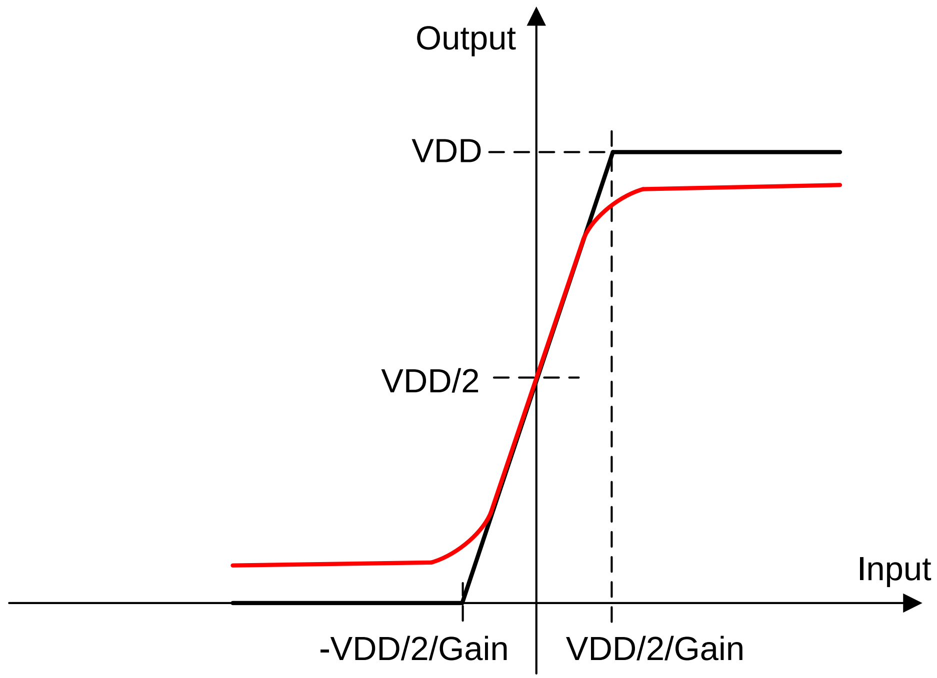
Output swing definition

Definition:

Output swing defines how close the current shunt amplifier output can be driven to either of power supply and ground under specified operating conditions.



Typical Unidirectional CSA Input/output relationship



Typical Bidirectional CSA Input/output relationship (REF=VDD/2)

Output swing defines how close the current sense amplifier output can be driven to either of power supply and ground under specified operating conditions.

This relationship is easily demonstrated with an input/output curve. Such relationship is shown for a unidirectional CSA and a bidirectional CSA.

Ideally, the CSA output should only be limited by ground and power supply. In between these extremes, the output should vary linearly with input. In other words, the entire range of Ground to VS should be usable, and linear. The black line shows this desired behavior.

An actual CSA output typically has an output that is slightly below Vs and slightly above Ground. In between is a linear section with curved ends. As the red line shows. It is exaggerated in order to show the swing limits.

How to use the output swing spec

A necessary condition

Determine if the output high and low levels are sufficient under maximum and minimum input conditions for a given circuit configuration.

- Apply below equations to validate input/output relationship:

$$(V_{in\_min} - V_{os}) \times Gain > Swing\ to\ GND$$

$$(V_{in\_max} + V_{os}) \times Gain < Swing\ to\ V_s$$

- Output swing /= linear output range, refer to other specs:

E_G	Gain error	V_{OUT} = 0.1 V to V_S – 0.1 V	A1 devices	–0.04%	±0.2%	
			A2, A3, A4 devices	–0.06%	±0.3%	
			A5 devices	–0.08%	±0.4%	

In order for the CSA output to be able to support a certain input range, the follow set of equations, a necessary condition, must be true, one: (Vin_min – Vos) *Gain > Swing to GND and two: (Vin_max + Vos) *Gain < Swing to VS. The Vos terms in these equations can be omitted if they are much smaller compared to the input voltage terms.

The datasheet may not say it explicitly, but we must always make sure that the output is within the range of swing. Otherwise the calculation and design may not be valid. More on this later with an example.

It should also be noted that the Swing to VS and Swing to GND are normally obtained with some input over drive. Therefore the range of swing includes both linear output region and nonlinear region. It is a good idea to refer to other parameters for linear output range. For example, in this datasheet the gain error spec tells us that the output is guaranteed to be linear in the range of 100mV above ground and 100mV below Vs.

Output swing example – INA282

Conditions

- V_S = 5 V; Gain = 50
- V_{in_min} = 0.5 mV; V_{in_max} = 95 mV
- Swing to Vs = 4.6 V; Swing to GND = 40 mV

VOLTAGE OUTPUT[6]				
Swing to V+ power-supply rail	V+ = 5 V, R_{LOAD} = 10 kΩ to GND, T_A = –40°C to +125°C	(V+) – 0.17	(V+) – 0.4	V
Swing to GND	R_{LOAD} = 10 kΩ to GND, T_A = –40°C to +125°C	GND + 0.015	GND + 0.04	V

Calculations

$$\begin{cases} (V_{in\_min} - V_{os}) \times Gain > Swing\ to\ GND \\ (V_{in\_max} + V_{os}) \times Gain < Swing\ to\ V_s \end{cases} \rightarrow \begin{cases} V_{out\_min} = (0.5 - 0.070) \times 50 = 21.5mV < 40mV \\ V_{out\_max} = (95 + 0.070) \times 50 = 4.753V > 4.6V \end{cases}$$

How to mitigate

- Decrease the measured shunt voltage range
- Improve the swing range – choose a better device

Let's look at an example how to quickly select the right current sense amplifier by applying the Swing to rails as a criterion.
In this example, we have VS=5V, Gain=50. the min and max input voltages are 0.5mV and 95mV respectively. We want to see if INA282 can work from the perspective of output swing. From the datasheet, we calculate the swing range to be 40mV to 4.6V.

Using the min and max output equations from previous slide, we get the required lowest output voltage level is below the swing to ground spec, and the required highest output voltage level is above the swing to Vs spec. Therefore in this example, both swing specs will be violated. We can draw the conclusion that the INA282 will not satisfy the swing requirement of this application.

How do we make it work? There are two possible ways to approach this.

First, you can adjust the requirement and measurement range.
Second, you can select a different device with better swing to rails spec.

Output swing example – INA190A2

Conditions

- V_S = 5 V; Gain = 50
- Swing to Vs = 4.96 V; Swing to GND = 1 mV
- V_{in_min} = 0.5 mV; V_{in_max} = 95 mV.

VOLTAGE OUTPUT					
V_{SP}	Swing to V_S power-supply rail	V_S = 1.8 V, R_L = 10 kΩ to GND, T_A = –40°C to +125°C	$(V_S) - 20$	$(V_S) - 40$	mV
V_{SN}	Swing to GND	V_S = 1.8 V, R_L = 10 kΩ to GND, T_A = –40°C to +125°C, V_{SENSE} = –10 mV, V_{REF} = 0 V	$(V_{GND}) + 0.05$	$(V_{GND}) + 1$	mV

Calculations

$$\begin{cases} (V_{in\_min} - V_{os}) \times Gain > Swing\ to\ GND \\ (V_{in\_max} + V_{os}) \times Gain < Swing\ to\ V_s \end{cases}$$

→

$$\begin{cases} V_{out\_min} = (0.5 - 0.015) \times 50 = 24.25mV > 1\ mV \\ V_{out\_max} = (95 + 0.015) \times 50 = 4.751V < 4.96V \end{cases}$$

Note:

- Wider swing spec accommodates wider input range

Lets take the same example we looked at previously, but substitute with a device that has improved Swing to rails spec, the INA190. Everything being equal, the only difference is swing to rails spec.

As you can see in this case both swing test equations are true with sufficient head room.

The take away from this example is that in general, a device with wider output swing can accommodate wider input voltage range.

Output swing example – INA303A2 R_{LIMIT} calculation

Condition

- V_S = 5 V; Gain = 50
- REF = 0 V; Shunt = 15 mΩ
- $I_{Trip} = 8\ A; I_{LIMIT} = 80\ uA$

7.3.3.1.1 Resistor-Controlled Current Limit

The typical approach to set the limit threshold voltage is to connect resistors from the two LIMITx pins to ground. The voltage developed across the R_{LIMIT1}, R_{LIMIT2} resistors represents the desired fault current value at which the corresponding ALERTx pin becomes active. The values for the R_{LIMIT1}, R_{LIMIT2} resistors are calculated using Equation 3:

$$R_{LIMIT} = \frac{(I_{TRIP} \times R_{SENSE} \times GAIN) + V_{REF}}{I_{LIMIT}} \quad (3)$$

where

- I_{TRIP} is the desired out-of-range current threshold.
- R_{SENSE} is the current-sensing resistor.
- GAIN is the gain option of the device selected.
- V_{REF} is the voltage applied to the REF pin.
- I_{LIMIT} is the limit threshold output current for the selected comparator, typically 80 µA.

Example

$$R_{LIMIT} = \frac{(I_{Trip} \times R_{SENSE} \times GAIN) + V_{REF}}{I_{LIMIT}} \rightarrow R_{LIMIT} = \frac{(8A \times 15m\Omega \times 50) + 0}{80uA} = 75KOhm$$

Output check:

$$V_{out} = 8A \times 15mOhm \times 50 = \mathbf{6V > 5V}!$$

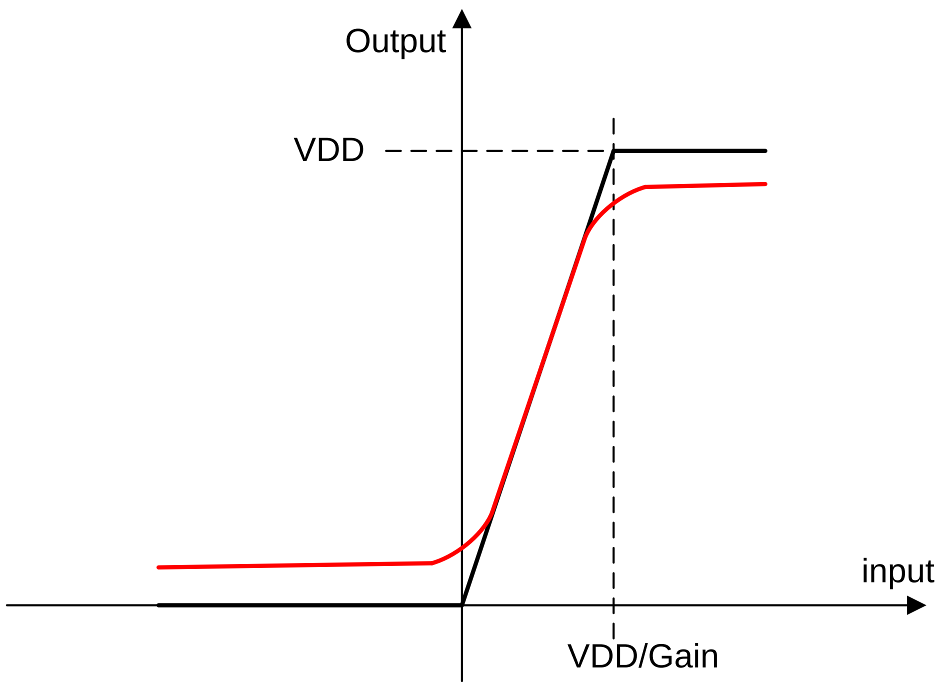
Even if the datasheet doesn't say it explicitly, always check the output.

We next look at an Over Current Protection design with INA303. In this example we wish to set the limit resistor for a given current threshold. In the INA303 datasheet, the equation is provided and the calculation is straightforward. Substituting the numbers into the equation, we see that the resulting limit resistor value is 75KOhm.

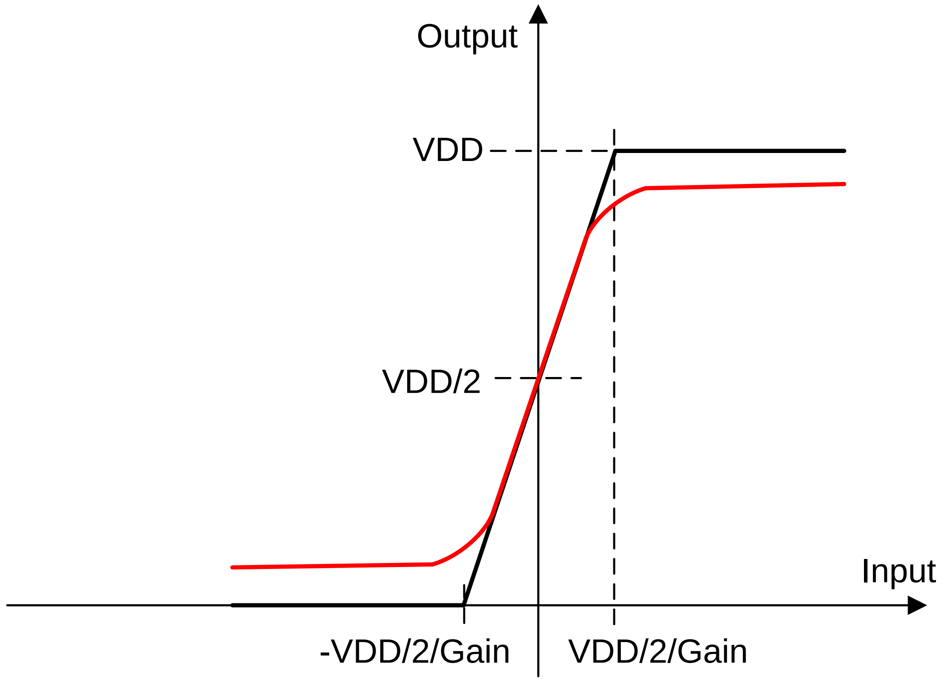
However if this design is implemented, it will not work. Because the output at the desired trip level is beyond the power supply.

The point to note is that we must check to make sure output is within swing spec at all times, and remember this is a necessary condition in order for the circuit to function correctly.

Output swing summary



Typical Unidirectional CSA Input/output relationship



Typical Bidirectional CSA Input/output relationship (REF=VDD/2)

- Output must be within swing to rails spec at all times.
- Swing range /= linear output range
  - Reference to other electrical parameters.
  - Wider swing range generally means wider linear range.

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

1. Swing to rails defines how close the current sense amplifier output can be driven to either of power supply and ground under specified operating conditions.

2. Device output must be within swing to rails spec at all times. It is a necessary condition in order for the circuit to function correctly.

3. Even though swing range does not equal to linear output range, wider swing range generally means wider linear range

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

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Output Swing

TI Precision Labs – Current Sense Amplifiers

Quiz

Output Swing – quiz

1. Output Swing defines how close the current sense amplifier output can be driven to either of power supply and ground under specified operating conditions.
   a) True
   b) False

2. In order to maximize signal dynamic range, I should design my circuit such that the full Output Swing range is utilized.
   a) True
   b) False

Output Swing – quiz

3. Which of the following statement is correct regarding Output Swing? (select all that apply)
   a) Swing range is dependent on power supply.
   b) Swing is not affected by the output current.
   c) Swing is a function of temperature.
   d) It is necessary to make sure output fits into the swing range under any use condition.

4. In selecting a device for a certain application, which of the following statement best describes the requirement imposed by Output Swing spec?
   a) The minimum output is higher than swing to GND
   b) The maximum output is lower than swing to Vs
   c) We don't need to consider the Swing spec because it doesn't equal to the linear output range anyway.
   d) Both a and b

Answers

Output Swing – quiz

1. Output Swing defines how close the current sense amplifier output can be driven to either of power supply and ground under specified operating conditions.
   a) True
   b) False

2. In order to maximize signal dynamic range, I should design my circuit such that the full Output Swing range is utilized.
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Output Swing – quiz

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   d) Both a and b