

Current Sense Amplifier Design Considerations

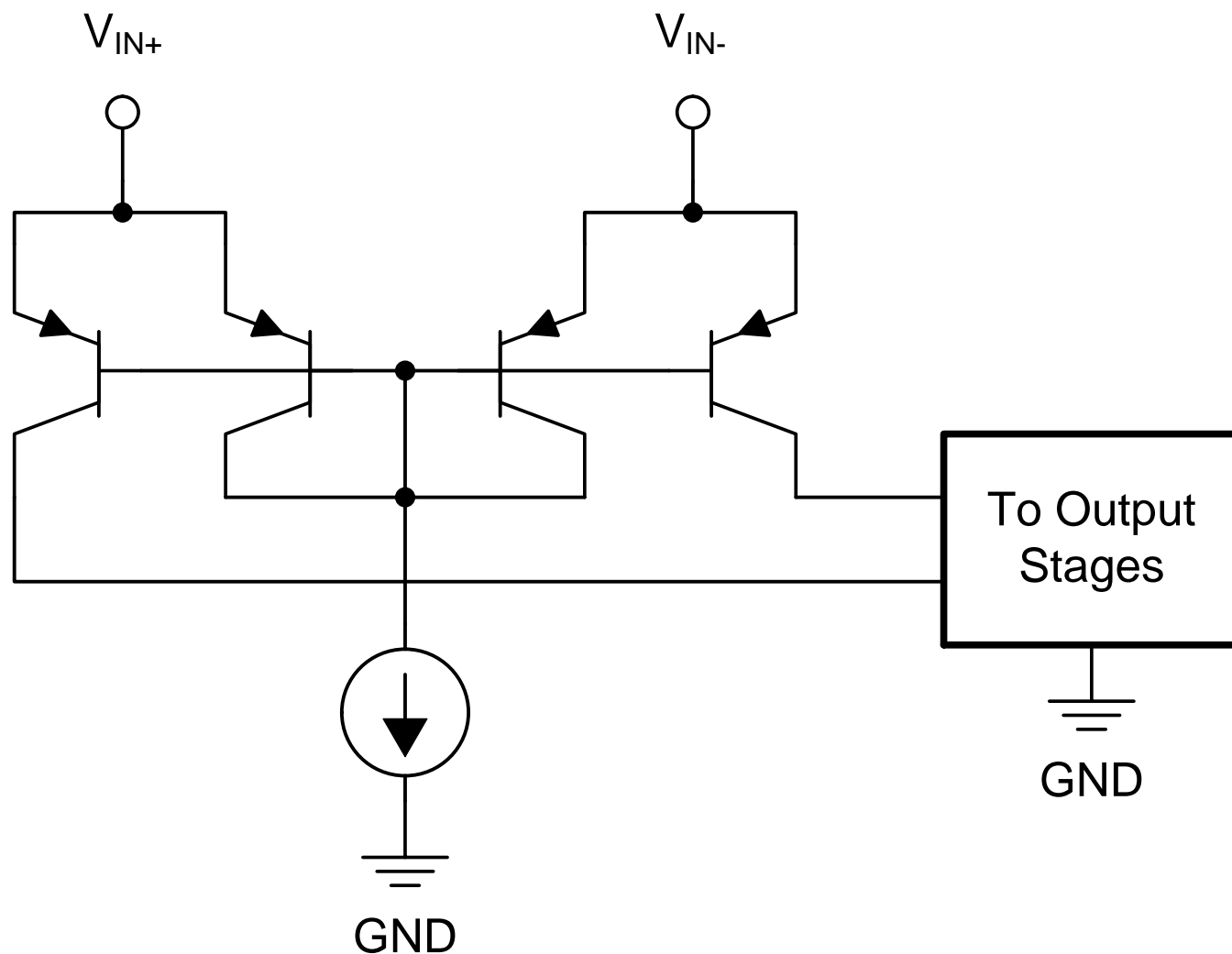
TI Precision Labs – Current Sense Amplifiers

Presented by Chukwudalu Udegboe

Prepared by Ian Williams and Chukwudalu Udegboe

Hello and welcome to the TI precision labs series on current sense amplifiers. My name is Chuk Udegbugue, and I'm a product marketing engineer in the Current & Position Sensing product line. In this video, we will discuss the most common design considerations for current sensing, including high-side vs. low-side, input common-mode voltage, measurement current range, bi-directional vs. uni-directional current flow, and output type.

Current sense amp design considerations



Application questions

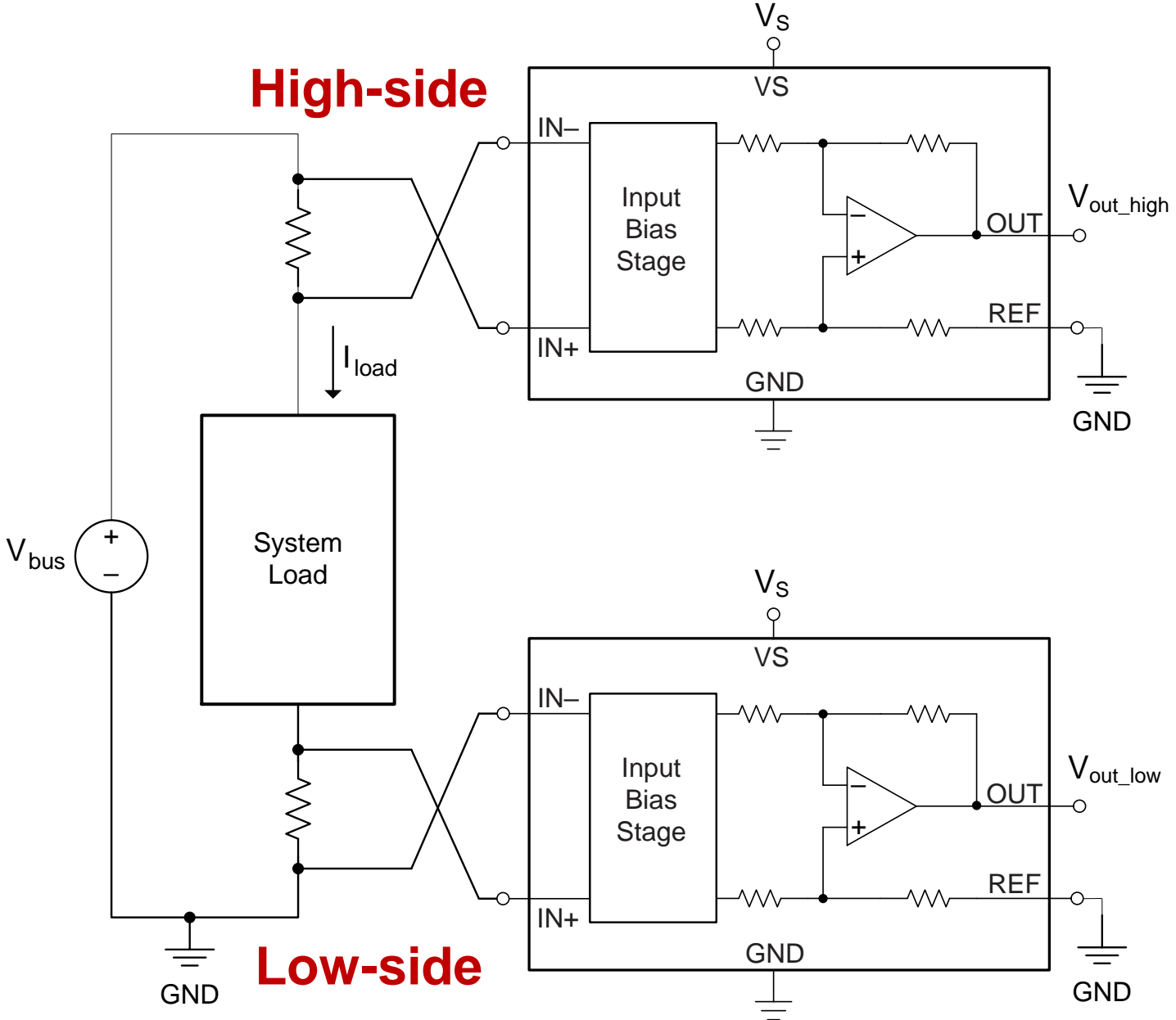
- Will the measurement be on the high-side or low-side?
- What is the common mode voltage to be measured?
- What current range is to be measured?
- Is the current bi-directional or uni-directional?
- How will the current value be used?

Unique floating input stage enables $V_{CM} > V_S$

Let's start with a quick recap on what makes a current sense amplifier special: First and most important is their unique, floating input stage which allows for common mode voltages much greater than the supply rail. Second is the integrated precision gain network that maximizes accuracy.

On the right is a list of questions you should ask before starting your design. The following slides will look at each question.

High-side or low-side?



	High-side	Low-side
Strengths	<ul style="list-style-type: none"> • Can detect load shorts to ground • Monitors current directly from source 	<ul style="list-style-type: none"> • $V_{CM} \approx 0V$ • Simple • Inexpensive
Challenges	<ul style="list-style-type: none"> • $V_{CM} \approx V_{BUS}$ 	<ul style="list-style-type: none"> • Can't detect load shorts to ground • System GND = $I_{LOAD} * R_{SHUNT}$

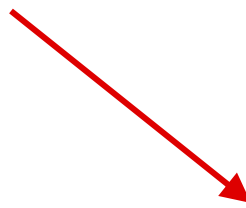
The concept of low-side or high-side sensing was introduced previously.

A high-side implementation has the shunt resistor placed between the supply voltage and the load, resulting in the common mode voltage being essentially equal to the bus voltage – in many applications, this can be well above the supply rail of the amplifier. High-side sensing allows for the system to not have any ground disturbance and to identify ground shorts.

A low-side implementation has the shunt resistor placed between the load and system ground – this is the most common method to monitor current since the common mode voltage is essentially 0V. However, this also disturbs the ground seen by the load as well as preventing the detection of load shorts to ground.

What is the common mode voltage?

- For high-side implementations, the bus voltage being monitored is essentially equal to the common mode voltage
- For low-side implementations, this is equal to 0V
 - The current sense amplifier chosen must have a common mode voltage range that includes 0V to be used for low-side applications:



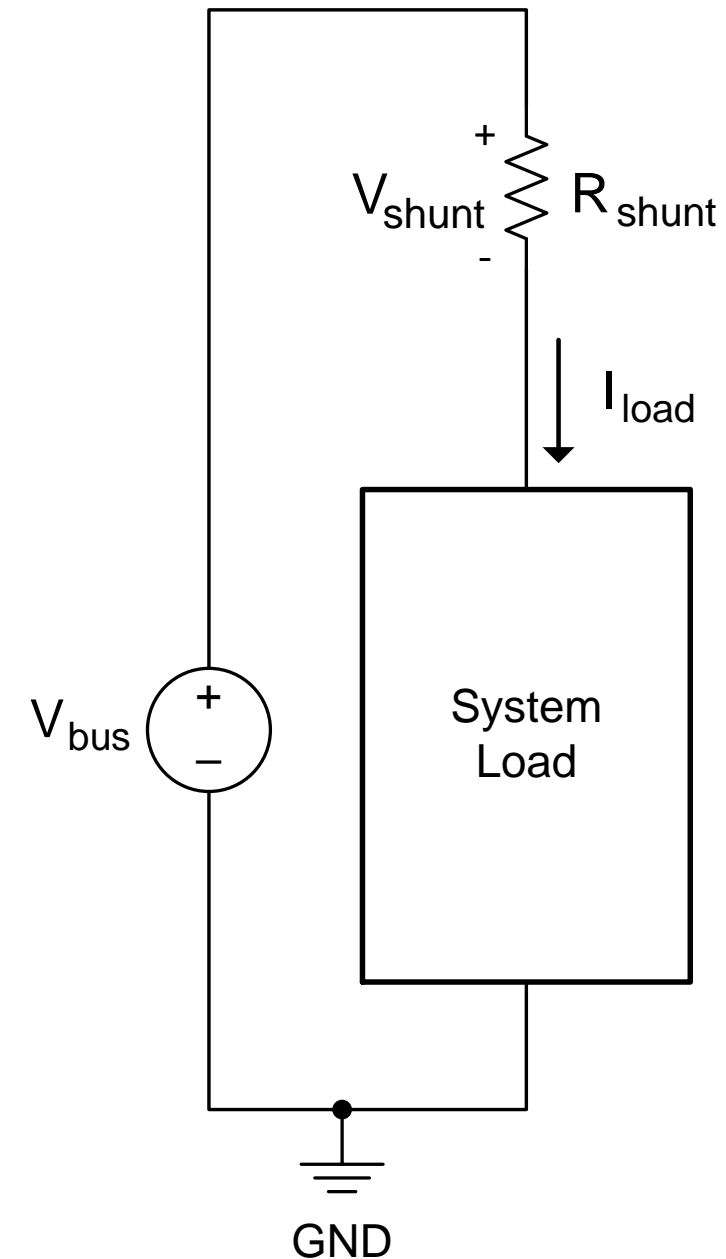
PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range	Version A $T_A = -40^{\circ}\text{C}$ to $+125^{\circ}\text{C}$	-0.3		26	V
		Versions B and C $T_A = -40^{\circ}\text{C}$ to $+125^{\circ}\text{C}$	-0.1		26	

Next let's re-visit the input common mode voltage range. If you are measuring on the high-side, the common-mode voltage is typically the bus voltage being monitored. You need to choose a current sense amplifier that includes this high voltage – plus any needed margin – within its common-mode voltage range.

For low-side measurements, as stated previously, the common mode voltage is essentially 0 Volts, so you need to choose a device that includes 0 in its common mode range. The specs table shown here illustrates a device with a common-mode voltage that can go several hundred millivolts below ground.

What is the current range?

- Load current range dictates three key specs:
 - R_{SHUNT} value
 - System gain
 - Minimum differential voltage
- **Maximum** load current sets the R_{SHUNT} value
 - V_{SHUNT} must not saturate amplifier input
 - R_{SHUNT} selection is discussed in later videos
- **Minimum** load current and R_{SHUNT} determine the minimum differential input voltage of the amplifier
 - V_{SHUNT} should be $\gg V_{OS}$ for high accuracy
 - V_{OS} error is discussed in later videos



While the current range itself does not derive any amplifier specifications, from it you can derive several key application constraints:

The necessary Rshunt value

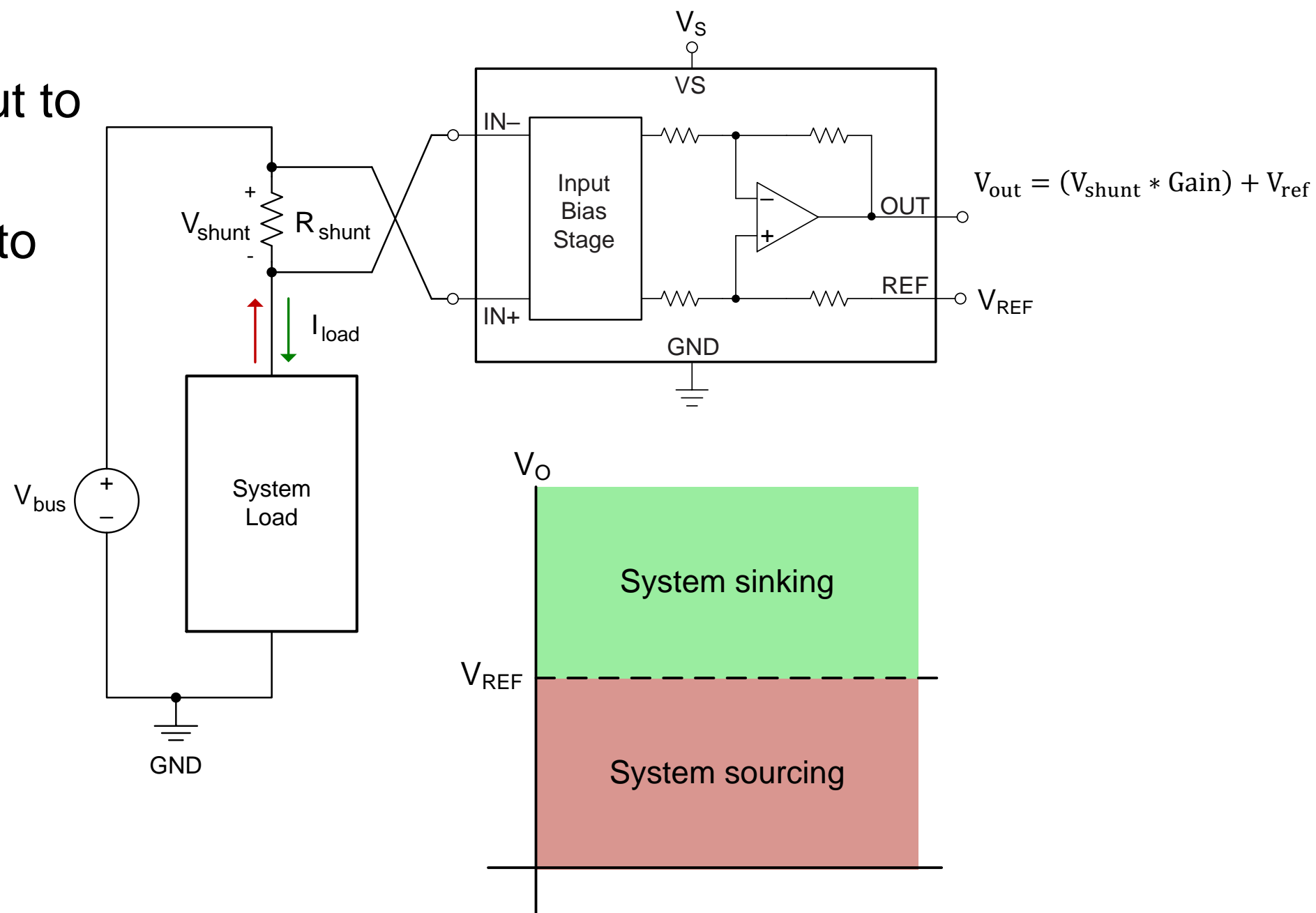
The required gain of the current sense amplifier stage, and

The minimum differential voltage requirements

The implications of these constraints, including Rshunt selection and the effects of V_{os} on system accuracy, will be discussed in later videos.

Bi- directional or uni-directional current flow?

- Requires an additional REF input to determine current flow direction
- V_{REF} centers the output voltage to some non-zero level
 - $V_{OUT} > V_{REF} \rightarrow$ the system is sinking current
 - $V_{OUT} < V_{REF} \rightarrow$ the system is sourcing current

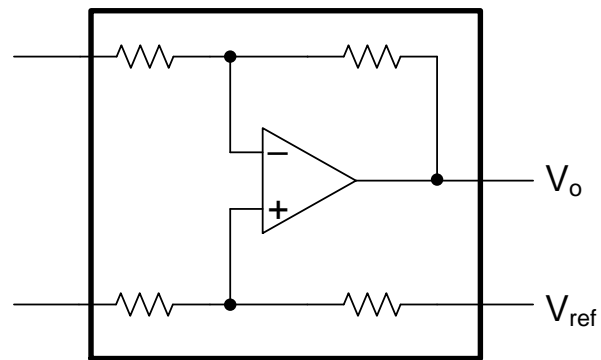


Next we will look at the concept of current flow directionality. In many applications, the current may flow in both directions – one simple example is a battery charging or discharging.

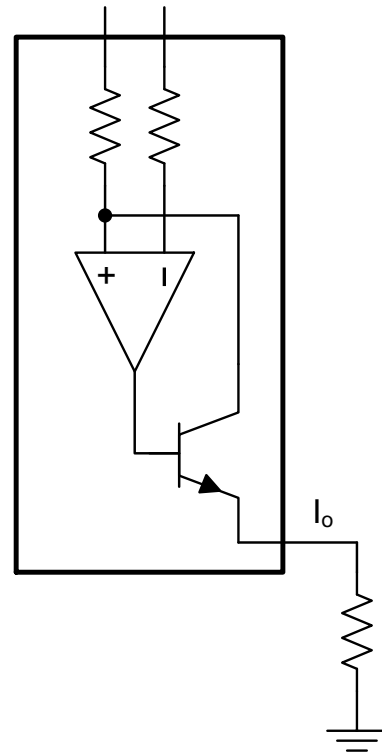
In order to determine which direction the current is flowing, the current sense amplifier must have an additional reference input pin that can be used to center the zero-current output voltage to some non-zero level. This allows the output voltage range to be divided such that the system is sinking current when $V_{out} > V_{ref}$, and sourcing current when $V_{out} < V_{ref}$. This is shown in the diagram on the bottom right.

What type of output is needed?

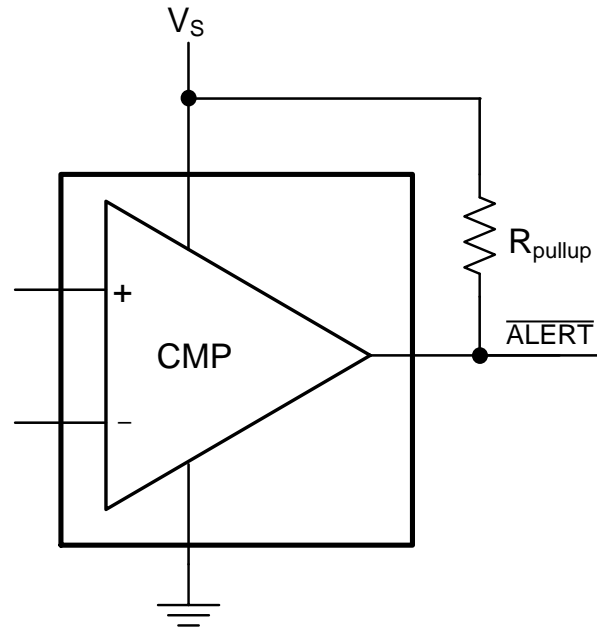
Voltage output



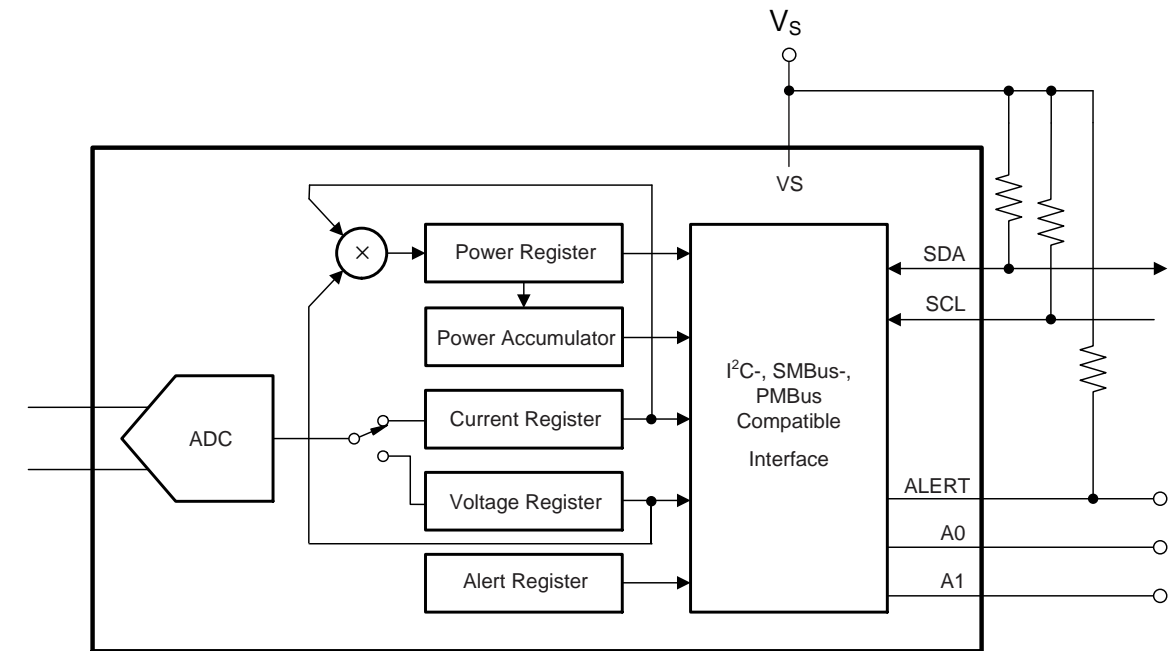
Current output



Alert output



Digital output



The last application constraint we'll consider is the output type. Many current sense amplifiers have an analog output, either voltage or current. If the current measurement result will be used for feedback or control of another analog device, then choosing an analog output makes sense. If the system simply needs to respond to an over-current condition, a current sense comparator with an ALERT output may be sufficient. Finally, if the current information will be processed by a microcontroller, then choosing a digital output device, on an interface like I2C or SPI, may be the best choice.

Design considerations summary

- Choosing the correct current sense amplifier device is driven by the application:
 - High-side vs. low-side
 - Common mode voltage
 - Current range
 - Bi-directional vs. uni-directional
 - Output type
 - **Accuracy** – will be addressed in later videos

There are many application requirements that will help determine the best current sense amplifier to use for any given system. This session has introduced five of these requirements. What may be the most important requirement – accuracy, was not addressed in this session but will be the focus of later videos in this series.

To find more current sense amplifier technical resources and search products, visit [ti.com/currentsense](https://www.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).

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Quiz

Current sense amp design considerations – quiz

1. In high-side sensing, the shunt resistor is placed between:
 - a) The system load and ground
 - b) The bus voltage and system load
 - c) The bus voltage and ground
 - d) Analog ground and digital ground

2. In high-side sensing, the common-mode voltage is typically:
 - a) The bus voltage
 - b) Ground
 - c) The difference between the input pins
 - d) $V_s/2$

Current sense amp design considerations – quiz

3. The value of R_{SHUNT} is primarily set by:
- a) Minimum load current
 - b) Maximum load current
 - c) Maximum bus voltage
 - d) Maximum quiescent current
4. For high accuracy, which of the below is required?
- a) $V_{SHUNT} \ll V_{OS}$
 - b) $V_{SHUNT} \gg V_{OS}$
 - c) $V_{BUS} < V_S$
 - d) $V_{BUS} > V_S$

Current sense amp design considerations – quiz

5. Bi-directional current flow can be measured by:
- a) Connecting the REF pin to GND
 - b) Connecting the REF pin to VS
 - c) Connecting the REF pin to OUT
 - d) Connecting the REF pin to a non-zero reference voltage
6. Which of the following is **not** a valid current sense amp output type?
- a) Voltage
 - b) Digital
 - c) Alert
 - d) Optical

Answers

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