Common Mode Rejection Ratio

TI Precision Labs – Current Sense Amplifiers

Presented by Patrick Simmons

Prepared by Patrick Simmons and Dan Harmon

Hello, and welcome to the TI precision labs series on current sense amplifiers. My name is Patrick Simmons, and I'm an applications engineer in the Current Sensing & Position Sensing product line. In this video, we will introduce common mode rejection ratio (abbreviated as CMRR), how to calculate the error it produces, and how to minimize the related error.

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	

TEXAS INSTRUMENTS

In previous videos, we introduced the root-sum-of-squares, RSS, which is a total error equation for current sense amplifier circuits, as shown here.   This video will focus on the error from common mode rejection, CMRR.

CMRR is a specification that is provided in the electrical characteristics table of the datasheet, as shown in this table.

Definition of CMRR

Definition

The measure of a device's ability to reject the signal common to both the positive and negative device inputs.

Common mode input

Unrejected portion of Common mode signal

V_{CM}
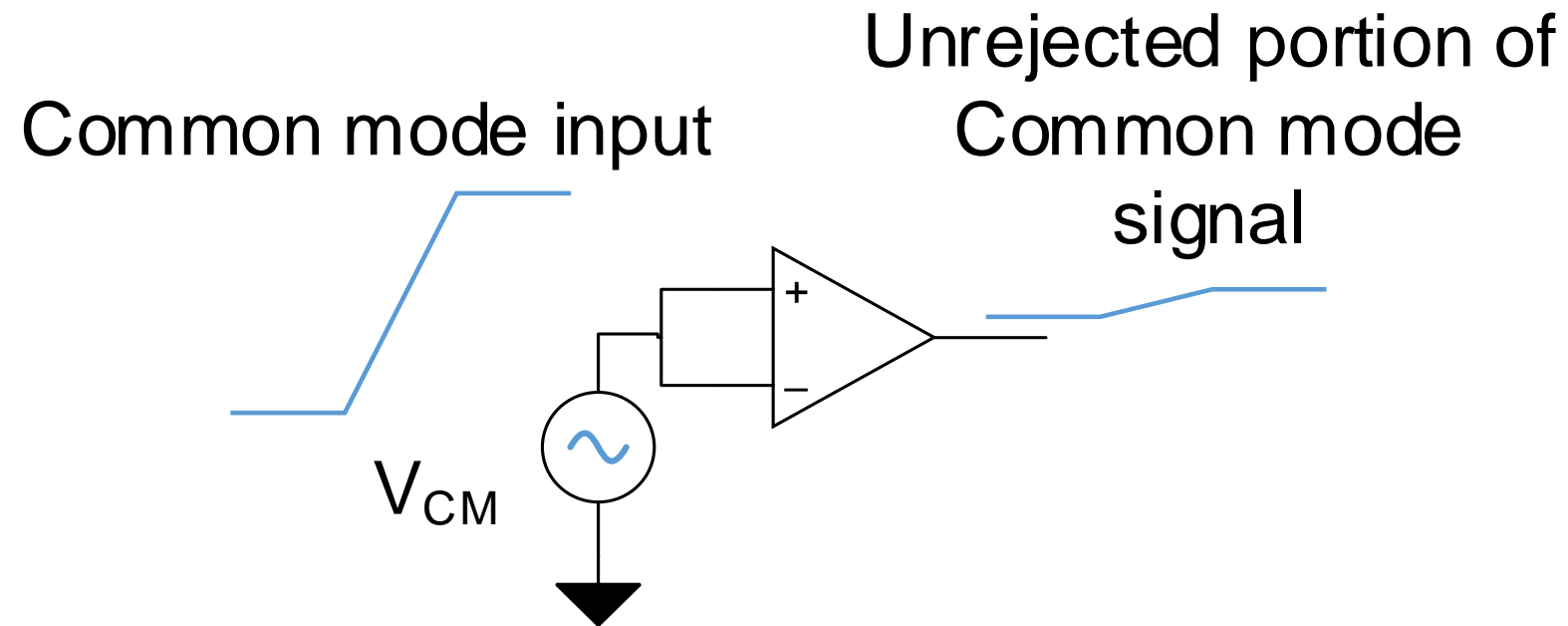
So what is common mode rejection ratio?

Common mode rejection ratio is the measure of a device's ability to reject the signal common to both the positive and negative device inputs.

An amplifier's ideal CMRR is infinite, and would produce no change in output with changes to the common mode voltage. However, material and design limitations lead to device CMRR falling far short of infinite. Consequently, the unrejected portion of the common mode adds to the sensed load and therefore has an impact on the accuracy of a current sense amplifier circuit.

In this figure, we see a large step signal at the inputs of the sense amplifier, which results in a significantly smaller step signal at the output.

The ratio of the change in output voltage with the change in common mode voltage is proportional to the device's CMRR for DC and low-frequency signals.

CMRR in the datasheet

DC specification

7.5 Electrical Characteristics

at T_A = 25 °C, VS = 5 V, V_{SENSE} = V_{IN+} − $V_{IN−}$, V_{CM} = 12 V, and V_{REF1} = V_{REF2} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range	V_{IN+} = −4 V to 80 V, V_{SENSE} = 0 mV T_A = − 40°C to 125°C	−4		80	V
CMRR	Common-mode rejection ratio	V_{IN+} = −4 V to 80 V, V_{SENSE} = 0 mV T_A = −40°C to 125°C	120	132		dB
		f = 50 kHz		93		

AC specification
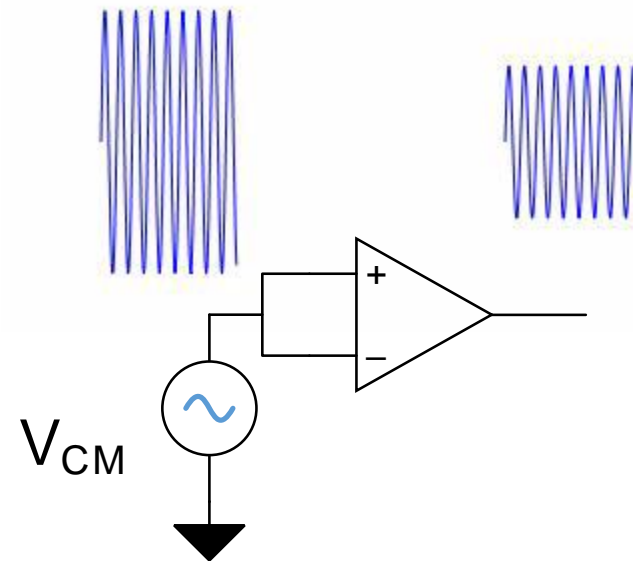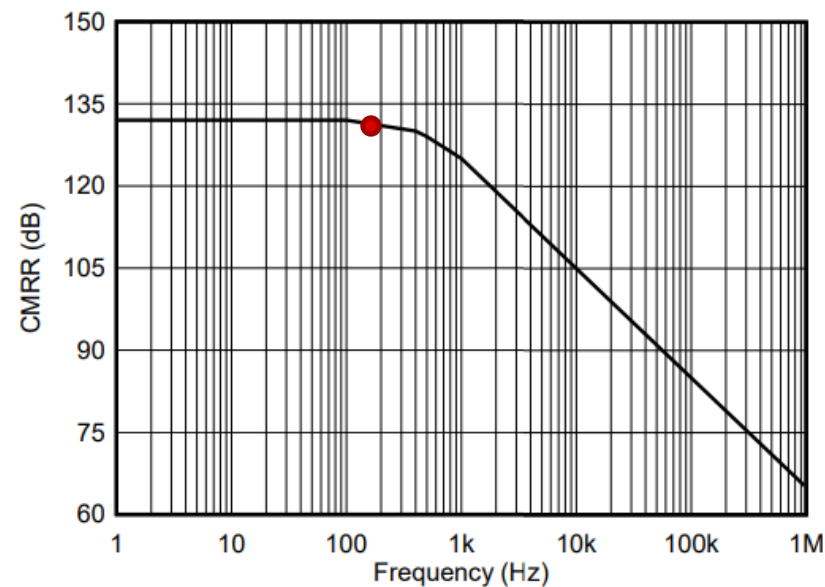
The DC measurements taken from a common mode step over a sample set of devices are used to generate the specification found in the electrical characteristics section. It is important to note that this specification is only valid for common mode signals at DC and low frequencies.

You might ask, what is considered low frequency, and what is the cut-off point? This can be determined from the CMRR vs. Frequency figure in the Typical characteristics section of the datasheet. What you should take away from that graph is that as the common mode signal increases in frequency past the minus 3-dB cut-off, the unrejected signal at the output will increase.

CMRR vs. common-mode step response

CMRR is for small signals:

- mV of change in common mode
- DC and periodic signals

Common–mode step response is for large signals:

- V of change in common mode
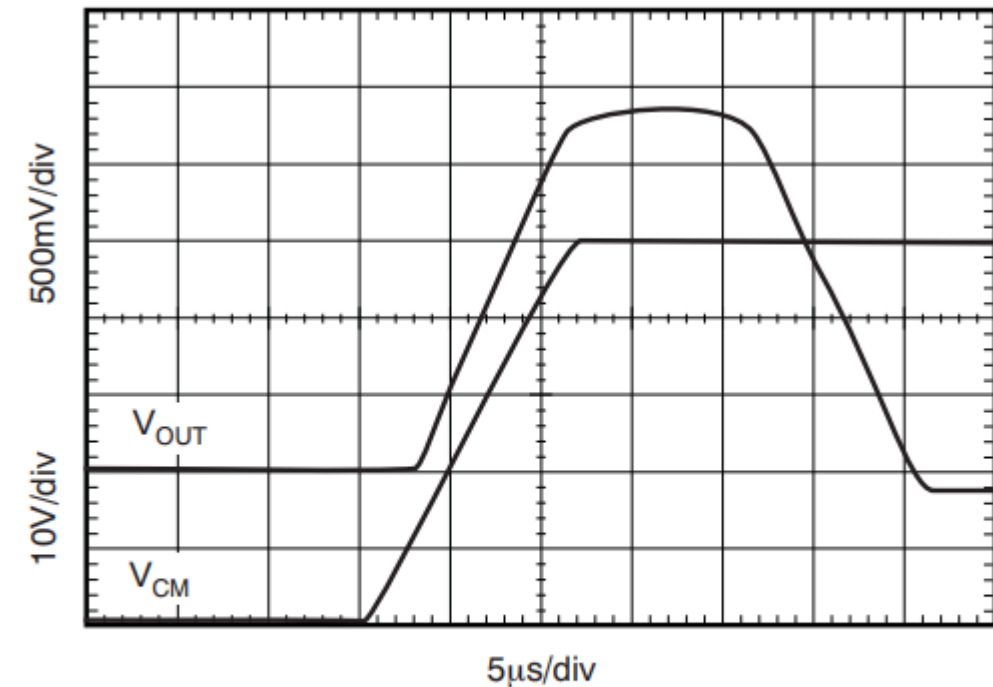- Transient signals
- Reveals settling time

Figure 25. 50-V Common-Mode Step Response

Another important detail to understand with the CMRR specification is that it applies to small, periodic common mode signals on the order of millivolts.

For large, transient common mode signals with a common-mode swing of a volt or greater, the common mode step response figure in the datasheet should be used. According to that figure, the device under consideration may have a longer settling time than what may be desired, such as the example here which takes a little over 25us before settling to a 100mV change in output for 50V common mode.

Note that this plot is not provided in every current sense amplifier datasheet.

CMRR equation

Gain equation

$$A = \frac{Output}{input}$$

CMRR equation

$$CMRR(dB) = 20\log\left(\frac{A_D}{|A_{CM}|}\right) = 20log\left(\frac{\frac{Gain \times V_{sense}}{V_{sense}}}{\left|\frac{Gain \times \Delta V_{OS}}{\Delta V_{CM}}\right|}\right) = 20log\left(\left|\frac{\Delta V_{CM}}{\Delta V_{OS}}\right|\right)$$

But… should not the ratio be reversed?

Having covered what CMRR is at a high level, let's now dive into the math. The conventional textbook definition is that CMRR is the ratio of the differential gain to common mode gain. From a high level, gain is defined as a transfer function of output over input. The input for the differential gain term is Vsense, while the input for the common mode gain is the change in the common mode signal Vcm. The output for differential gain would be simply the internal amplifier gain multiplied by Vsense. For the common mode gain, the same amplifier gain is multiplied by the input offset produced by the common mode. After we reduce the equation by cancelling Vsense terms and gain terms, we see a ratio of the change in Vcm to the change in Vos.

As CMRR should reduce a signal and therefore have a ratio less than 1, you might ask, "should not the ratio be reversed?"

CMRR equation

Log property

$$-\log(A) = \log\left(\frac{1}{A}\right)$$

- Datasheet gives positive dB value
- However, CMRR rejects changes to the common mode
- CMRR(dB) subtracted from common mode signal expressed in dB

dB to V/V conversion

$$-CMRR(dB) = -20log\left(\frac{\Delta V_{CM}}{\Delta V_{OS}}\right) \rightarrow CMRR\left(\frac{V}{V}\right) = \left(\frac{\Delta V_{OS}}{\Delta V_{CM}}\right) = 10^{\frac{-CMRR_{(dB)min}}{20}}$$

Actually, the ratio agrees with our previous definition when you consider that the CMRR value in dB would be subtracted, or "rejected" from the common mode signal in dB. According to the properties of logs, subtracting the log of a value A is equal to the log of 1 over A.

With this in mind, we can convert the logarithmic dB value provided in the datasheet to a linear volts-per-volt ratio which will be helpful for error calculations.

In our conversion you see that we use the minimum CMRR spec. This is because a smaller CMRR value in dB corresponds to weaker rejection. Therefore, if someone wants to know worst case what the error will be, the minimum value should be used.

CMRR error equation

Generic CSA error equation

$$e = \frac{V_{shunt_{real}} - V_{Shunt\_ideal}}{V_{Shunt\_ideal}} \times 100\%$$

CMRR error equation

$$e_{CMRR} = \frac{\Delta V_{CM} \times \frac{\Delta V_{OS}}{\Delta V_{CM}}}{V_{Shunt\_ideal}} = \frac{\left| V_{CM_{DS}} - V_{CM_{SYS}} \right| \times CMRR}{V_{Shunt\_ideal}} \times 100\%$$

- Error is calculated with respect to the ***ideal*** shunt voltage
- CMRR is non-zero at common modes not used for offset specification

TEXAS INSTRUMENTS

As a reminder, most current sense amplifier errors can be generalized as the ratio of the deviation from the real shunt voltage to the ideal shunt voltage. The deviation from the ideal shunt voltage is an offset. In another video we cover offset error, which includes the impact of a specific common mode voltage and a specific supply voltage, typically at room temperature. As the error from the datasheet defined common mode is already included in the offset error calculation, the CMRR error will be centered around the offset defined common mode and will only be non-zero above or below that value, which is 12V for most devices.

CMRR error example – LMP8646

Conditions

- CMRR (min) = **95dB at** $V_{CM_{DS}}$ **= 2.1V**

- $V_{CM_{SYS}}$ = 48V

- V_{Shunt_ideal} = 5 A * 1 mΩ = 5 mV

6.6 Electrical Characteristics: 5 V

Unless otherwise specified, all limits ensured for at T_A = 25°C, V_S= V⁺-V⁻, V⁺ = 5 V, V⁻ = 0 V, −2 V < V_{CM} < 76 V, R_g= 25 kΩ, R_L = 10 kΩ. [1]

PARAMETER		TEST CONDITIONS	MIN [2]	TYP [3]	MAX [2]	UNIT
V_{OFFSET}	Input Offset Voltage	V_{CM} = 2.1 V	−1		1	mV
		V_{CM} = 2.1 V, −40°C ≤ T_J ≤ 125°C	−1.7		1.7	
CMRR	Common-Mode Rejection Ratio	2.1 V <V_{CM} < 76 V	95			dB
		−2 V < V_{CM} < 2.1 V	55			

Calculations

$$CMRR_{LMP8646} = 10^{\frac{-CMRR_{(dB)min}}{20}} = 17.8 \frac{\mu V}{V}$$

$$e_{CMRR} = \frac{ABS(V_{CM_{DS}} - V_{CM_{SYS}}) \times CMRR}{V_{Shunt\_ideal}} \times 100\%$$

→

$$e_{CMRR} = \frac{ABS(2.1V - 48V) \times 17.8\frac{\mu V}{V}}{5mV} \times 100\% = \mathbf{16.3\%}$$

How to minimize

- Increase the shunt voltage drop – increase R_{SHUNT}

- Improve the common mode rejection ratio – select a different device

Let's calculate the CMRR error in an example system with a minimum load current of five amps and ideal shunt resistance of one milliohms. At first glance, the LMP8646 looks suitable as it can accommodate our common mode of 48V. Notice that there are two CMRR values defined depending on the common mode range. As our common mode is 48V, the 95dB value is used. Through the conversion equation we convert from 95dB to 17.8uV/V. Based upon the VOFFSET specification, there is only additional error from CMRR for common modes not equal to 2.1V. 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 a whopping 16.3%! This is not a very useful measurement. The first thing most engineers will ask is, how do we make it better and minimize the CMRR 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 increase the CMRR, 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 higher CMRR.

CMRR error example – INA240

Conditions

- CMRR (min) = **120dB at** $V_{CM_{DS}}$ **= 12V**

- $V_{CM_{SYS}}$ = 48V

- V_{Shunt_ideal} = 5 A * 1 mΩ = 5 mV

7.5 Electrical Characteristics

at T_A = 25 °C, VS = 5 V, V_{SENSE} = V_{IN+} − V_{IN-}, V_{CM} = 12 V, and V_{REF1} = V_{REF2} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range	V_{IN+} = −4 V to 80 V, V_{SENSE} = 0 mV T_A = − 40°C to 125°C	−4		80	V
CMRR	Common-mode rejection ratio	V_{IN+} = −4 V to 80 V, V_{SENSE} = 0 mV T_A = −40°C to 125°C	120	132		dB
		f = 50 kHz		93		
V_{OS}	Offset voltage, input-referred	V_{SENSE} = 0 mV		±5	±25	µV

Calculations

$$CMRR_{INA240} = 10^{\frac{-CMRR_{(dB)min}}{20}} = 1\frac{\mu V}{V}$$

$$e_{CMRR} = \frac{ABS(V_{CM_{DS}} - V_{CM_{SYS}}) \times CMRR}{V_{Shunt\_ideal}} \times 100\%$$ → $$e_{CMRR} = \frac{ABS(12V - 48V) \times 1\frac{\mu V}{V}}{5mV} \times 100\% = 0.72\%$$

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

Lets take the same example we looked at previously, but substitute a device with improved CMRR, like the INA240 with minimum CMRR of 120 dB. 120 dB corresponds to 1uV/V, which we can then plug into our equation from before.

As you can see, this swap in devices for the same system operating conditions drops the error from staggering 16.3% down to reasonable 0.72%.

Before moving on, I would like to emphasize the smallest operating load will yield the worst case error, which is why we used it in our analysis

CMRR error summary

- Ratio of how much the output changes for the change in common mode

- CMRR error equation:

$$e_{CMRR} = \frac{\left|V_{CM_{DS}} - V_{CM_{SYS}}\right| \times CMRR}{V_{Shunt\_ideal}} \times 100\%$$

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

- Minimum CMRR produces worst case error

- CMRR is dependent upon frequency

V_{CM}
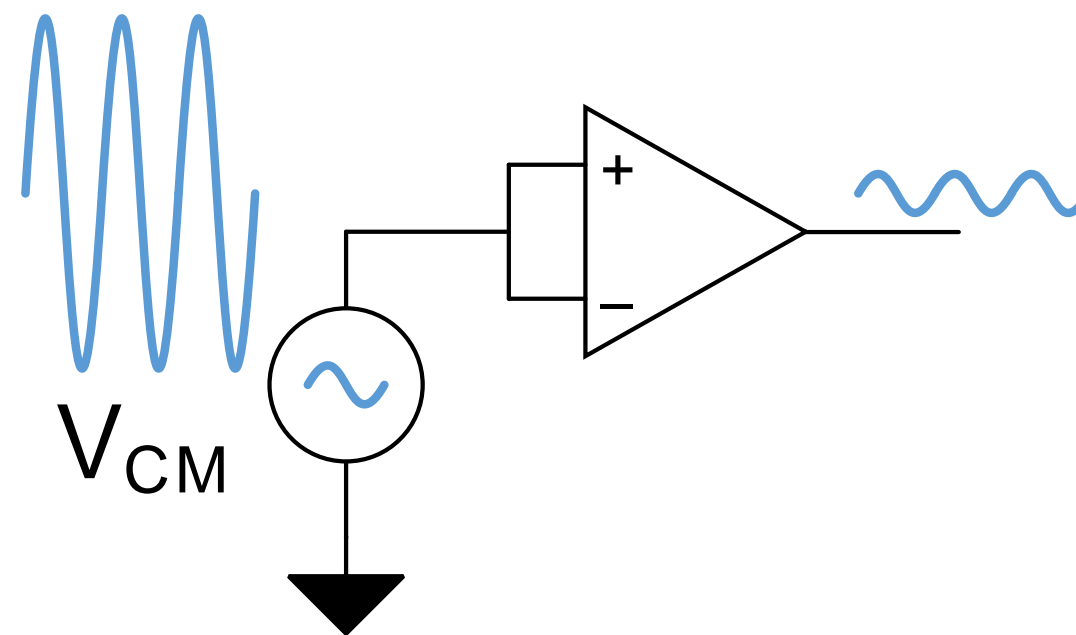
Let's take a minute to summarize what we learned in this video.

1. Common mode rejection ratio defines how much the output changes when changing the voltage common to both inputs of the current shunt amplifier.

2. To calculate CMRR error, you first convert CMRR into units of V/V if it is not already in that form, then you take the product of the CMRR and the difference between the datasheet common mode and intended design common mode. Lastly you take the ratio of this product to the ideal shunt voltage.

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

4. Use the minimum CMRR spec for worst case analysis

5. CMRR is frequency dependent

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.

Common Mode Rejection Ratio

TI Precision Labs – Current Sense Amplifiers
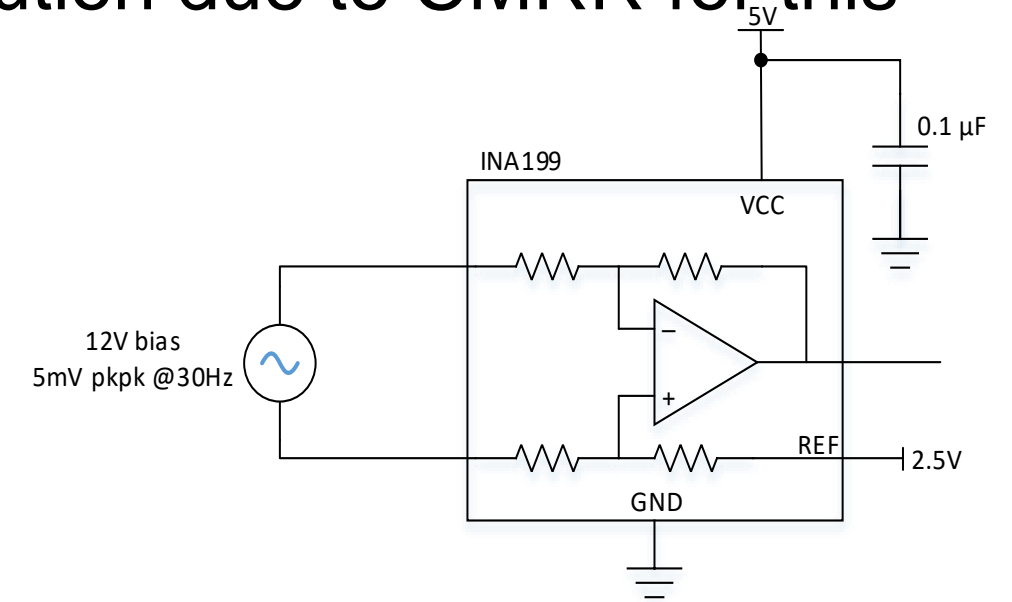
Quiz

TEXAS INSTRUMENTS

Current sensing CMRR – quiz

1. What is the additional max expected error contribution due to CMRR for this INA199?

   a) 140dB

   b) 0.00025%

   c) 12.5nV on the output

   d) 0%

at $T_A = 25°C$, $V_S = 5\ V$, $V_{IN+} = 12\ V$, $V_{SENSE} = V_{IN+} - V_{IN-}$, and $V_{REF} = V_S / 2$ (unless otherwise noted)
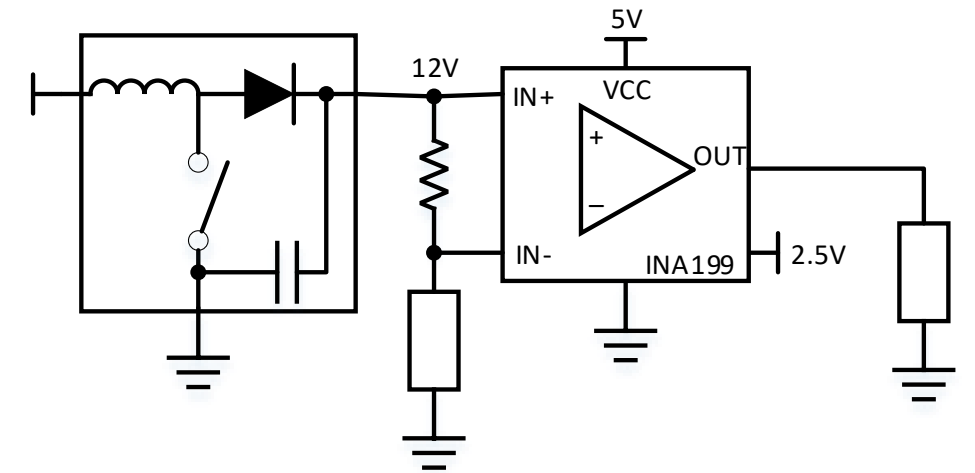
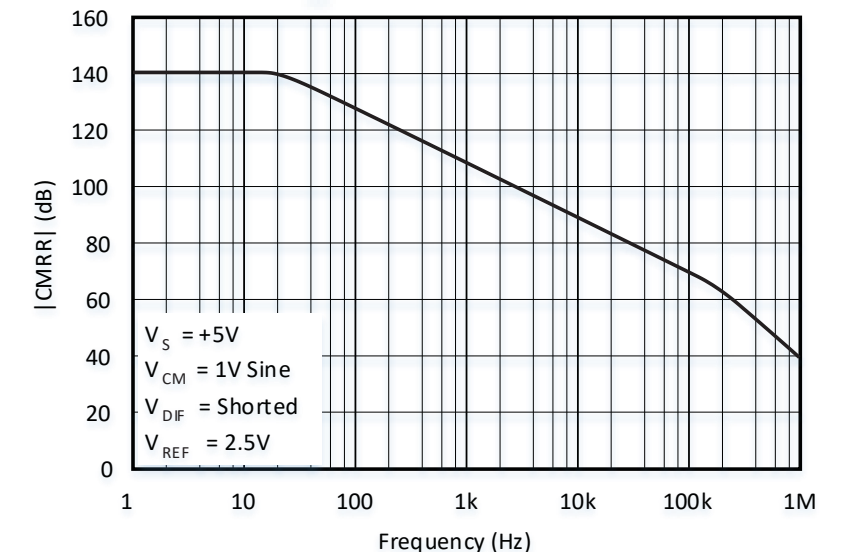| PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range	Version A, $T_A = -40°C$ to $125°C$	−0.3		26	V
		Version B and C, $T_A = -40°C$ to $125°C$	−0.1		26	
CMR	Common-mode rejection	$V_{IN+} = 0\ V$ to $26\ V$, $V_{SENSE} = 0\ mV$, $T_A = -40°C$ to $125°C$	100	120		dB
V_{OS}	Offset voltage, RTI [1]	$V_{SENSE} = 0\ mV$		±5	±150	µV

Current sensing CMRR – quiz

2. The INA199 has an LDO supplying VCC with 5V and REF with 2.5V, while the bus is provided by a boost supplying 12V with 1mV 100kHz switch noise. What typical CMR value should be used to calculate the additional error contribution from CMRR?

 a) 120 dB

 b) 140 dB

 c) 100 dB

 d) 70 dB

at T_A = 25°C, V_S = 5 V, V_{IN+} = 12 V, V_{SENSE} = V_{IN+} − $V_{IN−}$, and V_{REF} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range	Version A, T_A = −40°C to 125°C	−0.3		26	V
		Version B and C, T_A = −40°C to 125°C	−0.1		26	
CMR	Common-mode rejection	V_{IN+} = 0 V to 26 V, V_{SENSE} = 0 mV, T_A = −40°C to 125°C	100	120		dB
V_{OS}	Offset voltage, RTI [1]	V_{SENSE} = 0 mV		±5	±150	µV

Current sensing CMRR – quiz

3. You need to design a high-side monitor for a 24V bus with an expected range of 100mA-10A. Additionally your boss wants you to use that company's large reserve of INA180 (all variants available). Assuming you power with a 5.03V rail, what shunt value will help minimize the error observed from CMRR?

a) 3 mΩ

b) 25 mΩ

c) 27 mΩ

d) 10 mΩ

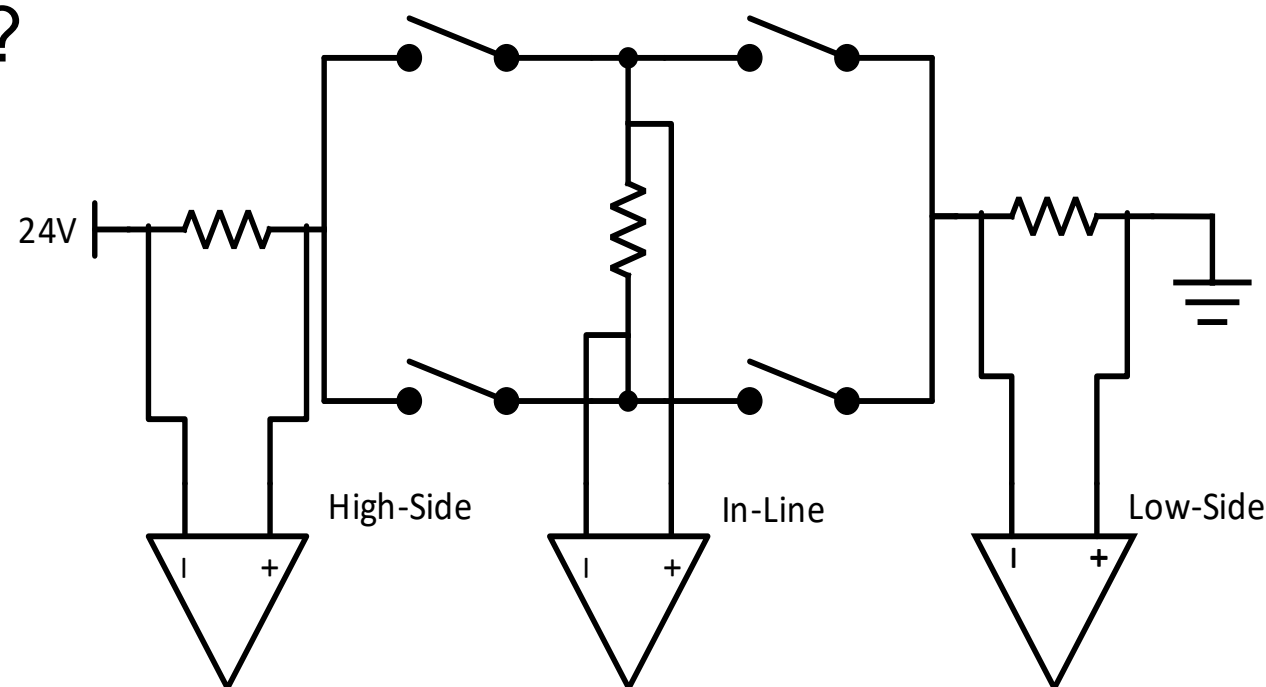at T_A = 25°C, V_S = 5 V, V_{IN+} = 12 V, and V_{SENSE} = $V_{IN+} - V_{IN-}$ (unless otherwise noted)

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+} = 0V		±25	±150	
		A1 devices		20		
G	Gain	A2 devices		50		V/V
		A3 devices		100		
		A4 devices		200		
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

Current sensing CMRR – quiz

4. Your colleague wants to sense current through an H-bridge switching at a 100kHz (10µs period) connected to a 24V supply. He is convinced the INA282 is sufficient for this task. Assuming the sense voltage of interest will be 100mV, which sensing configuration(s) will provide an error from the common mode at or below 0.12%?

   a) Low-side
   b) High-side
   c) In-line
   d) Both high-side and low-side
   e) All of the above

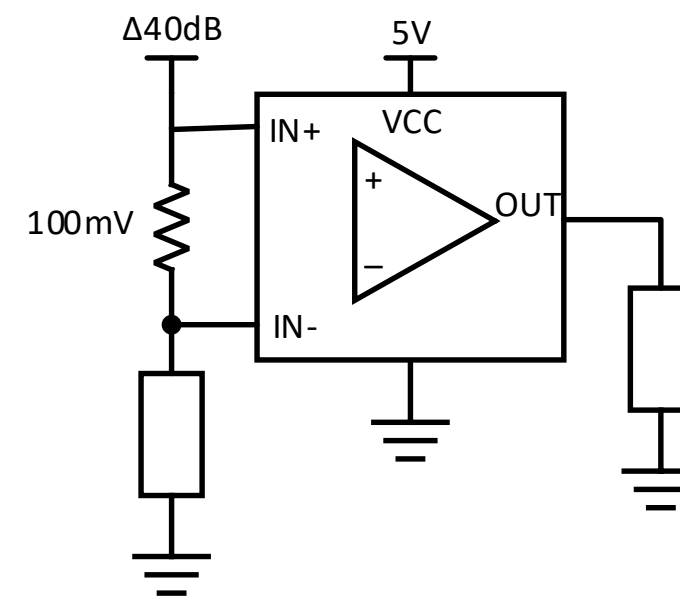High-Side   In-Line   Low-Side

Current sensing CMRR – quiz

5. The common mode may change by as much as 40dB signal (referenced to 1V) over a 10s period while a 100mV voltage is seen across the shunt. If the EC table specification is as follows, what is the max error that could be observed due to CMRR?

   a) Device Operated out of Spec

   b) 0.03099%

   c) 0.00098%

   d) 0.031623%

at T_A = 25 °C, V_S = 5 V, $V_{SENSE} = V_{IN+} - V_{IN-}$, V_{SENSE} = 5 mV, and V_{CM} = 12 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input voltage range	$V_{IN+} = V_{IN-}$ = −4 V to +110 V, T_A = −40°C to +125°C	−4		110	V
CMRR	Common-mode rejection ratio	$V_{IN+} = V_{IN-}$ = −4 V to +110 V, T_A = −40°C to +125°C	130	160		dB
		f = 50 kHz		85		dB
V_{OS}	Offset voltage, input referred	$V_{IN+} = V_{IN-}$ = 12 V		25	200	µV

Current sensing CMRR – quiz

3. You have a 48V bus that you would like to monitor the high-side of. A quick look shows the INA210-Q1 within your price point and above your minimum CMRR requirement. With a minimum sense voltage of 10mV, how much error do you expect to see due to the common mode?

   a) 2.024 %

   b) 20.24 %

   c) 0.84 %

   d) Invalid use case

at T_A = 25°C and V_{SENSE} = $V_{IN+} - V_{IN-}$
INA210-Q1, INA213-Q1, INA214-Q1, and INA215-Q1: V_S = 5 V, V_{IN+} = 12 V, and V_{REF} = V_S/2, (unless otherwise noted)
INA211-Q1 and INA212-Q1: V_S = 12 V, V_{IN+} = 12 V, and V_{REF} = V_S/2, (unless otherwise noted)

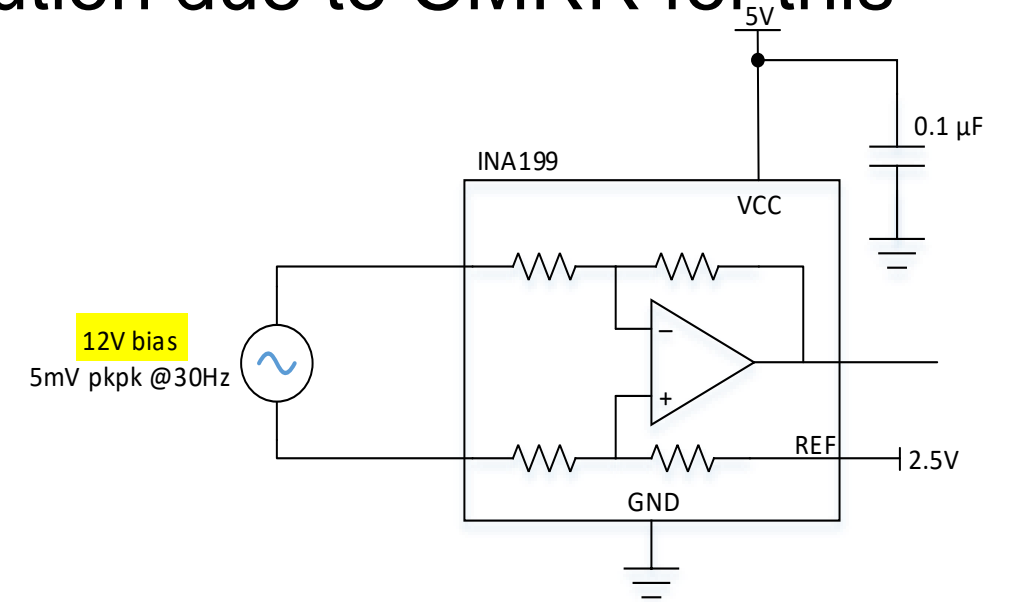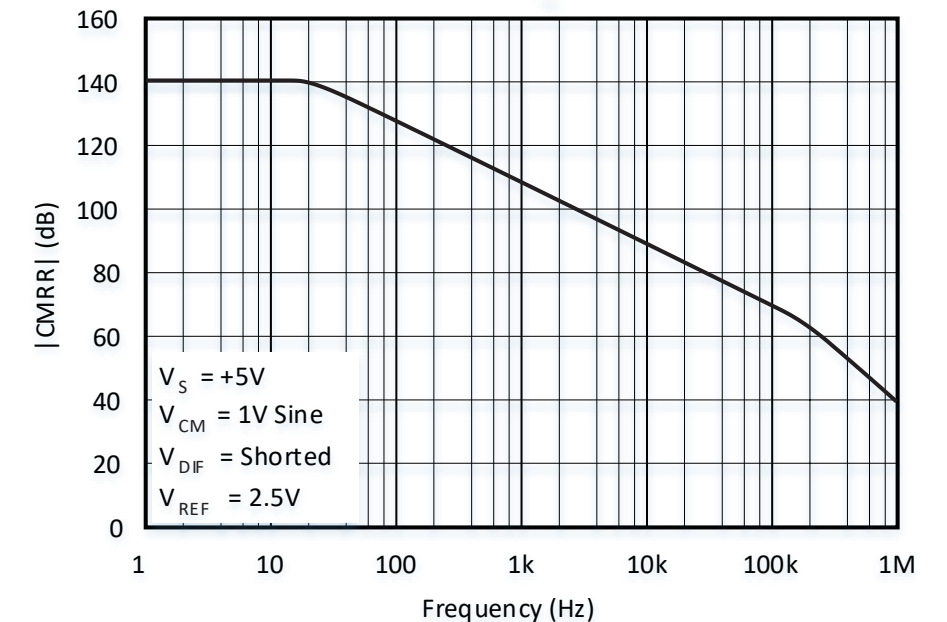| PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
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V_{CM}	Common-mode input	Version A T_A = −40°C to 125°C		−0.3		26	V
		Versions B and C T_A = −40°C to 125°C		−0.1		26	
CMRR	Common-mode rejection ratio	V_{IN+} = 0 V to 26 V V_{SENSE} = 0 mV T_A = −40°C to 125°C	INA210-Q1 INA211-Q1 INA212-Q1 INA214-Q1 INA215-Q1	105	140		dB
			INA213-Q1	100	120		
V_{OS}	Offset voltage, RTI [1]	V_{SENSE} = 0 mV T_A = 25°C	INA210-Q1 INA211-Q1 INA212-Q1		±0.55	±35	µV
			INA213-Q1		±5	±100	
			INA214-Q1 INA215-Q1		±1	±60	

Answers

Current sensing CMRR – quiz

1. What is the additional max expected error contribution due to CMRR for this INA199A1?

   a) 140dB

   b) 0.00025%

   c) 12.5nV on the output

   d) 0%

at T_A = 25°C, V_S = 5 V, V_{IN+} = 12 V, V_{SENSE} = $V_{IN+} - V_{IN-}$, and V_{REF} = V_S / 2 (unless otherwise noted)
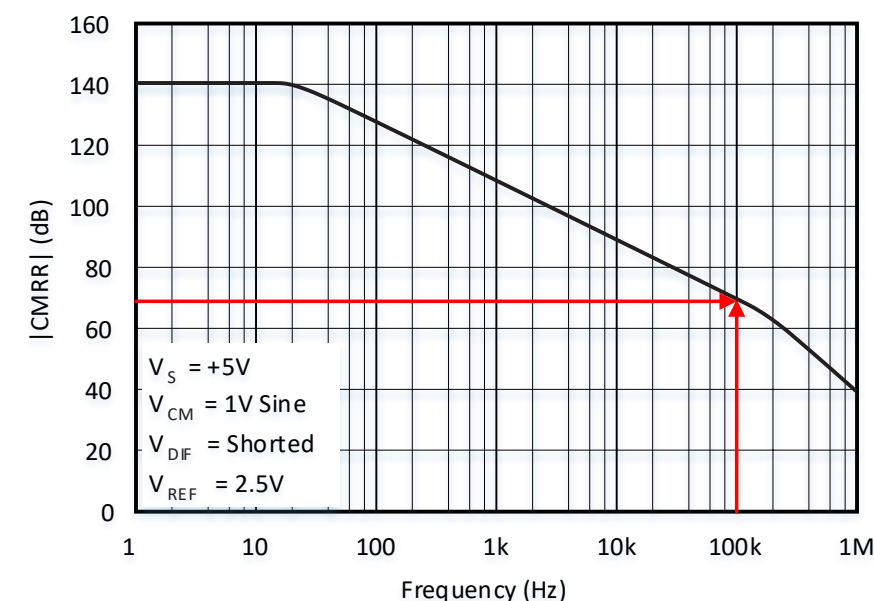
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Current sensing CMRR – quiz

2. The INA199 has an LDO supplying VCC with 5V and REF with 2.5V, while the bus is provided by a boost supplying 12V with 1mV 100kHz switch noise. What typical CMR value should be used to calculate the additional error contribution from CMRR?
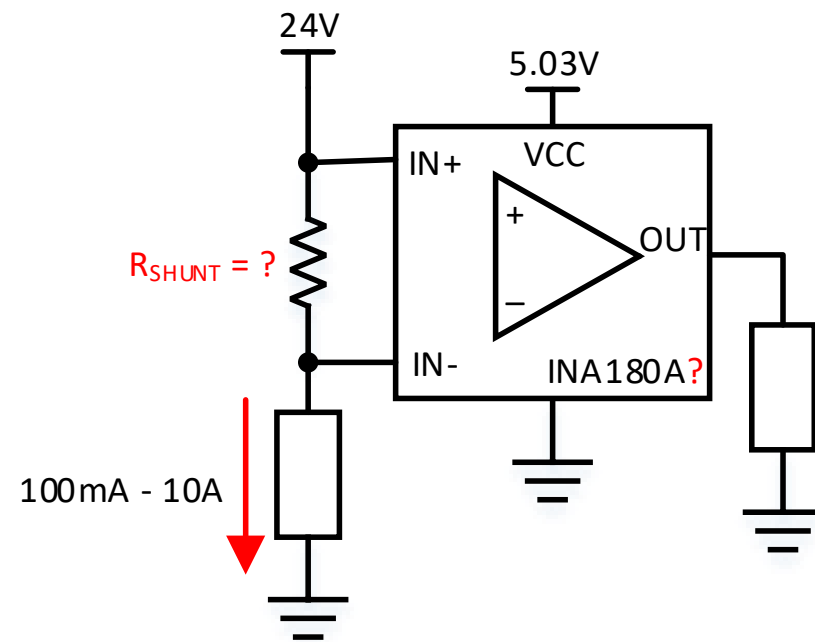
   a) 120 dB

   b) 140 dB

   c) 100 dB

   d) 70 dB

$V_S = +5V$
$V_{CM} = 1V$ Sine
$V_{DIF} = $ Shorted
$V_{REF} = 2.5V$

|CMRR| (dB) vs Frequency (Hz)

Current sensing CMRR – quiz

3. You need to design a high-side monitor for a 24V bus with an expected range of 100mA-10A. Additionally your boss wants you to use that company's large reserve of INA180 (all variants available). Assuming you power with a 5.03V rail, what shunt value will help minimize the error observed from CMRR?

a) 3 mΩ

b) **25 mΩ**

c) 27 mΩ

d) 10 mΩ

$$e_{CMRR} = \frac{\left| V_{CM_{DS}} - V_{CM_{SYS}} \right| \times CMRR}{V_{Shunt\_ideal}} \times 100\%$$

$$V_{Shunt\_ideal} \uparrow \quad \longrightarrow \quad e_{CMRR} \downarrow$$

See next page for calculations

Current sensing CMRR – quiz

$$R_{SHUNT} = \frac{V_{SP_{Max}}}{Gain \times I_{max}}$$

$$R_{SHUNT_{A1}} = \frac{5.03V - 0.03\,V}{20\,^V\!/_V \times 10A} = \mathbf{0.025\Omega}$$

$$R_{SHUNT_{A2}} = \frac{5.03\,V - 0.03\,V}{50\,^V\!/_V \times 10A} = 0.01\Omega$$

$$R_{SHUNT_{A3}} = \frac{5.03\,V - 0.03\,V}{100\,^V\!/_V \times 10A} = .005\Omega$$

$$R_{SHUNT_{A4}} = \frac{5.03\,V - 0.03\,V}{200\,^V\!/_V \times 10A} = 0.0025\Omega$$

at T_A = 25°C, V_S = 5 V, V_{IN+} = 12 V, and V_{SENSE} = V_{IN+} − V_{IN-} (unless otherwise noted)

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+} =0V		±25	±150	
		A1 devices		20		
G	Gain	A2 devices		50		V/V
		A3 devices		100		
		A4 devices		200		
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

Current sensing CMRR – quiz

4. Your colleague wants to sense current through an H-bridge switching at a 100kHz connected to a 24V supply. He is convinced the INA282 is sufficient for this task. Assuming the sense voltage of interest will be 100mV, which sensing configuration(s) will provide an error from the common mode at or below 0.12%?

   a) Low-side
   b) High-side
   c) In-line
   d) **Both high-side and low-side**
   e) All of the above
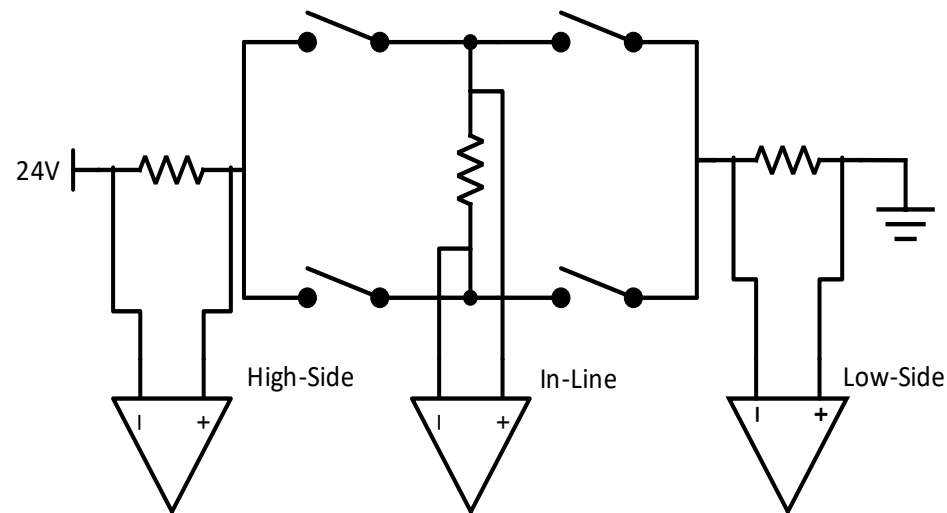
Assuming no supply droop, high-side only sees Vcm = 24V. Assuming no ground bounce, low-side only sees 10mV/2 = 5mV = ~0V

$$CMRR = 120dB \Rightarrow CMRR = 10^{\frac{-120}{20}} = 1\mu V/V$$

$$e_{CMRR} = \frac{\left|V_{CM_{DS}} - V_{CM_{SYS}}\right| \times CMRR}{V_{Shunt\_ideal}} \times 100\%$$

$$e_{CMRR\ high-side} = \frac{|12V - 24V| \times 1\mu V/V}{10mV} \times 100\% = 0.12\%$$

$$e_{CMRR\ low-side} = \frac{|12V - 0V| \times 1\mu V/V}{10mV} \times 100\% = 0.12\%$$

See Next Page for In-line analysis

High-Side   In-Line   Low-Side

Current sensing CMRR – quiz

Assuming a 50% duty cycle, the INA282 only has 5µs to adjust. The datasheet does not show a 24V Vcm step test. However, it does provide 12V step and 50V step conditions. From those we can extrapolate that the device does not have sufficient settling time. Therefore error from settling will also contribute to the overall error, which should push the error well Past 0.12%.
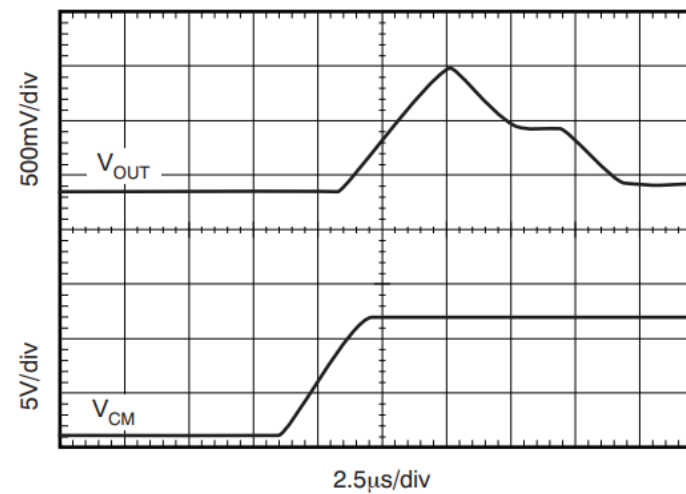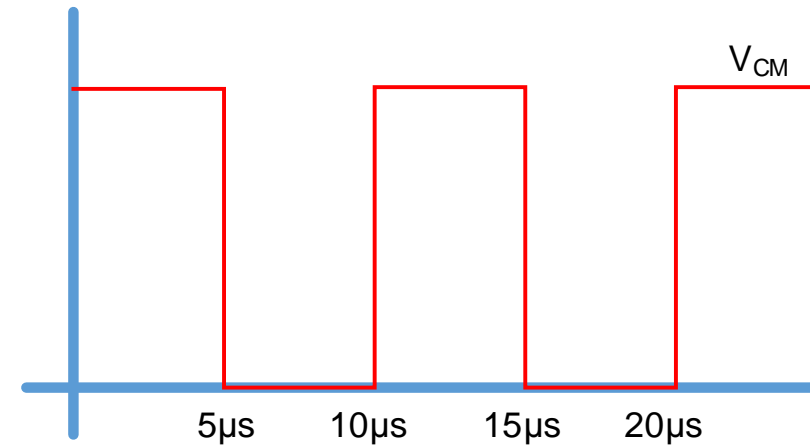
In-line Sensing V$_{CM}$ Signal

V$_{CM}$

5µs   10µs   15µs   20µs

500mV/div

V$_{OUT}$

5V/div

V$_{CM}$

2.5µs/div

Figure 22. 12-V Common-Mode Step Response

500mV/div
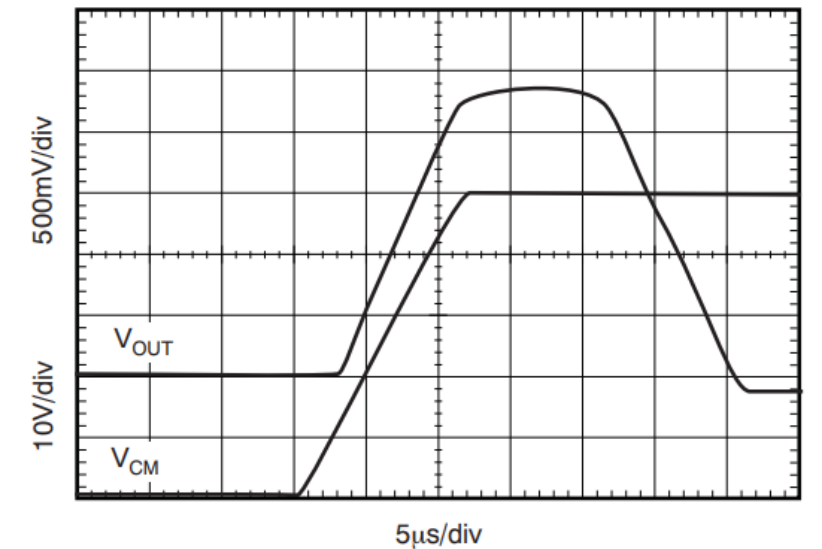
V$_{OUT}$

10V/div

V$_{CM}$

5µs/div

Figure 25. 50-V Common-Mode Step Response

Current sensing CMRR – quiz

5. The common mode may change by as much as 40dB signal (referenced to 1V) over a 10s period while a 100mV voltage is seen across the shunt. If the EC table specification is as follows, what is the max error that could be observed due to CMRR?

a) Device Operated out of Spec

b) 0.03099%

c) 0.00098%

d) 0.031623%

$$\Delta 40dB = 10^{\frac{40}{20}}\left(\frac{V}{1V\ Reference}\right) = \Delta 100V$$

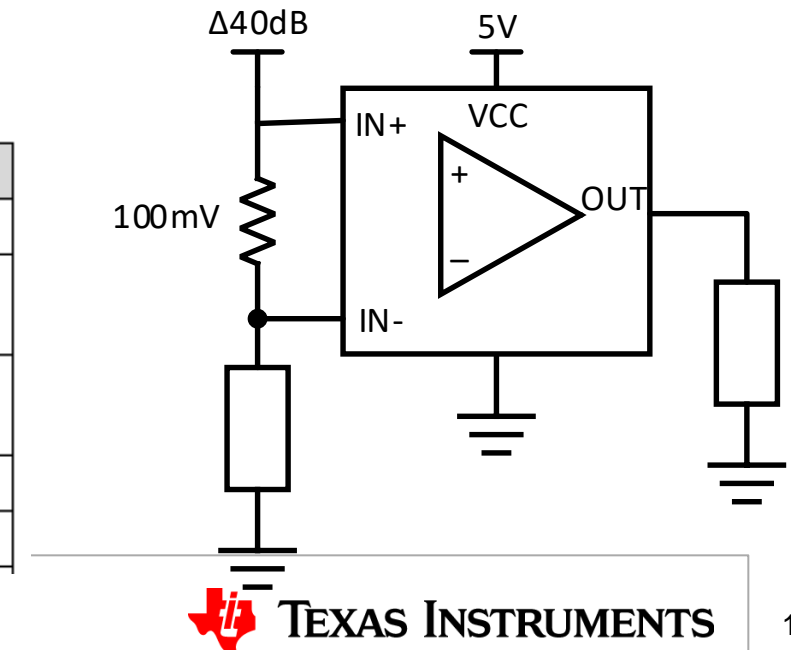$V_{CM\ Range} > 100V,\ Greatest\ error\ at\ V_{CM}\ furthest\ from\ 12V$

$$CMRR = 130dB \Rightarrow CMRR = 10^{\frac{-130}{20}} = 0.316\mu V/V$$

$$eCMRR = \frac{(110V - 12V) \times 0.316\mu V/V}{0.1V} = 0.03099\%$$

at T_A = 25 °C, V_S = 5 V, $V_{SENSE} = V_{IN+} - V_{IN-}$, V_{SENSE} = 5 mV, and V_{CM} = 12 V (unless otherwise noted)
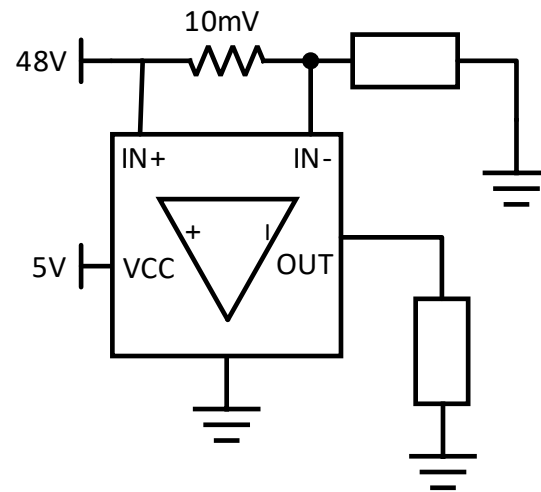
PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input voltage range	$V_{IN+} = V_{IN-}$ = −4 V to +110 V, T_A = −40°C to +125°C	−4		110	V
CMRR	Common-mode rejection ratio	$V_{IN+} = V_{IN-}$ = −4 V to +110 V, T_A = −40°C to +125°C	130	160		dB
		f = 50 kHz		85		dB
V_{OS}	Offset voltage, input referred	$V_{IN+} = V_{IN-}$ = 12 V		25	200	µV

Current sensing CMRR – quiz

6. You have a 48V bus that you would like to monitor the high-side of. A quick look shows the INA210-Q1 within your price point and above your minimum CMRR requirement. With a minimum sense voltage of 10mV, how much error do you expect to see due to the common mode?

   a) 2.024 %

   b) 20.24 %

   c) 0.84 %

   d) Invalid use case

at T_A = 25°C and V_{SENSE} =V_{IN+} − V_{IN-}
INA210-Q1, INA213-Q1, INA214-Q1, and INA215-Q1: V_S = 5 V, V_{IN+} = 12 V, and V_{REF} =V_S/2, (unless otherwise noted)
INA211-Q1 and INA212-Q1: V_S = 12 V, V_{IN+} = 12 V, and V_{REF} =V_S/2, (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
INPUT							
V_{CM}	Common-mode input	Version A T_A = −40°C to 125°C		−0.3		26	V
		Versions B and C T_A = −40°C to 125°C		−0.1		26	
CMRR	Common-mode rejection ratio	V_{IN+} = 0 V to 26 V V_{SENSE} = 0 mV T_A = −40°C to 125°C	INA210-Q1 INA211-Q1 INA212-Q1 INA214-Q1 INA215-Q1	105	140		dB
			INA213-Q1	100	120		
V_{OS}	Offset voltage, RTI [(1)]	V_{SENSE} = 0 mV T_A = 25°C	INA210-Q1 INA211-Q1 INA212-Q1		±0.55	±35	μV
			INA213-Q1		±5	±100	
			INA214-Q1 INA215-Q1		±1	±60	

48V 10mV IN+ IN− 5V VCC OUT