

# Low-Drift, Low-Side, Bidirectional Current Sensing Circuit with Integrated Precision Gain

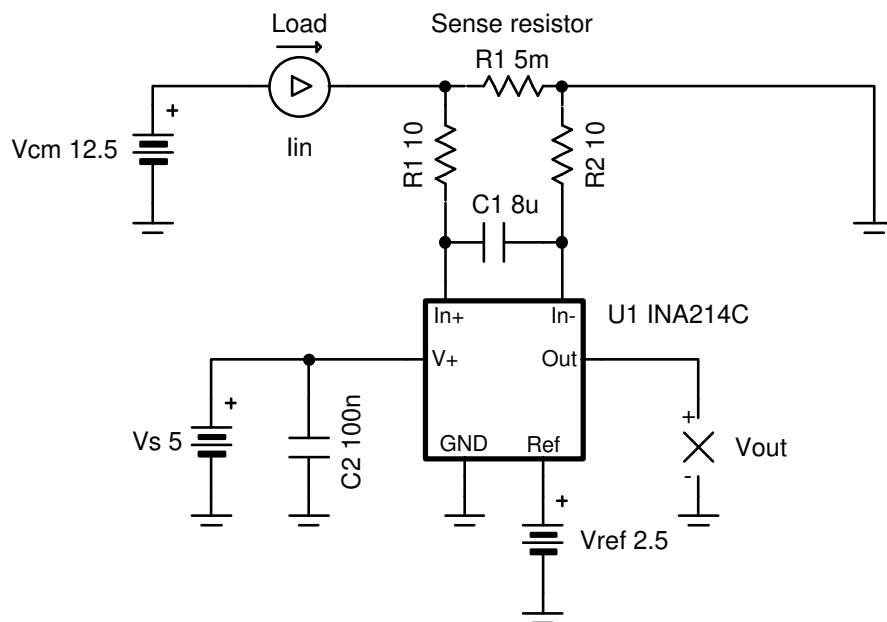


## Design Goals

Input			Output		Supply	
$I_{inMin}$	$I_{inMax}$	$V_{cm}$	$V_{outMin}$	$V_{outMax}$	$V_s$	$V_{ref}$
-4A	4A	12.5 V	0.5 V	4.5 V	5	2.5 V

## Design Description

The low-side bidirectional current-shunt monitor solution illustrated in the following image can accurately measure currents from  $-4A$  to  $4A$ , and the design parameters can easily be changed for different current measurement ranges. Current-shunt monitors from the INA21x family have integrated precision gain resistors and a zero-drift architecture that enables current sensing with maximum drops across the shunt as low as  $10mV$  full-scale.



## Design Notes

- To avoid additional error, use  $R_1 = R_2$  and keep the resistance as small as possible (no more than  $10\Omega$ , as stated in [INA21x Voltage Output, Low- or High-Side Measurement, Bidirectional, Zero-Drift Series, Current-Shunt Monitors](#)).
- Low-side sensing should not be used in applications where the system load cannot withstand small ground disturbances or in applications that need to detect load shorts.
- The [Getting Started with Current Sense Amplifiers](#) video series introduces implementation, error sources, and advanced topics that are good to know when using current sense amplifiers.

## Design Steps

1. Determine  $V_{ref}$  based on the desired current range:

With a current range of  $-4A$  to  $4A$ , then half of the range is below  $0V$ , so set:

$$V_{ref} = \frac{1}{2} V_s = \frac{5}{2} = 2.5 V$$

2. Determine the desired shunt resistance based on the maximum current and maximum output voltage:

To not exceed the swing-to-rail and to allow for some margin, use  $V_{outMax} = 4.5V$ . This, combined with maximum current of  $4A$  and the  $V_{ref}$  calculated in step 1, can be used to determine the shunt resistance using the equation:

$$R_1 = \frac{V_{outMax} - V_{ref}}{Gain \times I_{loadMax}} = \frac{4.5 - 2.5}{100 \times 4} = 5 m\Omega$$

3. Confirm  $V_{out}$  will be within the desired range:

At the maximum current of  $4A$ , with  $Gain = 100V/V$ ,  $R_1 = 5m\Omega$ , and  $V_{ref} = 2.5V$ :

$$V_{out} = I_{load} \times Gain \times R_1 + V_{ref} = 4 \times 100 \times 0.005 + 2.5 = 4.5 V$$

At the minimum current of  $-4A$ , with  $Gain = 100V/V$ ,  $R_1 = 5m\Omega$ , and  $V_{ref} = 2.5V$ :

$$V_{out} = I_{load} \times Gain \times R_1 + V_{ref} = -4 \times 100 \times 0.005 + 2.5 = 0.5 V$$

4. Filter cap selection:

To filter the input signal at  $1kHz$ , using  $R_1 = R_2 = 10\Omega$ :

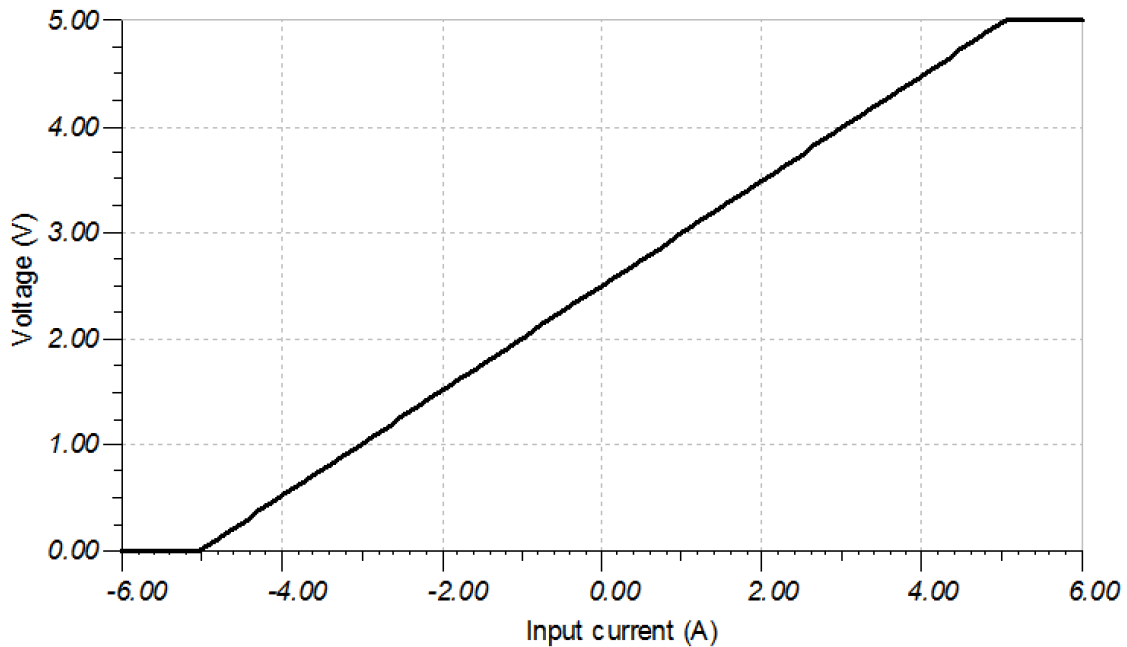
$$C_1 = \frac{1}{2 \pi (R_1 + R_2) F_{-3dB}} = \frac{1}{2 \pi (10 + 10) 1000} = 7.958 \times 10^{-6} \approx 8 \mu F$$

For more information on signal filtering and the associated gain error, see [INA21x Voltage Output, Low- or High-Side Measurement, Bidirectional, Zero-Drift Series, Current-Shunt Monitors](#).

## Design Simulations

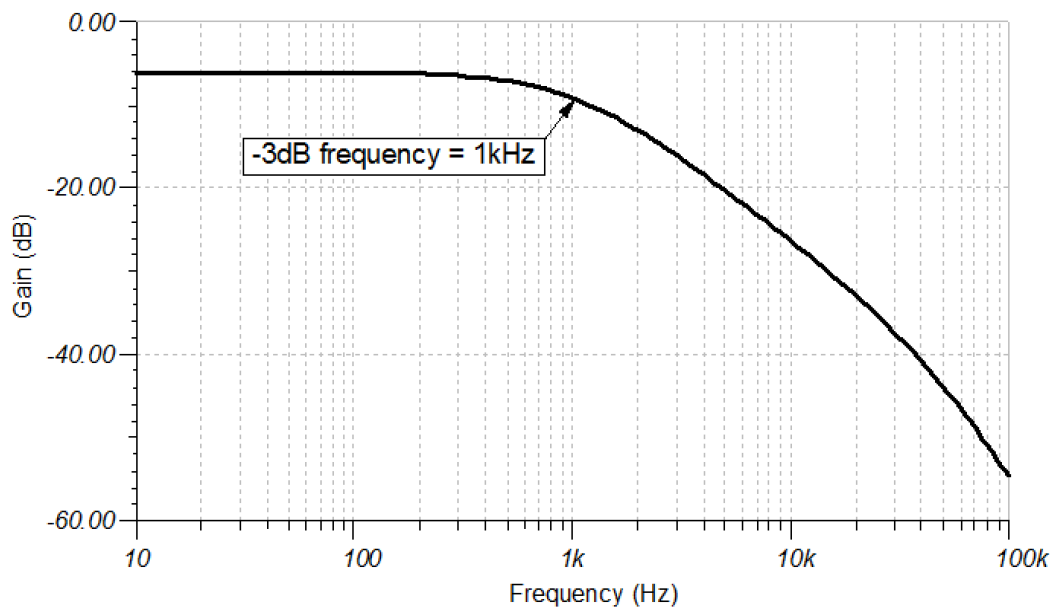
### DC Analysis Simulation Results

The following plot shows the simulated output voltage  $V_{out}$  for the given input current  $I_{in}$ .



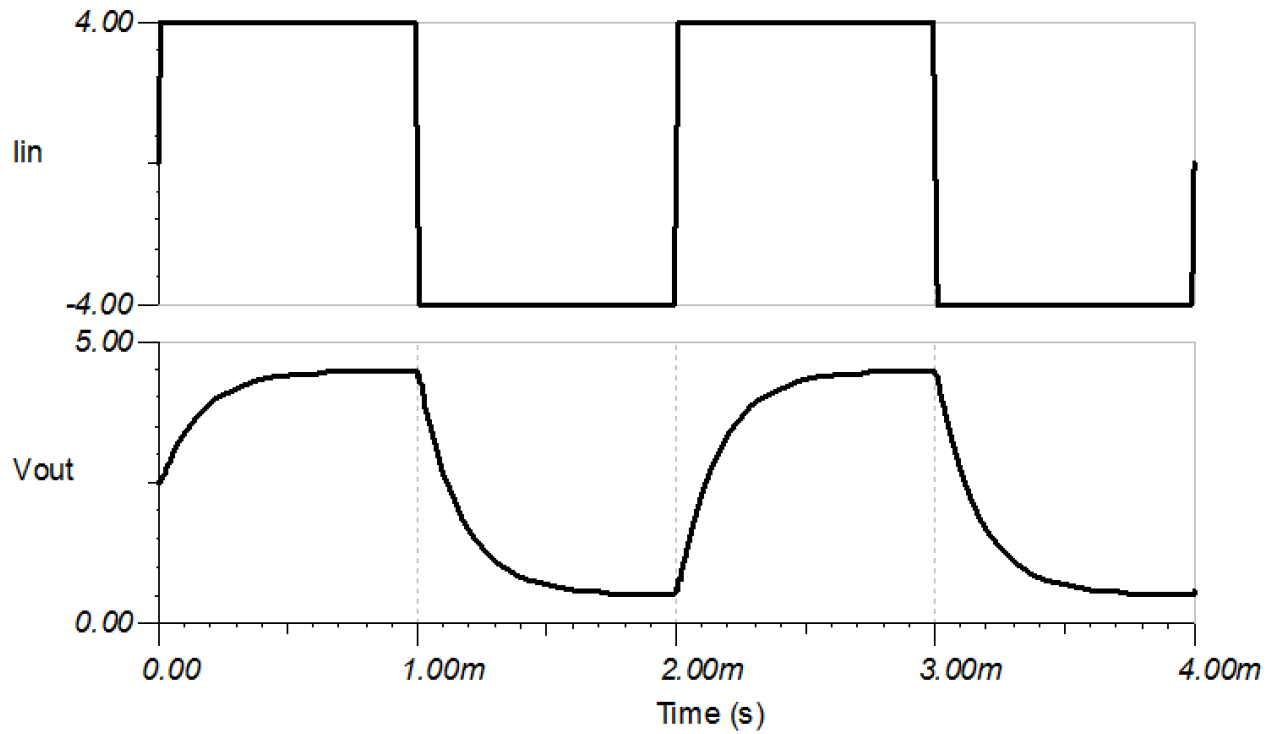
### AC Analysis Simulation Results

The following plot shows the simulated gain vs frequency, as designed for in the design steps.



### Transient Analysis Simulation Results

The following plot shows the simulated delay and settling time of the output  $V_{out}$  for a step response in  $I_{in}$  from  $-4A$  to  $4A$ .



## Design References

See [Analog Engineer's Circuit Cookbooks](#) for TI's comprehensive circuit library.

Circuit SPICE simulation File: <http://proddms.itg.ti.com/fnview/sboc518>

Getting Started with Current Sense Amplifiers video series: <https://training.ti.com/getting-started-current-sense-amplifiers>

Current Sense Amplifiers on TI.com: <http://www.ti.com/amplifier-circuit/current-sense/products.html>

For direct support from TI Engineers use the E2E community: <http://e2e.ti.com>

## Design Featured Current Sense Amplifier

INA214C	
$V_s$	2.7 V to 26 V
$V_{cm}$	GND-0.1 V to 26 V
$V_{out}$	GND-0.3V to $V_s+0.3$ V
$V_{os}$	$\pm 1\mu\text{V}$ typical
$I_q$	65 $\mu\text{A}$ typical
$I_b$	28 $\mu\text{A}$ typical
<a href="http://www.ti.com/product/INA214">http://www.ti.com/product/INA214</a>	

## Design Alternate Current Sense Amplifiers

INA199C	
$V_s$	2.7 V to 26 V
$V_{cm}$	GND-0.1 V to 26 V
$V_{out}$	GND-0.3 V to $V_s+0.3$ V
$V_{os}$	$\pm 5\mu\text{V}$ typical
$I_q$	65 $\mu\text{A}$ typical
$I_b$	28 $\mu\text{A}$ typical
<a href="http://www.ti.com/product/INA199">http://www.ti.com/product/INA199</a>	

INA181	
$V_s$	2.7 V to 5.5 V
$V_{cm}$	GND-0.2 V to 26 V
$V_{out}$	GND-0.3 V to $V_s+0.3$ V
$V_{os}$	$\pm 100\mu\text{V}$ typical
$I_q$	65 $\mu\text{A}$ typical
$I_b$	195 $\mu\text{A}$ typical
<a href="http://www.ti.com/product/INA181">http://www.ti.com/product/INA181</a>	

## Revision History

Revision	Date	Change
A	December 2020	Changed step three from "At the minimum current of 4A" to "At the minimum current of -4A"

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