

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

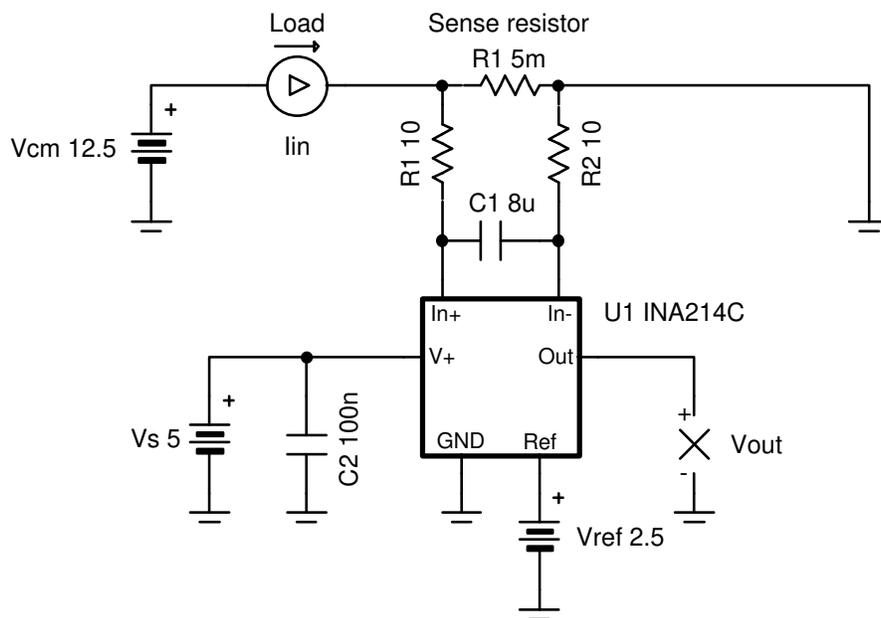


## Design Goals

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  $R_1 = R_2 = 10\Omega$ :

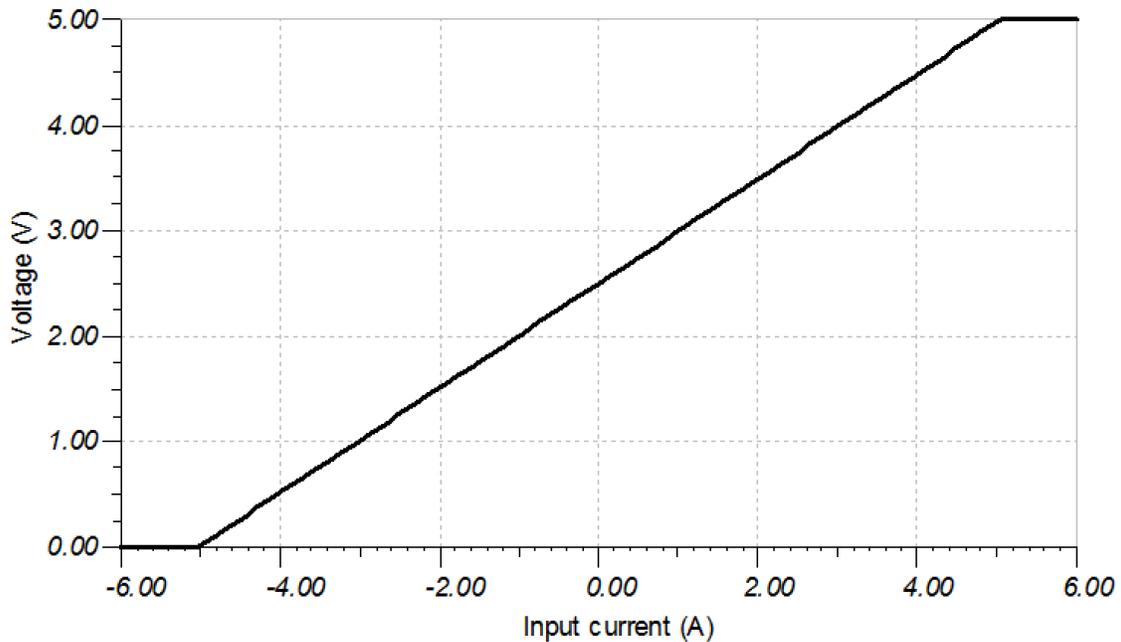
$$C_1 = \frac{1}{2 \pi (R_1 + R_2) F_{-3dB}} = \frac{1}{2 \pi (10 + 10) 1000} = 7.958 \times 10^{-6} \approx 8 \mu F$$

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

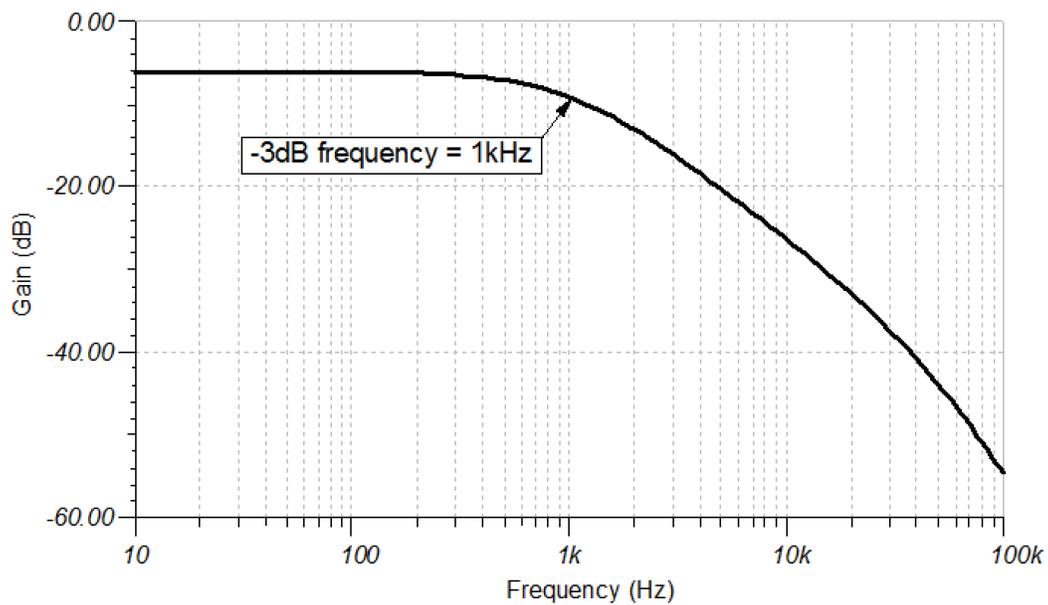
### DC Analysis Simulation Results

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



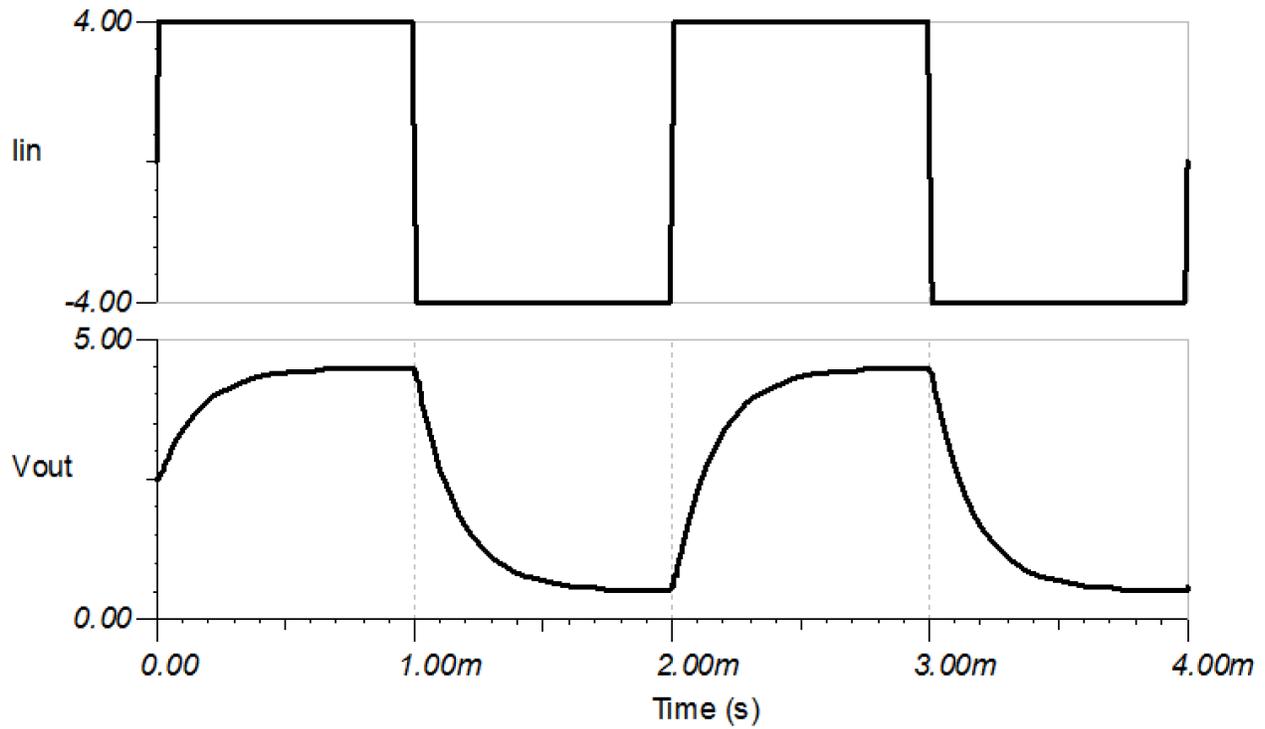
### AC Analysis Simulation Results

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"

## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](http://ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2022, Texas Instruments Incorporated