Analog Engineer's Circuit Amplifiers

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

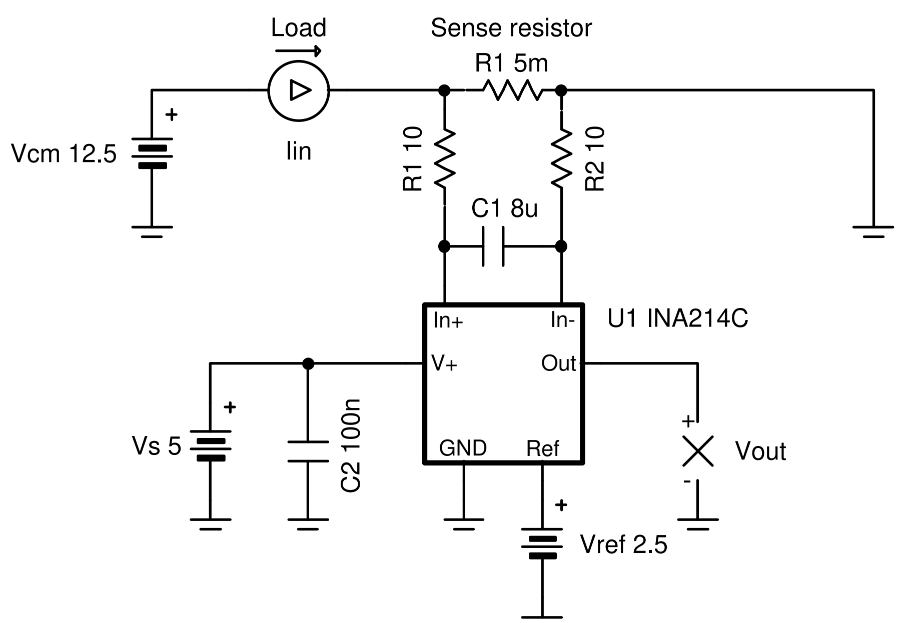
TEXAS INSTRUMENTS

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 10Ω, 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 = 5mΩ, 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 = 5mΩ, 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 $R_1 = R_2 = 10\Omega$:

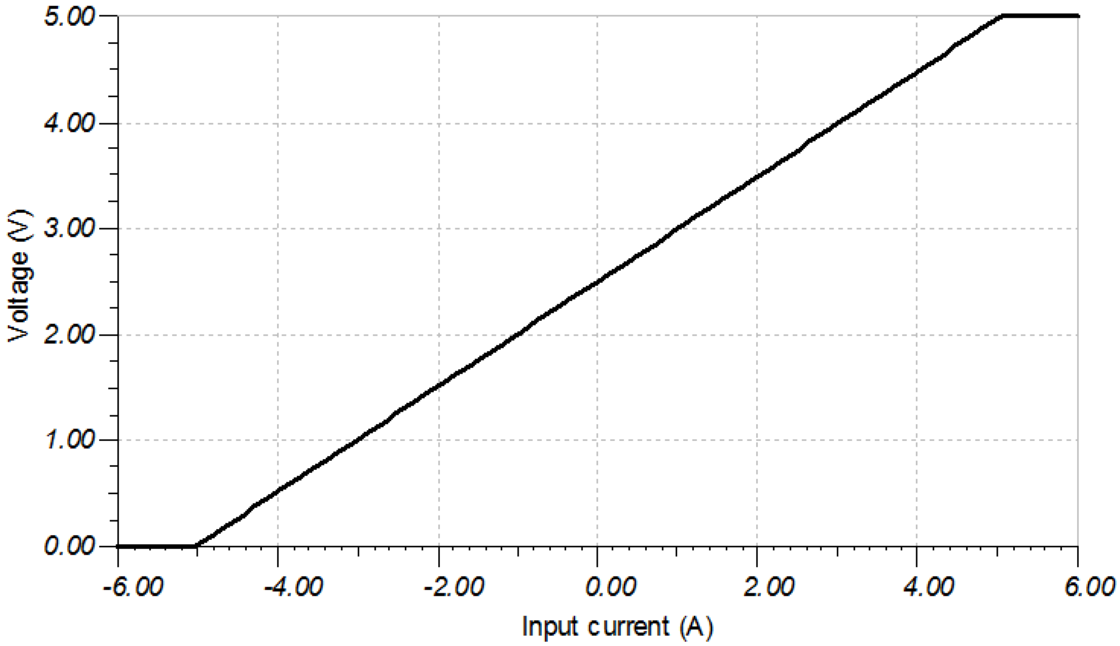
   $$C_1 = \frac{1}{2\pi(R_1 + R_2)F_{-3dB}} = \frac{1}{2\pi(10 + 10)1000} = 7.958 \times 10^{-6} \approx 8\,\mu F$$

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

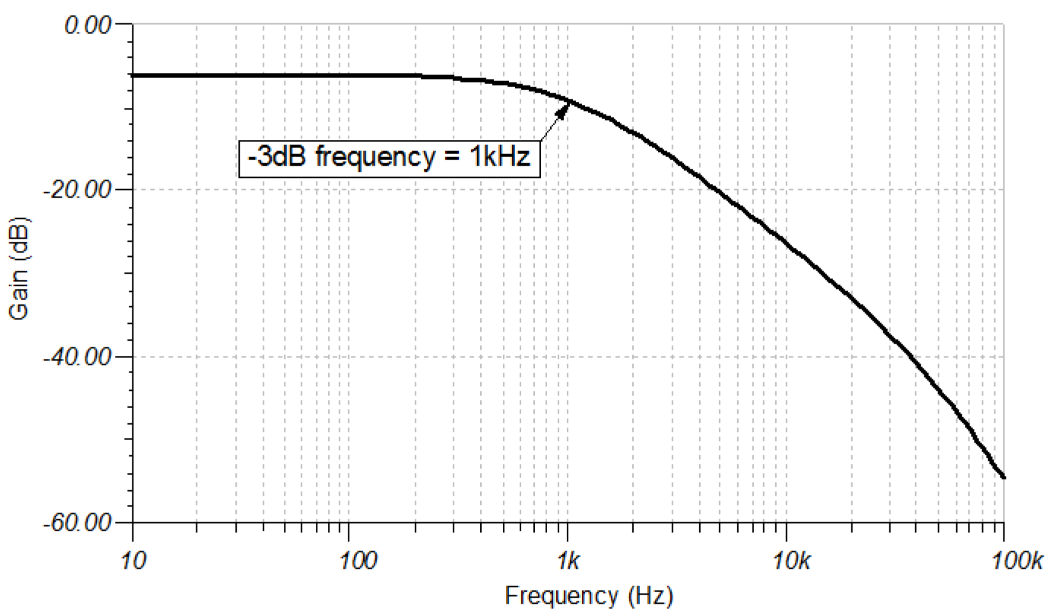
DC Analysis Simulation Results

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



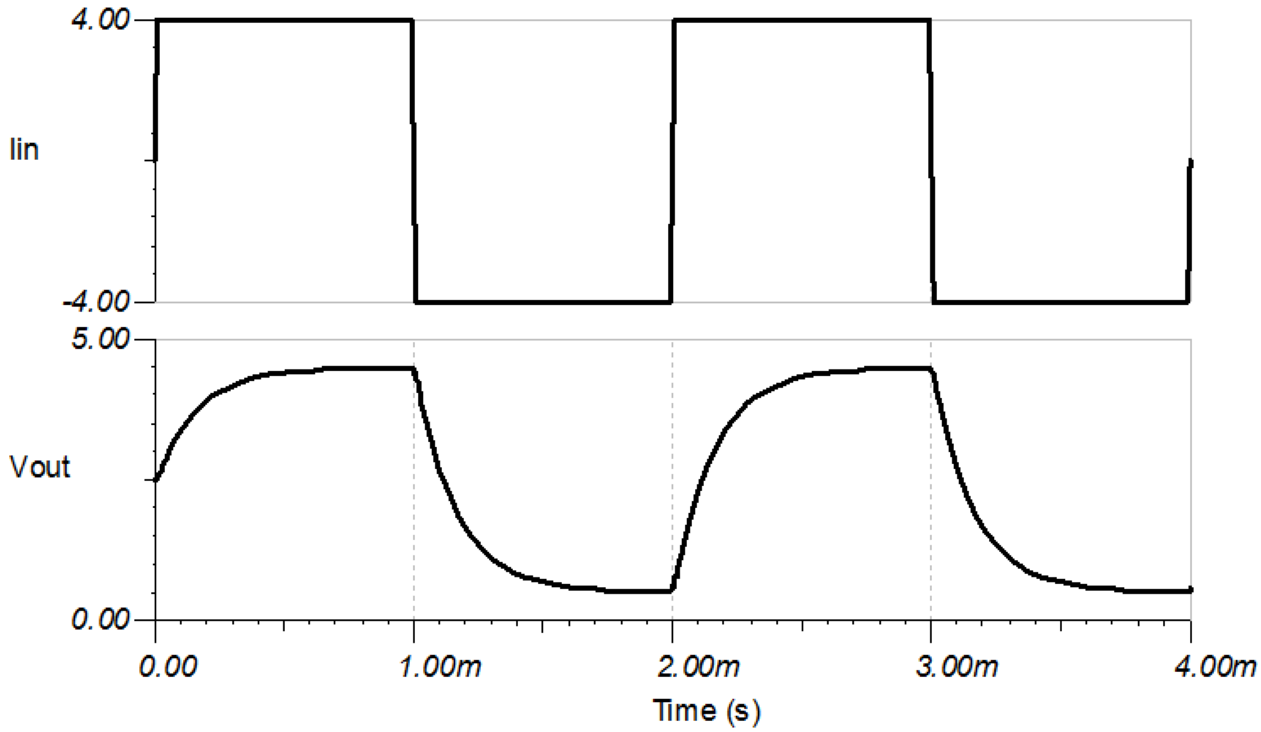
AC Analysis Simulation Results

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}	±1μV typical
I_q	65μA typical
I_b	28μA typical
http://www.ti.com/product/INA214	

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}	±5μV typical
I_q	65μA typical
I_b	28μA typical
http://www.ti.com/product/INA199	

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}	±100μV typical
I_q	65μA typical
I_b	195μA typical
http://www.ti.com/product/INA181	

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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