Analog Engineer's Circuit

Low-Side, Bidirectional Current Sensing Circuit

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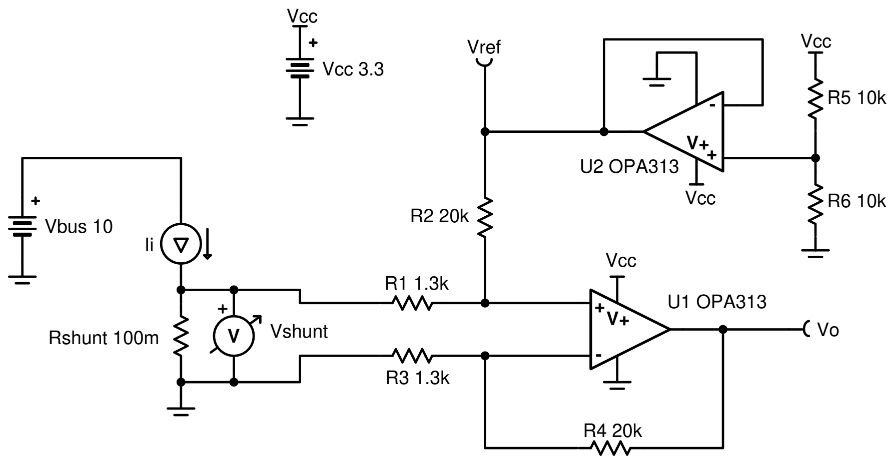
Design Goals

Input		Output		Supply		
I_{iMin}	I_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}	V_{ref}
–1A	1A	110mV	3.19V	3.3V	0V	1.65V

Design Description

This single-supply low-side, bidirectional current sensing solution can accurately detect load currents from –1A to 1A. The linear range of the output is from 110mV to 3.19V. Low-side current sensing keeps the common-mode voltage near ground, and is thus most useful in applications with large bus voltages.



Design Notes

1. To minimize errors, set $R_3 = R_1$ and $R_4 = R_2$.
2. Use precision resistors for higher accuracy.
3. Set output range based on linear output swing (see A_{ol} specification).
4. Do not use low-side sensing in applications where the system load cannot withstand small ground disturbances or in applications that need to detect load shorts.

Design Steps

1. Determine the transfer equation given $R_4 = R_2$ and $R_1 = R_3$.

$$V_o = \left(I_i \times R_{shunt} \times \frac{R_4}{R_3}\right) + V_{ref}$$

$$V_{ref} = V_{cc} \times \left(\frac{R_6}{R_5 + R_6}\right)$$

2. Determine the maximum shunt resistance.

$$R_{shunt} = \frac{V_{shunt}}{I_{imax}} = \frac{100mV}{1\ \ A} = 100m\Omega$$

3. Set reference voltage. Since the input current range is symmetric, set the reference to mid supply. Therefore, make R_5 and R_6 equal.

$$R_5 = R_6 = 10k\Omega$$

4. Set the difference amplifier gain based on the op amp output swing. The op amp output can swing from 100mV to 3.2V, given a 3.3-V supply.

$$Gain = \frac{V_{oMax} - V_{oMin}}{R_{shunt} \times (I_{iMax} - I_{iMin})} = \frac{3.2\ V - 100mV}{100m\Omega \times (1\ \ A - (-1\ \ A))} = 15.5\ \frac{V}{V}$$

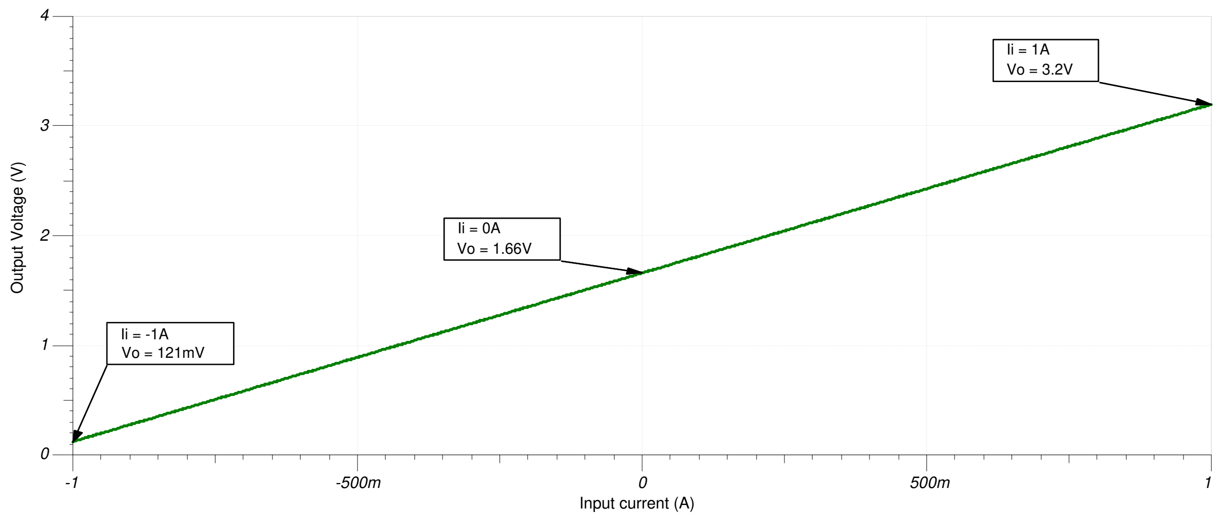
$$Gain = \frac{R_4}{R_3} = 15.5\ \frac{V}{V}$$

$$\text{Choose } R_1 = R_3 = 1.3k\Omega \text{ (Standard Value)}$$

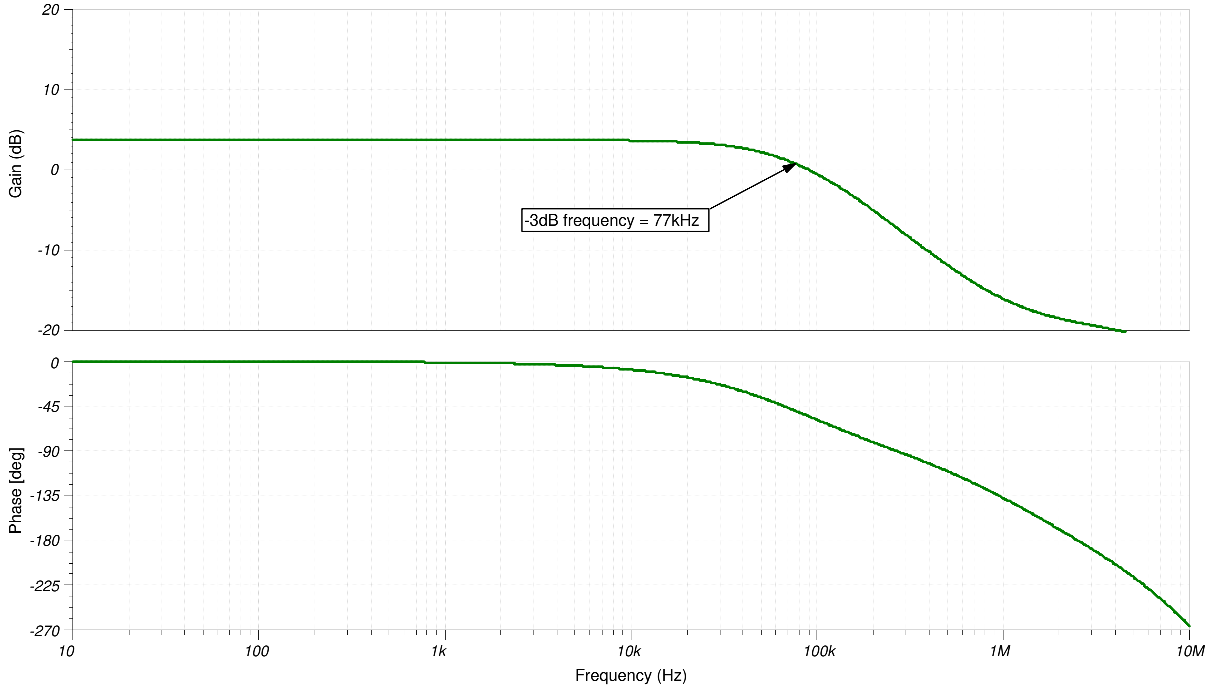
$$R_2 = R_4 = 15.5\frac{V}{V} \times 1.3k\Omega = 20.15\ k\Omega \approx 20k\Omega \text{ (Standard Value)}$$

Design Simulations

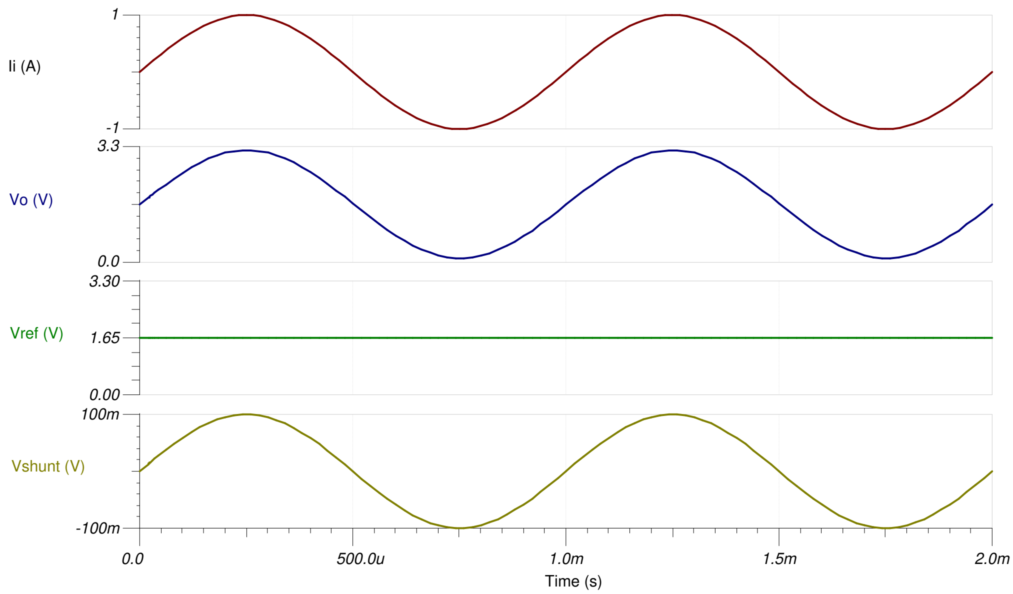
DC Simulation Results



Closed Loop AC Simulation Results



Transient Simulation Results



Design References

Texas Instruments, *Simulation for Low-Side Bidirectional Current-Sensing Circuit*, circuit SPICE simulation file

Texas Instruments, *±1A Single-Supply Low-Side Current Sensing Solution*, reference design

Design Featured Op Amp

OPA313	
V_{cc}	1.8V to 5.5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	500µV
I_q	50µA/Ch
I_b	0.2pA
UGBW	1MHz
SR	0.5V/µs
#Channels	1, 2, 4
OPA313	

Design Alternate Op Amp

	TLV9062	OPA376
V_{cc}	1.8V to 5.5V	2.2V to 5.5V
V_{inCM}	Rail-to-rail	Rail-to-rail
V_{out}	Rail-to-rail	Rail-to-rail
V_{os}	300µV	5µV
I_q	538µA/Ch	760µA/Ch
I_b	0.5pA	0.2pA
UGBW	10MHz	5.5MHz
SR	6.5V/µs	2V/µs
#Channels	1, 2, 4	1, 2, 4
	TLV9062	OPA376

For battery-operated or power-conscious designs, outside of the original design goals described earlier, where lowering total system power is desired.

LPV821	
V_{cc}	1.7V to 3.6V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	1.5µV
I_q	650nA/Ch
I_b	7pA
UGBW	8KHz
SR	3.3V/ms
#Channels	1
LPV821	

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Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision B (January 2019) to Revision C (October 2024)	Page
• Updated the format for tables, figures, and cross-references throughout the document	1

Changes from Revision A (May 2018) to Revision B (January 2019)	Page
• Downscale the title	1
• Added link to circuit cookbook landing page	1

Changes from Revision * (February 2018) to Revision A (May 2018)	Page
• Changed title role to *Amplifiers*	1
• Added SPICE simulation file link	1
• Added LPV821 as a *Design Alternate Op Amp* for battery-operated or power-conscious designs	1