*Analog Engineer's Circuit*

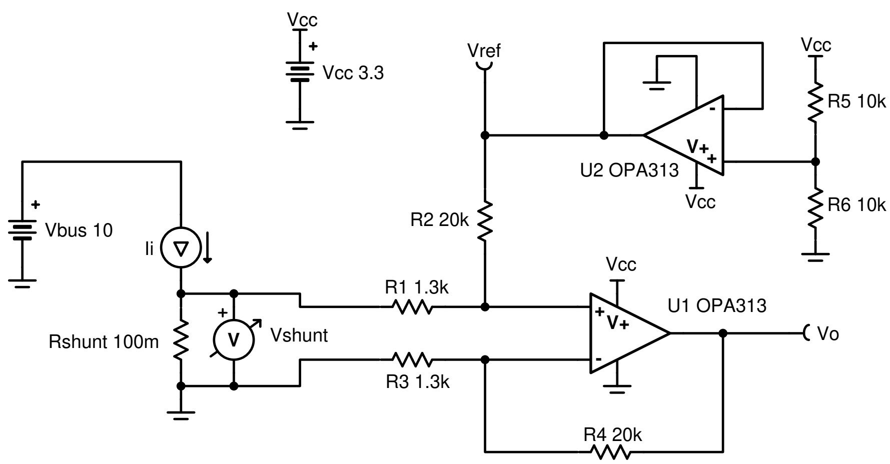
# ***Low-side, bidirectional current sensing circuit***

## 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. 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.

### 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.
   a. Since the input current range is symmetric, the reference should be set 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.

$$\text{Gain} = \frac{V_{oMax} - V_{oMin}}{R_{shunt} \times (I_{iMax} - I_{iMin})} = \frac{3\ .2\ V - 100mV}{100m\Omega \times (1\ \ A - (-1\ \ A))} = 15\ .5\ \frac{V}{V}$$

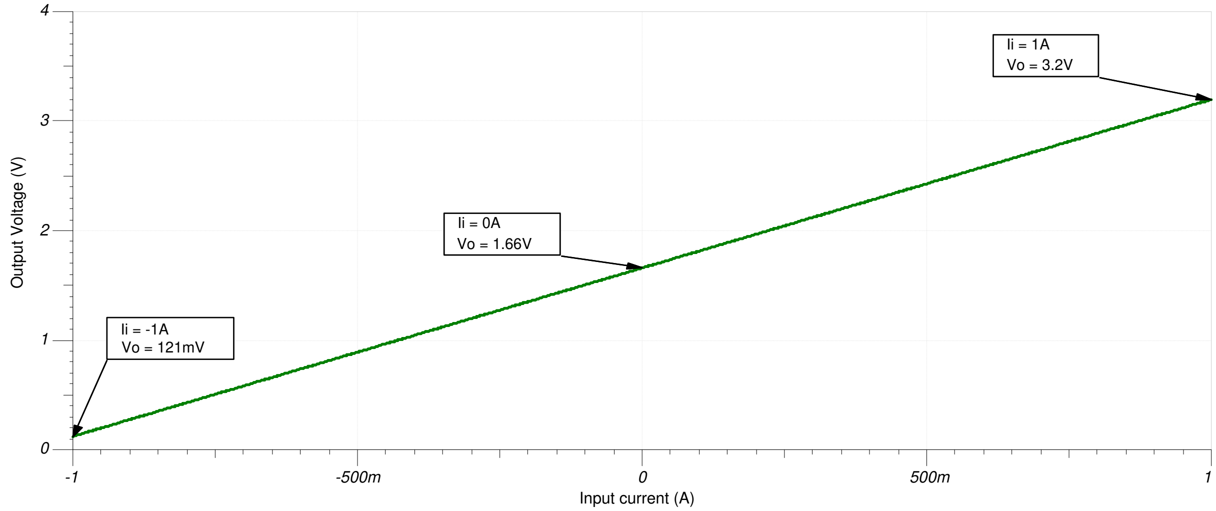
$$\text{Gain} = \frac{R_4}{R_3} = 15\ .5\ \frac{V}{V}$$

$$\text{Choose } R_1 = R_3 = 1\ .\ 3k\Omega \text{ (Standard Value)}$$

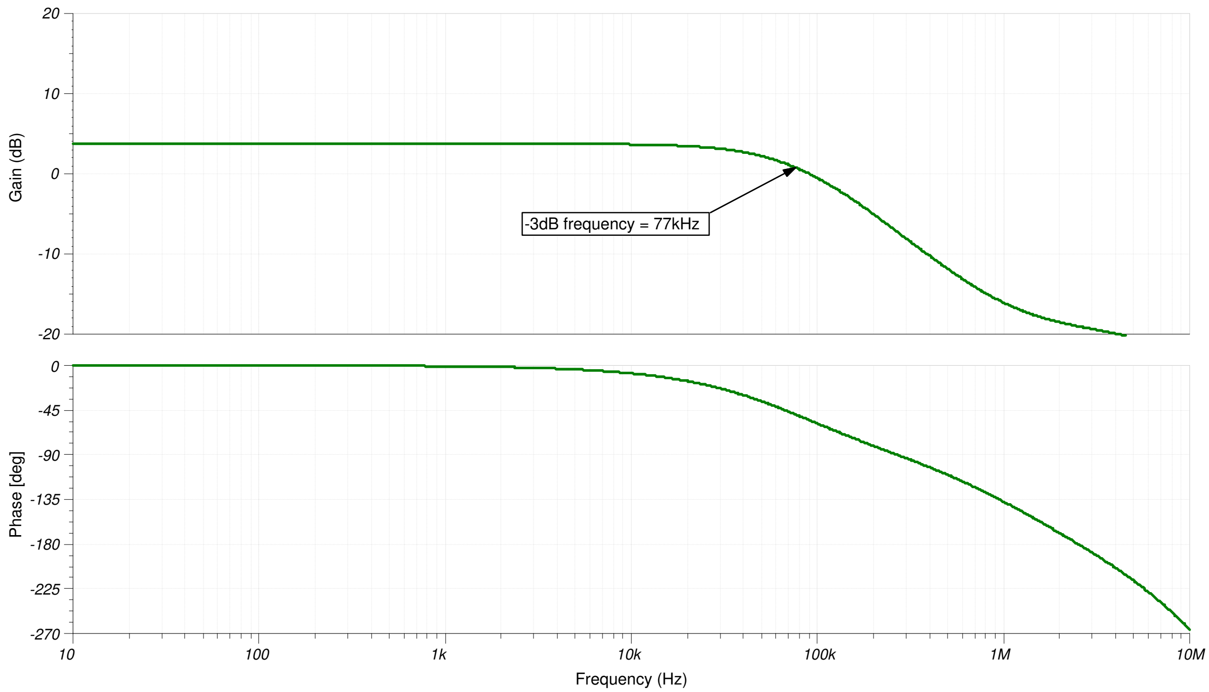
$$R_2 = R_4 = 15\ .\ 5\frac{V}{V} \times 1\ .\ 3k\Omega = 20\ .15\ k\Omega \approx 20k\Omega \text{ (Standard Value)}$$

## Design Simulations

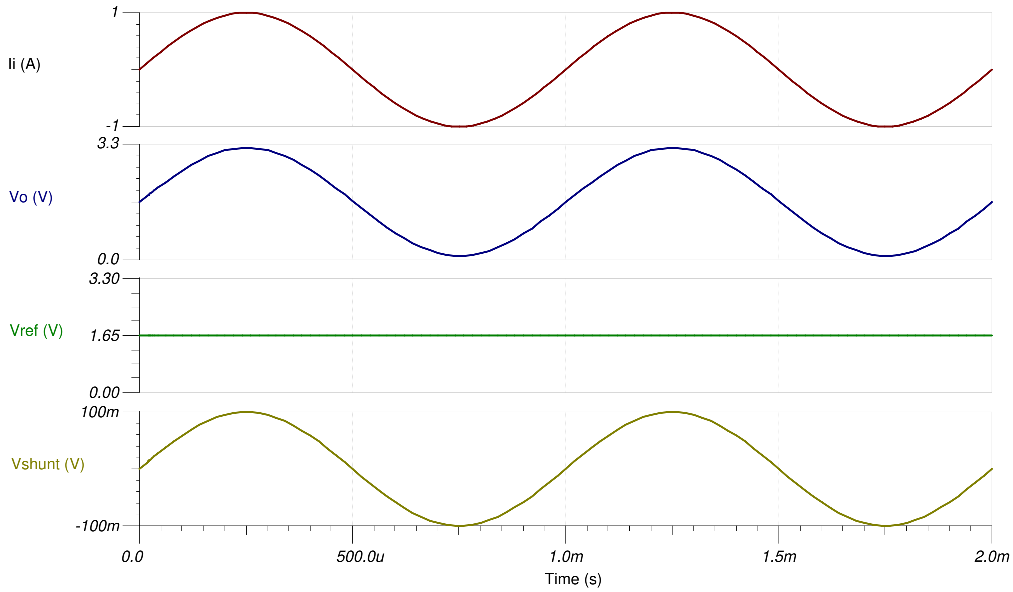
### DC Simulation Results




### Closed Loop AC Simulation Results



## Transient Simulation Results



### Design References

See *Analog Engineer's Circuit Cookbooks* for TI's comprehensive circuit library.

See circuit SPICE simulation file SBOC500.

See TIPD175, www.ti.com/tipd175.

### 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 |
| www.ti.com/product/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 |
| | www.ti.com/product/tlv9062 | www.ti.com/product/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 |
| www.ti.com/product/lpv821 | |

## Revision History

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

**Changes from Revision A (May 2018) to Revision B (January 2019)** **Page**

- Downscale the title ........ 1
- Added link to the 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