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

### Design Goals

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
<th>Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_{\text{Min}} )</td>
<td>( I_{\text{Max}} )</td>
<td>( V_{\text{dMin}} )</td>
</tr>
<tr>
<td>1A</td>
<td>1A</td>
<td>110mV</td>
</tr>
</tbody>
</table>

### Design Description

This single-supply low-side, bidirectional current sensing solution can accurately detect load currents from \(-1\text{A}\) to \(1\text{A}\). 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 \( A_{\text{ol}} \) 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 $R_1 = R_3$.
   \[
   V_o = (I_1 \times R_{\text{shunt}} \times \frac{R_1}{R_3}) + V_{\text{ref}}
   \]
   \[
   V_{\text{ref}} = V_{\text{cc}} \times \left( \frac{R_s}{R_3 + R_s} \right)
   \]

2. Determine the maximum shunt resistance.
   \[
   R_{\text{shunt}} = \frac{V_{\text{shunt}}}{I_{\text{max}}} = \frac{100\text{mV}}{1\text{ A}} = 100\text{mΩ}
   \]

   a. Since the input current range is symmetric, the reference should be set to mid supply. Therefore, make $R_5$ and $R_6$ equal.
      \[
      R_5 = R_6 = 10\text{kΩ}
      \]

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.
   \[
   \text{Gain} = \frac{V_{\text{gain}} - V_{\text{gain}}}{R_{\text{shunt}} \times (I_{\text{max}} - I_{\text{min}})} = \frac{3.2\text{V} - 100\text{mV}}{100\text{mΩ} \times (1\text{ A} - (-1\text{ A})}) = 15.5 \frac{\text{V}}{\text{V}}
   \]
   \[
   \text{Gain} = \frac{R_4}{R_1} = 15.5 \frac{\text{V}}{\text{V}}
   \]
   Choose $R_1 = R_3 = 1.3\text{kΩ}$ (Standard Value)
   \[
   R_2 = R_4 = 15.5 \times 1.3\text{kΩ} = 20.15\text{kΩ} \approx 20\text{kΩ}$ (Standard Value)
Design Simulations

DC Simulation Results

Closed Loop AC Simulation Results
Transient Simulation Results

![Graph showing transient simulation results for current (Ii), output voltage (Vo), reference voltage (Vref), and shunt voltage (Vshunt) over time (s).]
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

<table>
<thead>
<tr>
<th>OPA313</th>
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<tbody>
<tr>
<td>$V_{cc}$</td>
<td>1.8V to 5.5V</td>
</tr>
<tr>
<td>$V_{icm}$</td>
<td>Rail-to-rail</td>
</tr>
<tr>
<td>$V_{out}$</td>
<td>Rail-to-rail</td>
</tr>
<tr>
<td>$V_{os}$</td>
<td>500µV</td>
</tr>
<tr>
<td>$I_{q}$</td>
<td>50µA/Ch</td>
</tr>
<tr>
<td>$I_{b}$</td>
<td>0.2pA</td>
</tr>
<tr>
<td>UGBW</td>
<td>1MHz</td>
</tr>
<tr>
<td>SR</td>
<td>0.5V/µs</td>
</tr>
<tr>
<td>#Channels</td>
<td>1, 2, 4</td>
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</tbody>
</table>

www.ti.com/product/opa313

Design Alternate Op Amp

<table>
<thead>
<tr>
<th>TLV9062</th>
<th>OPA376</th>
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</thead>
<tbody>
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<td>1.8V to 5.5V</td>
</tr>
<tr>
<td>$V_{icm}$</td>
<td>Rail-to-rail</td>
</tr>
<tr>
<td>$V_{out}$</td>
<td>Rail-to-rail</td>
</tr>
<tr>
<td>$V_{os}$</td>
<td>300µV</td>
</tr>
<tr>
<td>$I_{q}$</td>
<td>538µA/Ch</td>
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<tr>
<td>$I_{b}$</td>
<td>0.5pA</td>
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<tr>
<td>UGBW</td>
<td>10MHz</td>
</tr>
<tr>
<td>SR</td>
<td>6.5V/µs</td>
</tr>
<tr>
<td>#Channels</td>
<td>1, 2, 4</td>
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</tbody>
</table>


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

<table>
<thead>
<tr>
<th>LPV821</th>
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<tbody>
<tr>
<td>$V_{cc}$</td>
<td>1.7V to 3.6V</td>
</tr>
<tr>
<td>$V_{icm}$</td>
<td>Rail-to-rail</td>
</tr>
<tr>
<td>$V_{out}$</td>
<td>Rail-to-rail</td>
</tr>
<tr>
<td>$V_{os}$</td>
<td>1.5µV</td>
</tr>
<tr>
<td>$I_{q}$</td>
<td>650nA/Ch</td>
</tr>
<tr>
<td>$I_{b}$</td>
<td>7pA</td>
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<tr>
<td>UGBW</td>
<td>8KHz</td>
</tr>
<tr>
<td>SR</td>
<td>3.3V/µs</td>
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<tr>
<td>#Channels</td>
<td>1</td>
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www.ti.com/product/lpv821
## Revision History

<table>
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<tr>
<th>Revision</th>
<th>Date</th>
<th>Change</th>
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<tbody>
<tr>
<td>B</td>
<td>January 2019</td>
<td>Downscale the title. Added link to circuit cookbook landing page.</td>
</tr>
<tr>
<td>A</td>
<td>May 2018</td>
<td>Changed title role to 'Amplifiers'. Added SPICE simulation file link. Added LPV821 as a Design Alternate Op Amp for battery-operated or power-conscious designs.</td>
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