High-side current-sensing circuit design

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{ViMin}} )</td>
</tr>
<tr>
<td>50mA</td>
<td>1A</td>
<td>0.25V</td>
</tr>
</tbody>
</table>

Design Description

This single-supply, high-side, low-cost current sensing solution detects load current between 50mA and 1A and converts it to an output voltage from 0.25V to 5V. High-side sensing allows the system to identify ground shorts and does not create a ground disturbance on the load.

Design Notes

1. DC common mode rejection ratio (CMRR) performance is dependent on the matching of the gain setting resistors, \( R_2 - R_5 \).
2. Increasing the shunt resistor increases power dissipation.
3. Ensure that the common-mode voltage is within the linear input operating region of the amplifier. The common-mode voltage is set by the resistor divider formed by \( R_2, R_3 \), and the bus voltage. Depending on the common-mode voltage determined by the resistor divider a rail-to-rail input (RRI) amplifier may not be required for this application.
4. An op amp that does not have a common-mode voltage range that extends to \( V_{\text{cc}} \) may be used in low-gain or an attenuating configuration.
5. A capacitor placed in parallel with the feedback resistor will limit bandwidth, improve stability, and help reduce noise.
6. Use the op amp in a linear output operating region. Linear output swing is usually specified under the \( A_{\text{OL}} \) test conditions.
Design Steps

1. The full transfer function of the circuit is provided below.

\[ V_o = I_i R_1 \frac{R_7}{R_4} \]

Given \( R_2 = R_4 \) and \( R_3 = R_5 \)

2. Calculate the maximum shunt resistance. Set the maximum voltage across the shunt to 100mV.

\[ R_1 = \frac{V_{\text{shunt}}}{I_{\text{shunt}}} = \frac{100\text{mV}}{1\text{A}} = 100\text{m}\Omega \]

3. Calculate the gain to set the maximum output swing range.

\[ \text{Gain} = \frac{V_{\text{shunt}} - V_{\text{out}}}{(V_{\text{shunt}} - V_{\text{out}}) \times R_1} = \frac{5\text{V} - 0.25\text{V}}{(1\text{A} - 0.05\text{A}) \times 100\text{m}\Omega} = 50\frac{\text{V}}{\text{V}} \]

4. Calculate the gain setting resistors to set the gain calculated in step 3.

Choose \( R_2 = R_4 = 1.01\text{k}\Omega \) (Standard value)

\( R_3 = R_5 = R_2 \times \text{Gain} = 1.01\text{k}\Omega \times 50\frac{\text{V}}{\text{V}} = 50.5\text{k}\Omega \) (Standard value)

5. Calculate the common–mode voltage of the amplifier to ensure linear operation.

\[ V_{\text{cm}} = \frac{V_{\text{CC}} \times R_3}{R_2 + R_3} = 36\text{V} \times \frac{50.5\text{k}\Omega}{1.01\text{k}\Omega + 50.5\text{k}\Omega} = 35.294\text{V} \]

6. The upper cutoff frequency \( (f_u) \) is set by the non–inverting gain (noise gain) of the circuit and the gain bandwidth (GBW) of the op amp.

\[ f_u = \frac{\text{GBW}}{\text{Noise Gain}} = \frac{10\text{MHz}}{51\text{V}} = 196.1\text{kHz} \]
Design Simulations

DC Simulation Results

AC Simulation Results
References:
1. Analog Engineer’s Circuit Cookbooks
2. SPICE Simulation File SBOMAV4
3. TI Precision Labs

Design Featured Op Amp

<table>
<thead>
<tr>
<th>Parameter</th>
<th>OPA192</th>
<th>OPA2990</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{cc}$</td>
<td>4.5V to 36V</td>
<td>2.7V to 40V</td>
</tr>
<tr>
<td>$V_{inCM}$</td>
<td>Rail-to-rail</td>
<td>Rail-to-rail</td>
</tr>
<tr>
<td>$V_{out}$</td>
<td>Rail-to-rail</td>
<td></td>
</tr>
<tr>
<td>$V_{os}$</td>
<td>5µV</td>
<td>250µV</td>
</tr>
<tr>
<td>$I_q$</td>
<td>1mA</td>
<td>120µA</td>
</tr>
<tr>
<td>$I_b$</td>
<td>5pA</td>
<td>10pA</td>
</tr>
<tr>
<td>UGBW</td>
<td>10MHz</td>
<td>1.25MHz</td>
</tr>
<tr>
<td>SR</td>
<td>20V/µs</td>
<td>5V/µs</td>
</tr>
<tr>
<td>#Channels</td>
<td>1, 2, 4</td>
<td>2</td>
</tr>
</tbody>
</table>

www.ti.com/product/OPA192
www.ti.com/product/OPA2990

Design Alternate Op Amp

Revision History

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Change</th>
</tr>
</thead>
</table>
IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), 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, 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 (www.ti.com/legal/termsofsale.html) or other applicable terms available either on 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.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2019, Texas Instruments Incorporated