3-decade, load-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>$V_{\text{out,min}}$</td>
</tr>
<tr>
<td>10μA</td>
<td>10mA</td>
<td>100mV</td>
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</tbody>
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Design Description

This single-supply, low-side, current-sensing solution accurately detects load current between 10μA and 10mA. A unique yet simple gain switching network was implemented to accurately measure the three-decade load current range.

Design Notes

1. Use a maximum shunt resistance to minimize relative error at minimum load current.
2. Select 0.1% tolerance resistors for $R_1$, $R_2$, $R_3$, and $R_4$ in order to achieve approximately 0.1% FSR gain error.
3. Use a switch with low on-resistance ($R_{\text{on}}$) to minimize interaction with feedback resistances, preserving gain accuracy.
4. Minimize capacitance on INA326 gain setting pins.
5. Scale the linear output swing based on the gain error specification.
Design Steps

1. Define full-scale shunt resistance.
   \[ R_1 = \frac{V_{\text{Max}}}{I_{\text{Max}}} = \frac{250\text{mV}}{10\text{mA}} = 25\Omega \]

2. Select gain resistors to set output range.
   \[ G_{\text{Max}} = \frac{V_{\text{Max}}}{V_{\text{Max}}} = \frac{V_{\text{Max}}}{R_1 \times I_{\text{Max}}} = \frac{4.9\text{V}}{25\Omega \times 10\text{mA}} = 19.6\text{V} \]
   \[ G_{\text{Min}} = \frac{V_{\text{Min}}}{V_{\text{Min}}} = \frac{V_{\text{Min}}}{R_1 \times I_{\text{Min}}} = \frac{100\text{mV}}{25\Omega \times 10\mu\text{A}} = 400\text{V} \]
   \[ R_2 = \frac{R_1 \times G_{\text{Min}}}{2} = \frac{50\Omega \times 400\text{V}}{2} = 10\text{M}\Omega \]
   \[ R_2 \parallel R_3 = \frac{R_2 \times R_3}{R_2 + R_3} = \frac{50\Omega \times 19.6\text{V}}{50\Omega + 400\text{V}} = 490\text{k}\Omega \]
   \[ R_3 = \frac{490\text{k}\Omega \times R_2}{R_3 - 490\text{k}\Omega} = 515.25\text{k}\Omega \approx 511\text{k}\Omega \text{ (Standard Value)} \]

3. Select a capacitor for the output filter.
   \[ f_p = \frac{1}{2 \pi R_2 \times C_4} = \frac{1}{2 \pi \times 100\Omega \times 1\mu\text{F}} = 1.59\text{kHz} \]

4. Select a capacitor for gain and filtering network.
   \[ C_2 = \frac{1}{2 \pi \times R_3 \times f_p} = \frac{1}{2 \pi \times 10\text{M}\Omega \times 1.59\text{kHz}} = 10\text{pF} \]
   \[ C_3 = \frac{1}{2 \pi \times (R_2 \times R_3) \times f_p} - C_2 = \frac{1}{2 \pi \times (10\text{M}\Omega \times 511\text{k}\Omega) \times 1.59\text{kHz}} - 10\text{pF} \]
   \[ C_3 = 196\text{pF} \approx 194\text{pF} \text{ (Standard Value)} \]
Design Simulations

DC Simulation Results

![DC Simulation Results Graph]

AC Simulation Results

![AC Simulation Results Graph]
Design References

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

See circuit SPICE simulation file SBOC498.


Design Featured Op Amp

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<thead>
<tr>
<th>INA326</th>
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<tbody>
<tr>
<td>$V_{ss}$</td>
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<tr>
<td>$V_{inCM}$</td>
</tr>
<tr>
<td>$V_{out}$</td>
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<tr>
<td>$V_{os}$</td>
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<tr>
<td>$I_{q}$</td>
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<tr>
<td>$I_{b}$</td>
</tr>
<tr>
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</tr>
<tr>
<td>SR</td>
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<tr>
<td>#Channels</td>
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www.ti.com/product/ina326

Revision History

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Change</th>
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<tbody>
<tr>
<td>A</td>
<td>January 2019</td>
<td>Downscale the title and changed title role to 'Amplifiers'. Added link to circuit cookbook landing page.</td>
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