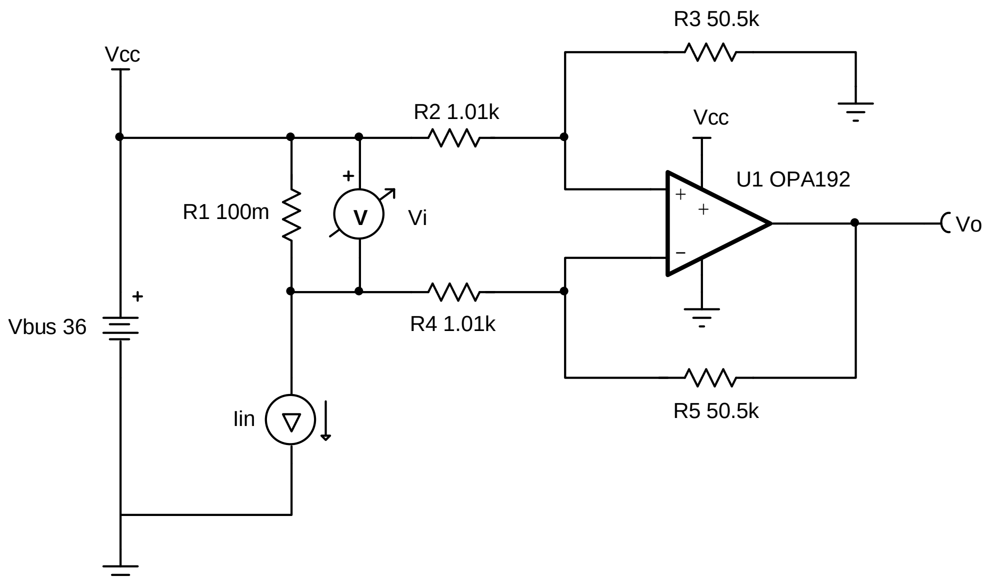
High-side current-sensing circuit design

Design Goals

Input		Output		Supply	
I_{iMin}	I_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}
50mA	1A	0.25V	5V	36V	0V

Design Description

This single–supply, high–side, low–cost current sensing solution detects load current between 50mA and 1A and converters it to an output voltage from 0.25V to 5V. High–side sensing allows for 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_{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_{OL} test conditions.

Design Steps

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

   $$V_o = I_{in} \times R_1 \times \frac{R_5}{R_4}$$

   $$\text{Given} \quad R_2 = R_4 \quad \text{and} \quad R_3 = R_5$$

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

   $$R_1 = \frac{V_{iMax}}{I_{iMax}} = \frac{100mV}{1A} = 100m\Omega$$

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

   $$Gain = \frac{V_{oMax} - V_{oMin}}{(I_{iMax} - I_{iMin}) \times R_1} = \frac{5V - 0.25V}{(1A - 0.05A) \times 100m\Omega} = 50\frac{V}{V}$$

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

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

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

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

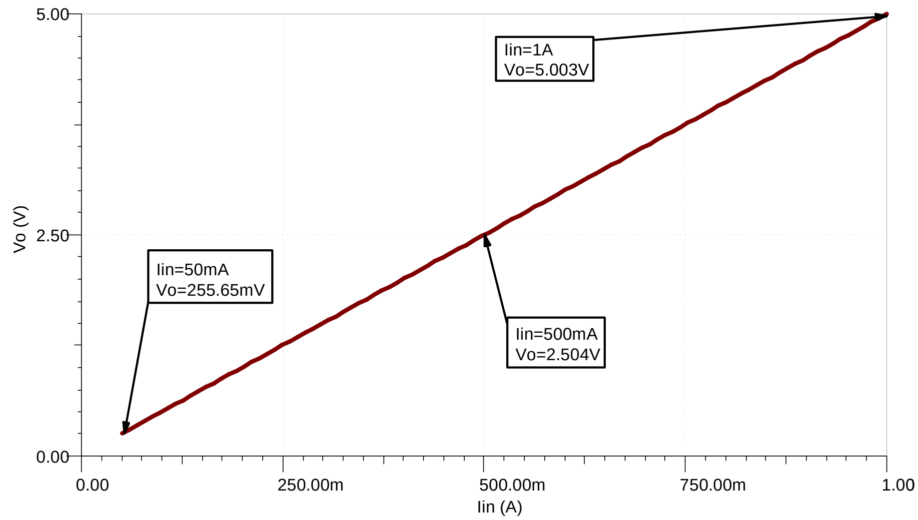
   $$V_{cm} = V_{CC} \times \frac{R_3}{R_2 + R_3} = 36V \times \frac{50.5k}{1.01k + 50.5k} = 35.294\,V$$

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

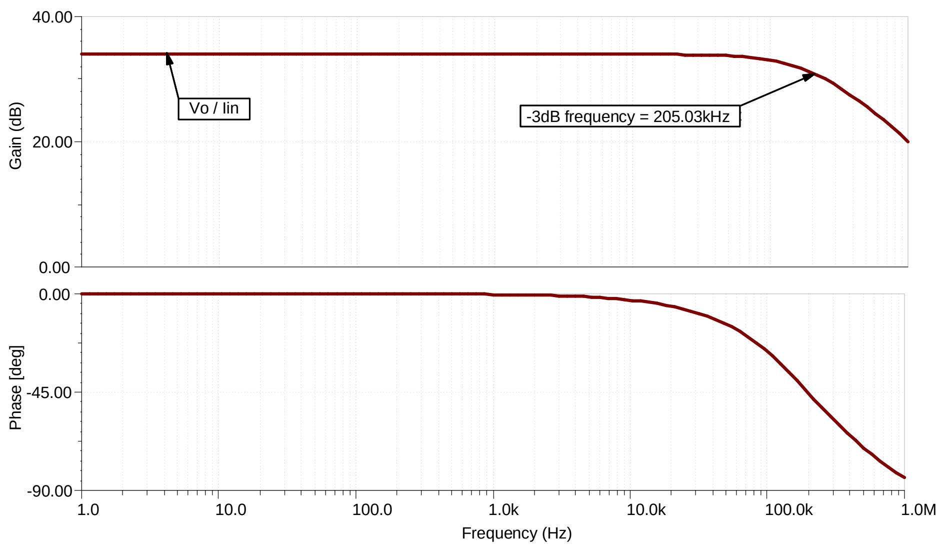
   $$f_H = \frac{GBW}{\text{Noise Gain}} = \frac{10MHz}{51\frac{V}{V}} = 196.1 \; kHz$$

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

OPA192	
V_{cc}	4.5V to 36V
V_{inCM}	Rail–to–rail
V_{out}	Rail–to–rail
V_{os}	5µV
I_q	1mA
I_b	5pA
UGBW	10MHz
SR	20V/µs
#Channels	1, 2, 4
www.ti.com/product/OPA192	

Design Alternate Op Amp

OPA2990	
V_{cc}	2.7V to 40V
V_{inCM}	Rail–to–rail
V_{out}	Rail–to–rail
V_{os}	250µV
I_q	120µA
I_b	10pA
UGBW	1.25MHz
SR	5V/µs
#Channels	2
www.ti.com/product/OPA2990	

Revision History

Revision	Date	Change
A	February 2019	Downstyle title. Added *Design Alternate Op Amp* table.

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