Analog Engineer's Circuit

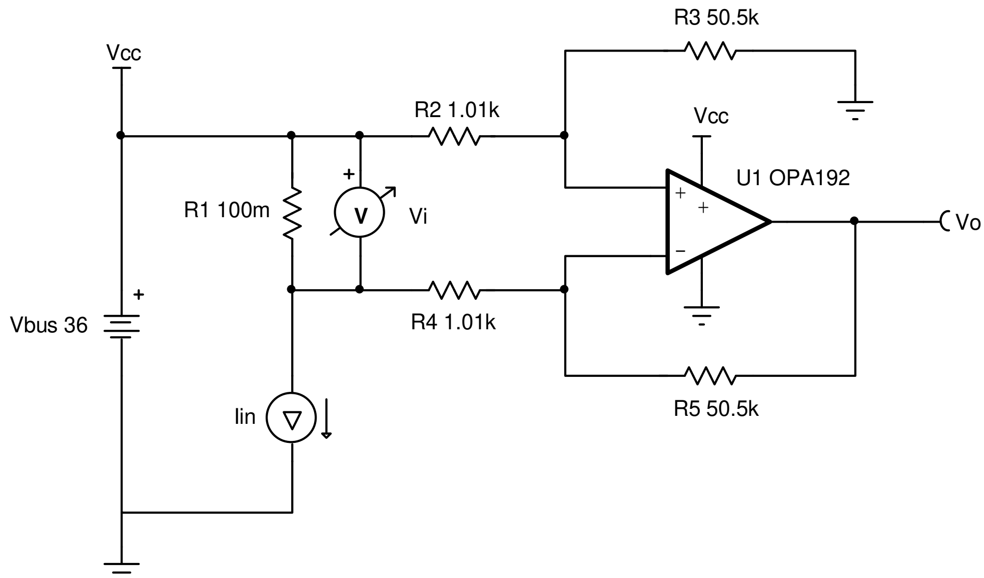
High-Side Current-Sensing Circuit Design

Design Goals

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

Design Description

This single–supply, high–side, low–cost current sensing solution detects load current between 50 mA and 1 A and converters it to an output voltage from 0.25 V to 5 V. 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 100 mV.

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

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

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

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

$$\text{Choose} \quad R_2 = R_4 = 1.01k\,\Omega \quad (\text{Standard value})$$
$$R_3 = R_5 = R_2 \times \text{Gain} = 1.01k\,\Omega \times 50\frac{V}{V} = 50.5k\,\Omega \; (\text{Standard value})$$

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

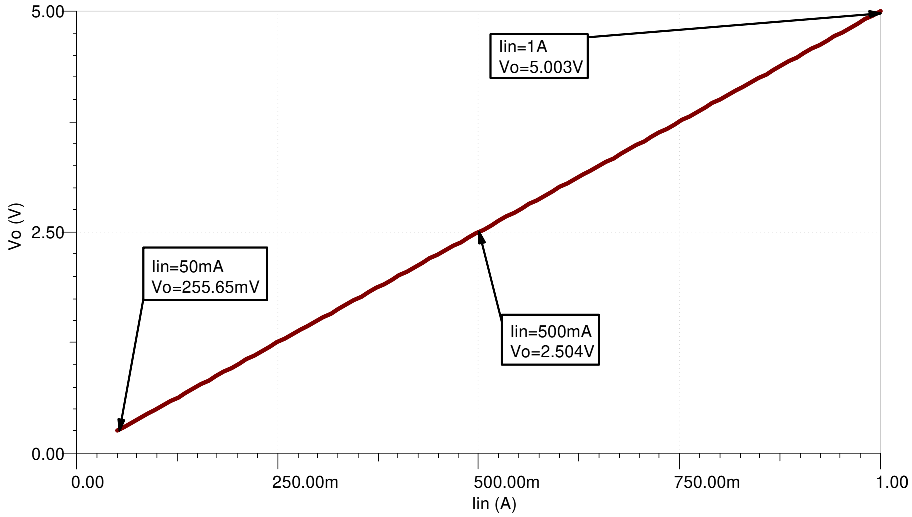
$$V_{cm} = V_{CC} \times \frac{R_3}{R_2 + R_3} = 36V \times \frac{50.5k}{1.01k + 50.5k} = 35.294\ V$$

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.

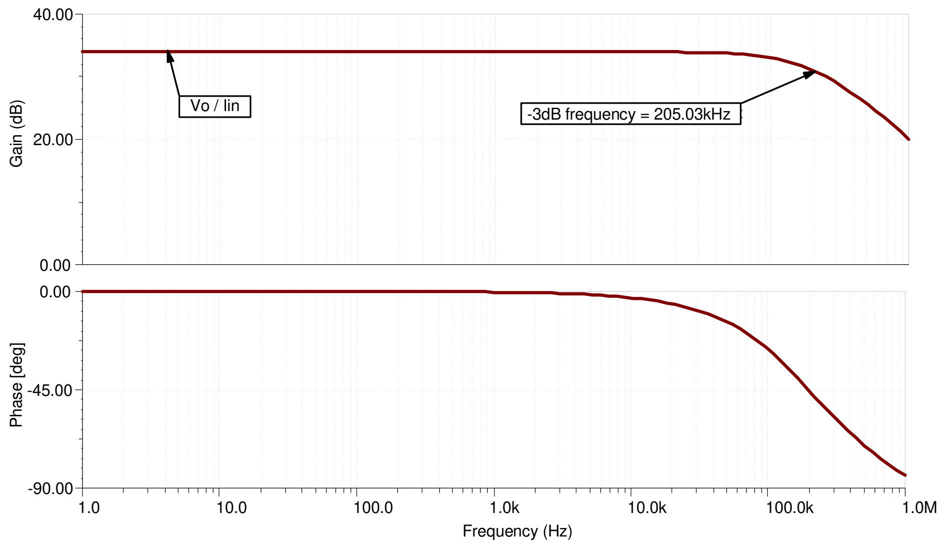
$$f_H = \frac{GBW}{\text{Noise Gain}} = \frac{10MHz}{51\frac{V}{V}} = 196.1\ \ kHz$$

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

Design Alternate Op Amp

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

Revision History

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

Changes from December 30, 2018 to February 13, 2019 **Page**

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