Analog Engineer's Circuit

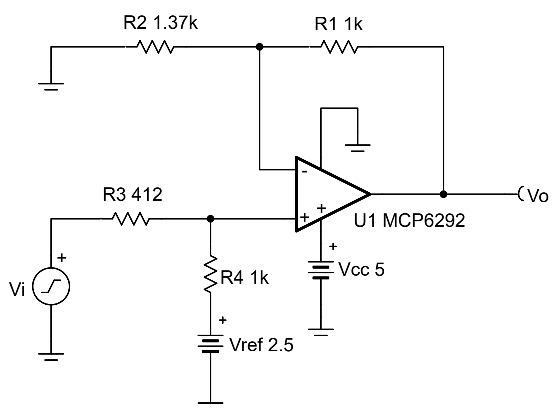
Non-Inverting Op Amp with Non-Inverting Positive Reference Voltage Circuit

Design Goals

Input		Output		Supply		
V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}	V_{ref}
–1 V	3 V	0.05 V	4.95 V	5 V	0 V	2.5 V

Design Description

This design uses a non-inverting amplifier with a non-inverting positive reference to translate an input signal of –1 V to 3 V to an output voltage of 0.05 V to 4.95 V. This circuit can be used to translate a sensor output voltage with a positive slope and negative offset to a usable ADC input voltage range.



Design Notes

1. Use op amp linear output operating range. Usually specified under A_{OL} test conditions.
2. Check op amp input common mode voltage range.
3. V_{ref} output must be low impedance.
4. Input impedance of the circuit is equal to the sum of R_3 and R_4.
5. Choose low-value resistors to use in the feedback. It is recommended to use resistor values less than 100 kΩ. Using high-value resistors can degrade the phase margin of the amplifier and introduce additional noise in the circuit.
6. The cutoff frequency of the circuit is dependent on the gain bandwidth product (GBP) of the amplifier.
7. Adding a capacitor in parallel with R_1 will improve stability of the circuit if high-value resistors are used.

Design Steps

$$V_o = V_i \times \left(\frac{R_4}{R_3 + R_4}\right)\left(\frac{R_1 + R_2}{R_2}\right) + V_{ref} \times \left(\frac{R_3}{R_3 + R_4}\right)\left(\frac{R_1 + R_2}{R_2}\right)$$

1. Calculate the gain of the input voltage to produce the desired output swing.

$$G_{input} = \left(\frac{R_4}{R_3 + R_4}\right)\left(\frac{R_1 + R_2}{R_2}\right)$$
$$V_{o\_max} - V_{o\_min} = (V_{i\_max} - V_{i\_min})\left(\frac{R_4}{R_3 + R_4}\right)\left(\frac{R_1 + R_2}{R_2}\right)$$
$$\frac{V_{o\_max} - V_{o\_min}}{V_{i\_max} - V_{i\_min}} = \left(\frac{R_4}{R_3 + R_4}\right)\left(\frac{R_1 + R_2}{R_2}\right)$$
$$\frac{4.95V - 0.05V}{3V - (-1V)} = \left(\frac{R_4}{R_3 + R_4}\right)\left(\frac{R_1 + R_2}{R_2}\right)$$
$$1.225V = \left(\frac{R_4}{R_3 + R_4}\right)\left(\frac{R_1 + R_2}{R_2}\right)$$

2. Select a value for R_1 and R_4 and insert the values into the previous equation. The other two resistor values must be solved using a system of equations. The proper output swing and offset voltage cannot be calculated if more than two variables are selected.

$$R_1 = R_4 = 1\ \ k\Omega$$
$$1.225V = \left(\frac{1\ \ k\Omega}{R_3 + 1\ \ k\Omega}\right)\left(\frac{1\ \ k\Omega + R_2}{R_2}\right)$$

3. Solve the previous equation for R_3 in terms of R_2.

$$R_3 = \frac{1\ \ M\Omega + (1\ \ k\Omega \times R_2)}{1.225 \times R_2} - 1\ \ k\Omega$$

4. Select any point along the transfer function within the linear output range of the amplifier to set the proper offset voltage at the output (for example, the minimum input and output voltage).

$$V_{o\_min} = V_{i\_min} \times \left(\frac{R_4}{R_3 + R_4}\right)\left(\frac{R_1 + R_2}{R_2}\right) + V_{ref} \times \left(\frac{R_3}{R_3 + R_4}\right)\left(\frac{R_1 + R_2}{R_2}\right)$$
$$0.05V = -1\ \ V \times \left(\frac{1\ \ k\Omega}{R_3 + 1\ \ k\Omega}\right)\left(\frac{1\ \ k\Omega + R_2}{R_2}\right) + 2.5V \times \left(\frac{R_3}{R_3 + 1\ \ k\Omega}\right)\left(\frac{1\ \ k\Omega + R_2}{R_2}\right)$$

5. Insert R_3 into the equation from step 1 and solve for R_2.

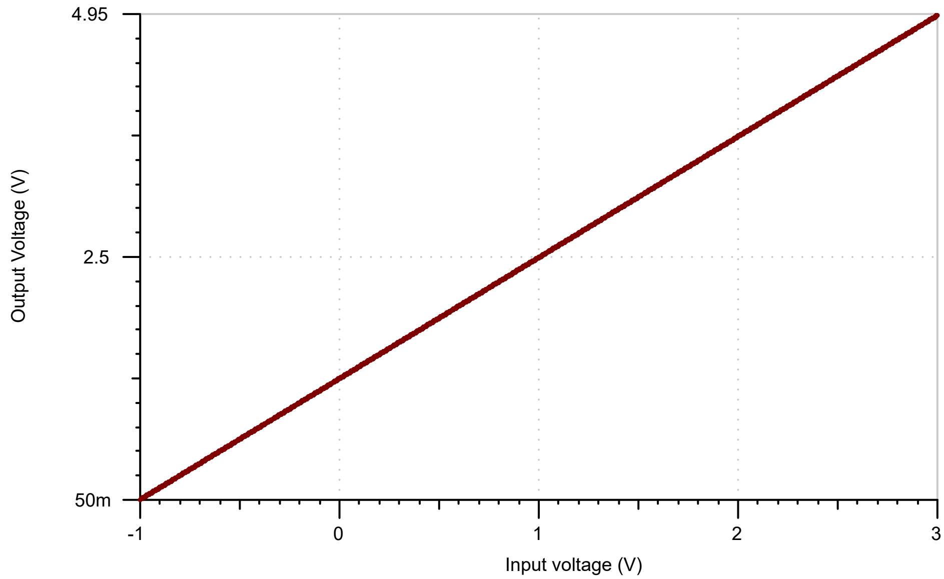
$$0.05V = -1\ \ V \times \left(\frac{1\ \ k\Omega}{\frac{1\ \ M\Omega + 1\ \ k\Omega \times R_2}{1.225 \times R_2} - 1\ \ k\Omega + 1\ \ k\Omega}\right)\left(\frac{1\ \ k\Omega + R_2}{R_2}\right) + 2.5V \times \left(\frac{\frac{1\ \ M\Omega + 1\ \ k\Omega \times R_2}{1.225 \times R_2} - 1\ \ k\Omega}{\frac{1\ \ M\Omega + 1\ \ k\Omega \times R_2}{1.225 \times R_2} - 1\ \ k\Omega + 1\ \ k\Omega}\right)$$
$$\left(\frac{1\ \ k\Omega + R_2}{R_2}\right)$$
$$R_2 = 1360.5\Omega \quad \approx 1370\Omega$$

6. Insert R_2 into the equation from step 1 to solve for R_3.

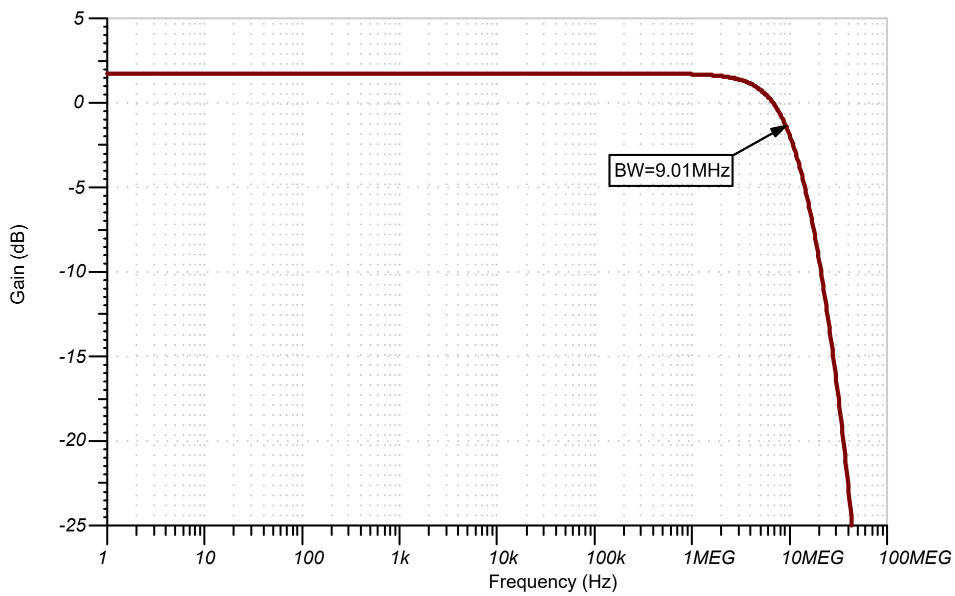
$$R_3 = \frac{1\ \ M\Omega + 1\ \ k\Omega \times (1370\Omega)}{1.225 \times (1370\Omega)} - 1\ \ k\Omega$$
$$R_3 = 412.18\Omega \approx 412\Omega$$

Design Simulations

DC Simulation Results



AC Simulation Results



Design References

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

See the circuit SPICE simulation file SBOC513.

See *Designing Gain and Offset in Thirty Seconds*.

Design Featured Op Amp

MCP6292	
V_{ss}	2.4 V to 5.5 V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	0.3 mV
I_q	600 µA
I_b	1 pA
UGBW	10 MHz
SR	6.5 V/µs
#Channels	1, 2, and 4
MCP6292	

Design Alternate Op Amp

OPA388	
V_{ss}	2.5 V to 5.5 V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	0.25 µV
I_q	1.9 mA
I_b	30 pA
UGBW	10 MHz
SR	5 V/µs
#Channels	1, 2, and 4
OPA388	

Revision History

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

Changes from February 1, 2018 to February 4, 2019 **Page**

- Downscale the title and changed title role to 'Amplifiers'. Added links to circuit cookbook landing page and SPICE simulation file... 1

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