

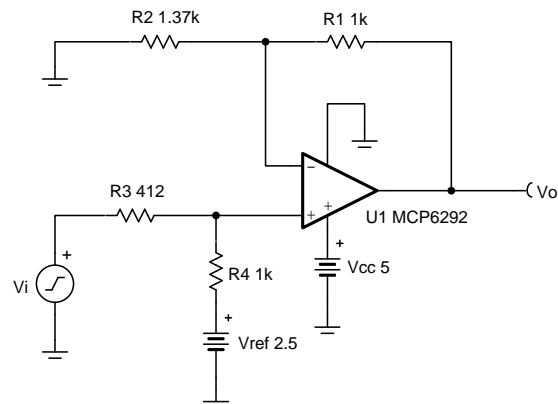
## ***Non-inverting op amp with non-inverting positive reference voltage circuit***

### Design Goals

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

### Design Description

This design uses a non-inverting amplifier with a non-inverting positive reference to translate an input signal of -1V to 3V to an output voltage of 0.05V to 4.95V. 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.



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### 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 100k $\Omega$ . 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.

$$G_{input} = \left( \frac{R_4}{R_3 + R_4} \right) \left( \frac{R_1 + R_2}{R_2} \right)$$

$$V_{o,max} - V_{o,min} = V_{i,max} - V_{i,min} \times \frac{R_4}{R_3 + R_4} \times \frac{R_1 + R_2}{R_2}$$

$$\frac{V_{o,max} - V_{o,min}}{V_{i,max} - V_{i,min}} = \frac{R_4}{R_3 + R_4} \times \frac{R_1 + R_2}{R_2}$$

$$\frac{4.95V - 0.05V}{3V - (-1V)} = \frac{R_4}{R_3 + R_4} \times \frac{R_1 + R_2}{R_2}$$

$$1.225V = \frac{R_4}{R_3 + R_4} \times \frac{R_1 + R_2}{R_2}$$

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.

$$R_1 = R_4 = 1 \text{ k}\Omega$$

$$1.225V = \frac{1 \text{ k}\Omega}{R_3 + 1 \text{ k}\Omega} \times \frac{1 \text{ k}\Omega + R_2}{R_2}$$

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

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

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).

$$V_{o,min} = V_{i,min} \times \left( \frac{R_4}{R_3 + R_4} \right) \left( \frac{R_1 + R_2}{R_2} \right) + V_{ref} \times \left( \frac{R_3}{R_3 + R_4} \right) \left( \frac{R_1 + R_2}{R_2} \right)$$

$$0.05V = -1 \text{ V} \times \frac{1 \text{ k}\Omega}{R_3 + 1 \text{ k}\Omega} \times \frac{1 \text{ k}\Omega + R_2}{R_2} + 2.5V \times \frac{R_3}{R_3 + 1 \text{ k}\Omega} \times \frac{1 \text{ k}\Omega + R_2}{R_2}$$

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

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

$$R_2 = 1360.5\Omega \approx 1370\Omega$$

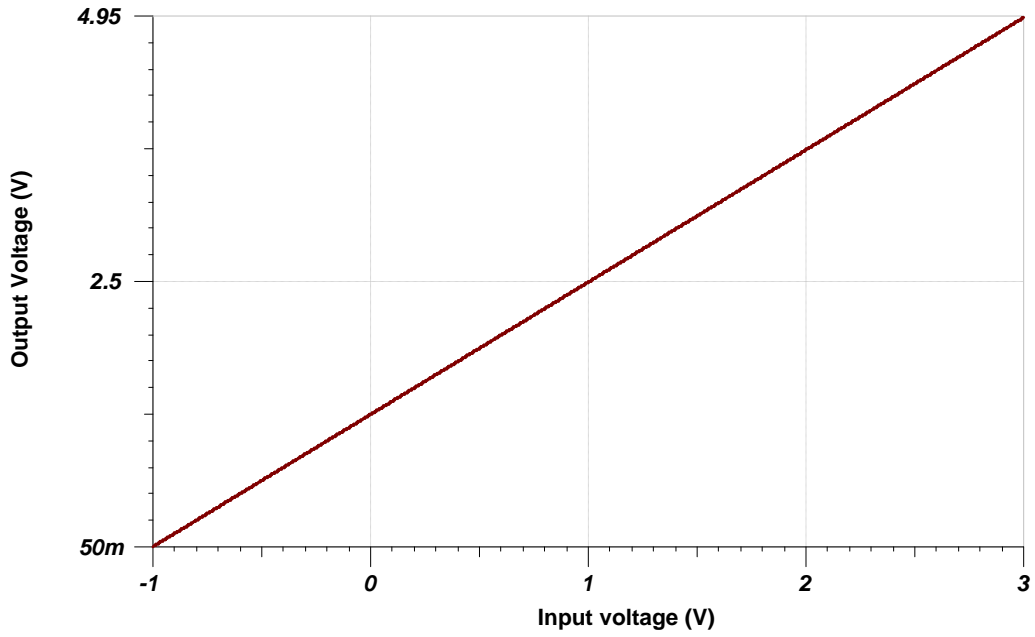
6. Insert  $R_2$  into the equation from step 1 to solve for  $R_3$ .

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

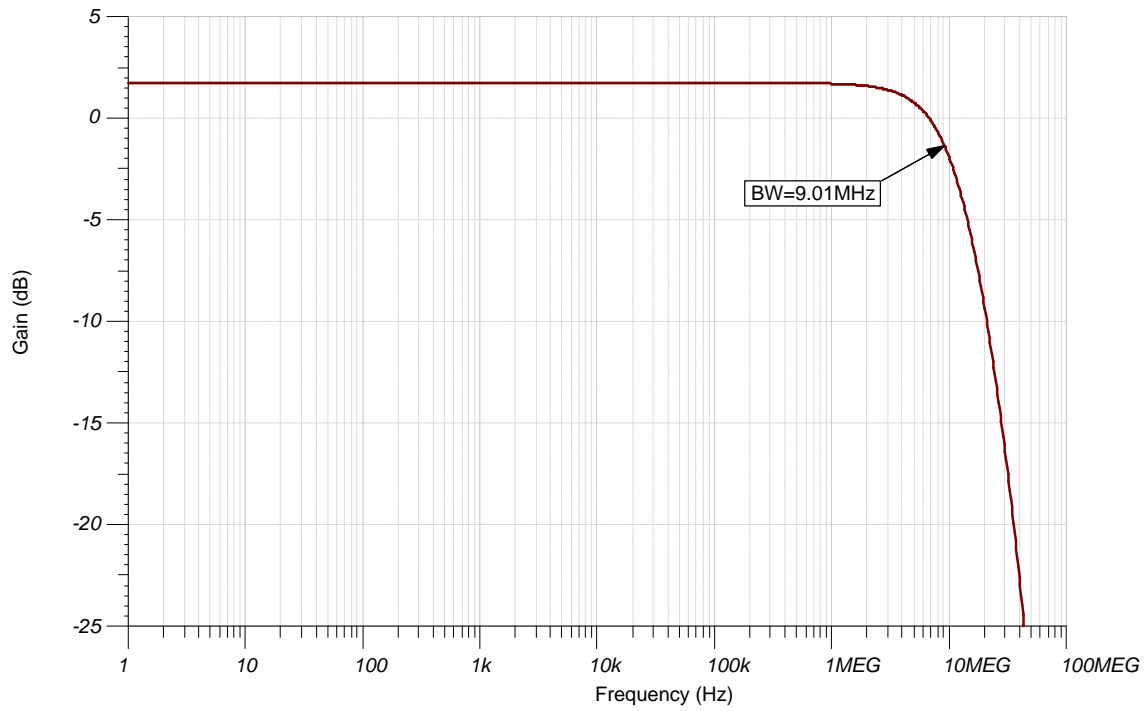
$$R_3 = 412.18\Omega \approx 412\Omega$$

**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	
$V_{SS}$	2.4V to 5.5V
$V_{inCM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{os}$	0.3mV
$I_q$	600 $\mu$ A
$I_b$	1pA
UGBW	10MHz
SR	6.5V/ $\mu$ s
#Channels	1, 2, 4
<a href="http://www.ti.com/product/MCP6292">www.ti.com/product/MCP6292</a>	

## Design Alternate Op Amp

OPA388	
$V_{SS}$	2.5V to 5.5V
$V_{inCM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{os}$	0.25 $\mu$ V
$I_q$	1.9mA
$I_b$	30pA
UGBW	10MHz
SR	5V/ $\mu$ s
#Channels	1, 2, 4
<a href="http://www.ti.com/product/opa388">www.ti.com/product/opa388</a>	

## Revision History

Revision	Date	Change
A	February 2019	Downscale the title and changed title role to 'Amplifiers'. Added links to circuit cookbook landing page and SPICE simulation file.

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