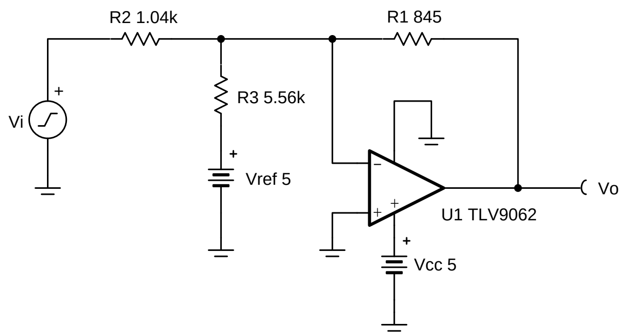
Inverting op amp with inverting positive reference voltage circuit

Design Goals

Input		Output		Supply		
V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}	V_{ref}
–5V	–1V	0.05V	3.3V	5V	0V	5V

Design Description

This design uses an inverting amplifier with an inverting positive reference to translate an input signal of –5V to –1V to an output voltage of 3.3V to 0.05V. This circuit can be used to translate a negative sensor output voltage 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. Common mode range must extend down to or below ground.
3. V_{ref} output must be low impedance.
4. Input impedance of the circuit is equal to R_2.
5. Choose low-value resistors to use in the feedback. It is recommended to use resistor values less than 100kΩ. 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. Additional filtering can be accomplished by adding a capacitor in parallel to R_1. Adding a capacitor in parallel with R_1 will also improve stability of the circuit if high-value resistors are used.

Design Steps

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

1. Calculate the gain of the input signal.

$$G_{input} = \frac{V_{o\_max} - V_{o\_min}}{V_{i\_max} - V_{i\_min}} = \frac{3.3V - 0.05V}{-1V - (-5\ V)} = 0.8125\frac{V}{V}$$

2. Calculate R_1 and R_2.

$$\text{Choose}\quad R_1 = 845\Omega$$

$$R_2 = \frac{R_1}{G_{input}} = \frac{R_1}{0.8125\frac{V}{V}} = 1.04\ \ k\Omega$$

3. Calculate the gain of the reference voltage required to offset the output.

$$G_{ref} = \frac{R_1}{R_3}$$

$$-V_{i\_min} \times \left(\frac{R_1}{R_2}\right) - V_{ref} \times \left(\frac{R_1}{R_3}\right) = V_{o\_min}$$

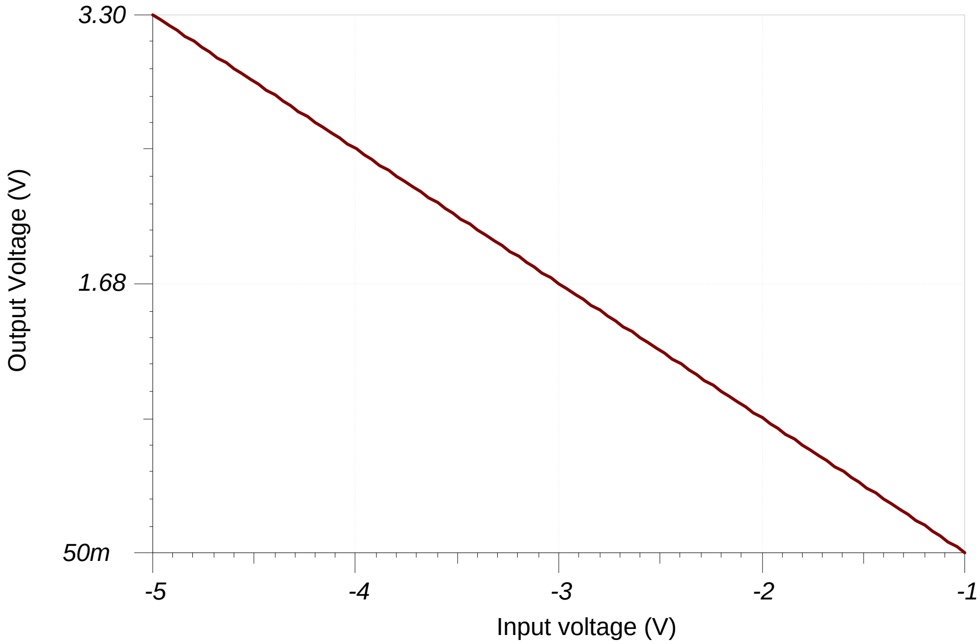
$$\frac{R_1}{R_3} = \frac{V_{o\_min} + V_{i\_min} \times \frac{R_1}{R_2}}{-V_{ref}} = \frac{0.05V + -1\ V\ \frac{845\Omega}{1.04k\Omega}}{-5} = 0.1525\frac{V}{V}$$

4. Calculate R_3.

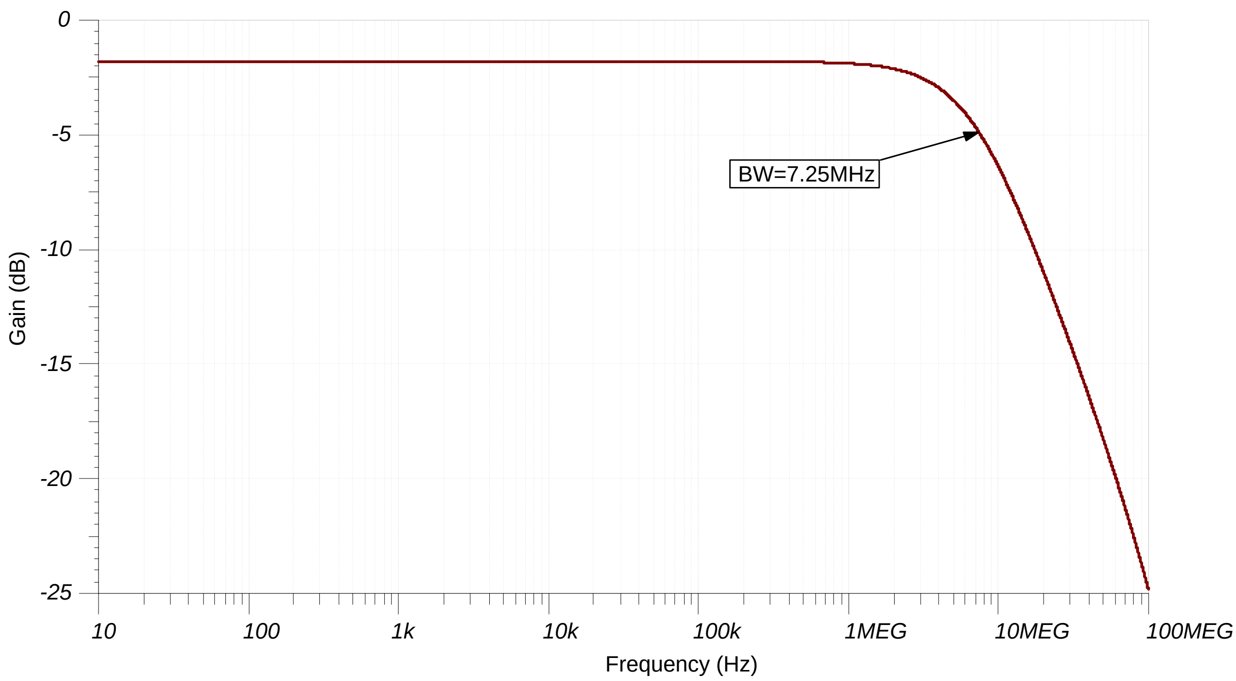
$$R_3 = \frac{R_1}{G_{ref}} = \frac{845\Omega}{0.1525\frac{V}{V}} = 5.54\ \ k\Omega \approx 5.56\ \ k\Omega$$

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 SBOC511.

See Designing Gain and Offset in Thirty Seconds .

Design Featured Op Amp

TLV9062	
V_{ss}	1.8V to 5.5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	0.3mV
I_q	538µA
I_b	0.5pA
UGBW	10MHz
SR	6.5V/µs
#Channels	1, 2, 4
www.ti.com/product/tlv9062	

Design Alternate Op Amp

OPA197	
V_{ss}	4.5V to 36V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	25µV
I_q	1mA
I_b	5pA
UGBW	10MHz
SR	20V/µs
#Channels	1, 2, 4
www.ti.com/product/opa197	

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.

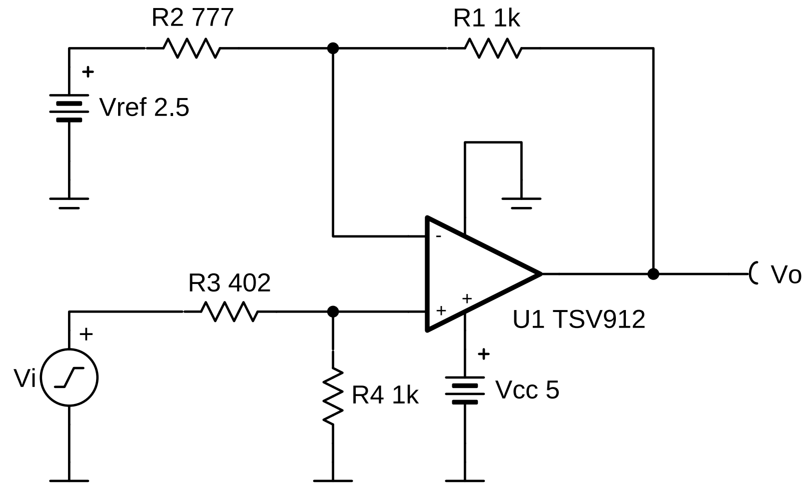
Non-inverting op amp with inverting positive reference voltage circuit

Design Goals

Input		Output		Supply		
V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}	V_{ref}
2V	5V	0.05V	4.95V	5V	0V	2.5V

Design Description

This design uses a non-inverting amplifier with an inverting positive reference to translate an input signal of 2V to 5V 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 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. The common mode voltage varies with the input voltage.
3. V_{ref} 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 100kΩ. 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

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

1. Calculate the gain of the input to produce the largest output swing.

$$V_{o\_max} - V_{o\_min} = (V_{i\_max} - V_{i\_min})\left(\frac{R_4}{R_3 + R_4}\right)\left(\frac{R_1 + R_2}{R_2}\right)$$
$$\frac{V_{o\_max} - V_{o\_min}}{V_{i\_max} - V_{i\_min}} = \frac{R_4}{R_3 + R_4} \quad \frac{R_1 + R_2}{R_2}$$
$$\frac{4.95V - 0.05V}{5V - 2V} = \frac{R_4}{R_3 + R_4} \quad \frac{R_1 + R_2}{R_2}$$
$$1.633\frac{V}{V} = \frac{R_4}{R_3 + R_4} \quad \frac{R_1 + R_2}{R_2}$$

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.

$$R_1 = R_4 = 1\ k\Omega \quad ($$
$$1.633\frac{V}{V} = \frac{1\ k\Omega}{R_3 + 1\ k\Omega} \quad \frac{1\ k\Omega + R_2}{R_2}$$

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

$$R_3 = \frac{1\ M\Omega + (1\ k\Omega \times R_2)}{1.633 \times R_2} - 1\ k\Omega$$

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).

$$V_{o\_min} = V_{i\_min} \times \left(\frac{R_4}{R_3 + R_4}\right)\left(\frac{R_1 + R_2}{R_2}\right) - V_{ref} \times \left(\frac{R_1}{R_2}\right)$$
$$0.05V = 2V \times \frac{1\ k\Omega}{R_3 + 1\ k\Omega} \quad \frac{1\ k\Omega + R_2}{R_2} - V_{ref} \times \frac{1\ k\Omega}{R_2}$$

5. Insert R_3 from step 3 into the equation from step 4 and solve for R_2.

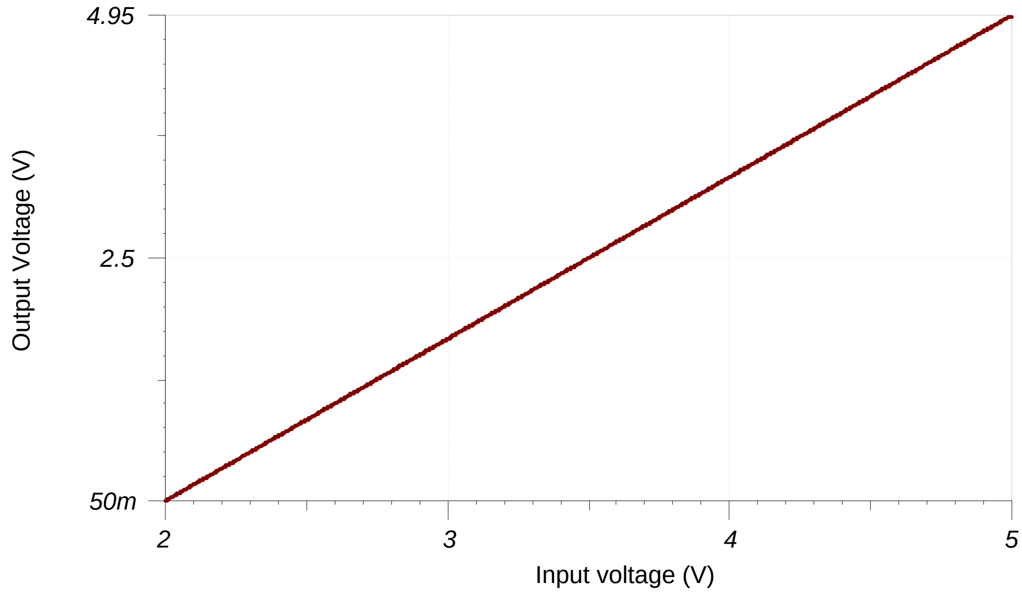
$$0.05V = 2V \times \left(\frac{1\ k\Omega}{\frac{1\ M\Omega + 1\ k\Omega \times R_2}{1.633 \times R_2} - 1\ k\Omega + 1\ k\Omega}\right)\left(\frac{1\ k\Omega + R_2}{R_2}\right) - V_{ref} \times \left(\frac{1\ k\Omega}{R_2}\right)$$
$$R_2 = 777.2\Omega \approx 777\Omega$$

6. Insert R_2 calculation from step 5, and solve for R_3.

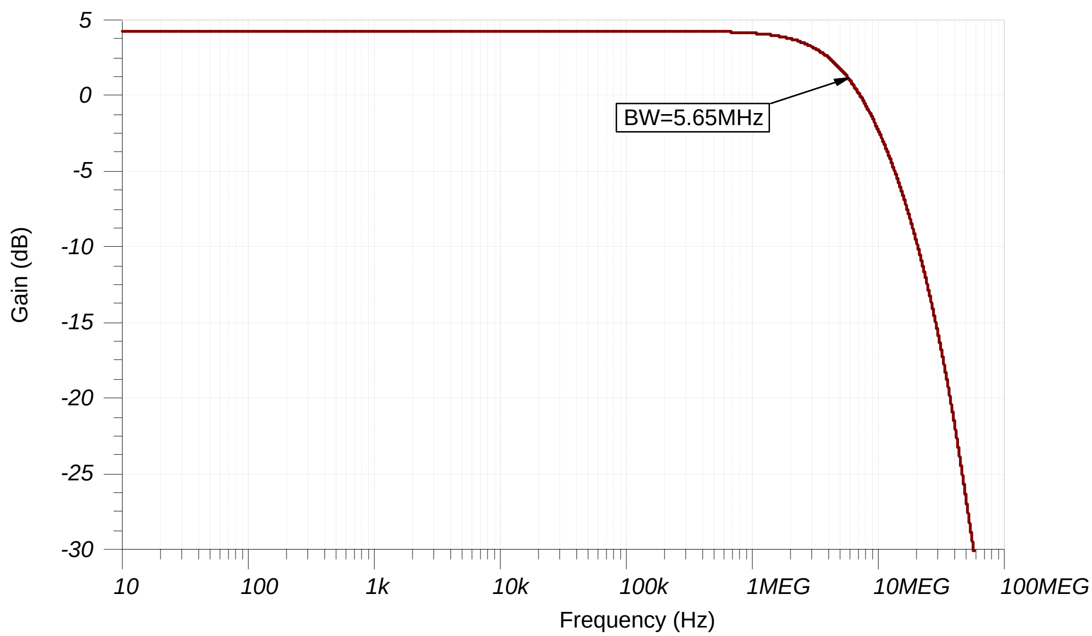
$$R_3 = \frac{1\ M\Omega + (1\ k\Omega \times R_2)}{1.633 \times R_2} - 1\ k\Omega \quad (\quad) \quad (\quad)$$
$$R_3 = \frac{1\ M\Omega + 1\ k\Omega \times 777\Omega}{1.633 \times 777\Omega} - 1\ k\Omega = 400.49\Omega \approx 402\Omega$$

Design Simulations

DC Simulation Results



AC Simulation Results



Design References

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

See circuit SPICE simulation file SBOC512.

See TI Precision Lab Videos on Input and Output Limitations.

Design Featured Op Amp

TSV912	
V_{ss}	2.5V to 5.5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	0.3mV
I_q	550µA
I_b	1pA
UGBW	8MHz
SR	4.5V/µs
#Channels	1, 2, 4
www.ti.com/product/tsv912	

Design Alternate Op Amp

OPA191	
V_{ss}	4.5V to 36V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	5µV
I_q	140µA/Ch
I_b	5pA
UGBW	2.5MHz
SR	5.5V/µs
#Channels	1, 2, 4
www.ti.com/product/opa191	

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.

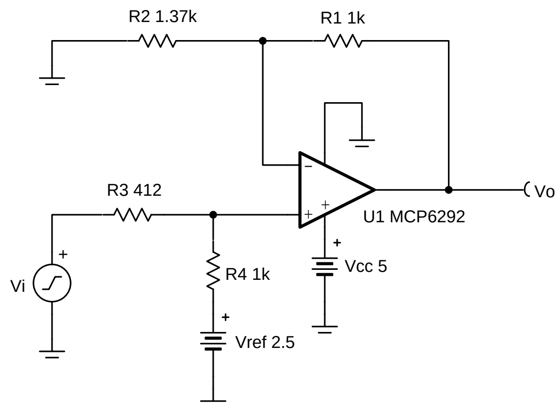
Non-inverting op amp with non-inverting positive reference voltage circuit

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.



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 100kΩ. 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.

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

$$V_{o\_max} - V_{o\_min} = V_{i\_max} - V_{i\_min} \quad \frac{R_4}{R_3+R_4} \quad \frac{R_1+R_2}{R_2}$$

$$\frac{V_{o\_max} - V_{o\_min}}{V_{i\_max} - V_{i\_min}} = \frac{R_4}{R_3+R_4} \quad \frac{R_1+R_2}{R_2}$$

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

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

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.

$$R_1 = R_4 = 1\ k\Omega \quad ($$

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

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).

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

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

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

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

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

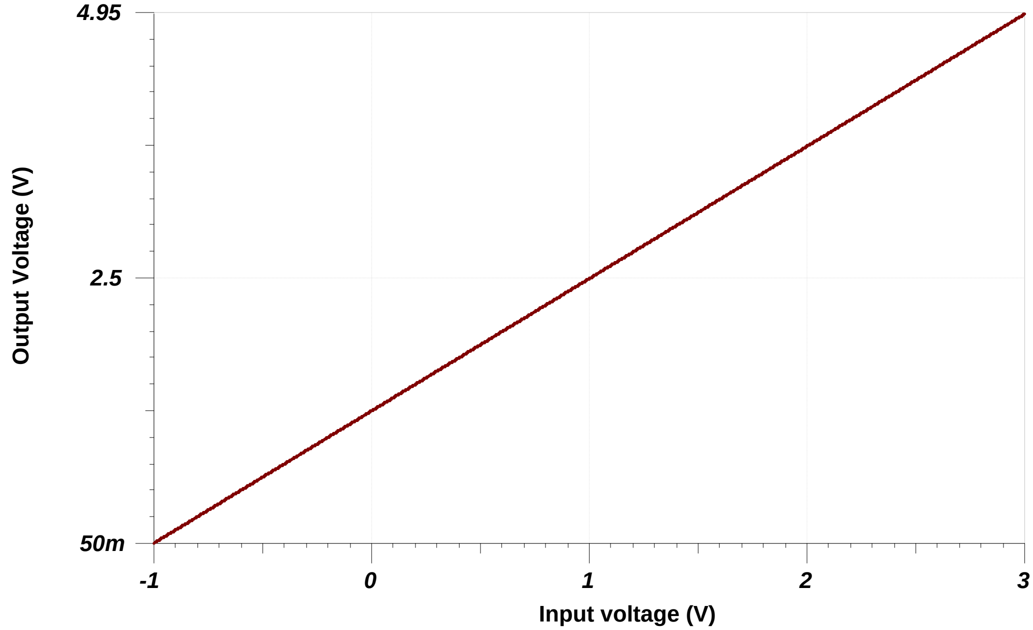
6. Insert R_2 into the equation from step 1 to solve for R_3.

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

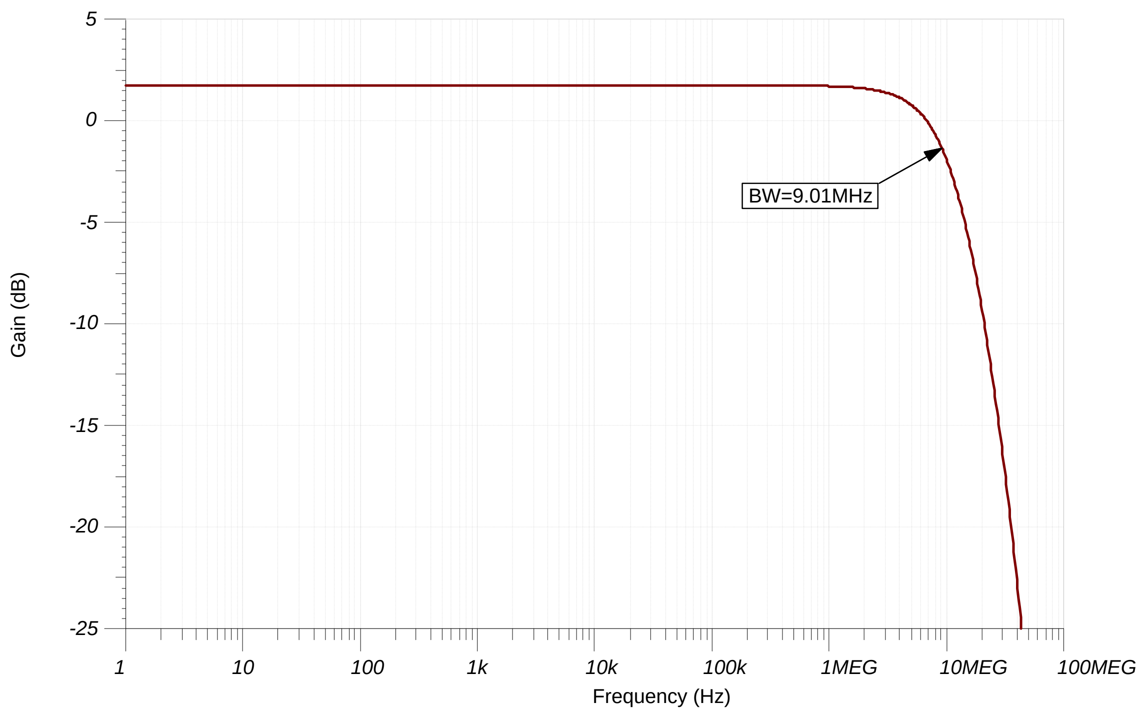
$$R_3 = 412.18\Omega \approx 412\Omega$$

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

Design Alternate Op Amp

OPA388	
V_{ss}	2.5V to 5.5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	0.25µV
I_q	1.9mA
I_b	30pA
UGBW	10MHz
SR	5V/µs
#Channels	1, 2, 4
www.ti.com/product/opa388	

Revision History

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

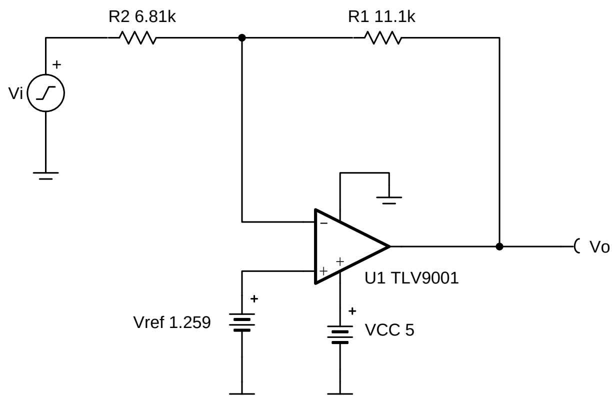
Inverting op amp with non-inverting positive reference voltage circuit

Design Goals

Input		Output		Supply		
V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}	V_{ref}
–1V	2V	0.05V	4.95V	5V	0V	1.259V

Design Description

This design uses an inverting amplifier with a non-inverting positive reference voltage to translate an input signal of –1V to 2V 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.



Design Notes

1. Use op amp linear output operating range. Usually specified under A_{OL} test conditions.
2. Amplifier common mode voltage is equal to the reference voltage.
3. V_{ref} can be created with a voltage divider.
4. Input impedance of the circuit is equal to R_2.
5. Choose low-value resistors to use in the feedback. It is recommended to use resistor values less than 100kΩ. 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. Additional filtering can be accomplished by adding a capacitor in parallel to R_1. Adding a capacitor in parallel with R_1 will also improve stability of the circuit, if high-value resistors are used.

Design Steps

$$V_o = -Vi \times \left(\frac{R_1}{R_2}\right) + V_{ref} \times \left(1 + \frac{R_1}{R_2}\right)$$

1. Calculate the gain of the input signal.

$$G_{input} = -\frac{R_1}{R_2} \quad (\quad)(\quad)$$

$$V_{o\_max} - V_{o\_min} = V_{i\_max} - V_{i\_min} \quad -\frac{R_1}{R_2}$$

$$-\frac{R_1}{R_2} = -\frac{V_{o\_max} - V_{o\_min}}{V_{i\_max} - V_{i\_min}} = -\frac{4.95V - 0.05V}{2V - \;\; -1\ V} = -1.633\frac{V}{V}$$

2. Select R_2 and calculate R_1.

$$R_2 = 6.81\ k\Omega$$

$$R_1 = G_{input} \times R_2 = 1.633\frac{V}{V} \times 6.81\ k\Omega = 11.123k\Omega \approx 11.1\ k\Omega \ \ \text{(Standard Value)}$$

3. Calculate the reference voltage.

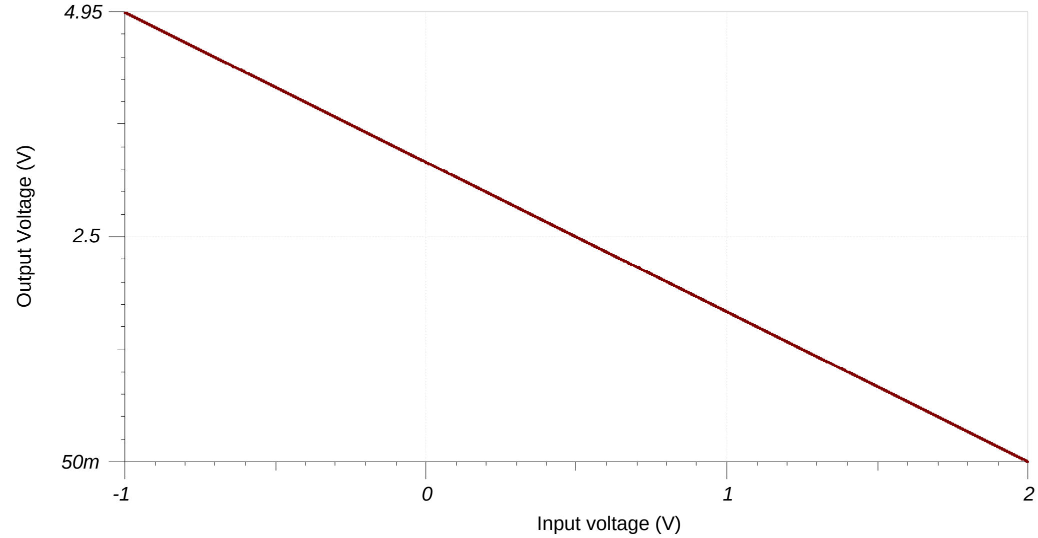
$$V_{o\_min} = -V_{i\_max} \times \left(\frac{R_1}{R_2}\right) + V_{ref} \times \left(1 + \frac{R_1}{R_2}\right)$$

$$0.05V = -2V \times \frac{11.11\ k\Omega}{6.81\ k\Omega} + V_{ref} \times \ 1 + \frac{11.11\ k\Omega}{6.81\ k\Omega}$$

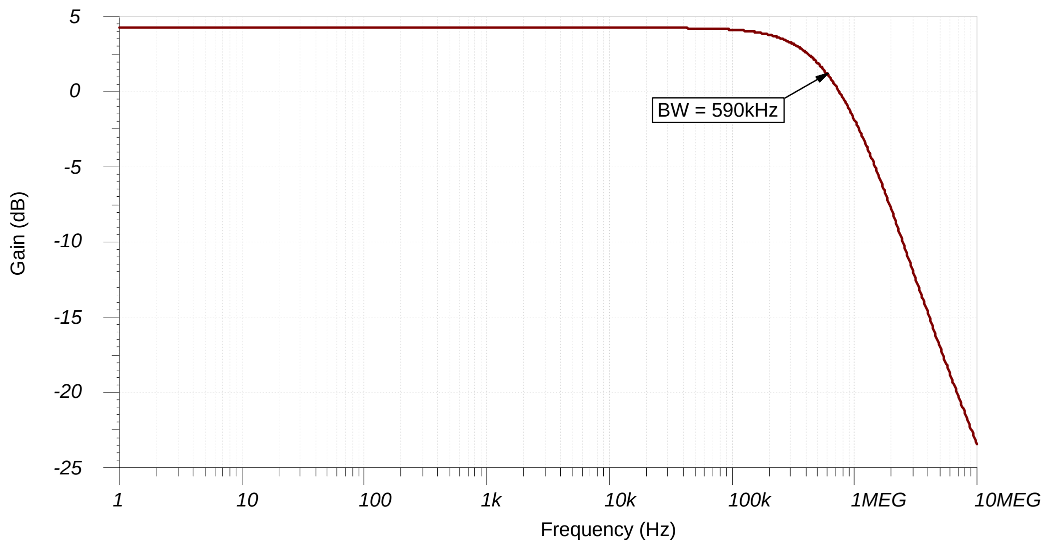
$$V_{ref} = \frac{V_{o\_min} + V_{i\_max} \times \frac{R_1}{R_2}}{1 + \frac{R_1}{R_2}} \frac{0.05V + 2V \times \frac{11.11\ k\Omega}{6.81\ k\Omega}}{1 + \frac{11.11\ k\Omega}{6.81\ k\Omega}} = 1.259V$$

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 SBOC514.

See the Designing gain and offset in thirty seconds application report.

Design Featured Op Amp

TLV9001	
V_{ss}	1.8V to 5.5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	0.4mV
I_q	60µA
I_b	5pA
UGBW	1MHz
SR	2V/µs
#Channels	1, 2, 4
www.ti.com/product/tlv9002	

Design Alternate Op Amp

OPA376	
V_{ss}	2.2V to 5.5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	5µV
I_q	760µA
I_b	0.2pA
UGBW	5.5MHz
SR	2V/µs
#Channels	1, 2, 4
www.ti.com/product/opa376	

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.