Analog Engineer's Circuit

Non-Inverting Op Amp with Inverting Positive Reference Voltage Circuit

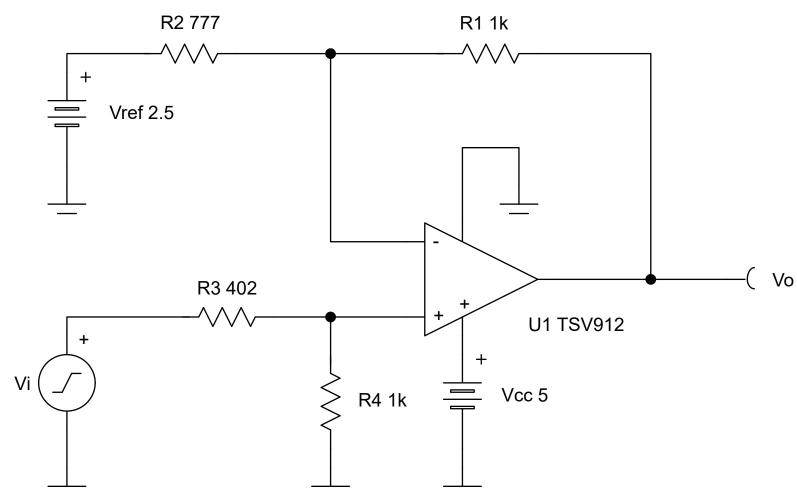
TEXAS INSTRUMENTS

Design Goals

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

Design Description

This design uses a non-inverting amplifier with an inverting positive reference to translate an input signal of 2 V to 5 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 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 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.

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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.

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

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.

$$R_1 = R_4 = 1\ \text{k}\Omega$$
$$1.633\frac{V}{V} = \left(\frac{1\ \text{k}\Omega}{R_3 + 1\ \text{k}\Omega}\right)\left(\frac{1\ \text{k}\Omega + R_2}{R_2}\right)$$

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

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

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).

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

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

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

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

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

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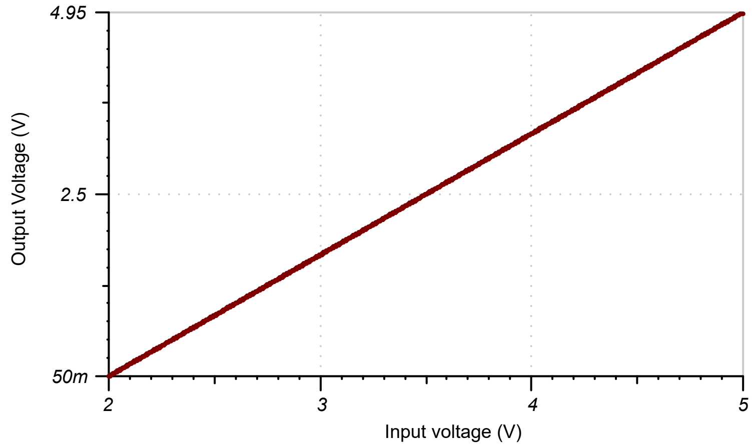
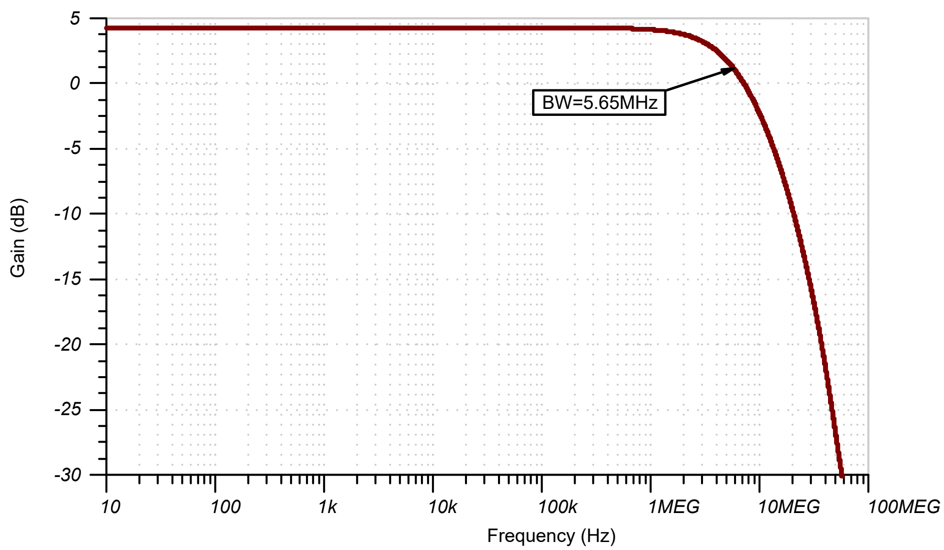
Design Simulations

DC Simulation Results



AC Simulation Results



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

Design Alternate Op Amp

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

Revision History

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

Changes from February 4, 2019 to February 5, 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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