Non-inverting op amp with inverting positive reference voltage circuit

Design Goals

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<tr>
<th>Input</th>
<th>Output</th>
<th>Supply</th>
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<tbody>
<tr>
<td>$V_{iMin}$</td>
<td>$V_{iMax}$</td>
<td>$V_{oMin}$</td>
</tr>
<tr>
<td>2V</td>
<td>5V</td>
<td>0.05V</td>
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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

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

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

\[
\begin{align*}
V_{o,\text{max}} - V_{o,\text{min}} &= (V_{i,\text{max}} - V_{i,\text{min}}) \left( \frac{R_1}{R_3+R_4} \right) \left( \frac{R_1+R_2}{R_2} \right) \\
\frac{V_{o,\text{max}} - V_{o,\text{min}}}{V_{i,\text{max}} - V_{i,\text{min}}} &= \left( \frac{R_1}{R_3+R_4} \right) \left( \frac{R_1+R_2}{R_2} \right) \\
&= \frac{5V - 2V}{4.06V - 0.05V} \\
&= 1.633 \frac{V}{V}
\end{align*}
\]

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.

\[
R_1 = R_4 = 1 \ \text{k}\Omega
\]

\[
1.633 \frac{V}{V} = \frac{1 \ \text{k}\Omega}{R_3+1 \ \text{k}\Omega} \left( \frac{1 \ \text{k}\Omega+R_2}{R_2} \right)
\]

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

\[
R_3 = \frac{1 \ \text{M}\Omega + \left( \frac{1 \ \text{k}\Omega \times R_2}{1.633 \times R_2} \right)}{-1 \ \text{k}\Omega}
\]

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).

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

\[
0.05V = 2V \times \left( \frac{1 \ \text{k}\Omega}{R_3+1 \ \text{k}\Omega} \right) \left( \frac{1 \ \text{k}\Omega+R_2}{R_2} \right) - V_{\text{ref}} \times \left( \frac{1 \ \text{k}\Omega}{R_2} \right)
\]

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

\[
0.05V = 2V \times \left( \frac{1 \ \text{k}\Omega}{1.633 \times R_2} \right) \left( \frac{1 \ \text{k}\Omega+R_2}{R_2} \right) - V_{\text{ref}} \times \left( \frac{1 \ \text{k}\Omega}{R_2} \right)
\]

\[
R_2 = 777.2 \ \Omega \approx 777\Omega
\]

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

\[
R_3 = \frac{1 \ \text{M}\Omega + \left( \frac{1 \ \text{k}\Omega \times R_2}{1.633 \times R_2} \right)}{-1 \ \text{k}\Omega}
\]

\[
R_3 = \frac{1 \ \text{M}\Omega + 1 \ \text{k}\Omega \times \frac{777\Omega}{1.633 \times 777\Omega}}{-1 \ \text{k}\Omega} = 400.49\Omega = 402\Omega
\]
Design Simulations

**DC Simulation Results**

![DC Simulation Graph](image1)

Input voltage (V) vs. Output Voltage (V)

**AC Simulation Results**

![AC Simulation Graph](image2)

Frequency (Hz) vs. Gain (dB)

BW=5.65MHz
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

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www.ti.com/product/tsv912

Design Alternate Op Amp

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Revision History

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<th>Revision</th>
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<tr>
<td>A</td>
<td>February</td>
<td>Downscale the title and changed title role to ’Amplifiers’. Added links to circuit cookbook landing page and SPICE simulation file.</td>
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