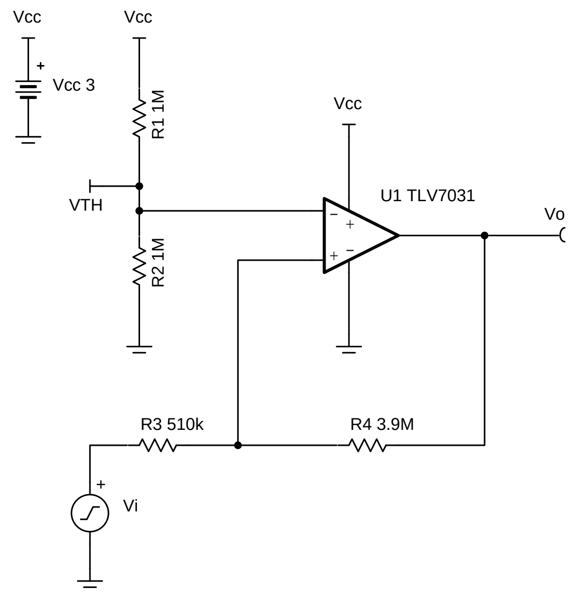
Non-inverting comparator with hysteresis circuit

Design Goals

Output		Hysteresis	Thresholds		Supply	
V_o = HIGH	V_o = LOW	V_{HYS}	V_H	V_L	V_{cc}	V_{ee}
$V_i > V_H$	$V_i < V_L$	400mV	1.7V	1.3V	3V	0V

Design Description

Comparators are used to differentiate between two different signal levels. When setup in a non-inverting fashion, the comparator output will be a digital high if the analog input is above a selected threshold. With noise, signal variation, or a slow-moving signal at the comparison threshold, undesirable transitions at the output can be observed. Setting upper and lower hysteresis thresholds eliminates these undesirable output transitions caused by the noise. This circuit example will focus on the steps required to design the positive feedback resistor network required to obtain the necessary hysteresis for a non-inverting comparator application.



Design Notes

1. Achieving balanced hysteresis will depend on the size of hysteresis and the threshold voltage to V_{cc} ratio.
2. In comparison to the inverting comparator circuit, this example has a lower impedance seen at the inputs.
3. The accuracy of the hysteresis threshold voltages are related to the tolerance of the resistors used in the circuit, the selected comparator's input offset voltage specification, and any internal hysteresis already applied to the device.
4. For the TLV7031, V_{OH} is approximately 200mV below V_{cc} and V_{OL} is approximately 250mV above V_{ee}.
5. The TLV7031 has a push-pull output stage, so no pull-up resistor is needed.

Design Steps

1. Select R_1. This can be a high resistance value due to the very low input bias current caused by the CMOS input of the device.

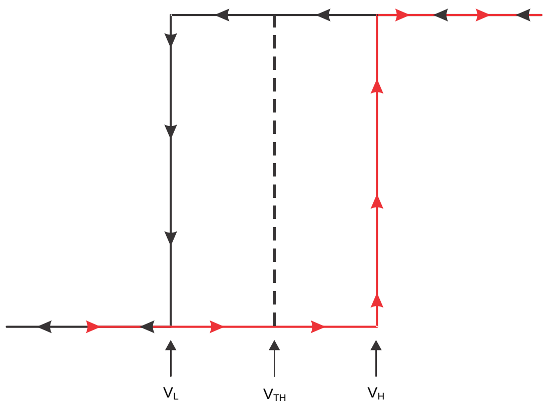
   $R_1 = 1M\,\Omega$ (Standard Value)

2. Solve for R_3. A common practice is to select R_3 to be the impedance seen at the inverting pin to provide input bias current cancellation. Since R_2 is not known, approximate R_3. Here V_{TH} is expected to be 50% of V_{cc}.

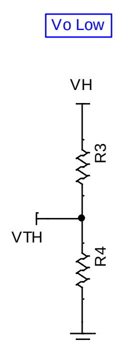
   $R_3 = R_1 || R_2 \cong \frac{1}{2} R_1 = 500k\Omega$

   $R_3 = 510k\Omega$ (Standard Value)

3. Observe the feedback resistor network in the two possible output states: Low and High. Note that the input signal plays a role in determining the hysteresis. The hysteresis eye diagram follows.

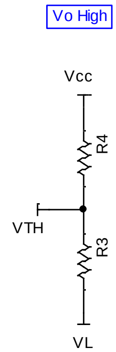


4. Derive the equation for V_H, the voltage that the input signal must rise to for the output to switch high. Set the voltage at the non-inverting pin to be equal to V_{TH}. This ensures the correct hysteresis window will be achieved.



   $V_H = R_3 \times \frac{V_{TH}}{R_4} + V_{TH}$

5. Derive the equation for V_L, the voltage that the input signal must drop to for the output to switch low. Again, set the voltage at the non-inverting pin to be equal to V_{TH}.



6. For push-pull outputs.

$$V_L = \frac{V_{TH} \times (R_3 + R_4) - V_{cc} \times R_3}{R_4}$$

7. If the comparator in use has an open-drain or open-collector output stage, then the pull-up resistor, R_{pu}, will be in series with R_3 and R_4. The following equation is true if $V_{pu} = V_{cc}$. Do note that for some applications, the pull-up resistor could be ignored in the V_L equation since the eventual feedback resistor value could be significantly larger (ideally 10 times larger) than the pull-up resistor.

$$V_L = \frac{V_{TH} \times (R_{pu} + R_4) - \left(V_{cc} - V_{TH}\right) \times R_3}{R_4 + R_{pu}}$$

8. If $V_{pu} \neq V_{cc}$, then use the following equation for V_L.

$$V_L = \frac{V_{TH} \times (R_{pu} + R_4) - \left(V_{pu} - V_{TH}\right) \times R_3}{R_4 + R_{pu}}$$

9. Derive the equation for V_{HYS}.

$$V_{HYS} = V_H - V_L = V_{cc} \times \frac{R_3}{R_4}$$

10. Solve for R_4.

$$R_4 = \frac{V_{cc}}{V_{HYS}} \times R_3 = \frac{3V}{0.4V} \times 510k\Omega = 3.83M\Omega$$

$$R_4 = 3.9M\Omega \quad \text{(Standard Value)}$$

11. Use the V_H equation found in step 4 to now solve for V_{TH}.

$$V_{TH} = \frac{R_4 \times V_H}{R_3 + R_4} = \frac{3.9M\Omega \times 1.7V}{510k\Omega + 3.9M\Omega} = 1.50V$$

12. Verify the V_{TH} value with the V_L equation found in step 6.

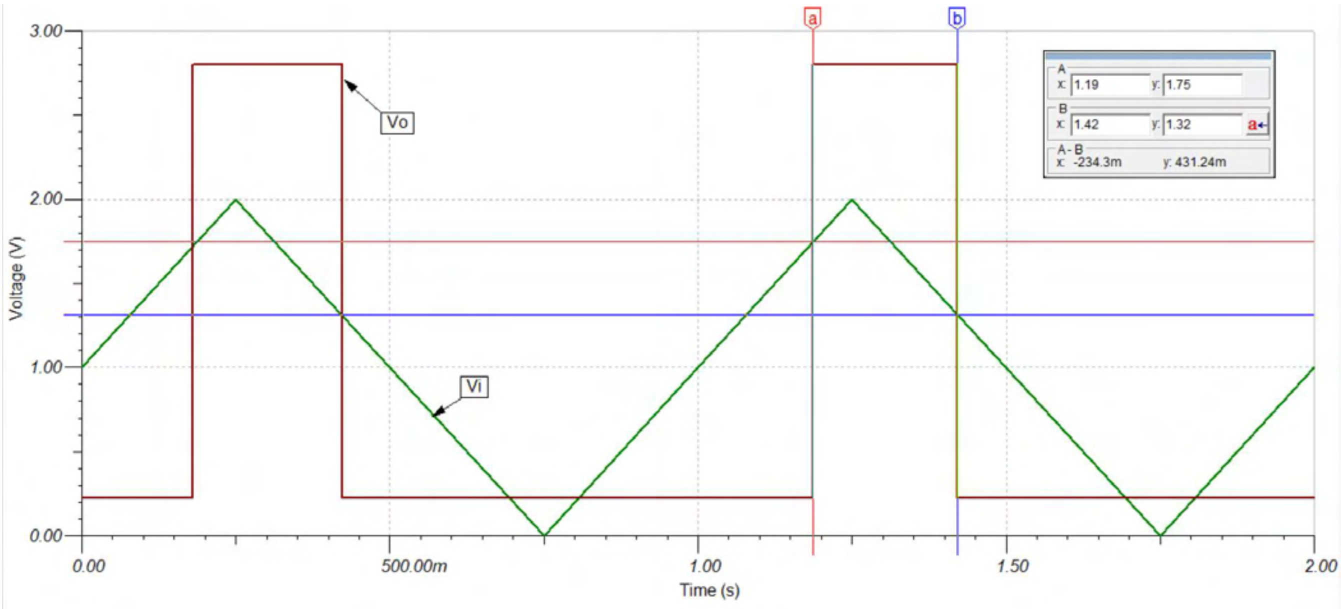
$$V_{TH} = \frac{R_4 \times V_H}{R_3 + R_4} = \frac{3.9M\Omega \times 1.7V}{510k\Omega + 3.9M\Omega} = 1.50V$$

13. Solve for R_2 based on the calculated threshold voltage, V_{TH}.

$$R_2 = \frac{R_1 \times V_{TH}}{V_{cc} - V_{TH}} = \frac{1M\Omega \times 1.5V}{3V - 1.5V} = 1M\,\Omega$$

Design Simulations

Transient Simulation Results



Design References

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

See Circuit SPICE Simulation File SLVMCR2.

For more information on many comparator topics including hysteresis, propagation delay and input common mode range please see training.ti.com/ti-precision-labs-op-amps.

Design Featured Comparator

TLV7031	
Output Type	Push-Pull
V_{cc}	1.6V to 6.5V
V_{inCM}	Rail-to-rail
V_{os}	±100µV
V_{HYS}	7mV
I_q	335nA/Ch
t_{pd}	3µs
#Channels	1
	www.ti.com/product/tlv7031

Design Alternate Comparator

TLV1701	
Output Type	Open Collector
V_{cc}	2.2V to 36V
V_{inCM}	Rail-to-rail
V_{HYS}	N/A
V_{os}	±500µV
I_q	55µA/Ch
t_{pd}	560ns
#Channels	1, 2, 4
	www.ti.com/product/tlv1701