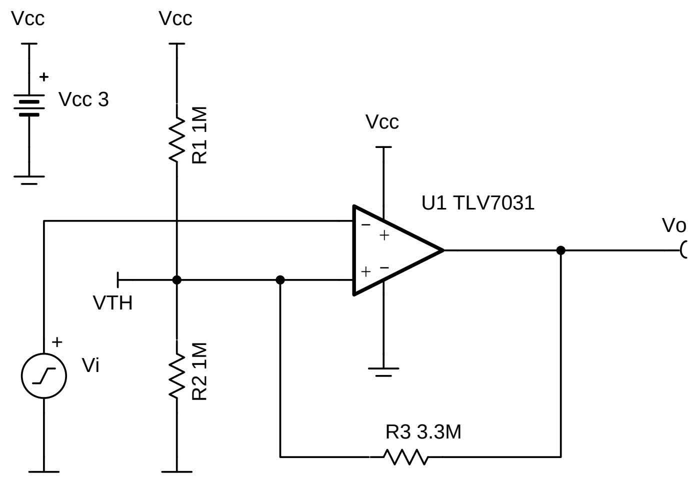
Inverting comparator with hysteresis circuit

Design Goals

Output		Threshold	Hysteresis	Supply	
V_0 = HIGH	V_o = LOW	V_{TH}	V_{HYS}	V_{cc}	V_{ee}
$V_i < V_L$	$V_i > V_H$	1.5V	400mV	3V	0V

Design Description

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

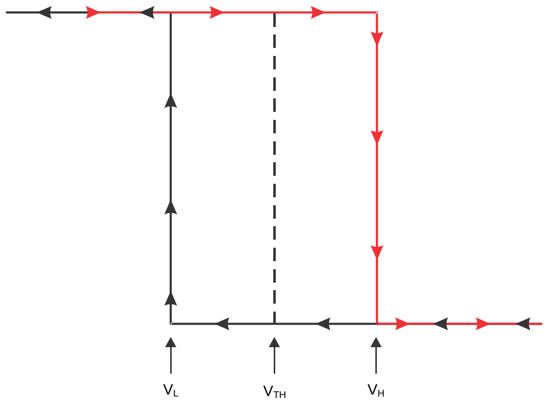


Design Notes

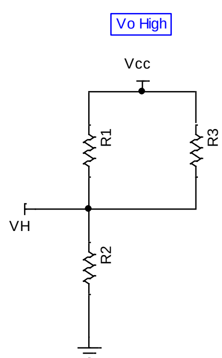
1. The accuracy of the hysteresis threshold voltages are related to the tolerance of the resistors used in the circuit, the selected comparator's input offset voltage specification, and any internal hysteresis already applied to the device.
2. For the TLV7031, V_{OH} is approximately 200mV below V_{cc} and V_{OL} is approximately 250mV above V_{ee}.
3. The TLV7031 has a push-pull output stage, so no pull-up resistor is needed.

Design Steps

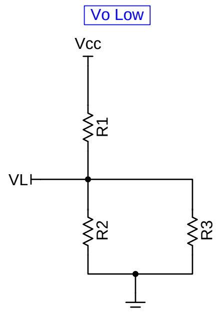
1. Select R_1. This can be a high resistance value due to the very low input bias current caused by the CMOS input of the device.
   $$R_1 = 1M\,\Omega \text{ (Standard Value)}$$
2. Solve for R_2 based on the desired threshold voltage. Set V_{TH} to be 50% of V_{cc} for balanced hysteresis.
   $$R_2 = \frac{R_1 \times V_{TH}}{V_{cc} - V_{TH}} = \frac{1M\Omega \times 1.5V}{3V - 1.5V} = 1M\,\Omega$$
3. Observe the feedback resistor network in the two possible output states: High and Low. Note that the threshold voltage applied to the non-inverting pin by the voltage divider (R_1 and R_2) can be further controlled by using the feedback resistor (R_3). Below is the hysteresis eye diagram.



4. Derive the equation for V_H, which is the threshold voltage when V_o is high. For simplicity, assume V_o switches to V_{cc} when $V_i < V_L$. When this occurs, R_1 and R_3 are in parallel.



5. For push-pull outputs.
   $$V_H = V_{cc} \times \frac{R_2}{(R_1 || R_3) + R_2}$$
   a. 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. 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_H equation since the eventual feedback resistor value could be significantly larger (ideally 10 times larger) than the pull-up resistor.
   $$V_H = V_{cc} \times \frac{R_2}{\left[R_1 || (R_3 + R_{pu})\right] + R_2}$$
   b. If $V_{pu} \neq V_{cc}$, then use the following equation for V_H.
   $$V_H = \frac{(R_1 \times V_{pu} + (R_3 + R_{pu}) \times V_{cc}) \times R_2}{R_1 \times (R_2 + R_3 + R_{pu}) + R_2 \times (R_3 + R_{pu})}$$
6. Derive the equation for V_L, which is the threshold voltage when V_o is low. For simplicity, assume V_o switches to V_{ee} when $V_i > V_H$. When this occurs, R_2 and R_3 are in parallel.



$$V_L = V_{cc} \times \frac{R_2 || R_3}{R_1 + (R_2 || R_3)}$$

7. Derive the equation for V_{HYS}.

$$V_{HYS} = V_H - V_L = \frac{R_1 \times R_2 \times V_{cc}}{R_1 \times (R_2 + R_3) + (R_2 \times R_3)}$$

8. Solve for R_3.

$$R_3 = \frac{R_1 \times R_2 \times (V_{cc} - V_{HYS})}{(R_1 + R_2) \times V_{HYS}} = \frac{1M\Omega \times 1M\Omega \times (3V - 0.4V)}{(1M\Omega + 1M\Omega) \times 0.4V} = 3.25M\Omega$$

$$R_3 = 3.3M\Omega \quad \text{(Standard Value)}$$

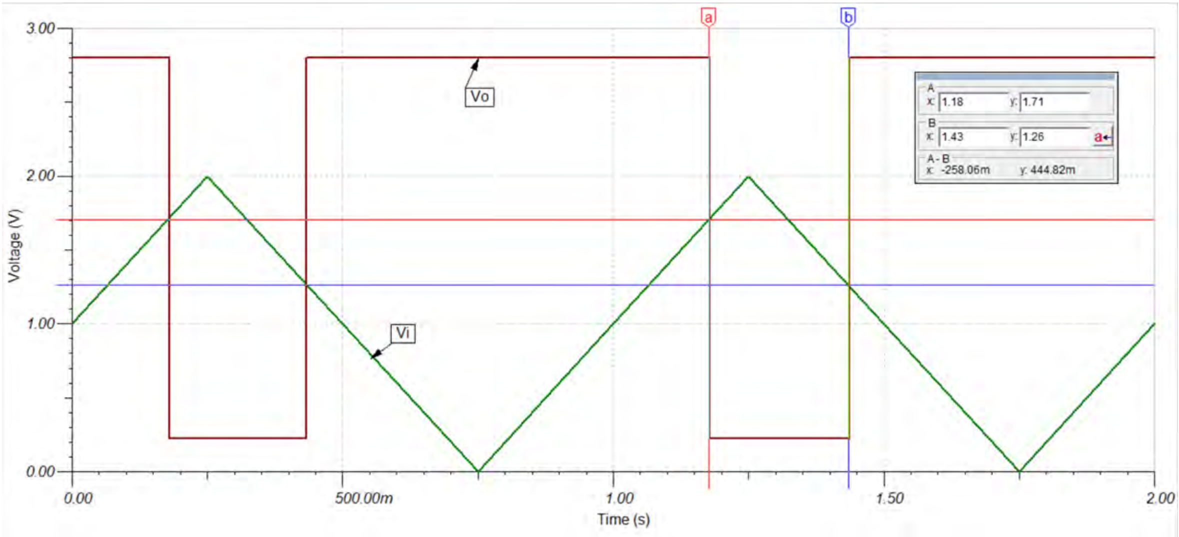
9. Verify V_{HYS}=400mV such that V_H = 1.7V and V_L = 1.3V.

$$V_H = V_{cc} \times \frac{R_2}{(R_1 || R_3) + R_2} = 3V \times \frac{1M\Omega}{(1M\Omega || 3.3M\Omega) + 1M\Omega} = 1.70V$$

$$V_L = V_{cc} \times \frac{R_2 || R_3}{R_1 + (R_2 || R_3)} = 3V \times \frac{(1M\Omega || 3.3M\Omega)}{1M\Omega + (1M\Omega || 3.3M\Omega)} = 1.30V$$

$$V_{HYS} = V_H - V_L = 1.70V - 1.30V = 400mV$$

Transient Simulation Results



Design References

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

See Comparator with Hysteresis Reference Design TIPD144, www.ti.com/tipd144.

See Circuit SPICE Simulation File SLVMCQ0, http://www.ti.com/lit/zip/slvmcq0.

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