Analog Engineer's Circuit

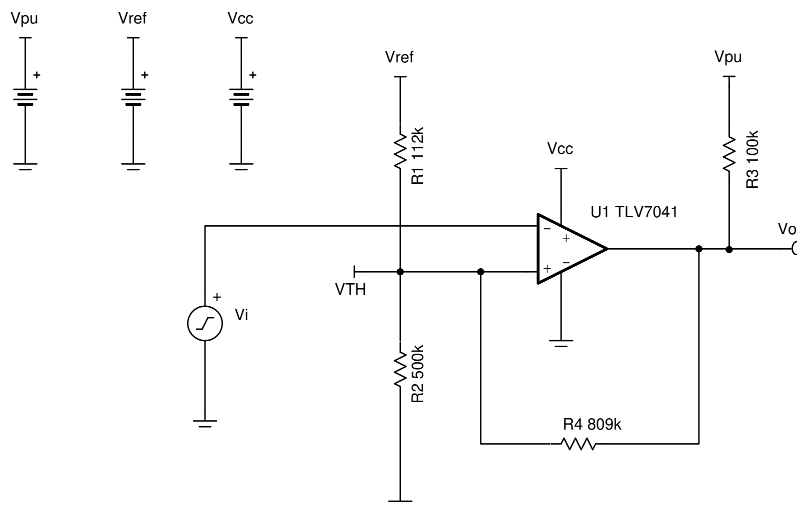
Inverting Comparator With Hysteresis Circuit

Design Goals

Output		Thresholds			Supply		
V_0 = HIGH	V_o = LOW	V_H	V_L	V_{HYS}	V_{cc}	V_{PU}	V_{ref}
$V_i < V_L$	$V_i > V_H$	2.5 V	2.2 V	300 mV	3 V	3 V	3 V

Design Description

Comparators are used to differentiate between two different signal levels. With noise, signal variation, or slow-moving signals, undesirable transitions at the output can be observed with a constant threshold. 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

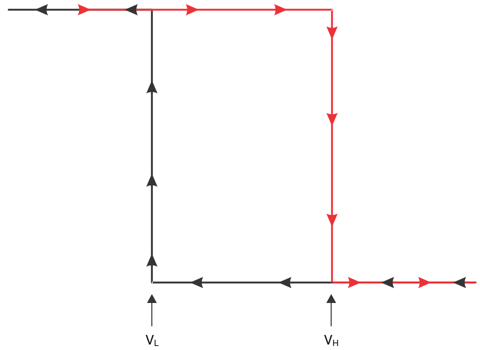
1. The accuracy of the hysteresis threshold voltages are related to the tolerance of the resistors used in the circuit, the selected comparator's input offset voltage specification, and any internal hysteresis of the device.
2. The TLV7041 has an open-drain output stage, so a pull-up resistor is needed.

Design Steps

1. Select the lower biasing resistor, R_2. This resistor can be modified for any design. In this case, it is assumed that power conservation is necessary, therefore, R_2 is selected to be large.

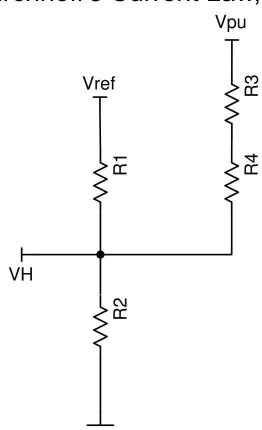
   $$R_2 = 500k\,\Omega$$

2. Select the switching thresholds for when the comparator will transition from high to low (V_L) and low to high (V_H). V_L is the necessary input voltage for the comparator output to transition low and V_H is the required input voltage for the comparator to output high.



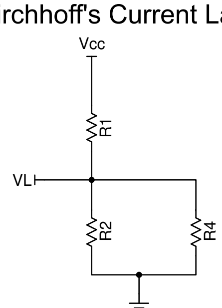
   $$V_L = 2.2V \text{ and } V_H = 2.5V$$

3. Analyze the circuit when the input voltage is V_H. At this point, V_o=3 V=V_{PU} and the transition to a logic low is initiated in the comparator output. Using Kirchhoff's Current Law, solve for an equation for R_1.



$$\frac{V_{PU} - V_H}{R_3 + R_4} + \frac{V_{REF} - V_H}{R_1} = \frac{V_H}{R_2} \Rightarrow R_1 = \frac{V_{REF} - V_H}{\frac{V_H}{R_2} - \frac{V_{PU} - V_H}{R_3 + R_4}}$$

4. Analyze the circuit when the input voltage is V_L. At this point, V_o=0 V and the transition to a logic high is initiated in the comparator output. Using Kirchhoff's Current Law, solve for an equation for R_1.



$$\frac{V_{REF} - V_L}{R_1} = \frac{V_L}{R_2} + \frac{V_L}{R_4} \Rightarrow R_1 = \frac{V_{REF} - V_L}{V_L \times \left(\frac{R_2 + R_4}{R_2 R_4}\right)}$$

5. After defining some constants, set the two equations for R_1 equal to obtain a quadratic equation for R_4.

   a. **Constants:**

$$A = \frac{V_{REF}}{V_L} - 1$$

$$B = V_{REF} - V_H$$

$$C = \frac{V_H}{R_2}$$

$$D = V_{PU} - V_H$$

Simplified Quadratic for R_4:

$$\left(\frac{B}{A} - C \times R_2\right) \times {R_4}^2 + \left[\frac{B}{A} \times (R_2 + R_3) - C \times R_2 \times R_3 + D \times R_2\right] \times R_4 + \left(\frac{B}{A} \times R_2 \times R_3\right) = 0$$

   b. If the output stage is push-pull, then make the following modifications to the above equations:

$$R_3 = 0$$

$$V_{PU} = V_{CC}$$

$$D = V_{CC} - V_H$$

6. Solve the quadratic equation for R_4 and pick the most logical result.

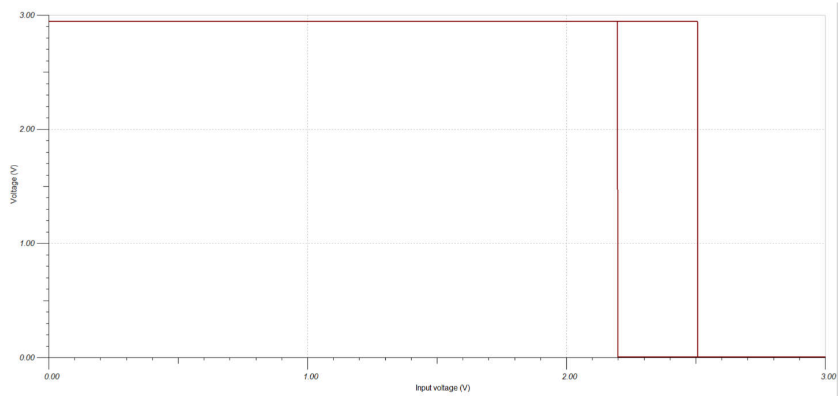
$$R_4 = 808.88\text{k}\Omega \cong 809\text{k}\Omega$$

7. Calculate R_1 by substituting the value for the *A* constant into the equation for R_1 found in step 4.

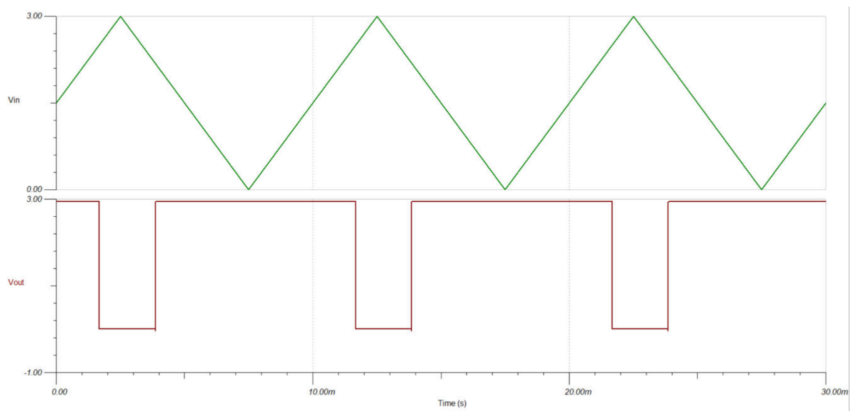
$$R_1 = \frac{V_{REF} - V_L}{V_L \times \left(\frac{R_2 + R_4}{R_2 R_4}\right)} = \left(\frac{V_{REF}}{V_L} - 1\right) \times \left(\frac{R_2 \times R_4}{R_2 + R_4}\right) = A \times \left(\frac{R_2 \times R_4}{R_2 + R_4}\right)$$

$$R_1 = 112.36\text{k}\Omega \cong 112\text{k}\Omega$$

DC Transfer Simulation Results



Transient Simulation Results



Design References

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

See Comparator with Hysteresis Reference Design TIPD144.

See Circuit SPICE Simulation File SLVMCQ0, Inverting Comparator with Hysteresis Circuit Reference Design.

For more information on many comparator topics including hysteresis, propagation delay and input common mode range please see TI Precision Labs – Op amps.

Design Featured Comparator

TLV7031 / TLV7041	
Output Type	PP (7031) / OD (7041)
V_{cc}	1.6V to 6.5V
V_{inCM}	Rail-to-rail
V_{os}	±100 µV
V_{HYS}	7 mV
I_q	335 nA/Ch
t_{pd}	3 µs
#Channels	1 and 2
TLV7041	

Design Alternate Comparator

	TLV1701	TLV7011 / TLV7021
Output Type	Open Collector	PP (7011) / OD (7021)
V_{cc}	2.2 V to 36 V	1.6 V to 5.5 V
V_{inCM}	Rail-to-rail	Rail-to-rail
V_{HYS}	N/A	4.2 mV
V_{os}	±500 µV	±500 µV
I_q	55 µA/Ch	5 µA
t_{pd}	560 ns	260 ns
#Channels	1, 2, and 4	1 and 2
	TLV1701	TLV7011

IMPORTANT NOTICE AND DISCLAIMER

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265