

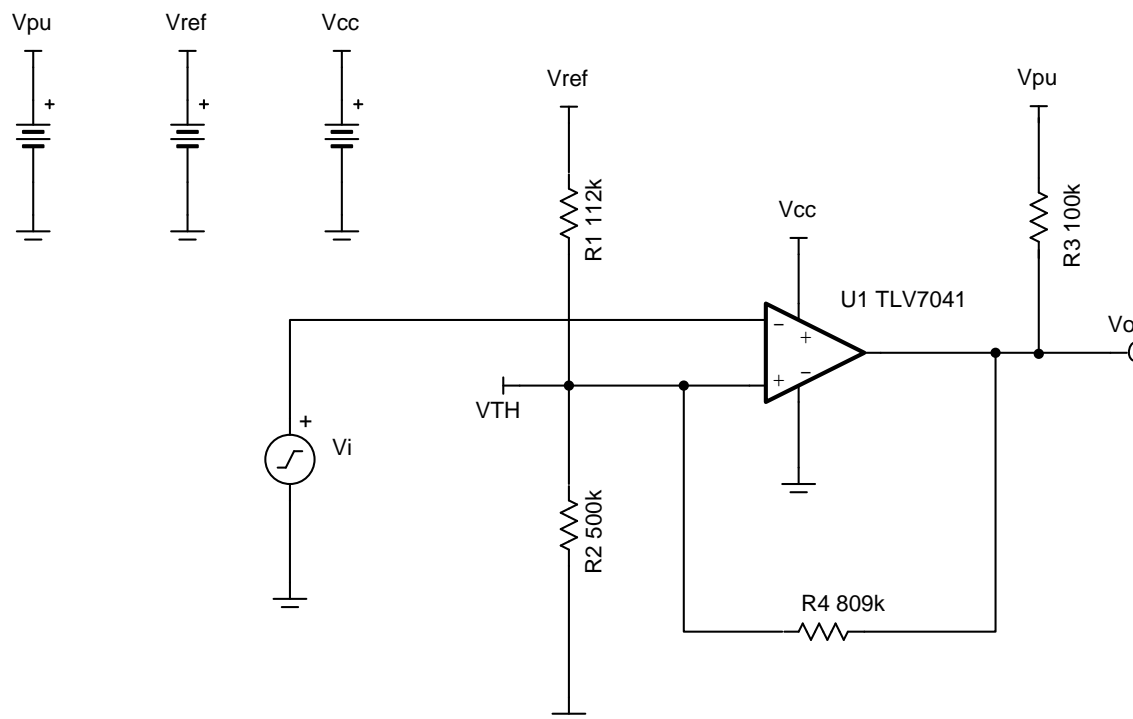
## Inverting Comparator With Hysteresis Circuit

### Design Goals

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

### 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.

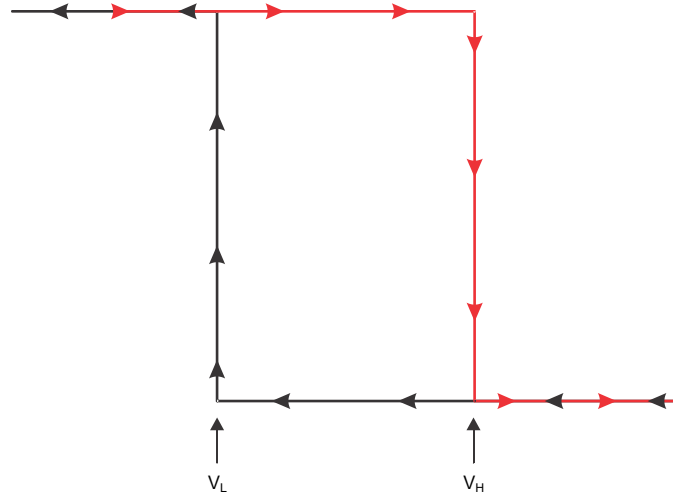


### Design Notes

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.

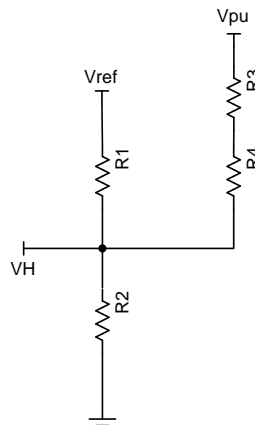
### Design Steps

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.



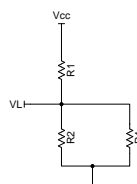
$$V_L = 2.2V \text{ and } V_H = 2.5V$$

3. Analyze the circuit when the input voltage is  $V_H$ . At this point,  $V_o = 3V = V_{PU}$  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,  $V_o = 0V$  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  $R_4$ .

**Constants:**

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

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

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

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

**Simplified Quadratic for  $R_4$ :**

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

- a. 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.

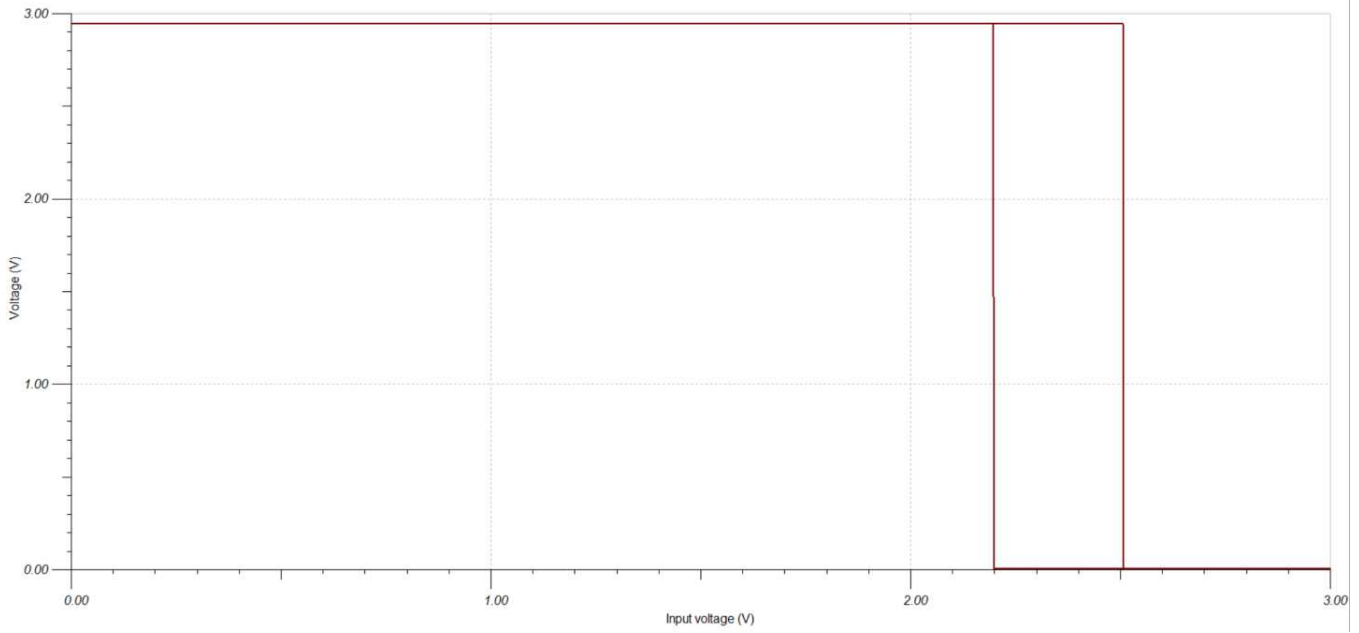
$$R_4 = 808.88\text{k}\Omega \cong 809\text{k}\Omega$$

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

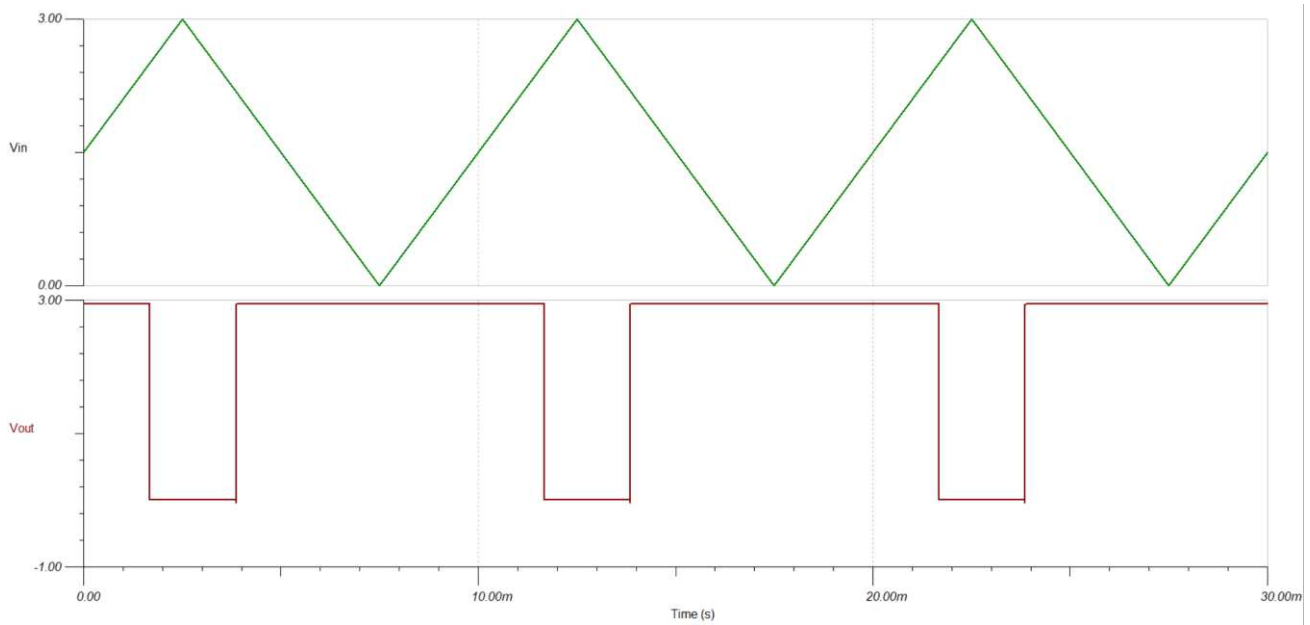
$$R_1 = \frac{V_{REF} - V_L}{V_L \times \left( \frac{R_2 + R_4}{R_2 R_4} \right)} = \left( \frac{V_{REF}}{V_L} - 1 \right) \times \left( \frac{R_2 \times R_4}{R_2 + R_4} \right) = A \times \left( \frac{R_2 \times R_4}{R_2 + R_4} \right)$$

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

### 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, [www.ti.com/tipd144](http://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](http://training.ti.com/ti-precision-labs-op-amps).

## Design Featured Comparator

TLV7031 / TLV7041	
<b>Output Type</b>	PP (7031) / OD (7041)
<b>V<sub>cc</sub></b>	1.6V to 6.5V
<b>V<sub>inCM</sub></b>	Rail-to-rail
<b>V<sub>os</sub></b>	±100µV
<b>V<sub>HYS</sub></b>	7mV
<b>I<sub>q</sub></b>	335nA/Ch
<b>t<sub>pd</sub></b>	3µs
<b>#Channels</b>	1, 2
<a href="http://www.ti.com/product/tlv7041">www.ti.com/product/tlv7041</a>	

## Design Alternate Comparator

	TLV1701	TLV7011 / TLV7021
<b>Output Type</b>	Open Collector	PP (7011) / OD (7021)
<b>V<sub>cc</sub></b>	2.2V to 36V	1.6V to 5.5V
<b>V<sub>inCM</sub></b>	Rail-to-rail	Rail-to-rail
<b>V<sub>HYS</sub></b>	N/A	4.2mV
<b>V<sub>os</sub></b>	±500µV	±500µV
<b>I<sub>q</sub></b>	55µA/Ch	5µA
<b>t<sub>pd</sub></b>	560ns	260ns
<b>#Channels</b>	1, 2, 4	1, 2
	<a href="http://www.ti.com/product/tlv1701">www.ti.com/product/tlv1701</a>	<a href="http://www.ti.com/product/TLV7011">http://www.ti.com/product/TLV7011</a>

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