# Comparator Applications TIPL Presentation

## TI Precision Labs – Op Amps

**Presented by Paul Grohe**

**Prepared by Thomas Kuehl, Ian Williams and Paul Grohe**

# The Comparator Function – Non-inverting

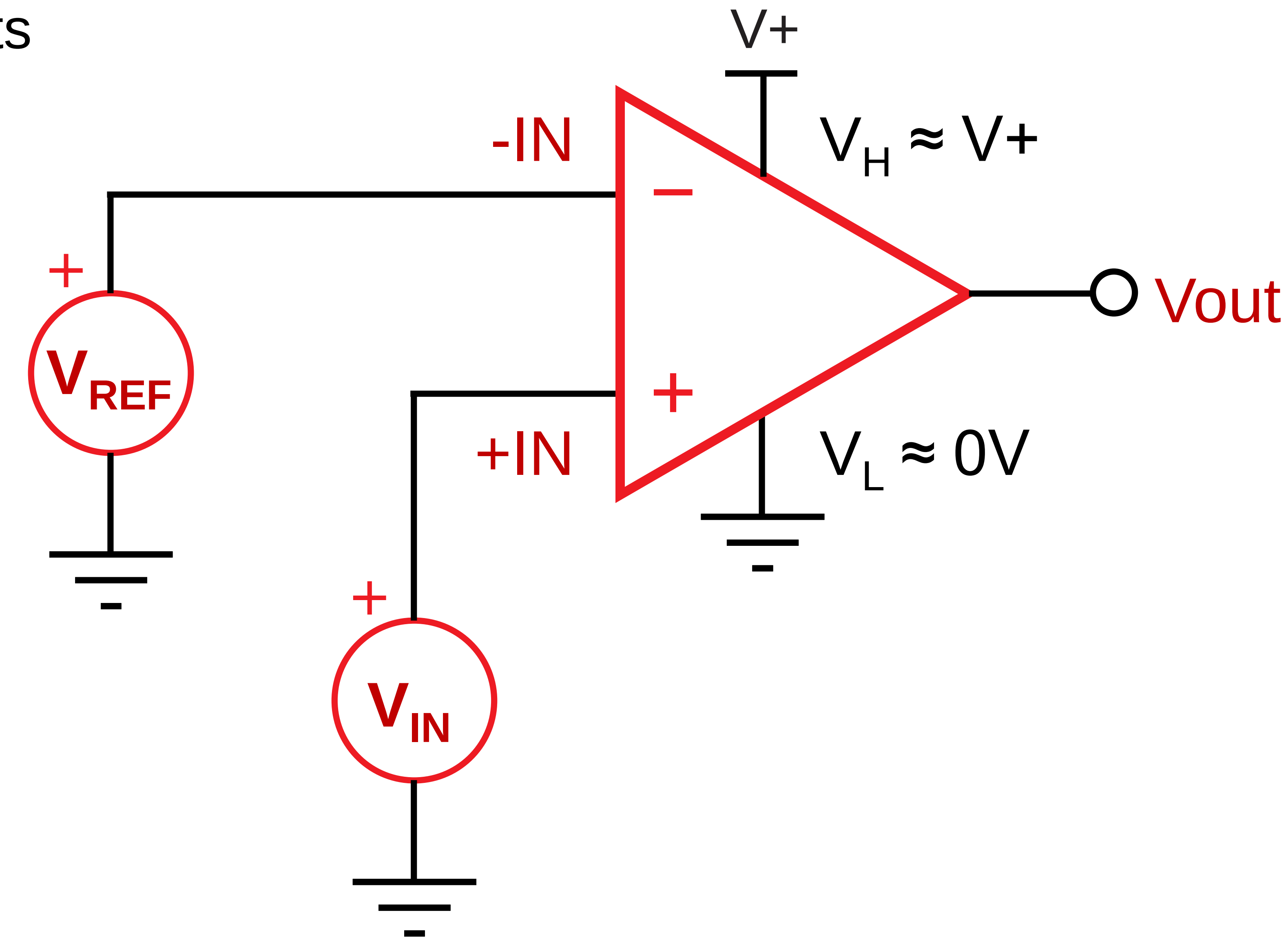
**$V_{IN}$** and **$V_{REF}$** applied to **+IN** and **-IN** inputs

- **$V_{IN}$** = input signal
- **$V_{REF}$** = reference signal
- may have both dc and ac components

**Vout** can be one of two levels

- $V_H$ = HIGH (1)
- $V_L$ = LOW (0)

| Input | Output |
|---|---|
| $V_{IN}$ => $V_{REF}$ | **HIGH (1)** |
| $V_{IN}$ < $V_{REF}$ | **LOW (0)** |

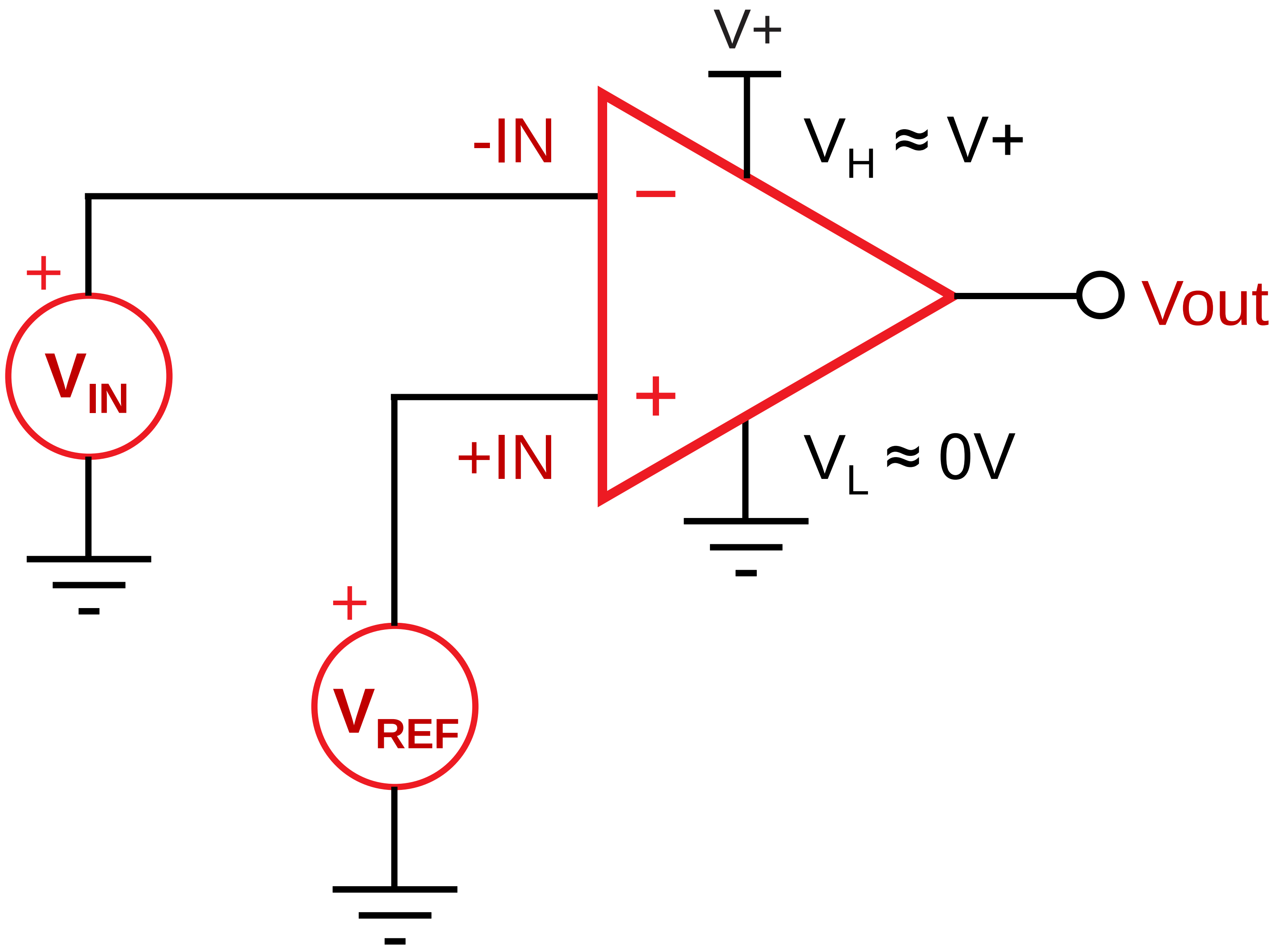


# The Comparator Function – Inverting

Switch the input and reference signals to use the comparator in an inverting configuration

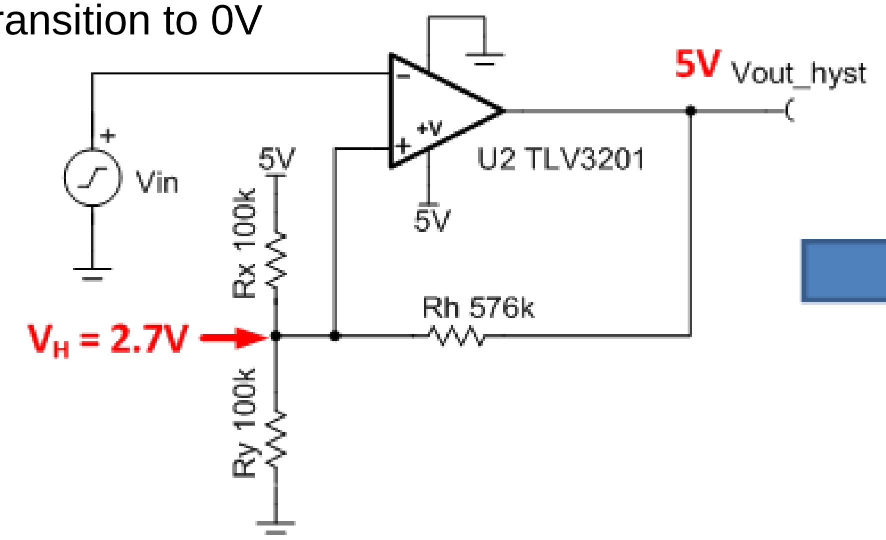
- $V_{IN}$ applied to **–IN**
- $V_{REF}$ applied to **+IN**

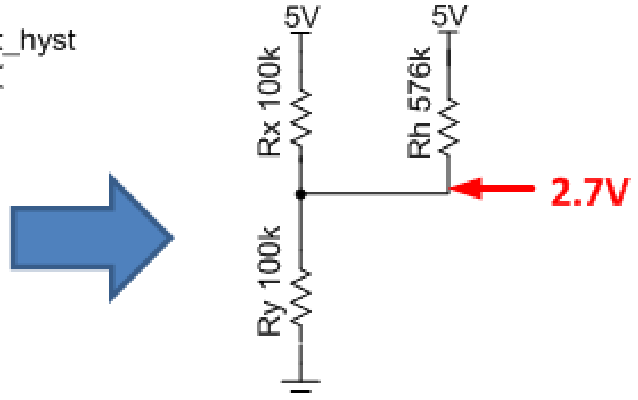
| Input | Output |
|---|---|
| $V_{IN} > V_{REF}$ | **LOW (0)** |
| $V_{IN} <= V_{REF}$ | **HIGH (1)** |



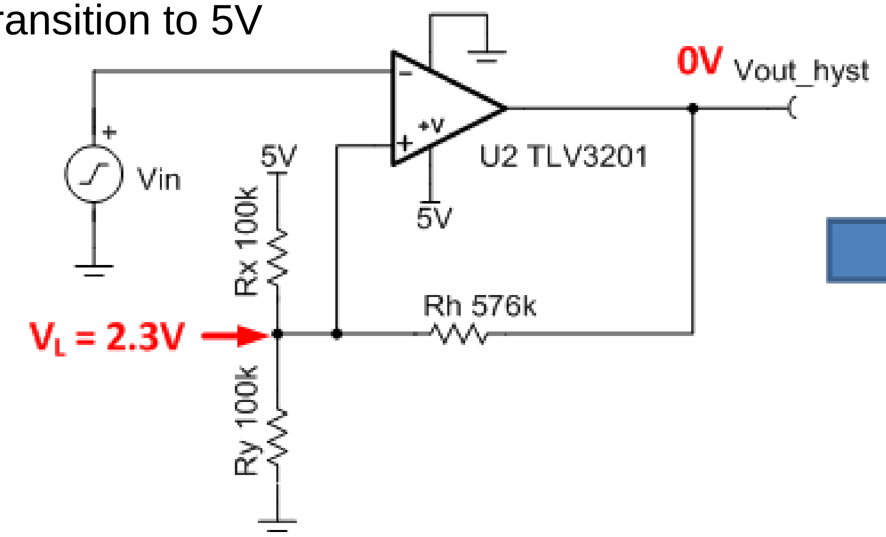
# Reducing Noise Sensitivity with Hysteresis

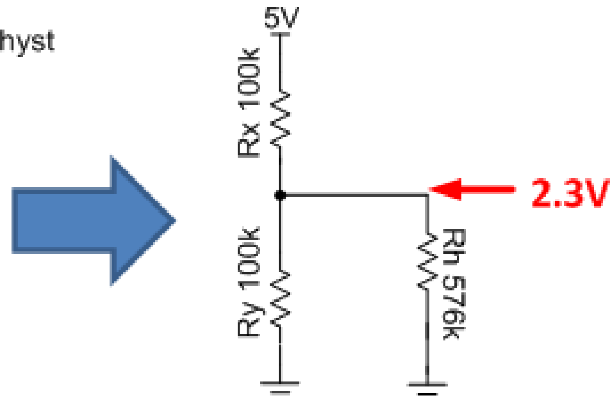
Vin > 2.7V causes Vout to transition to 0V



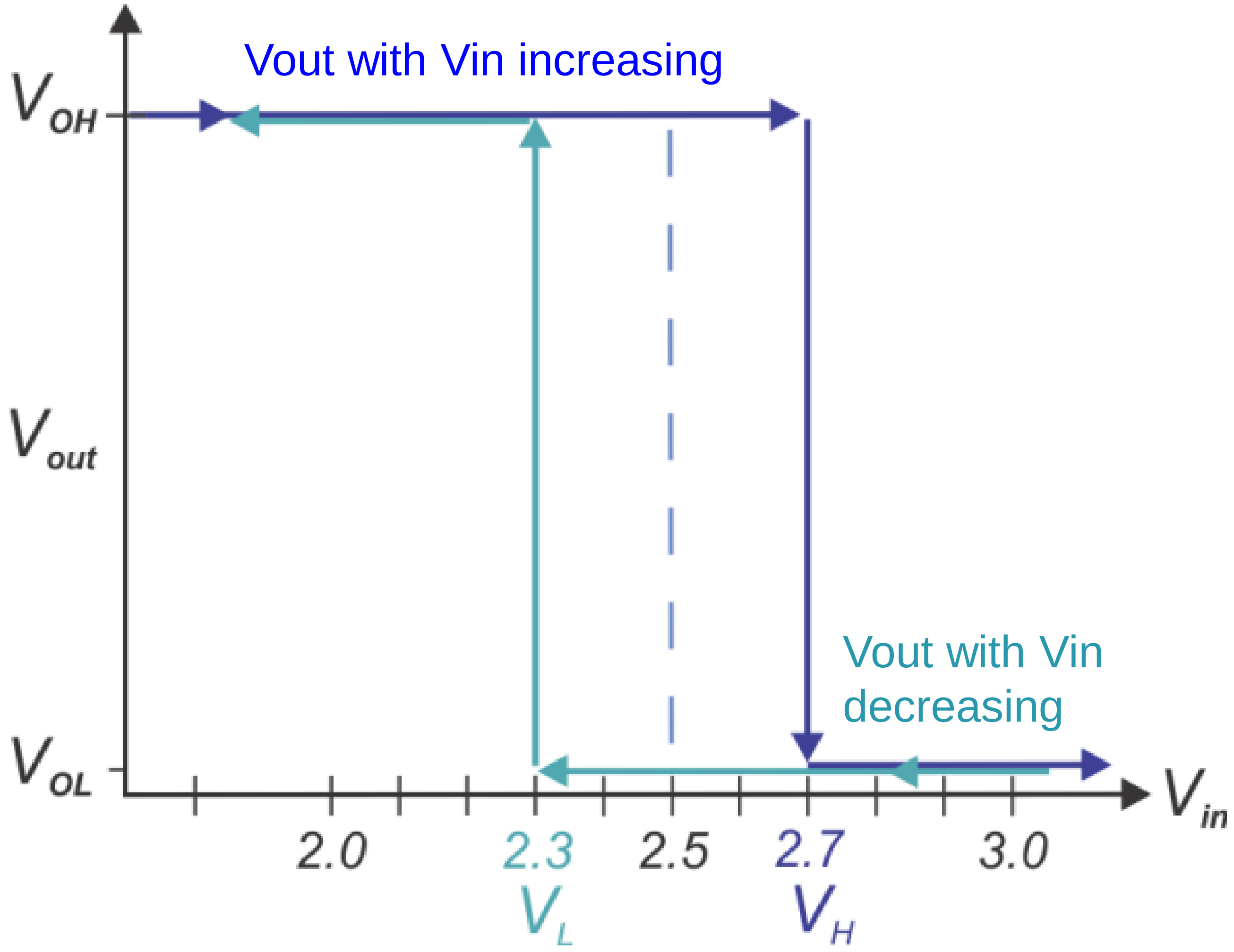




Vin < 2.3V causes Vout to transition to 5V

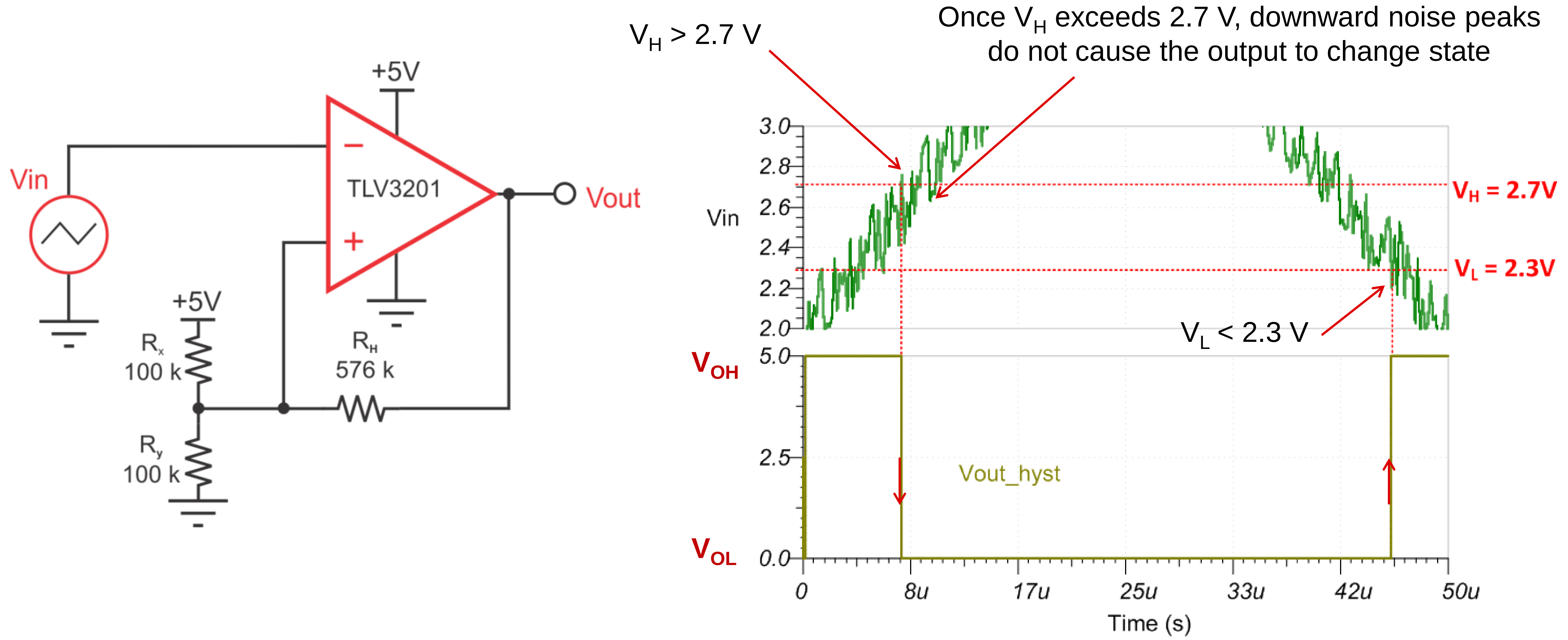



**Vout vs Vin with 400 mV of hysteresis**



# Reducing Noise Sensitivity with Hysteresis

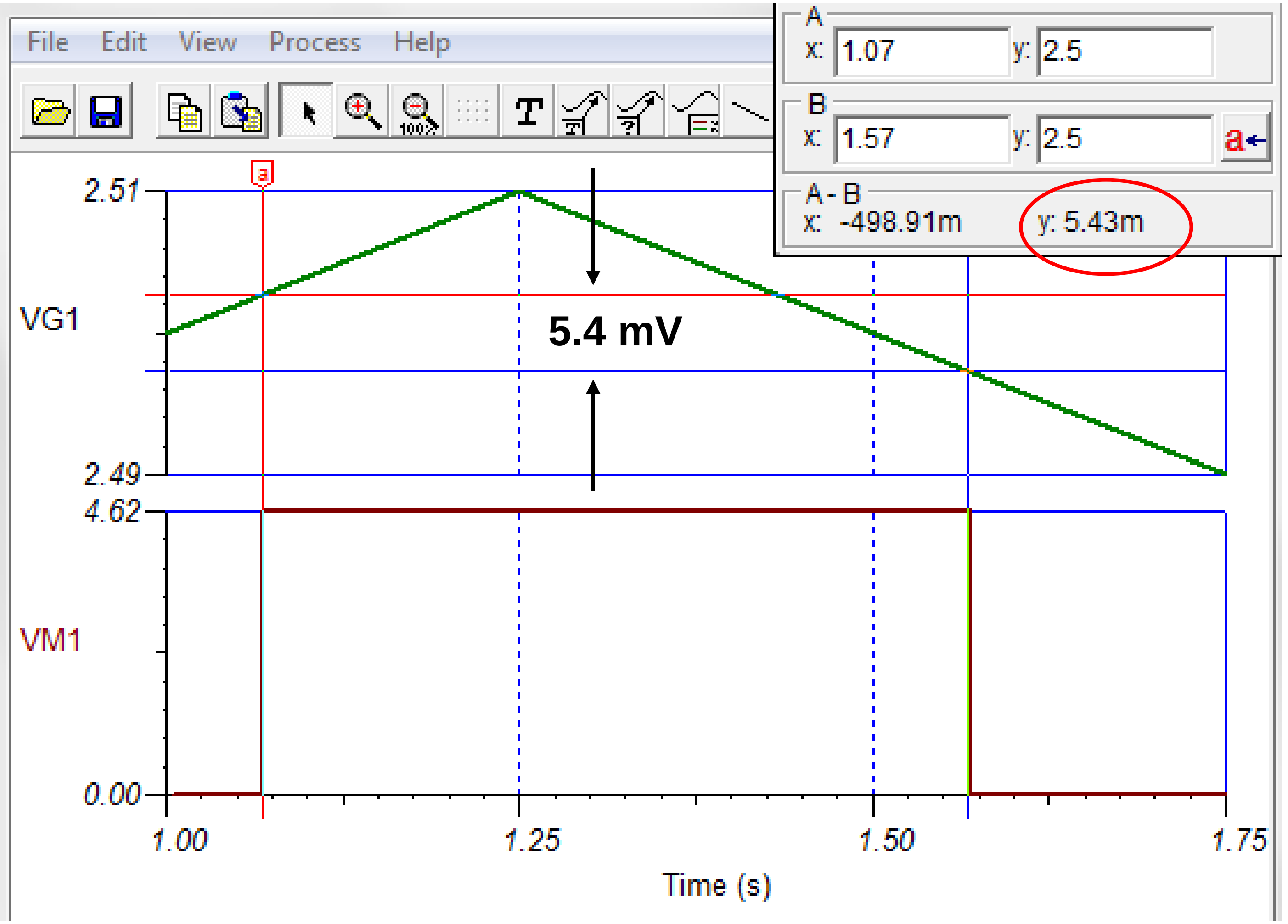


# Some Comparators Have Built-in Hysteresis

TI comparators with built-in hysteresis:

- **TLV7011** – 350 ns micropower, push-pull output, $V_{HYST}$ 4.2 mV typ.
- **TLV3202** – 40 ns micropower, push-pull output, $V_{HYST}$ 1.2 mV typ.
- **TLV3501** – 4.5 ns high speed, push-pull output, $V_{HYST}$ 6 mV typ.
- **TL712** – 25 ns high speed, differential open-collector, $V_{HYST}$ 5 mV typ.
- **TL714** – 5 ns high speed, push-pull output, $V_{HYST}$ 10 mV typical
- **TLV3691** – 24us, 75nA nanopower, push-pull output, $V_{HYST}$ 17 mV typical
- **LMP7300** – µPower, open-collector, positive and negative hysteresis set independently (0 to 110mV)

TLV3501 simulation model with built-in hysteresis

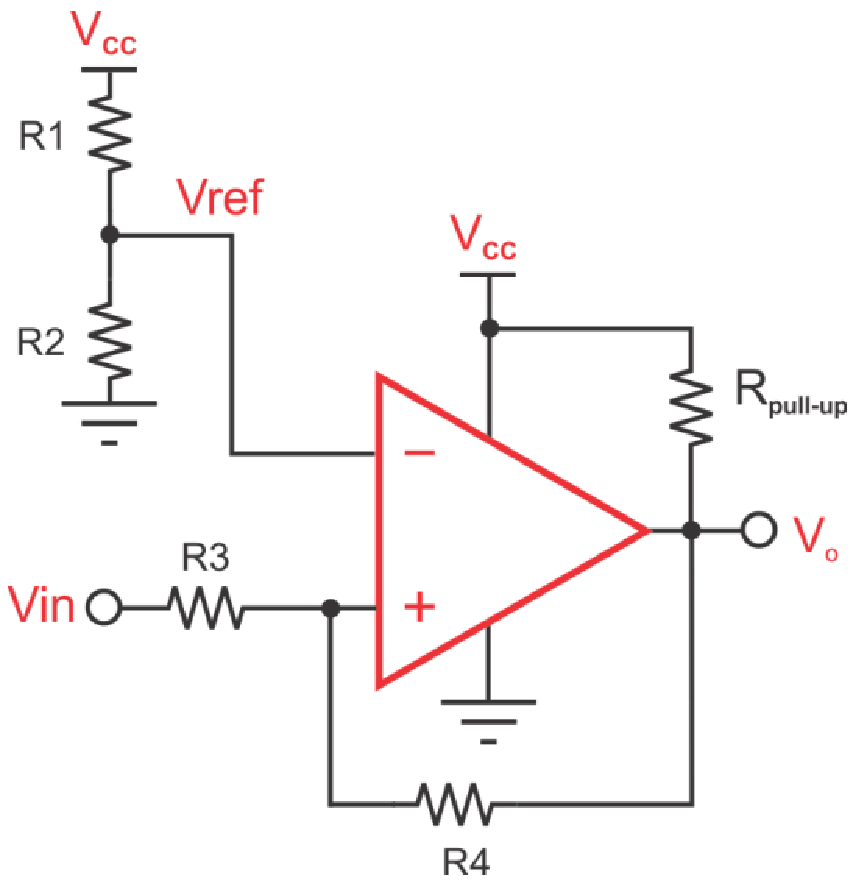



**NOTE: External hysteresis can still be applied!**

# Hysteresis Design Procedure – Non-inverting

## Design goals

- $V_{HYST} = 100$ mV
- $V_{ref} = 2.5$ V




## Select starting values

$\mathrm{Vcc} = 5\ \mathrm{V}, \quad V_{O(max)} = 5\ \mathrm{V}, \quad V_{O(min)} = 50\ \mathrm{mV}$

$\mathrm{R1} = 100\ \mathrm{k}, \quad R_{pull\text{-}up} = 10\ \mathrm{k}$

## Calculate remaining values

$$\mathrm{R2} = \frac{\mathrm{R1}}{\left(\frac{\mathrm{Vcc}}{\mathrm{Vref}} - 1\right)} = \frac{100\ \mathrm{k}}{\left(\frac{5.0}{2.5} - 1\right)} = 100\ \mathrm{k}$$

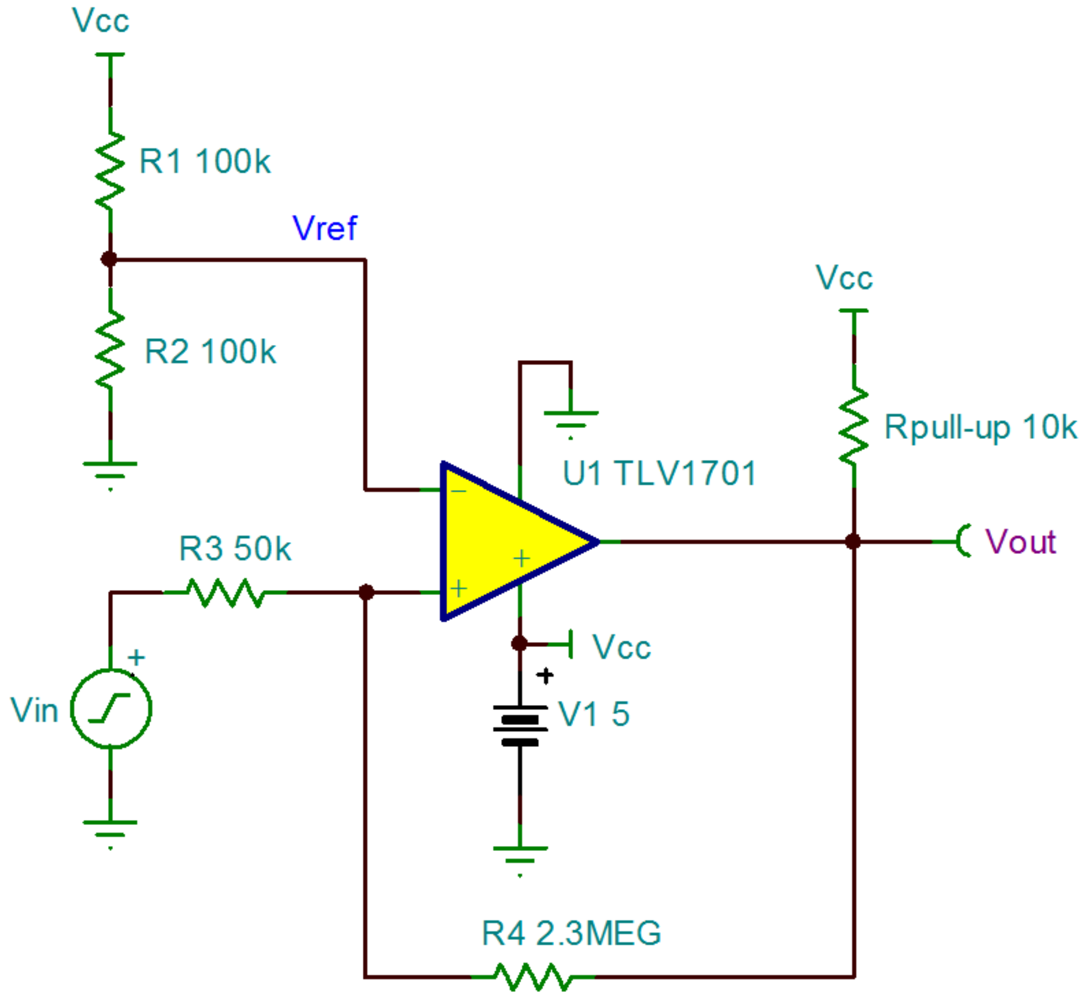
$$\mathrm{R3} = \frac{(\mathrm{R1} \cdot \mathrm{R2})}{(\mathrm{R1} + \mathrm{R2})} = \frac{(10^5 \cdot 10^5)}{(10^5 + 10^5)} = 50\ \mathrm{k}$$

$$\mathrm{R4} = \mathrm{R3}\left[\frac{(V_{O(max)} - V_{O(min)})}{V_{HYST}} - 1\right] = 5 \cdot 10^4\left[\frac{(5.0 - 0.05)}{0.10} - 1\right]$$

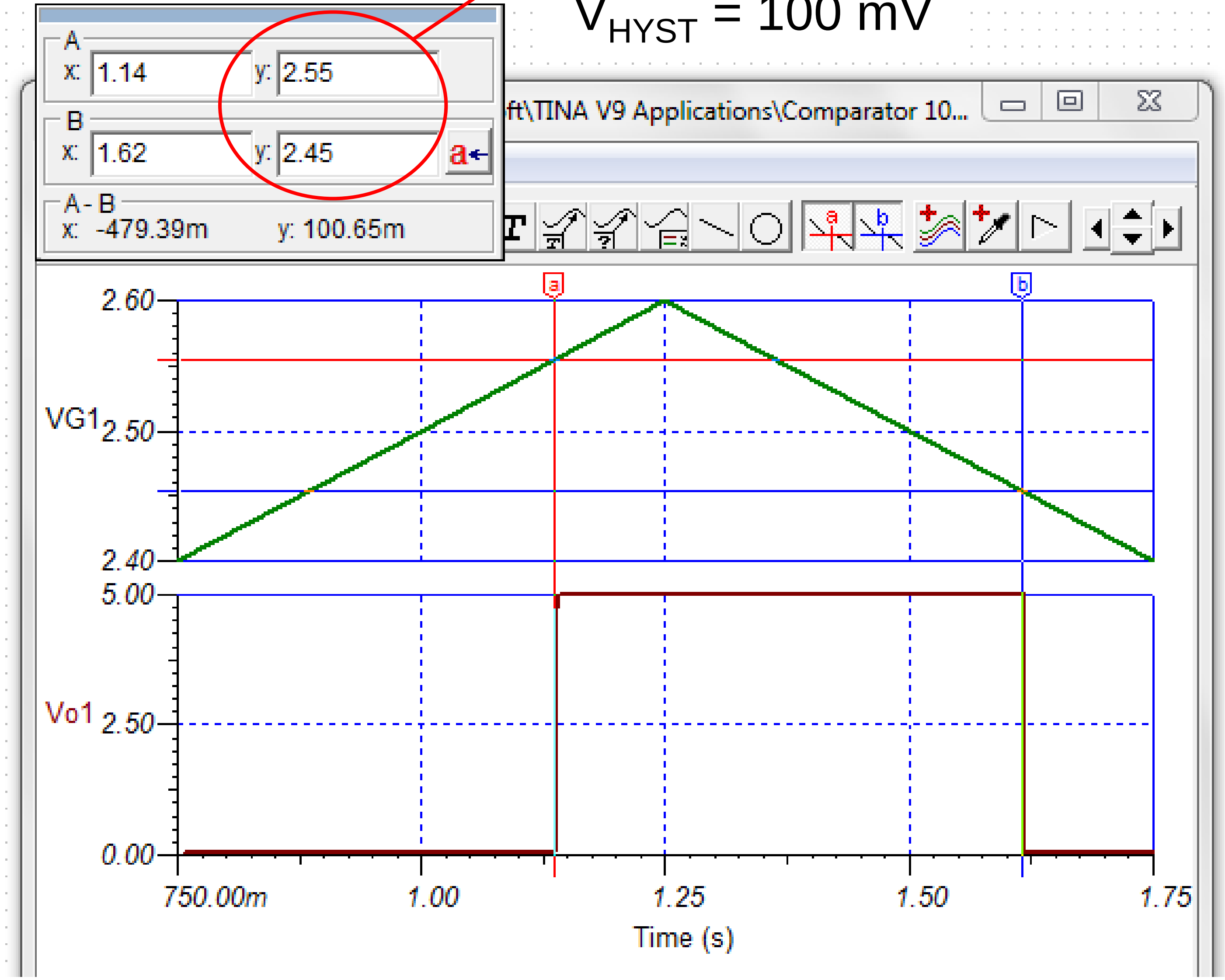
$$\mathrm{R4} = 2.43\ \mathrm{MEG}$$

Make sure $R_{pull\text{-}up}$ is less than $1/10^{th}$ the value of R4!

# Hysteresis Verification with Simulation




$V_H = 2.55$ V
$V_L = 2.45$ V
$V_{HYST} = 100$ mV

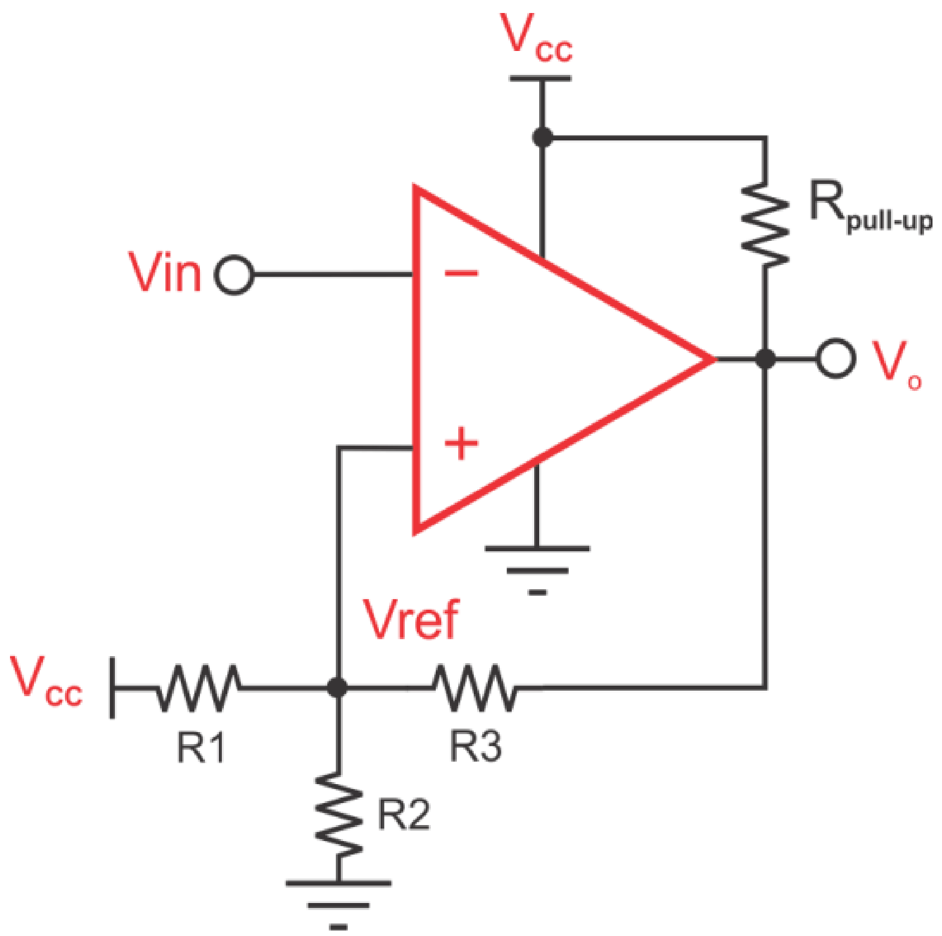



- Hysteresis accuracy improves when $R_{pull\text{-}up} < 0.1 * R4$

# Hysteresis Design Procedure – Inverting

## Design goals

- $V_{HYST}$ = 50 mV
- $V_{ref}$ = 2.5 V




## Select starting values

$\mathrm{Vcc} = 5\ \mathrm{V}, \quad V_{O(max)} = 5.0\ \mathrm{V}, \quad V_{O(min)} = 0.05\ \mathrm{V}$

$\mathrm{R1} = 10\ \mathrm{k}, \quad R_{\text{pull-up}} = 10\ \mathrm{k}$

## Calculate remaining values

Note that equations are different from previous non-inverting!!

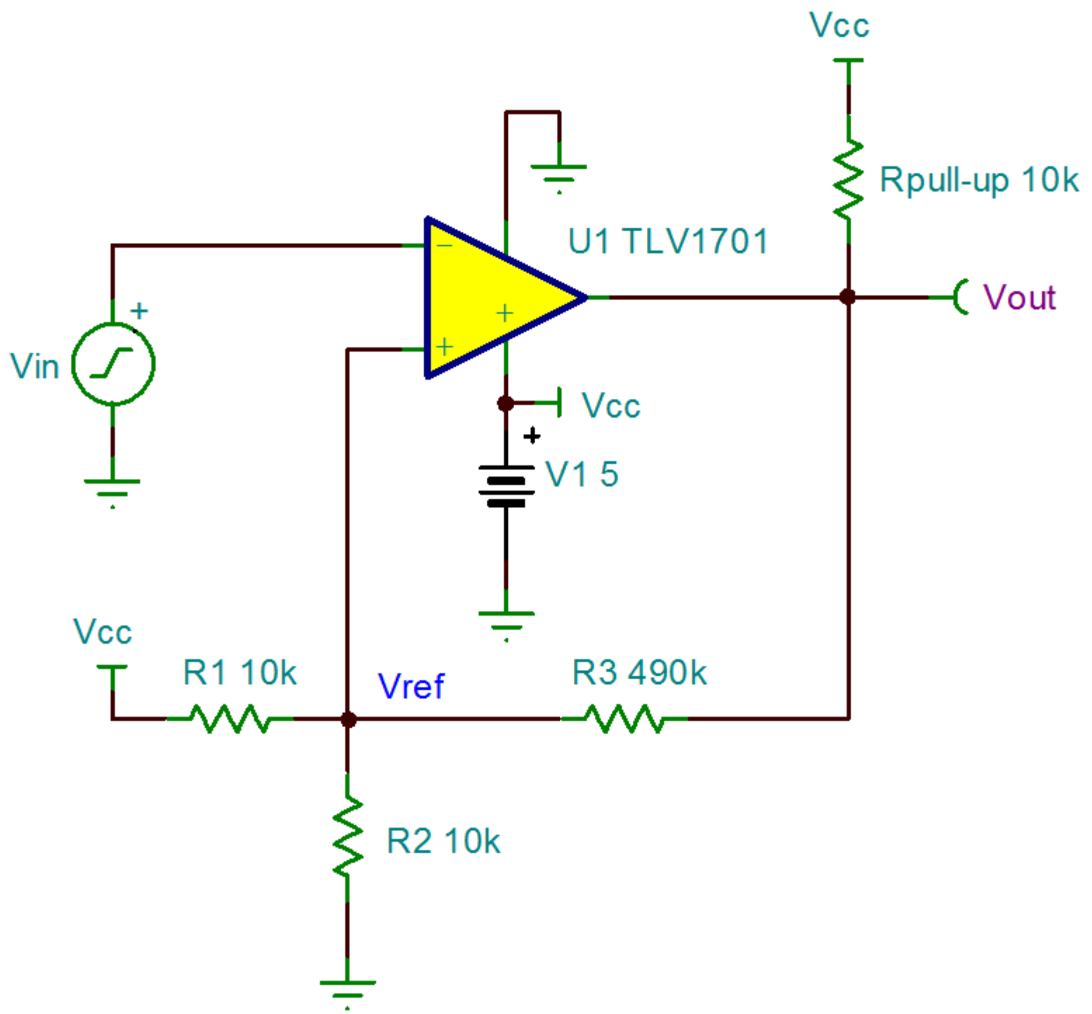
$$\mathrm{R2} = \frac{R1}{\left(\frac{Vcc}{Vref} - 1\right)} = \frac{10\ \mathrm{k}}{\left(\frac{5.0}{2.5} - 1\right)} = 10\ \mathrm{k}$$

$$\mathrm{R3} = \frac{(R1 \cdot R2)}{(R1 + R2)}\left[\frac{\left(V_{O(max)} - V_{O(min)}\right)}{V_{HYST}} - 1\right]$$

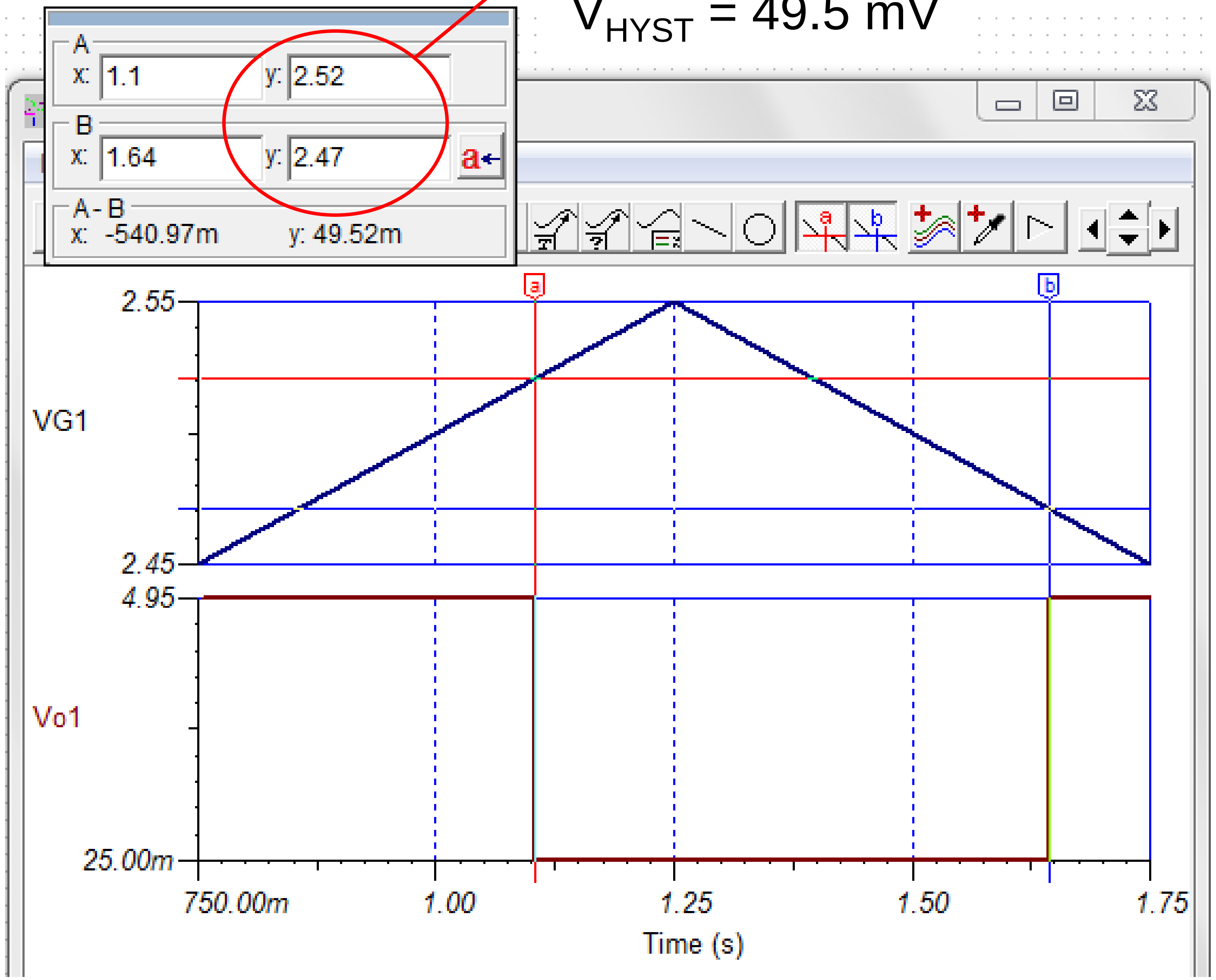
$$\mathrm{R3} = \frac{(10^4 \cdot 10^4)}{(10^4 + 10^4)}\left[\frac{(5.0 - 0.05)}{0.05} - 1\right] = 490\ \mathrm{k}$$

Make sure $R_{\text{pull-up}}$ is less than 1/10th the value of R3!

# Hysteresis Verification with Simulation




$V_H$ = 2.52 V
$V_L$ = 2.47 V
$V_{HYST}$ = 49.5 mV




- Hysteresis accuracy improves with $R_{pull-up}$ < 0.1 * R3
- Equations can be used for push-pull output too!

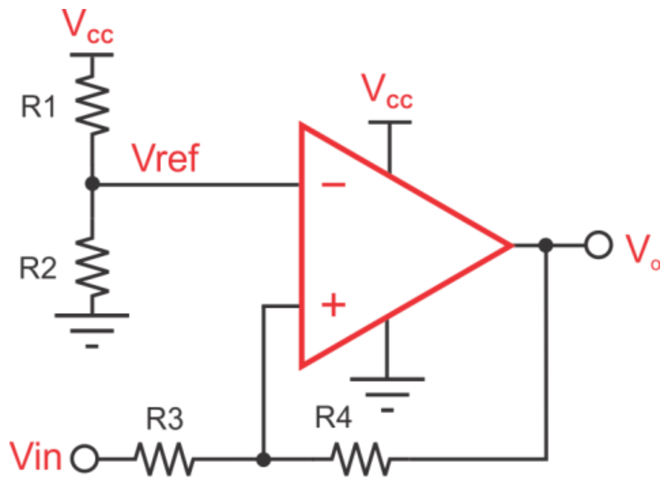
# Hysteresis Design Procedure – Summary

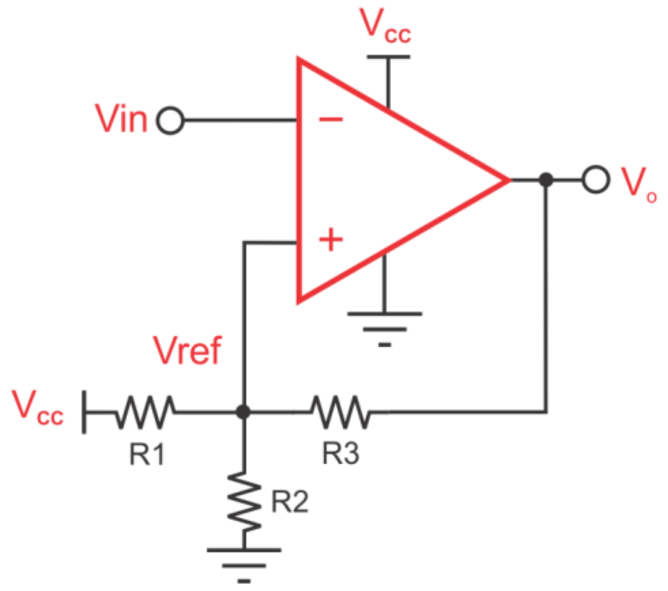
- The resistor values affect either the reference voltage and/or the $V_H$ and $V_L$ levels. Their tolerances are an important factor in hysteresis accuracy.

- The feedback resistor is usually very high in value compared to the others. Its loading on the non-inverting input divider is usually minimal.

- Keeping $R_{pull\text{-}up}$ less than 10 % of the feedback resistor value assures more accurate $V_H$ and $V_L$ voltage levels.

- The inverting and non-inverting equations can also be used for push-pull output comparators if:
  - Remove $R_{pull\text{-}up}$ from the circuit
  - Use the datasheet *Output Voltage vs Output Current* curves to establish $V_{O(max)}$ and $V_{O(min)}$ from the $V_{OH}$ and $V_{OL}$ levels




**Push-pull comparators with hysteresis applied**