Lecture 10: Schmitt Trigger

0. Review
1. Intro
2. Relaxation Oscillator
3. Schmitt Trigger

- PreLab 4 due today
- HW4 due Fri (Oct 25)
- Exam #1 re-do } next Tue (Oct 29)
  Quiz
- Lab 3 report due Nov 04 (Mon)

Textbook Reading:

Ch 20-1 Comparators with zero reference

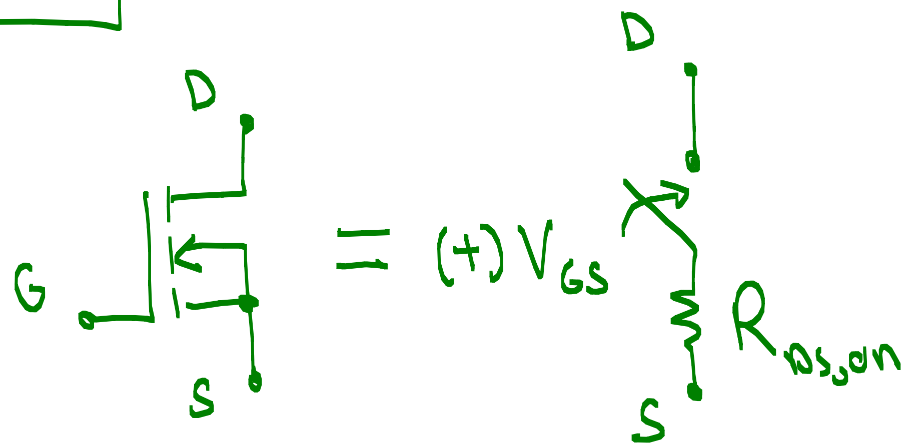
20-3 Comparators with hysteresis

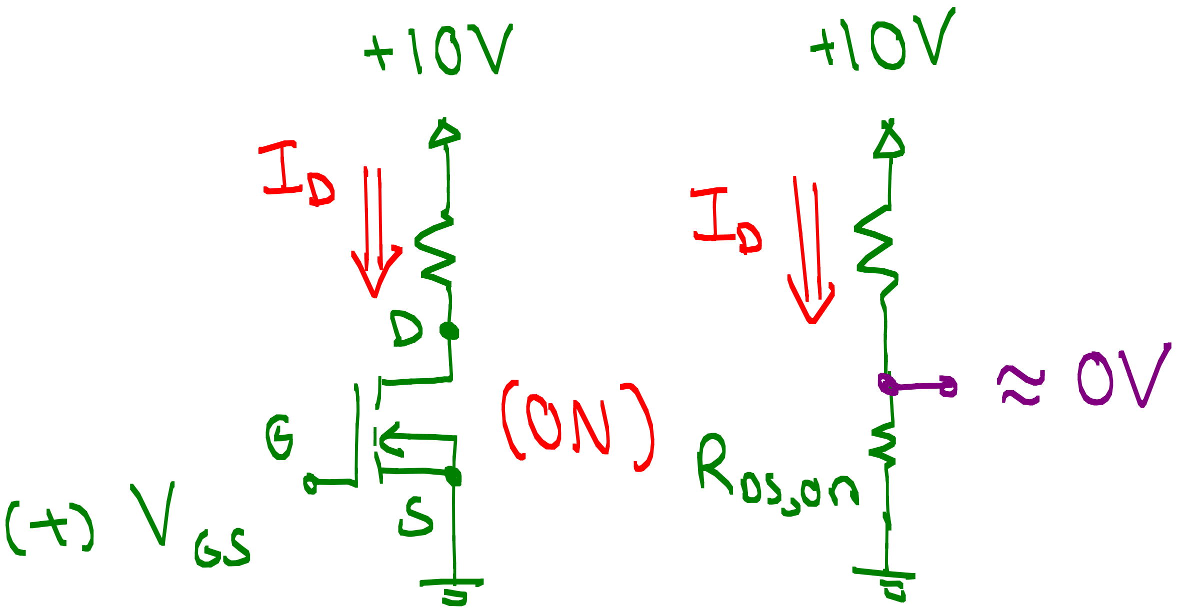
20-7 Waveform Generation

0. Review

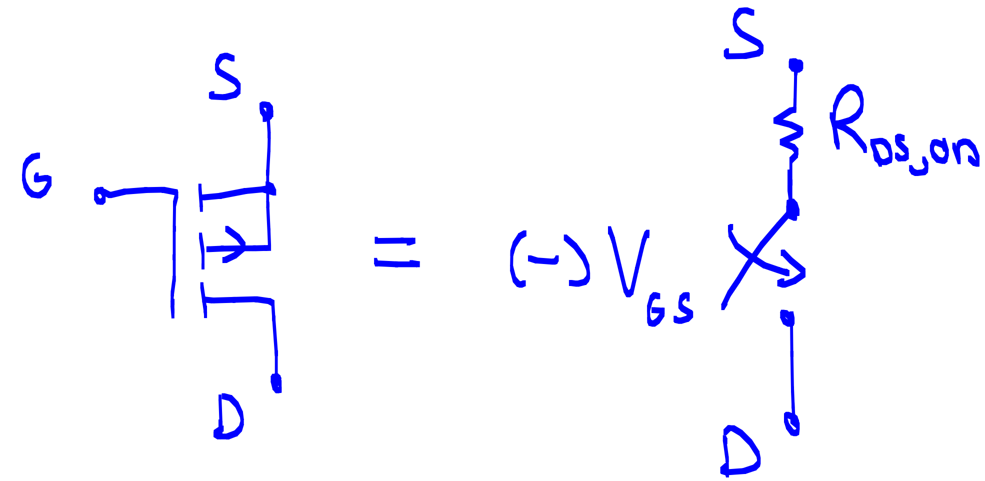
• MOSFET switches

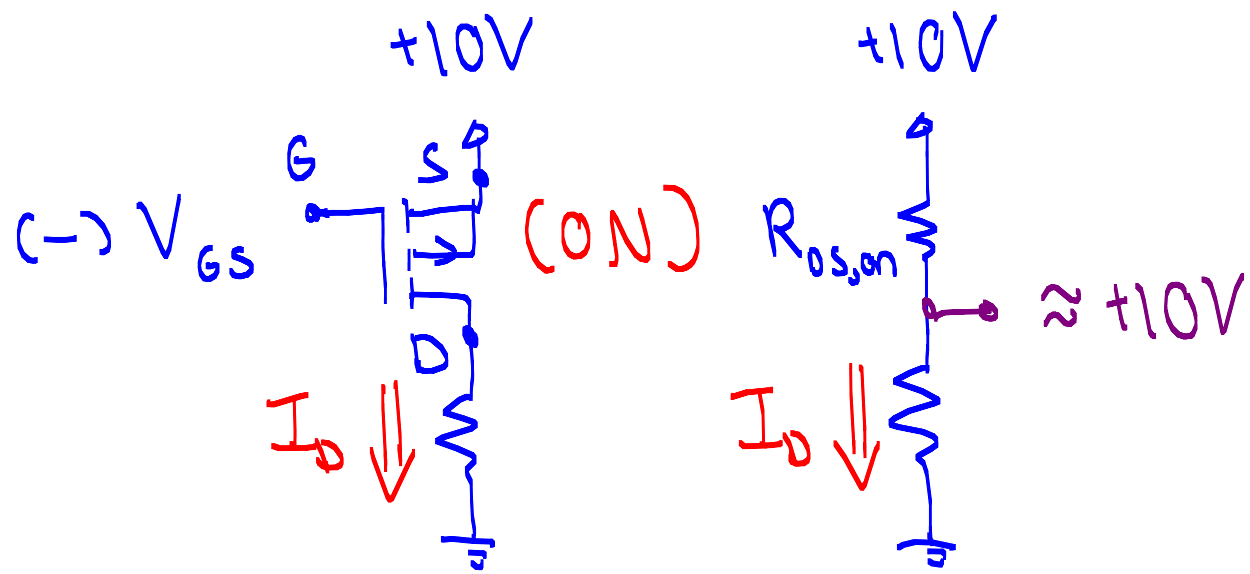
NMOS





PMOS



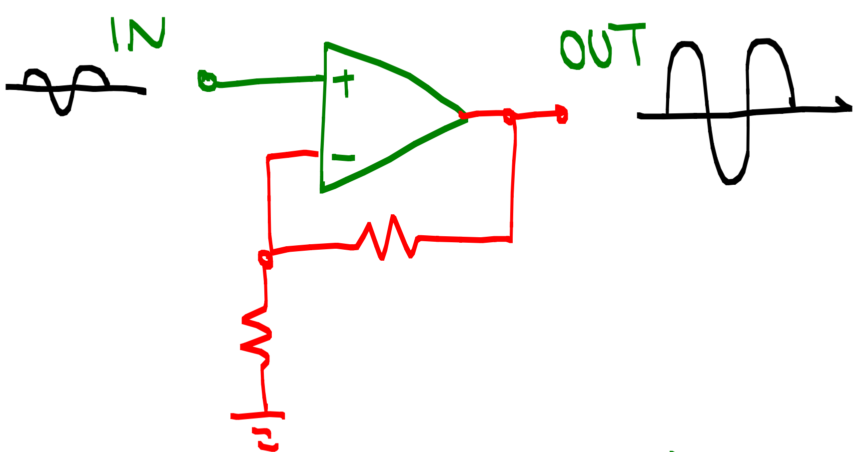


1. Intro

• Unlike amplifiers, waveform generators use positive feedback!

Negative Feedback

Ex:



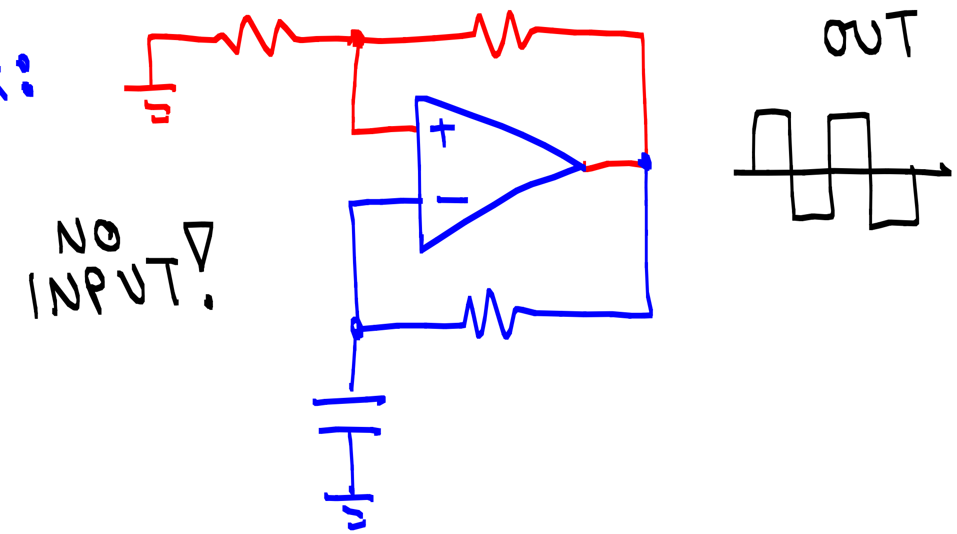
⇒ Most common configuration for op amps

⇒ Amplifiers, current sources, filters, voltage references, etc.

☆ Golden Rules!

Positive Feedback

Ex:



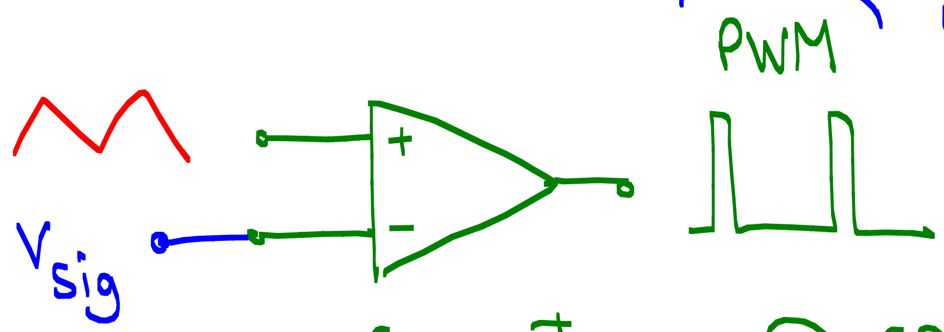
→ useful to make oscillators, comparators, etc.

☆ No Golden Rules! :(

Example: Pulse Width Modulation (PWM)

Const Freq, Variable duty cycle
(PWM)

- Many applications!
  - Motors
  - Servos
  - Lighting
  - Class D amps
  - Communication
  - etc.



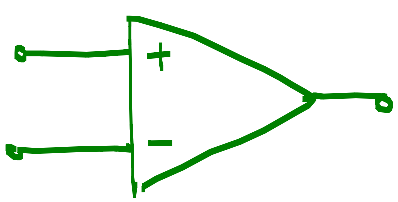
Comparator ← ① op amp (OK)
② Comparator IC (better)

Q: How to implement PWM?

A: Use a voltage comparator

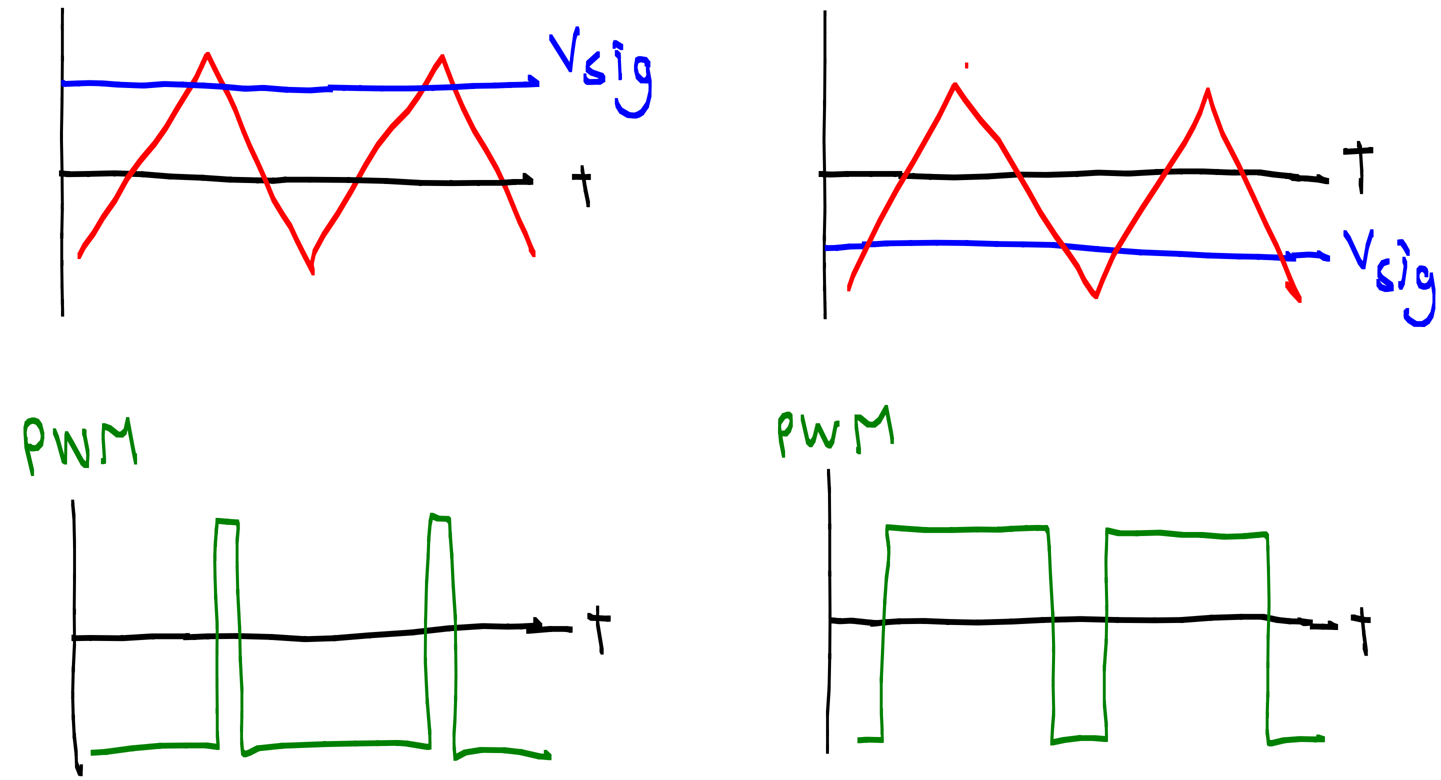
to compare a triangle wave (or sawtooth)

with a signal input



$V_+ > V_-$?

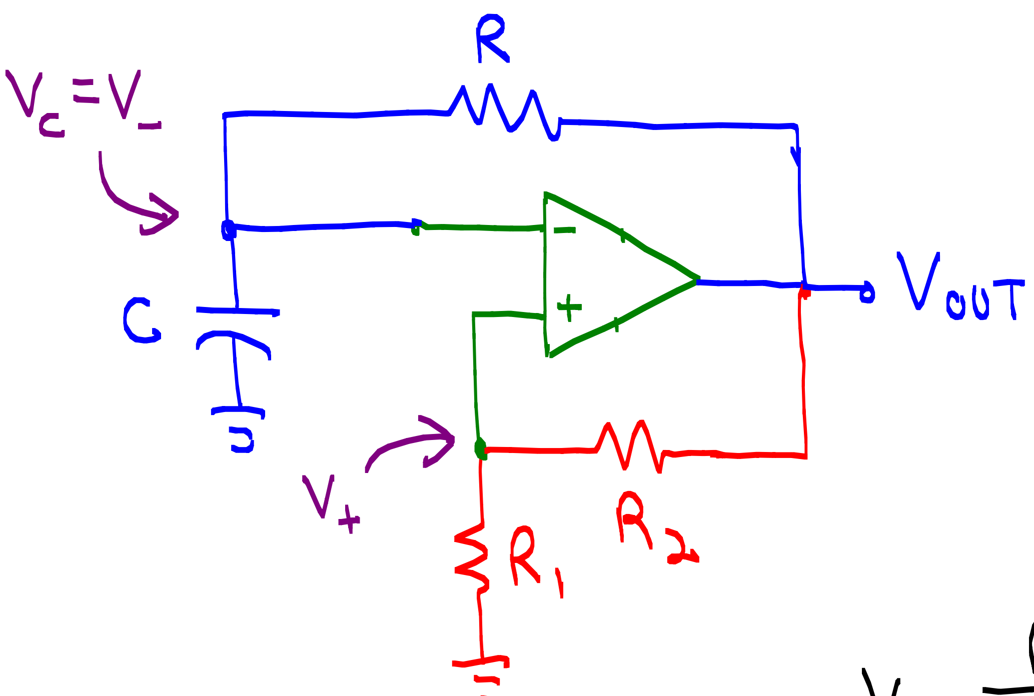
Comparator

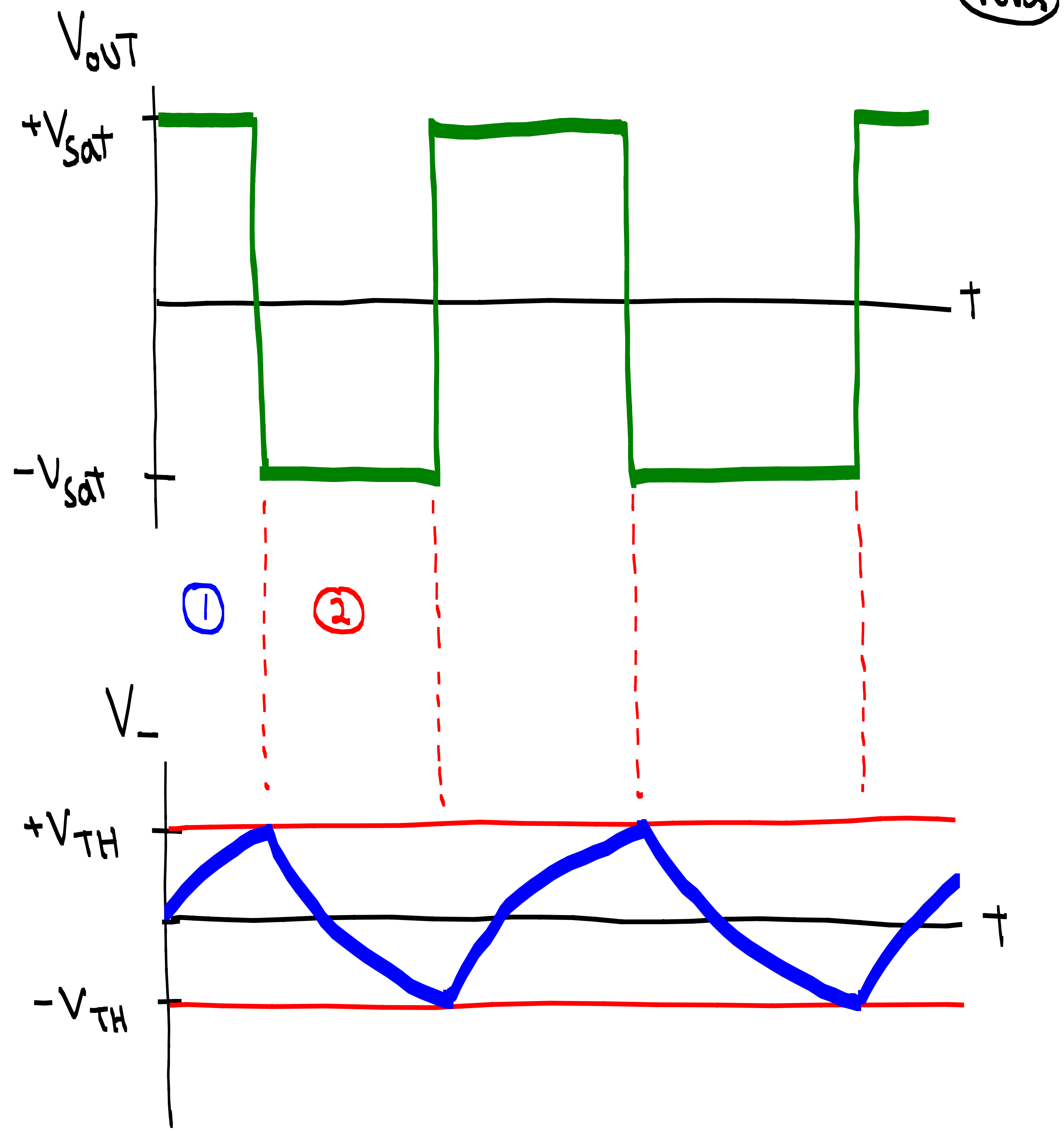


2. Relaxation Oscillator

- Simple example of (+) feedback.

→ Produces a square wave.





$$V_{sat}\frac{R_1}{R_1+R_2}$$

Q: How does this work?

→ Op amp is an ultra-high gain differential amplifier.

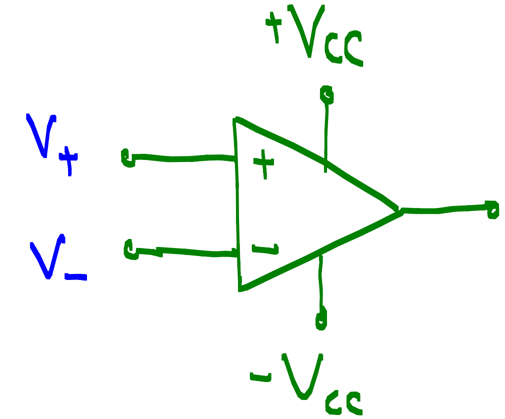
Ⓐ If $V_+ > V_-$, then $V_{OUT} = +V_{sat}$

Ⓑ If $V_+ < V_-$, then $V_{OUT} = -V_{sat}$

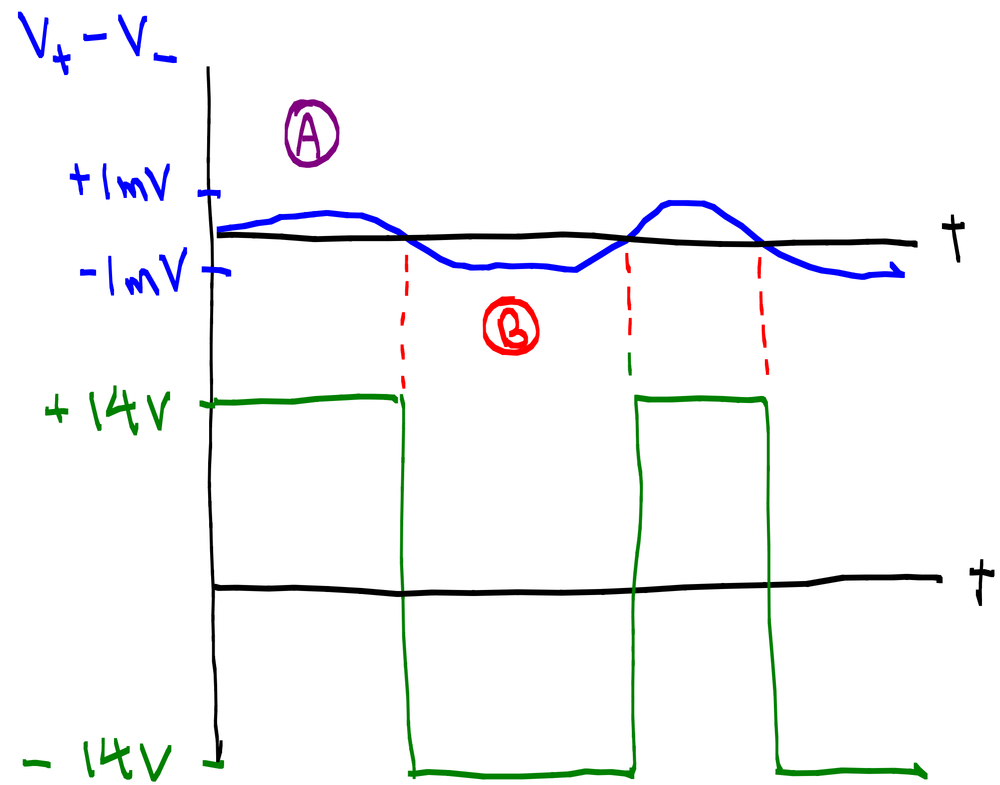
Typically, $V_{sat} \approx V_{cc} - 1$

Ex: $V_{cc} = 15V \rightarrow V_{sat} = 14V$

Ex:



$V_{OUT} = A(V_+ - V_-)$, $A \sim 10^5$



Output only has 2 possible values.

- Start with Region ①:

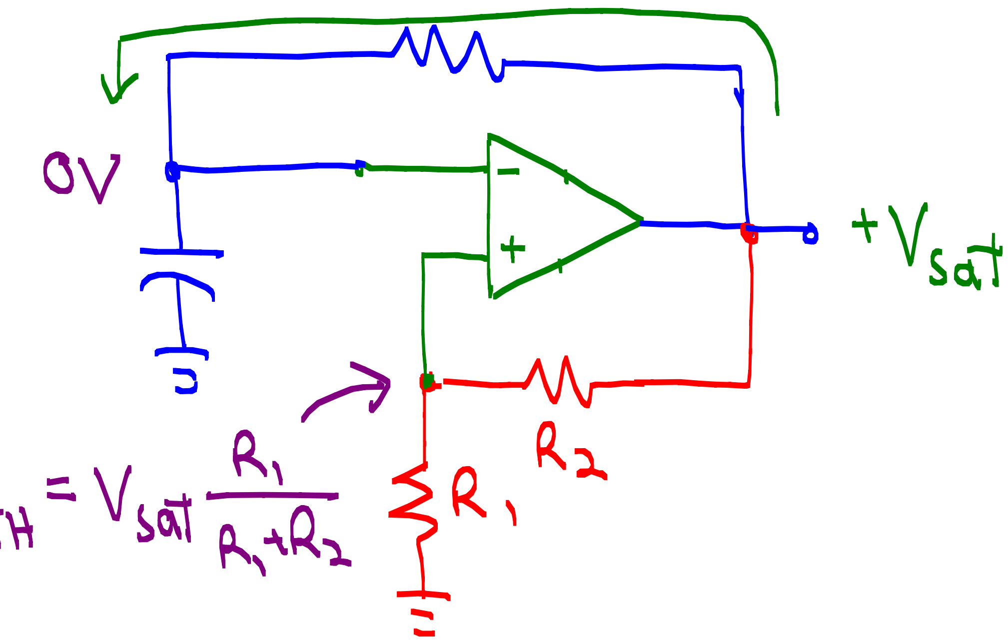
Initially, $V_{OUT} = +V_{sat}$ and $V_c = 0$

$V_- = V_c = 0$

$V_+ = V_{sat} \frac{R_1}{R_1+R_2} = +V_{TH}$

} $V_+ - V_- > 0$

$\Rightarrow V_{OUT} = +V_{sat}$



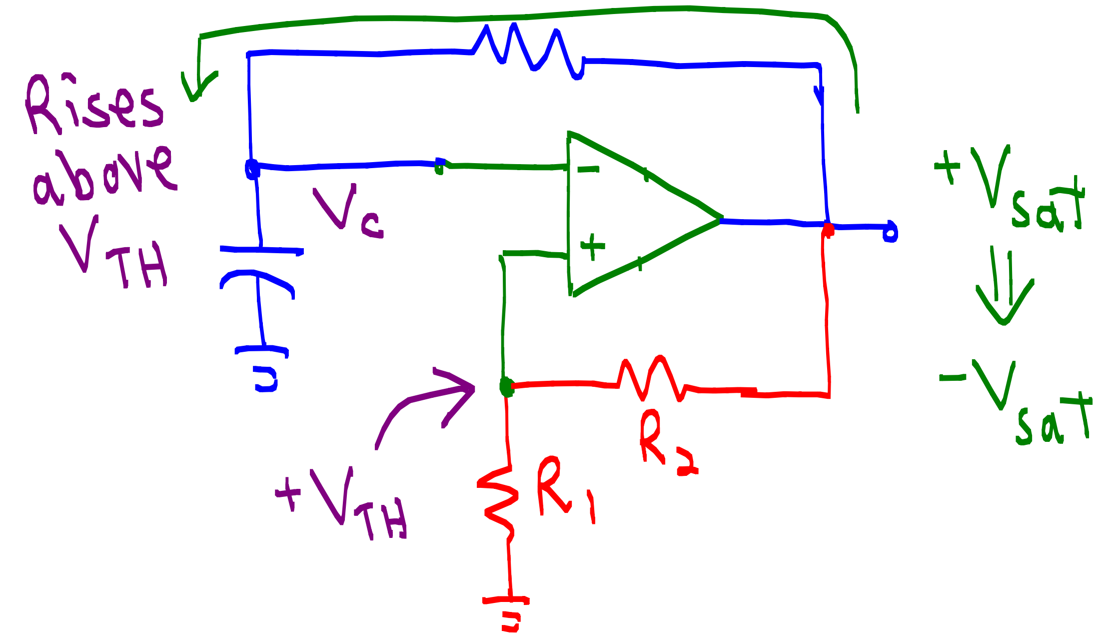
HOWEVER, the capacitor is charging up!

$\Rightarrow$ capacitor voltage starts to rise

$\Rightarrow$ As soon as V_c rises above $+V_{TH}$

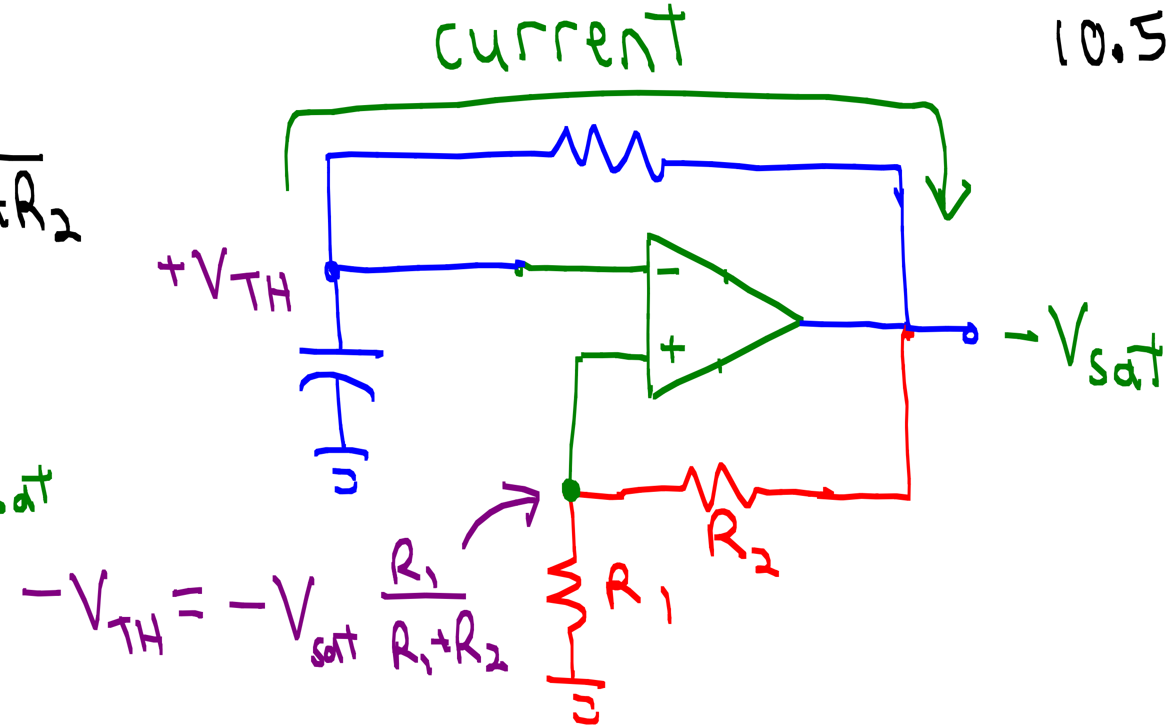
$\Rightarrow V_+ - V_- < 0$

$\Rightarrow V_{OUT}$ jumps to $-V_{sat}$!



- Now consider region ②:

Now have $V_{OUT} = -V_{sat}$ and $V_c = +V_{sat}\dfrac{R_1}{R_1+R_2}$



$$V_- = V_c = +V_{TH}$$

$$V_+ = -V_{sat}\frac{R_1}{R_1+R_2} = -V_{TH}$$

$\Big\}$ $V_+ - V_- < 0$

$\Rightarrow V_{OUT} = -V_{sat}$

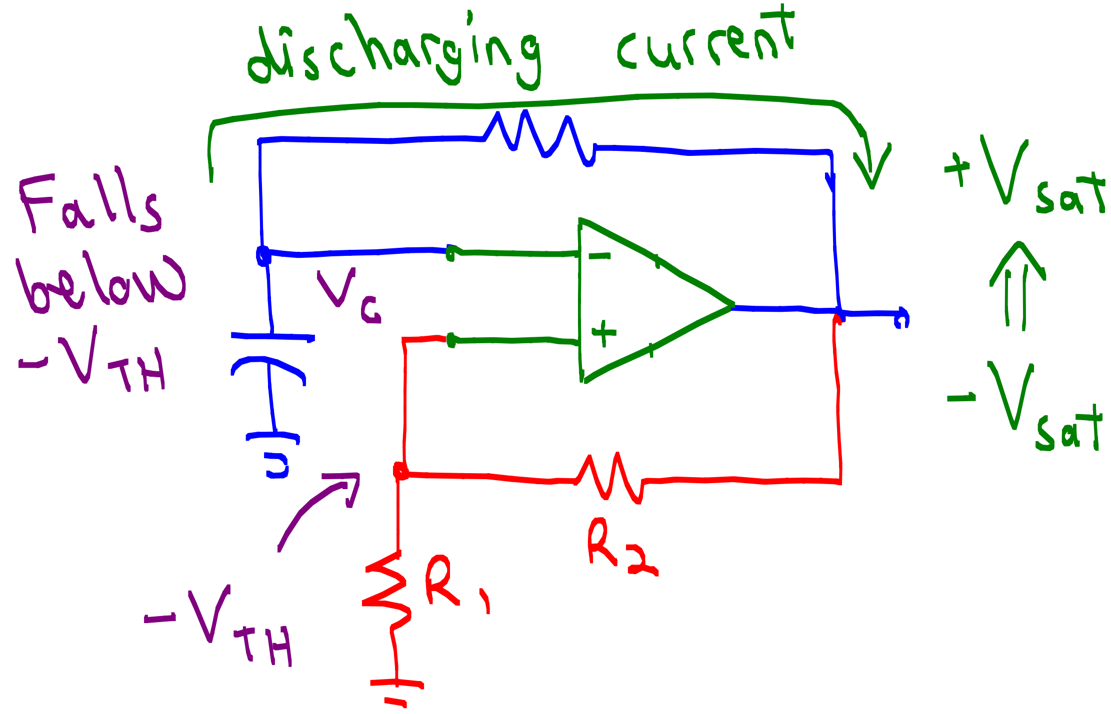
HOWEVER, the capacitor is discharging!

→ capacitor voltage starts to fall

⇒ As soon as V_c dips below $-V_{TH}$

⇒ $V_+ - V_- > 0$

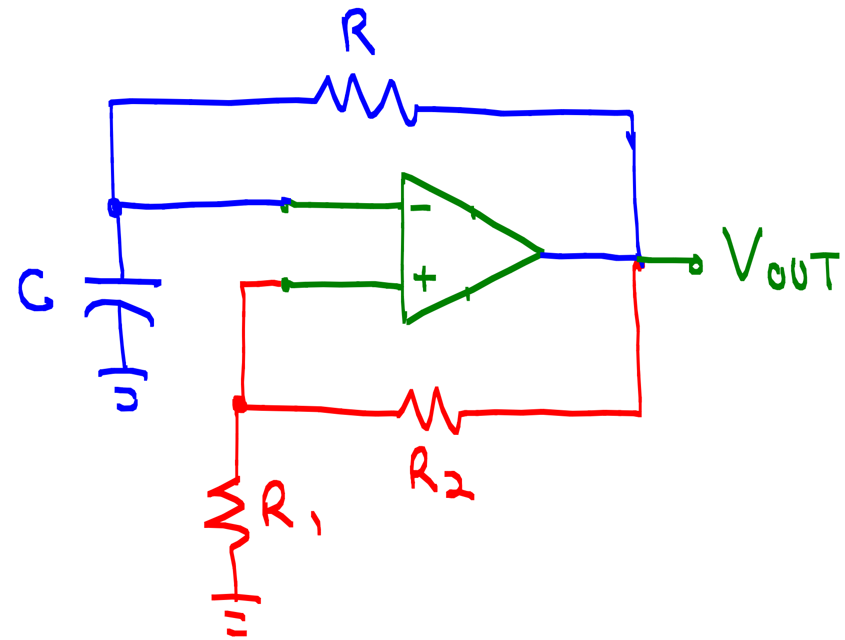
⇨ V_{OUT} jumps to $+V_{sat}$

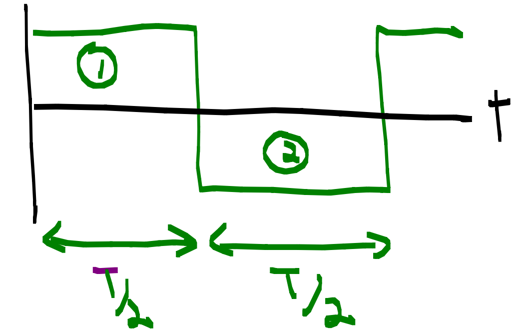


- Period?

$$T = 2RC \ln\left(\frac{1+B}{1-B}\right)$$

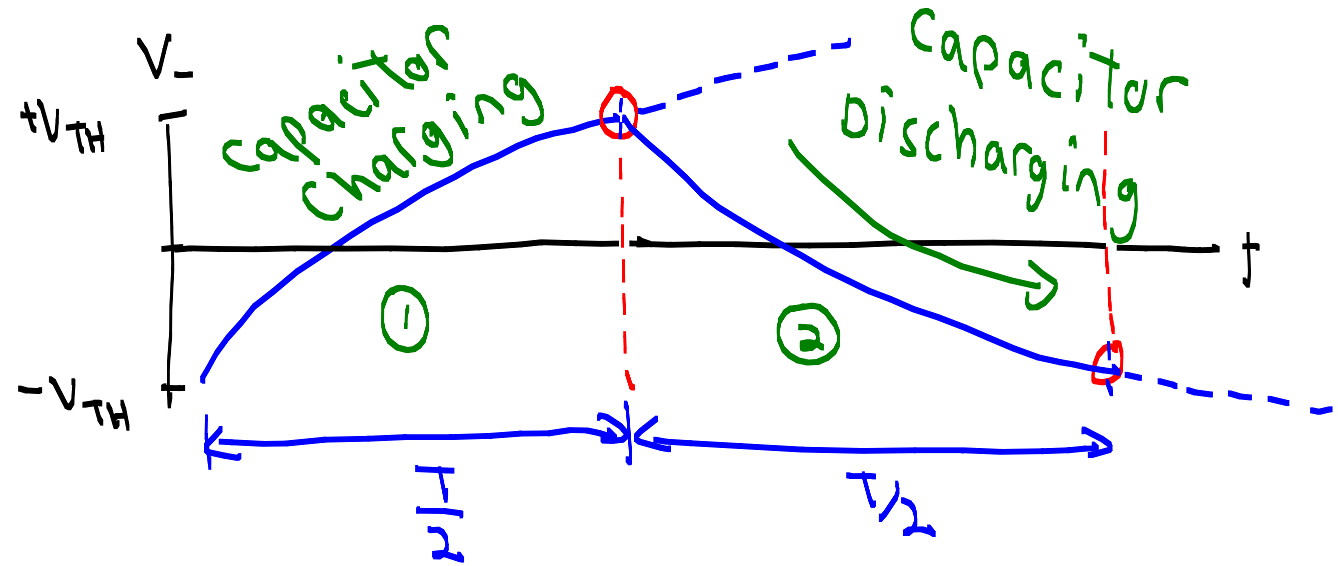
$$B = \frac{R_1}{R_1+R_2}$$





Ex: $R_1 = 18K$
$R_2 = 2K$
$C = 0.1\mu F$
$R = 1K$

$$B = \frac{18K}{18K+2K} = 0.9$$

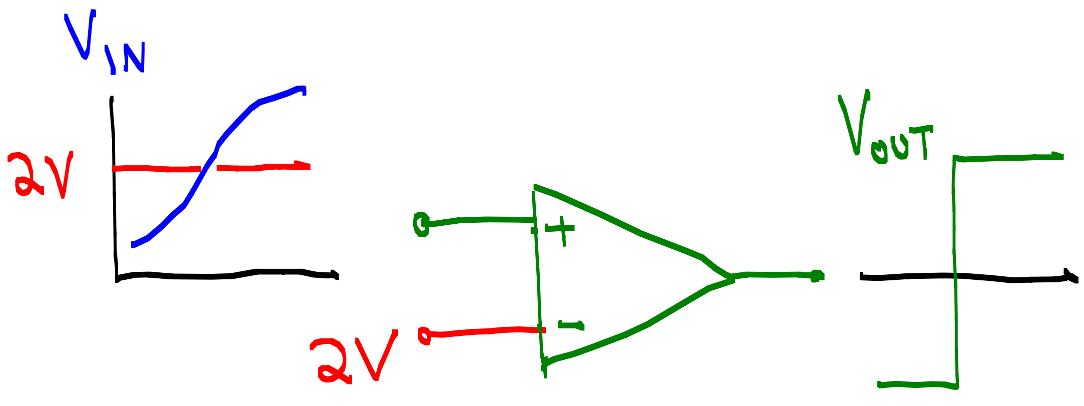


$$T = 2(10^3 \Omega)(10^{-7} F) \ln\left(\frac{1+0.9}{1-0.9}\right)$$

$$= 589 \mu s \quad (f = 1.7 kHz)$$

3. Schmitt Trigger

- An open loop op amp can be used as a <u>threshold detector</u>.

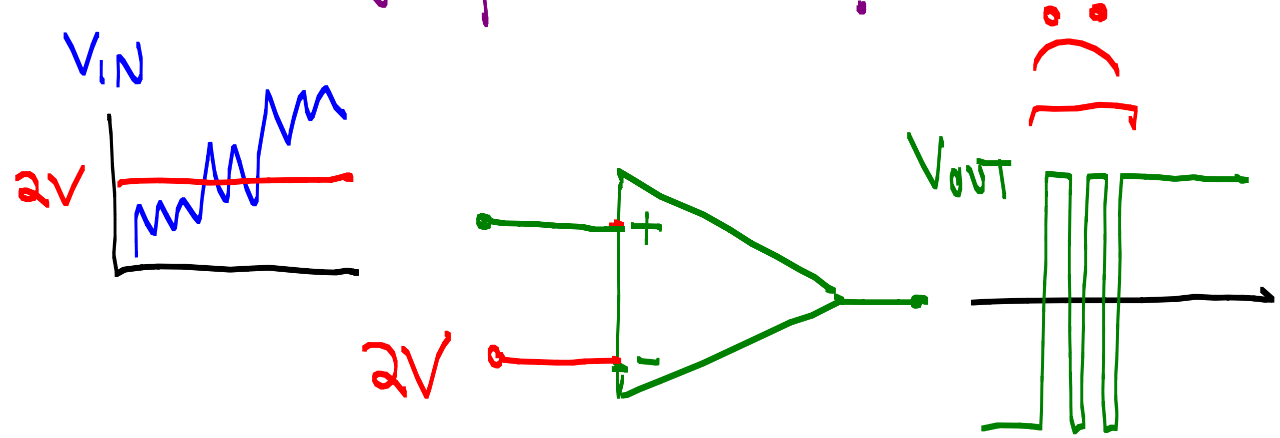


e.g. ($V_{TH} = +2V$)

$V_{IN} > 2V \Rightarrow V_{OUT} = +V_{sat}$

$V_{IN} < 2V \Rightarrow V_{OUT} = -V_{sat}$

- Problem with this circuit...
  - ⇒ noise can make V_{OUT} very erratic!

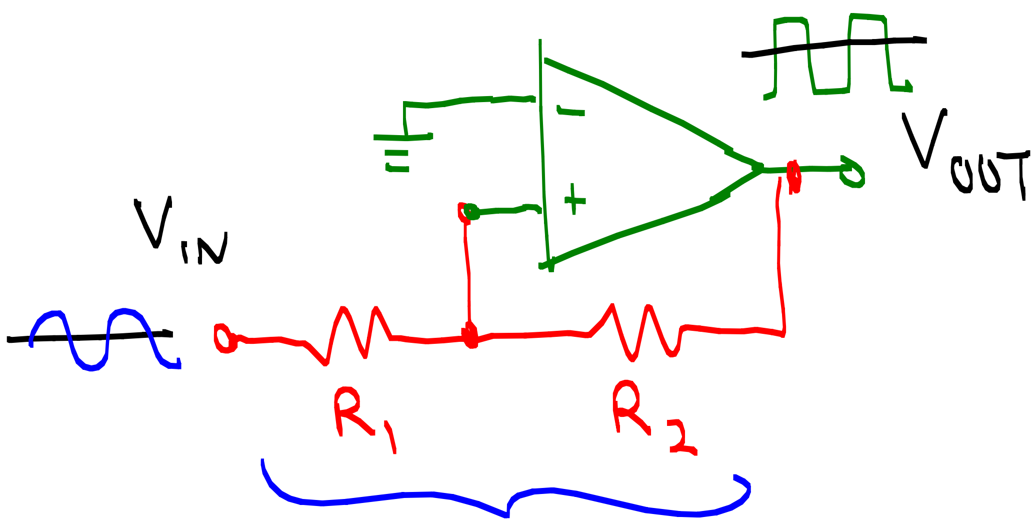


Q: How to make V_{OUT} less susceptible to noise?

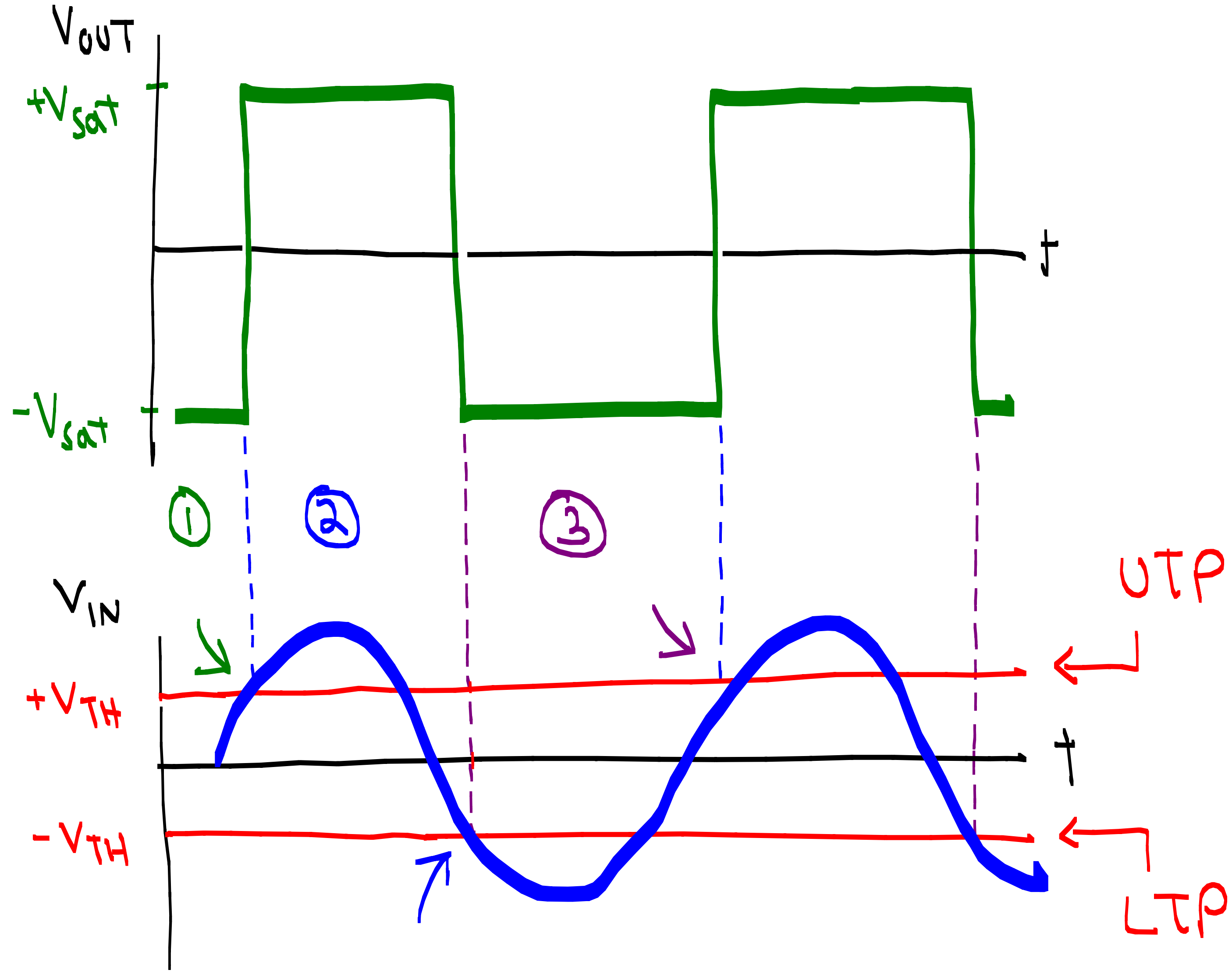
⇒ Need to include some <u>hysteresis</u>!

- Threshold detector with hysteresis

→ Value of V_{OUT} depends on whether V_{IN} crosses V_{TH} from below or above.



"Non-inverting Schmitt Trigger"



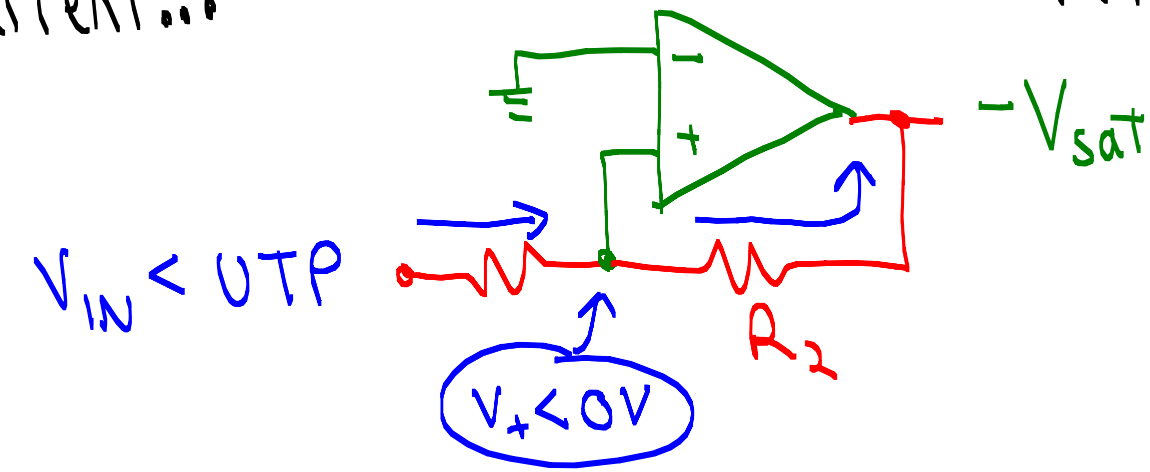
UTP = Upper Trip Point

LTP = Lower Trip Point

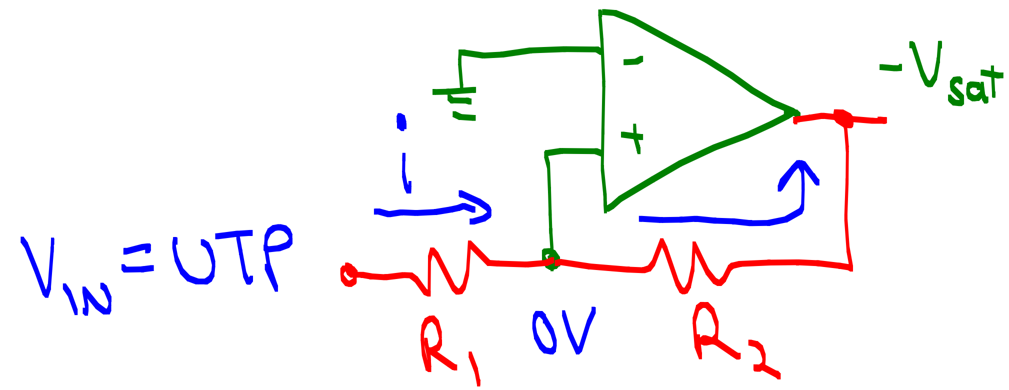
How does this work? Assume V_+ draws no current...

Region ①: $V_{OUT} = -V_{sat}$

(V_{IN} approaches UTP from below)



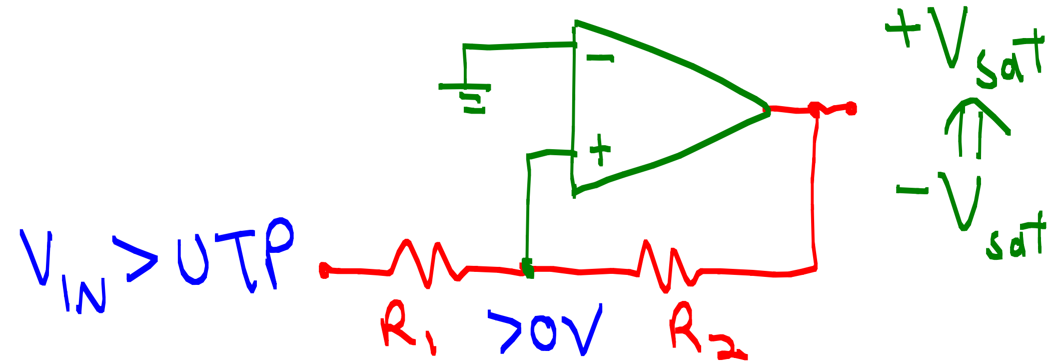
- While $V_{IN} < UTP$, then $V_+ < 0V \Rightarrow V_{OUT} = -V_{sat}$



- When V_{IN} rises above UTP, then $V_+ > 0V \Rightarrow V_{out}$ jumps to $+V_{sat}$!

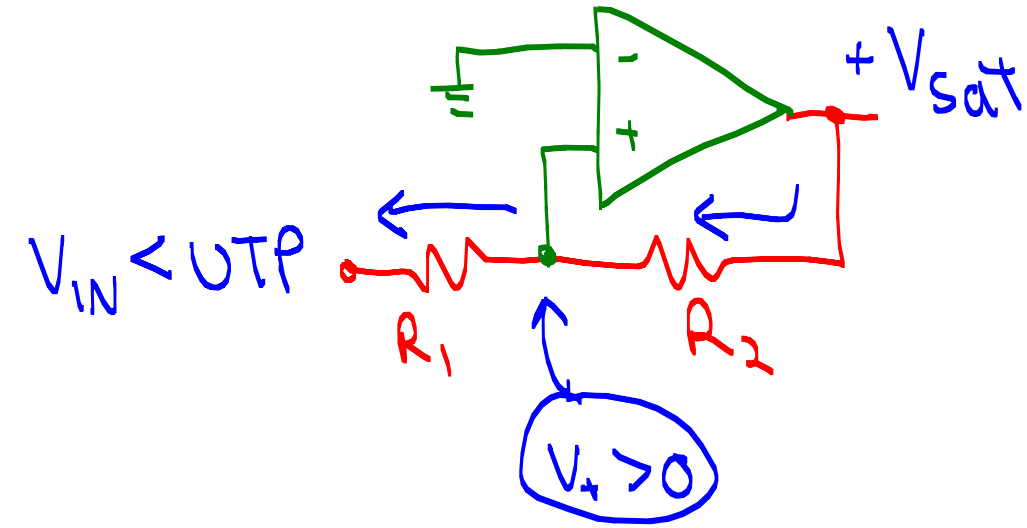
What is the UTP?

$$i = \frac{UTP - 0}{R_1} = \frac{0 - (-V_{sat})}{R_2} \Rightarrow \boxed{UTP = \frac{R_1}{R_2} V_{sat}}$$



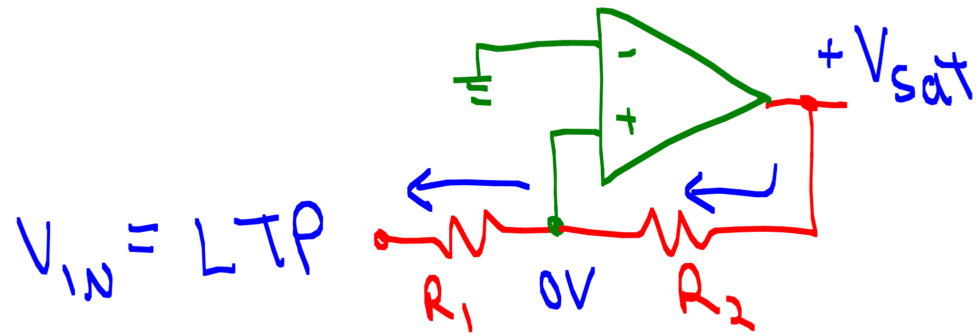
Region ②: $V_{out} = +V_{sat}$

- V_{out} does NOT change, even if V_{IN} dips below UTP because V_+ is still > 0!



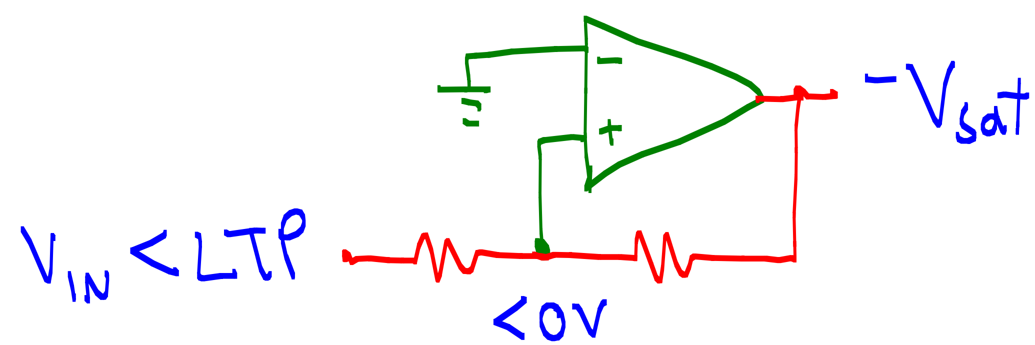
- when V_{IN} sinks below LTP, then $V_+ < 0 \Rightarrow V_{out}$ jumps to $-V_{sat}$!

LTP?: $i = \frac{0 - LTP}{R_1} = \frac{V_{sat} - 0}{R_2} \Rightarrow \boxed{LTP = -\frac{R_1}{R_2} V_{sat}}$

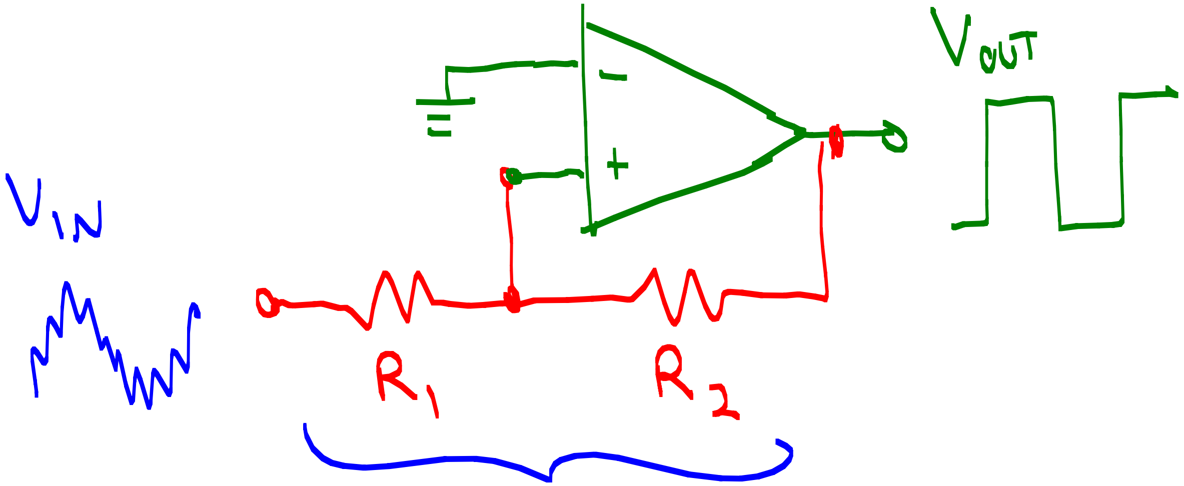


Region ③: $V_{out} = -V_{sat}$

- V_{out} remains same, even if V_{IN} rises above LTP.
- V_{out} flips when $V_{IN} > UTP$...



- Noise immunity with Schmitt trigger



"Non-inverting Schmitt Trigger"