

# Lecture 11: Oscillators

(Quiz)

0. Review

1. Triangle Wave Generator

2. 555 Timer

3. Voltage Comparator

Textbook Reading:

20-6 Waveform Conversion

20-8 Another Triangular Generator

18-10 Single supply operation

• Quiz today

• HW 5 due Fri (Nov 01)

• PreLab 5 due Thu

→ Team Project (2-3 people)

→ Choose from 4 topics

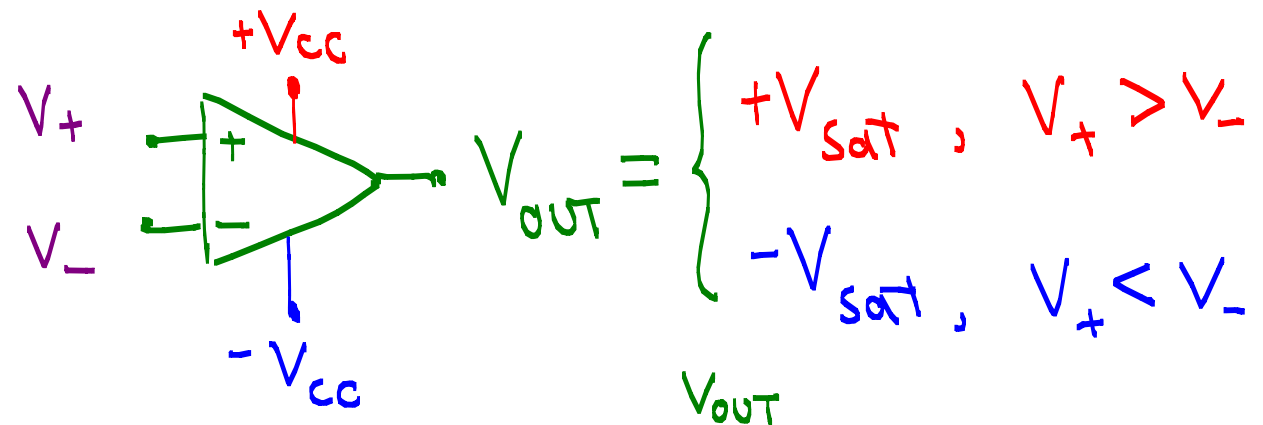
→ Determine responsibilities  
(who does what circuit)

→ Formulate design requirements  
(e.g. servo pulse freq)

→ "Rough" circuit schematics  
(no component values)

0. Review

- ① Open Loop Op Amp
- ② Relaxation Oscillator



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

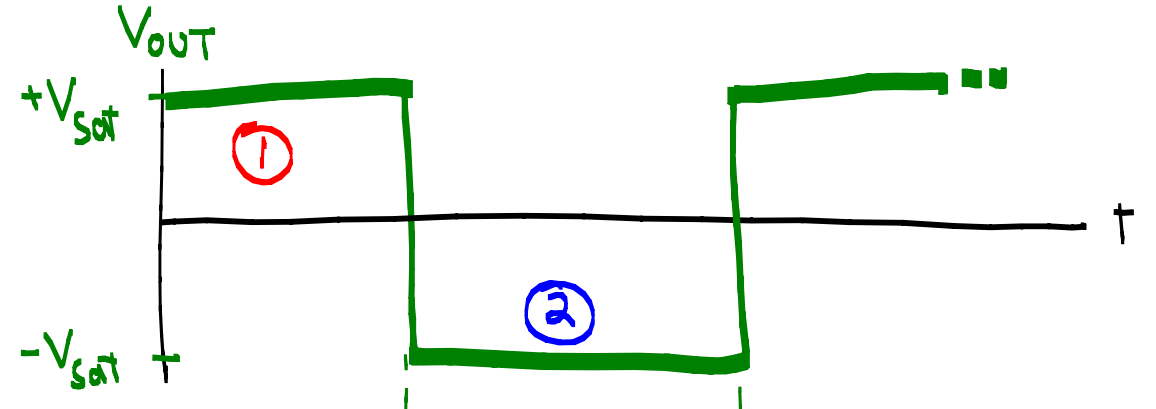
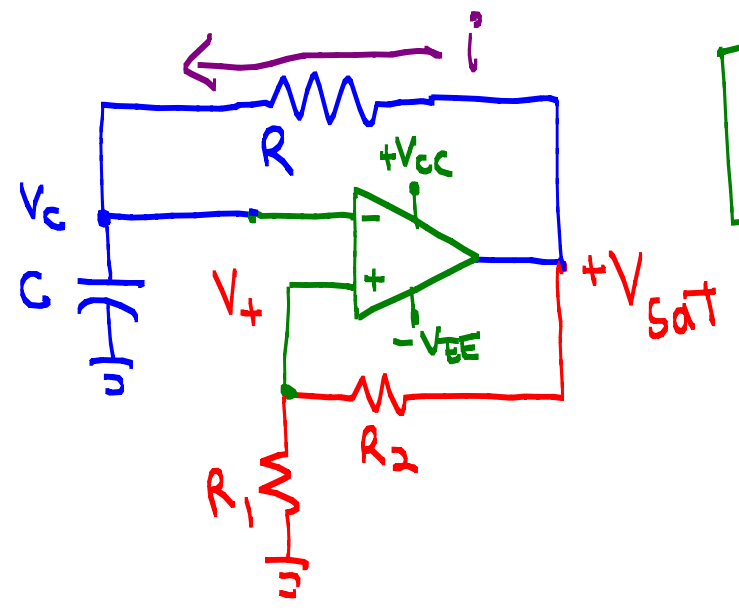
$$B = \frac{R_1}{R_1 + R_2}$$

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

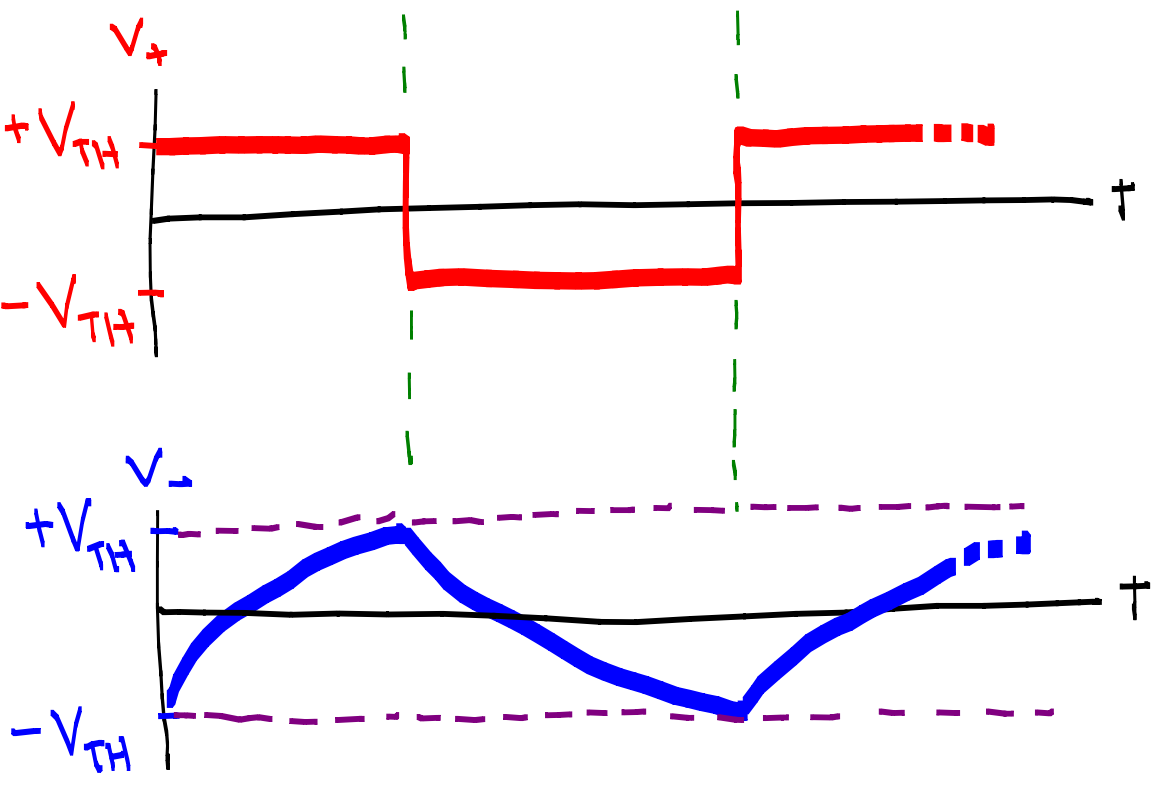
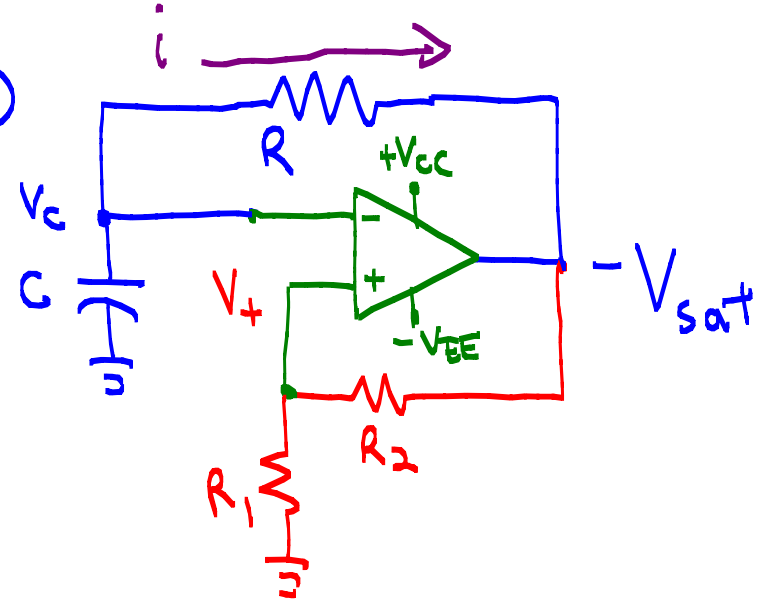
$$-V_{sat} \frac{R_1}{R_1 + R_2} = -V_{TH}$$

★ Charging current  $i$  alternates direction!

①



②

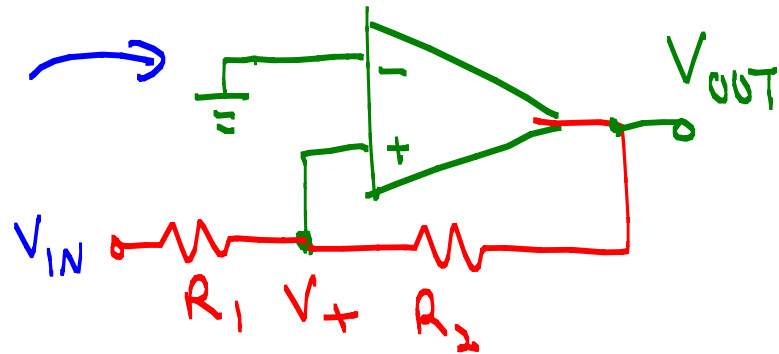


# • Schmitt Trigger

Non-inverting

$V_{OUT}$  has similar polarity as  $V_{IN}$

Always OV!



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

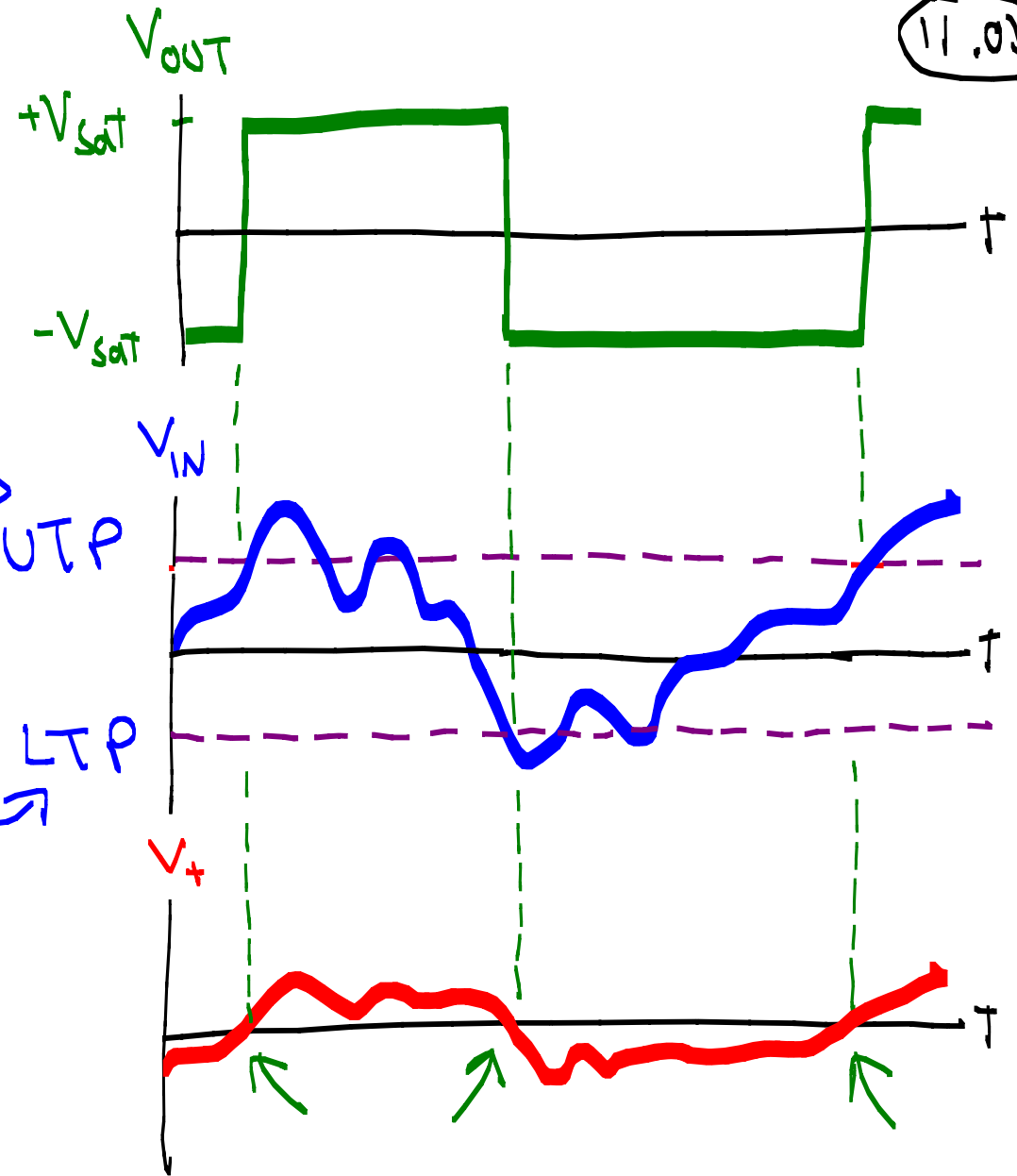
$-\frac{R_1}{R_2} V_{sat}$  LTP

• When  $V_{IN}$  rises above UTP

→  $V_+$  rises above OV ⇒  $V_{OUT}$  becomes  $+V_{sat}$

• When  $V_{IN}$  dips below LTP

→  $V_+$  dips below OV ⇒  $V_{OUT}$  becomes  $-V_{sat}$

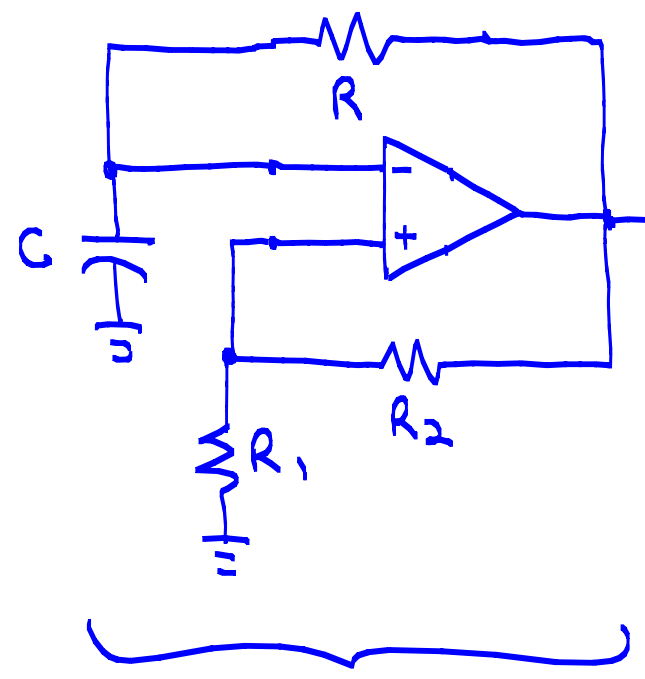
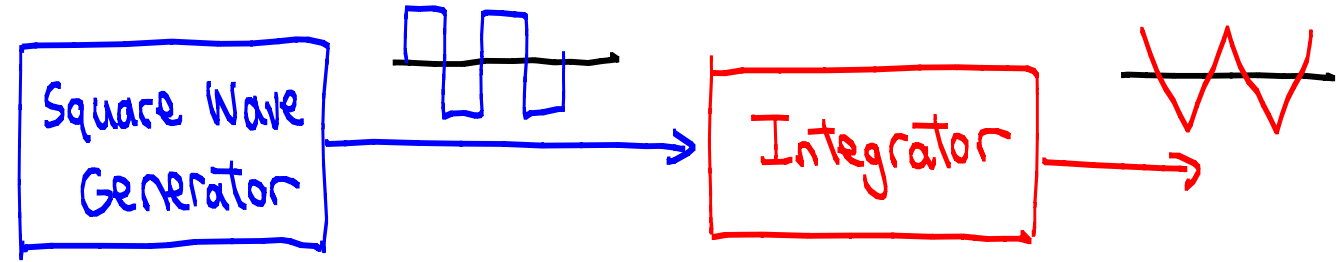
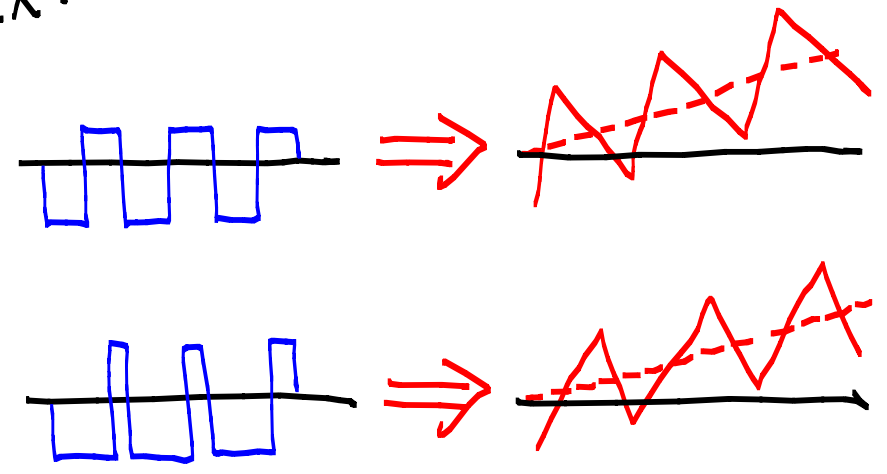


# 1. Triangle Wave Generator

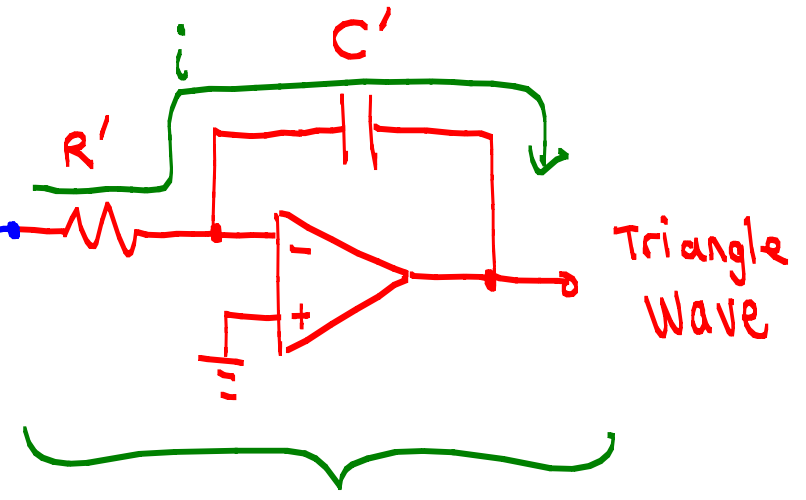
## Method #1

- Pretty straightforward
- Disadvantage:  
Triangle output may drift due to imperfect square wave

Ex:



Relaxation oscillator

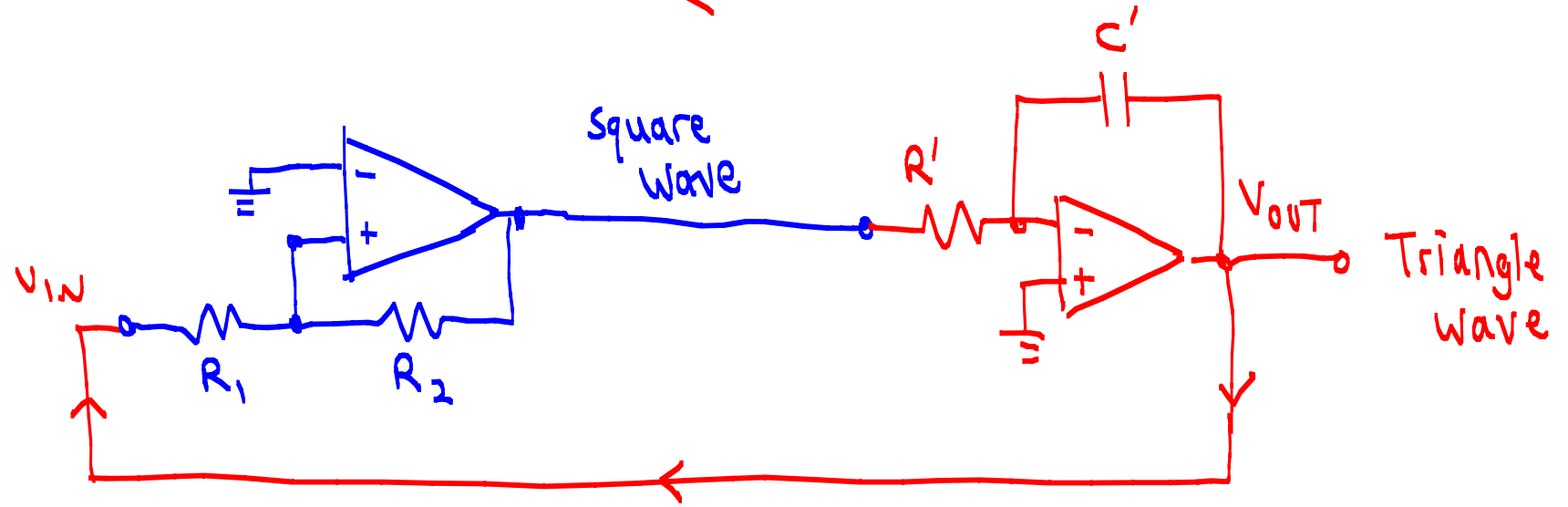
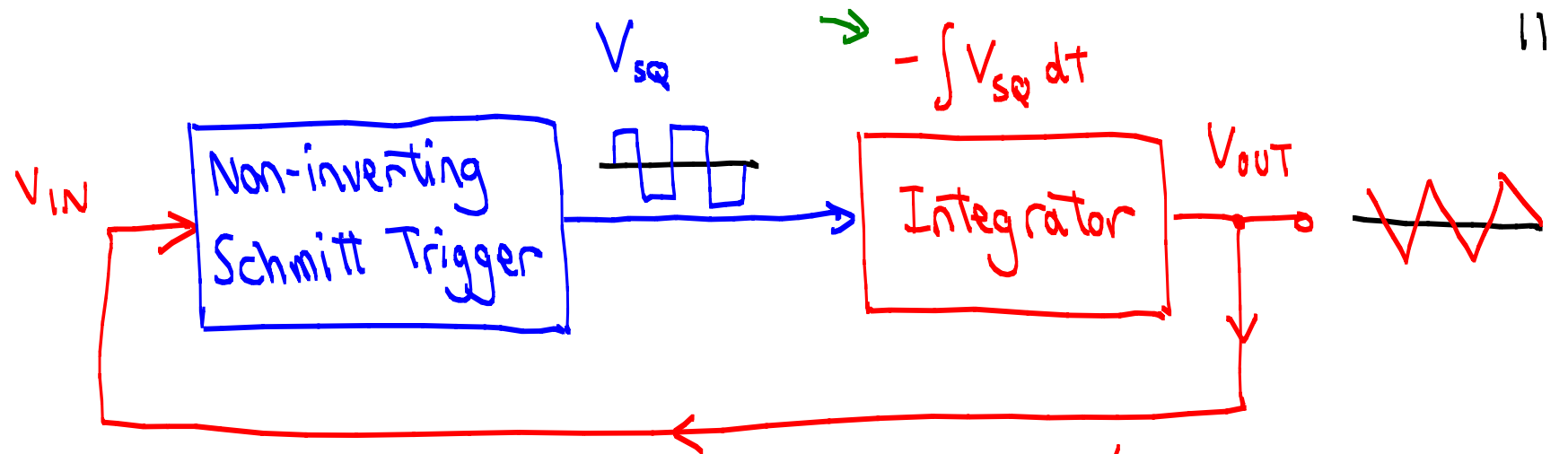
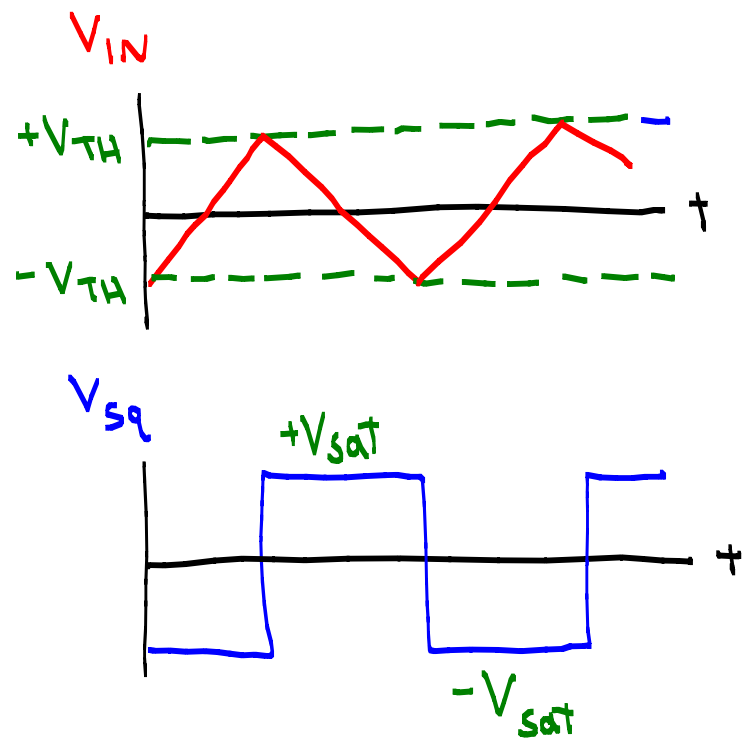


$$i = \frac{V_{sq} - 0}{R'} = C' \frac{d}{dt} (0 - V_{out})$$

$$V_{out} = -\frac{1}{R' C'} \int V_{sq} dt$$

**Method #2 (better)**

- Integrator output is fed back into the non-inv Schmitt trigger

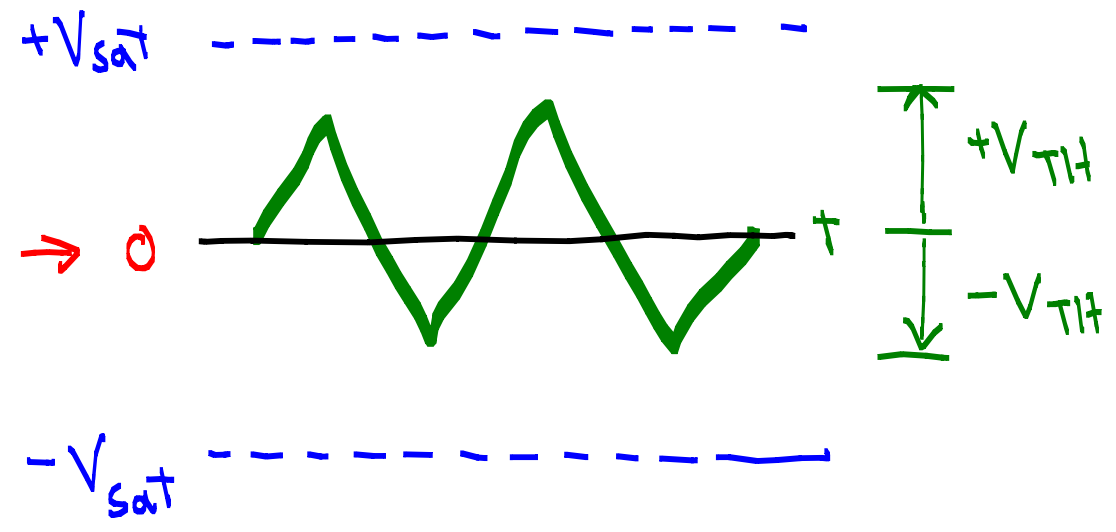
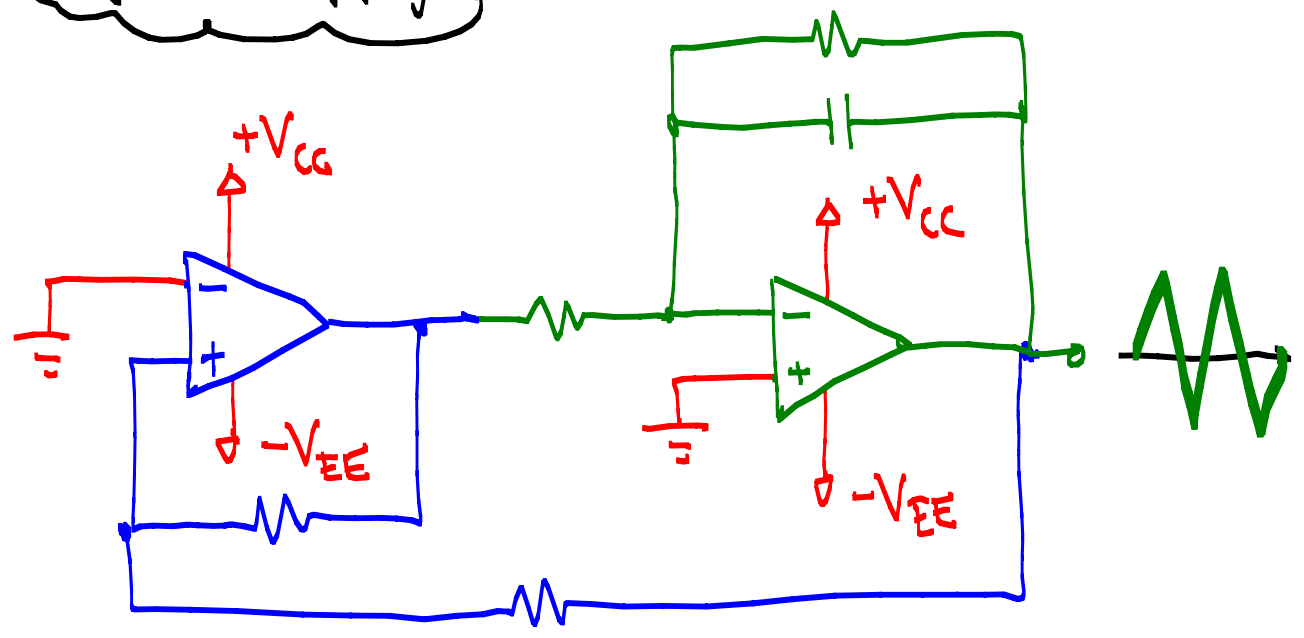


NOTE: Integrator "inverts" the square wave!  $\int -V_{sq} dt$

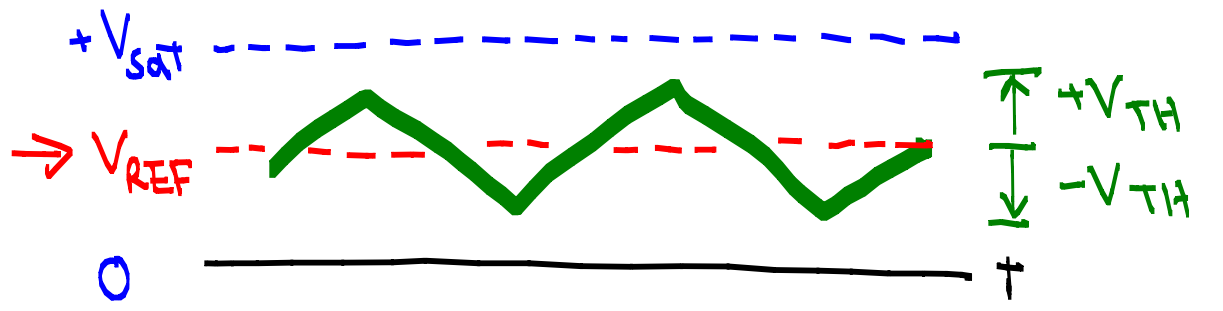
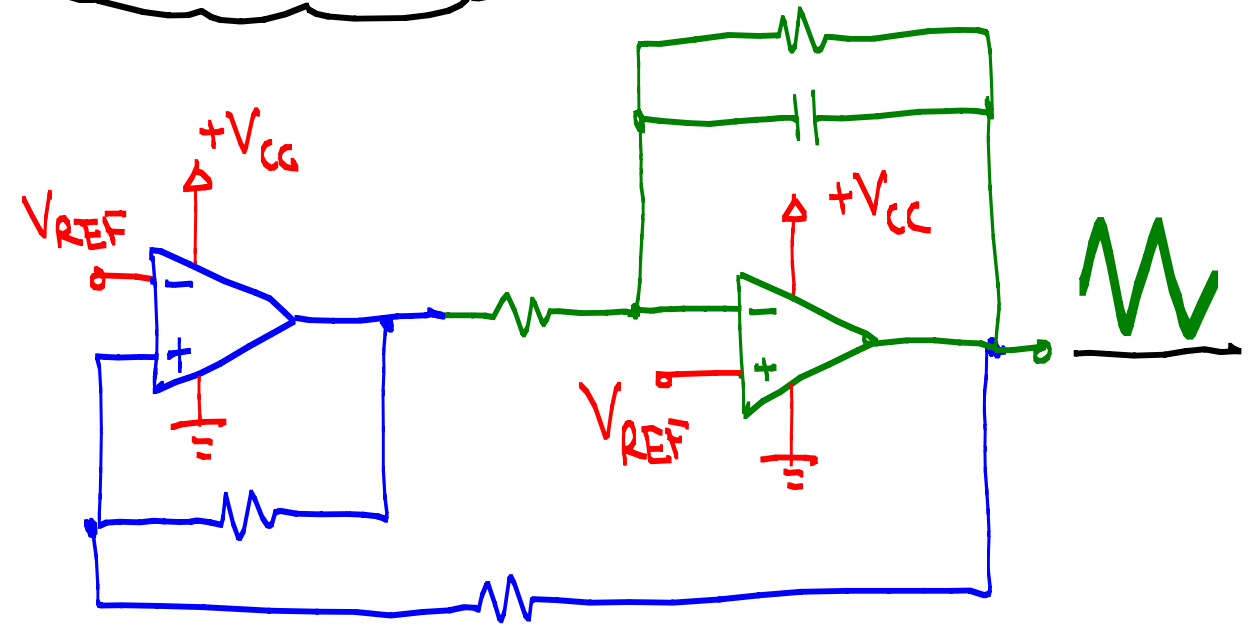
★ Key concept: Schmitt trigger's UTP and LTP prevent  $V_{out}$  from going "out of bounds"

# Split vs. Single-Supply Op Amps

Split-Supply



Single Supply



- General formulas can be used for both cases!

$$V_{TH} = \frac{R_1}{R_2} \times \frac{V_{sat(+)} - V_{sat(-)}}{2}$$

$$V_{REF} = \frac{V_{sat(+)} + V_{sat(-)}}{2}$$

$$f = \frac{R_2}{4R_1 R_3 C}$$

## Split Supply

$$V_{sat(+)} = +V_{sat} = V_{cc} - 1$$

$$V_{sat(-)} = -V_{sat}$$

$$V_{TH} = \frac{R_1}{R_2} V_{sat} \quad \checkmark$$

$$V_{REF} = 0 \quad \checkmark$$

## Single Supply

$$V_{sat(+)} = +V_{sat} = V_{cc} - 1$$

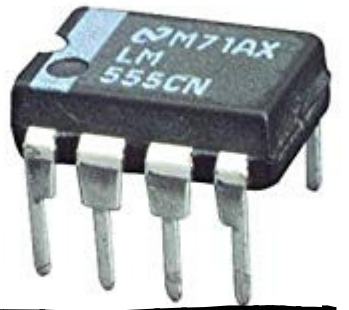
$$V_{sat(-)} = 0$$

$$V_{TH} = \frac{R_1}{R_2} \frac{V_{sat}}{2}$$

$$V_{REF} = \frac{V_{sat}}{2}$$

# 2. 555 Timer IC

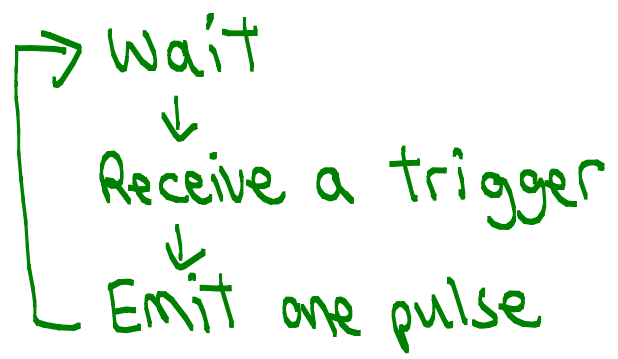
(Amazon)



• Two modes of operation:

① Monostable mode ← "one shot" timer

② Astable mode ← oscillator

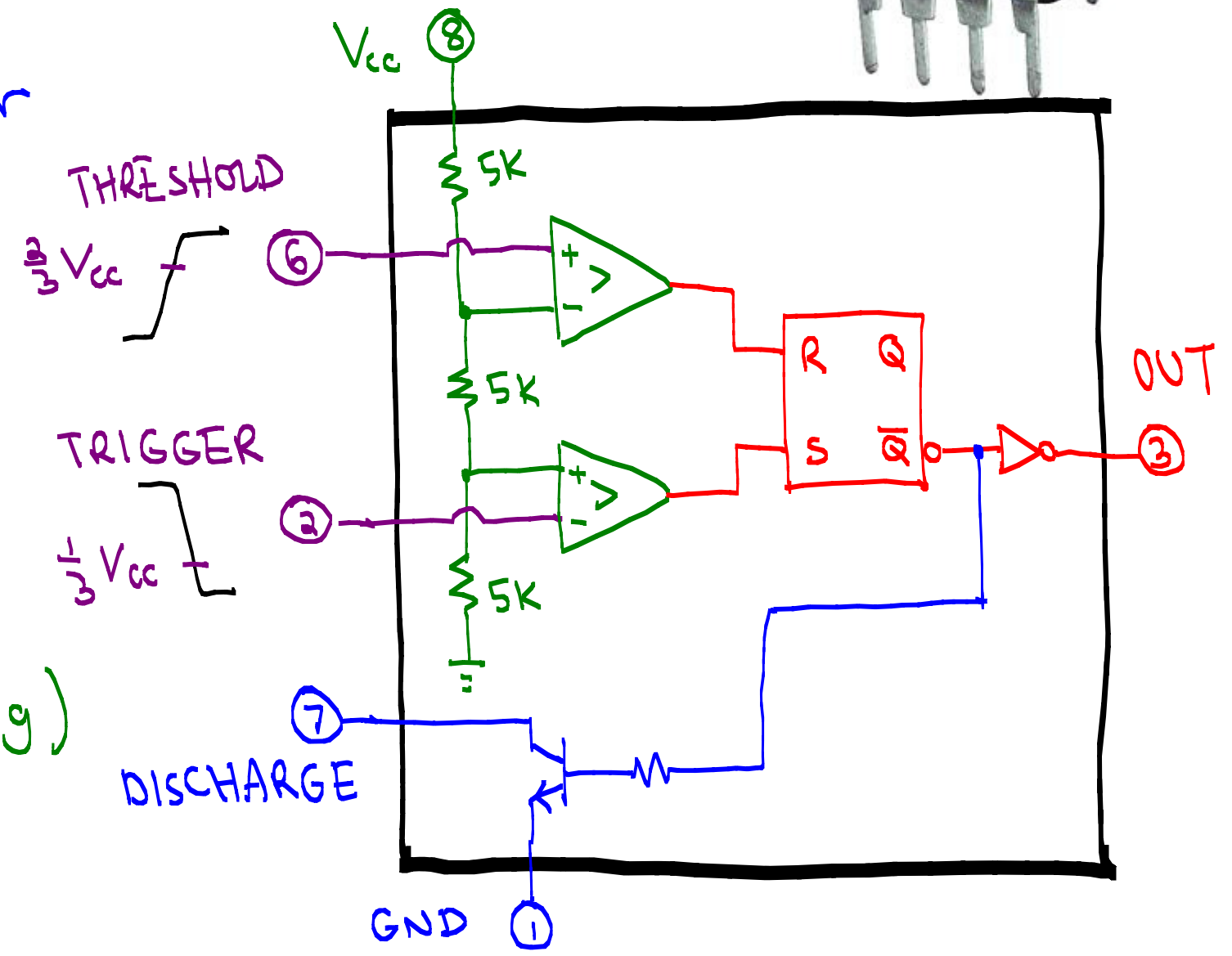


• Lots of applications:

- clock waveform generator,
- LED flasher, tone generator,
- freq divider, etc.

• "Mini tool kit" w/3 parts:

- (1) Comparators (Threshold, Trig)
- (2) SR Latch
- (3) Discharge transistor



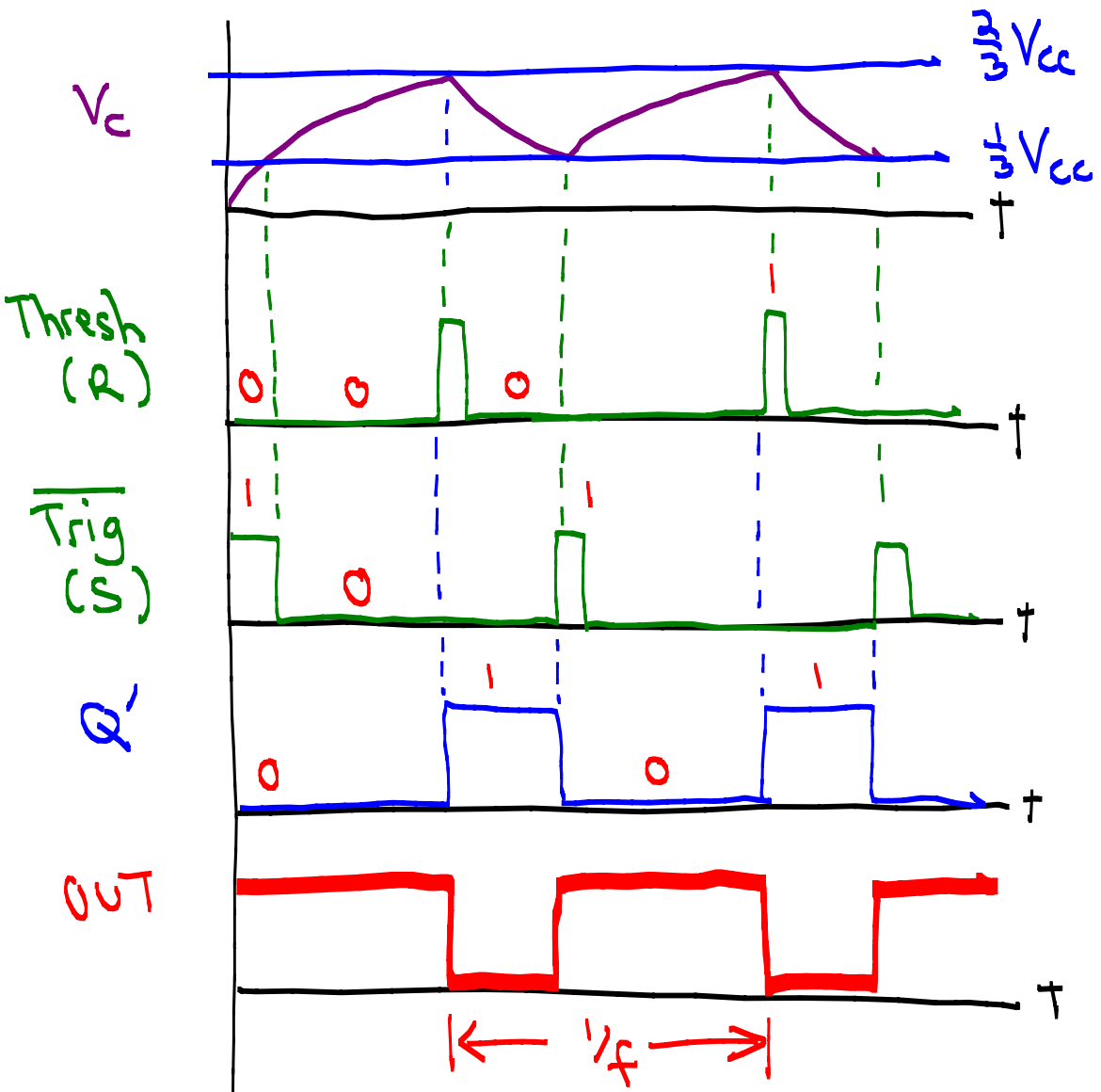


# • Square Wave Oscillator :

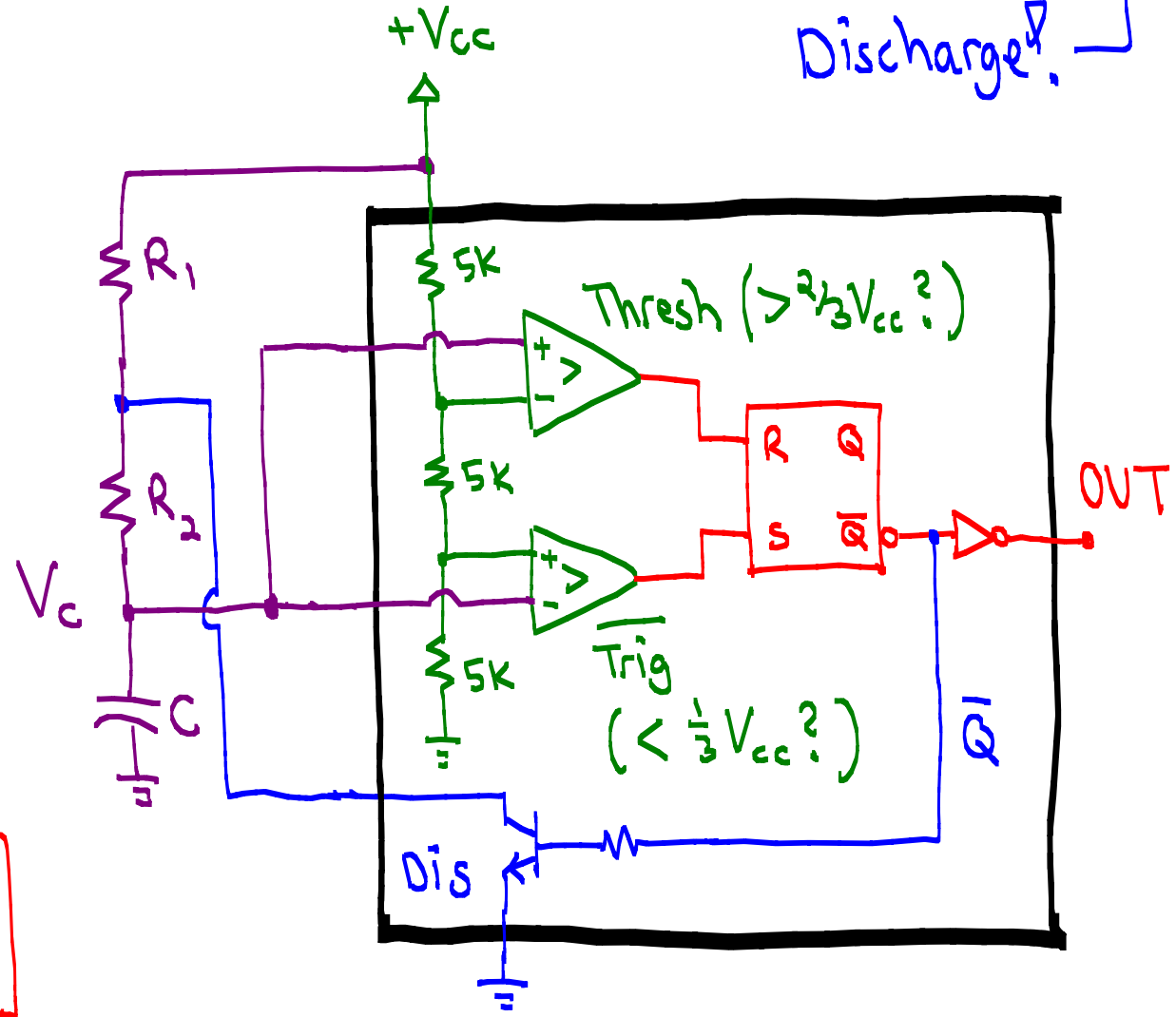
RS Latch

R	S	Q	Q'
0	0	HOLD	
0	1	1	0
1	0	0	1
1	1	X	X

Discharge?



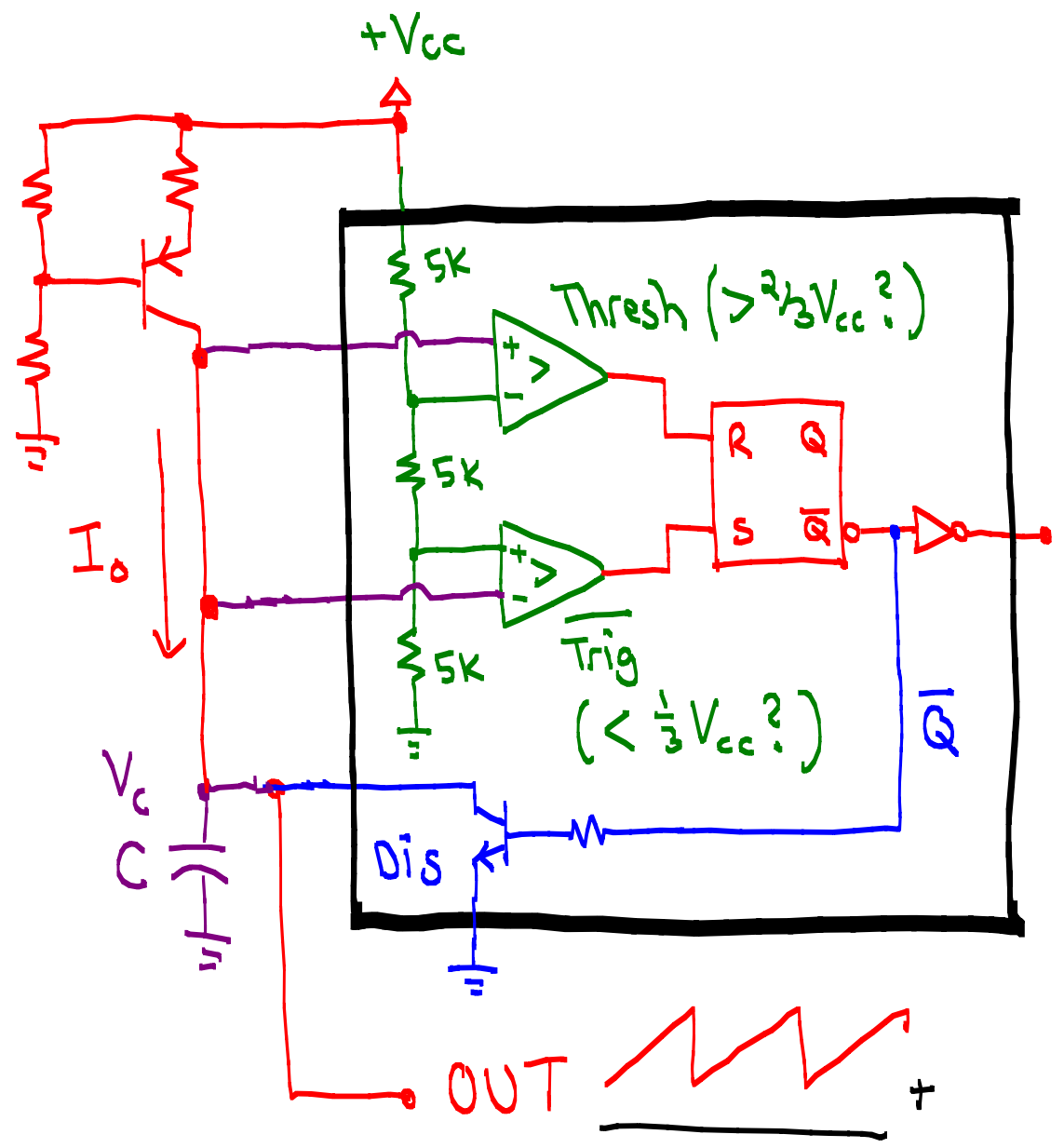
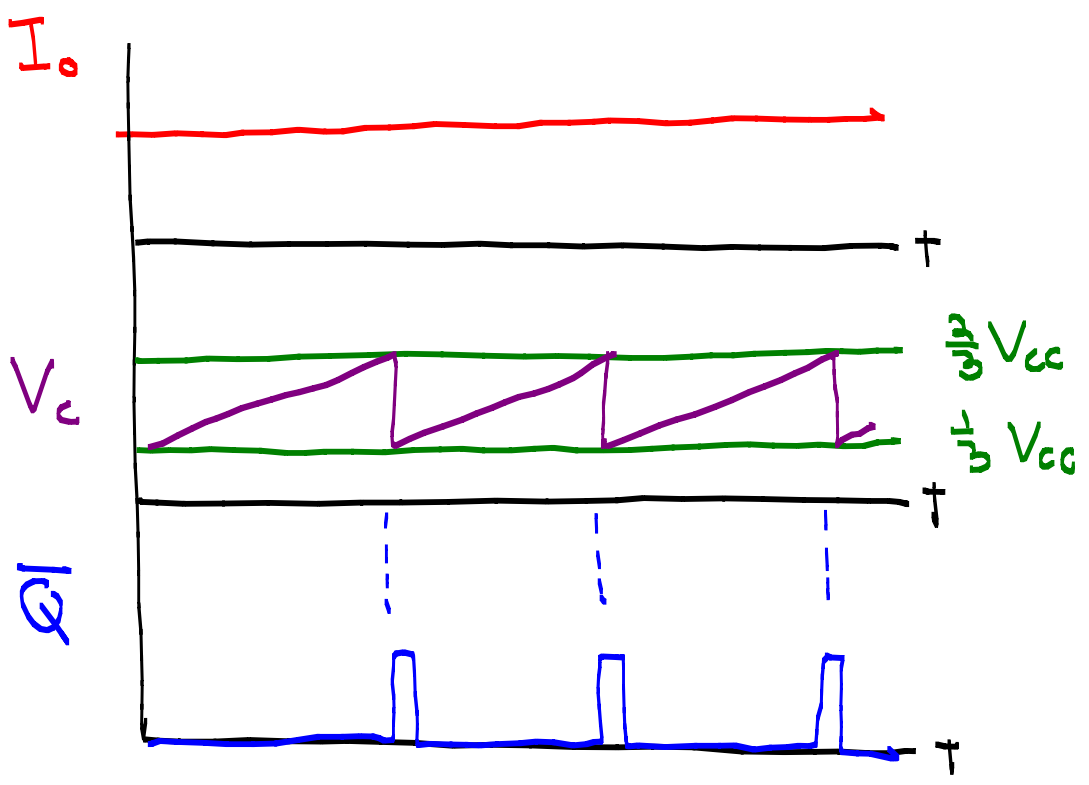
$$T = \frac{1.44}{(R_1 + 2R_2)C}$$



# Sawtooth Generator

Constant current source  $I$  charges the capacitor?

$$I_0 = C \frac{dV_c}{dt} \rightarrow V_c(t) = \frac{1}{C} \int_0^t I dt$$



# 3. Voltage Comparator

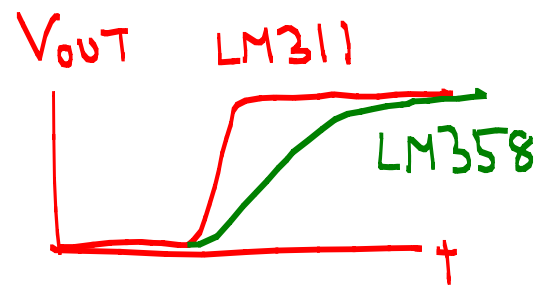
Integrated circuit (IC) →

## LM111-N/LM211-N/LM311-N Voltage Comparator

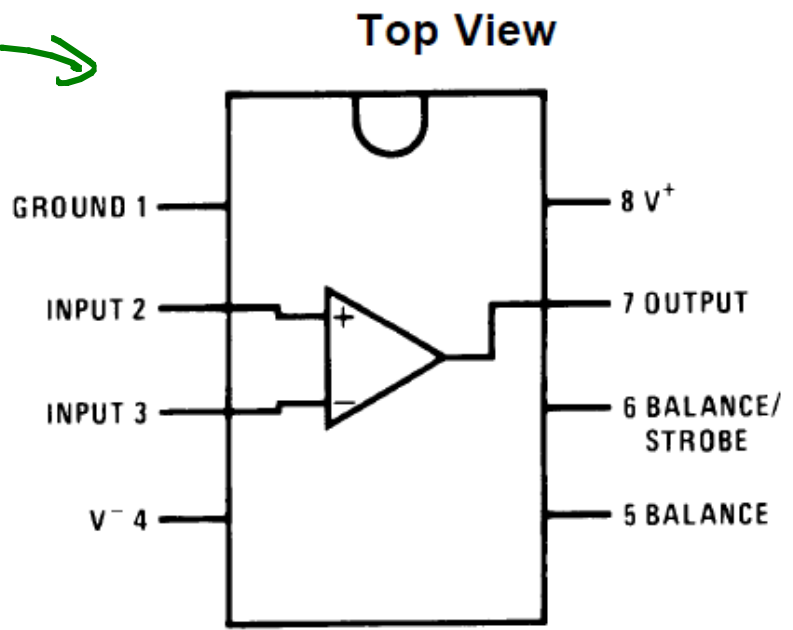
Advantages compared with op amp :

- ① Capable of single supply operation down to 5V (4.5V is OK)  
→ Compatible with TTL, CMOS logic

② High speed



③ Open collector output provides flexible  $V_{out}$  and higher  $I_{out}$  (~50 mA)

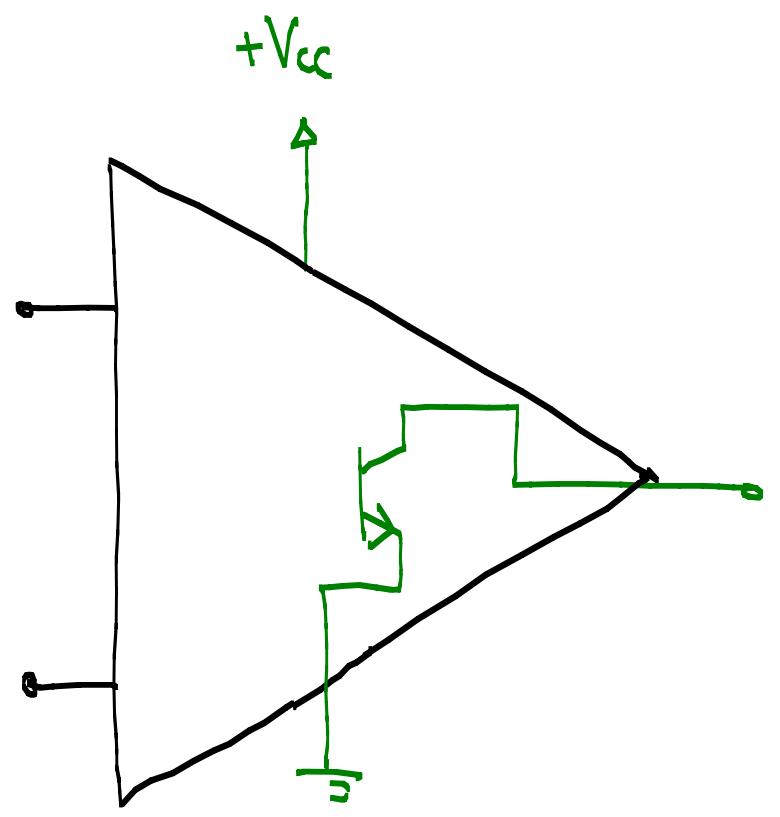


### DESCRIPTION

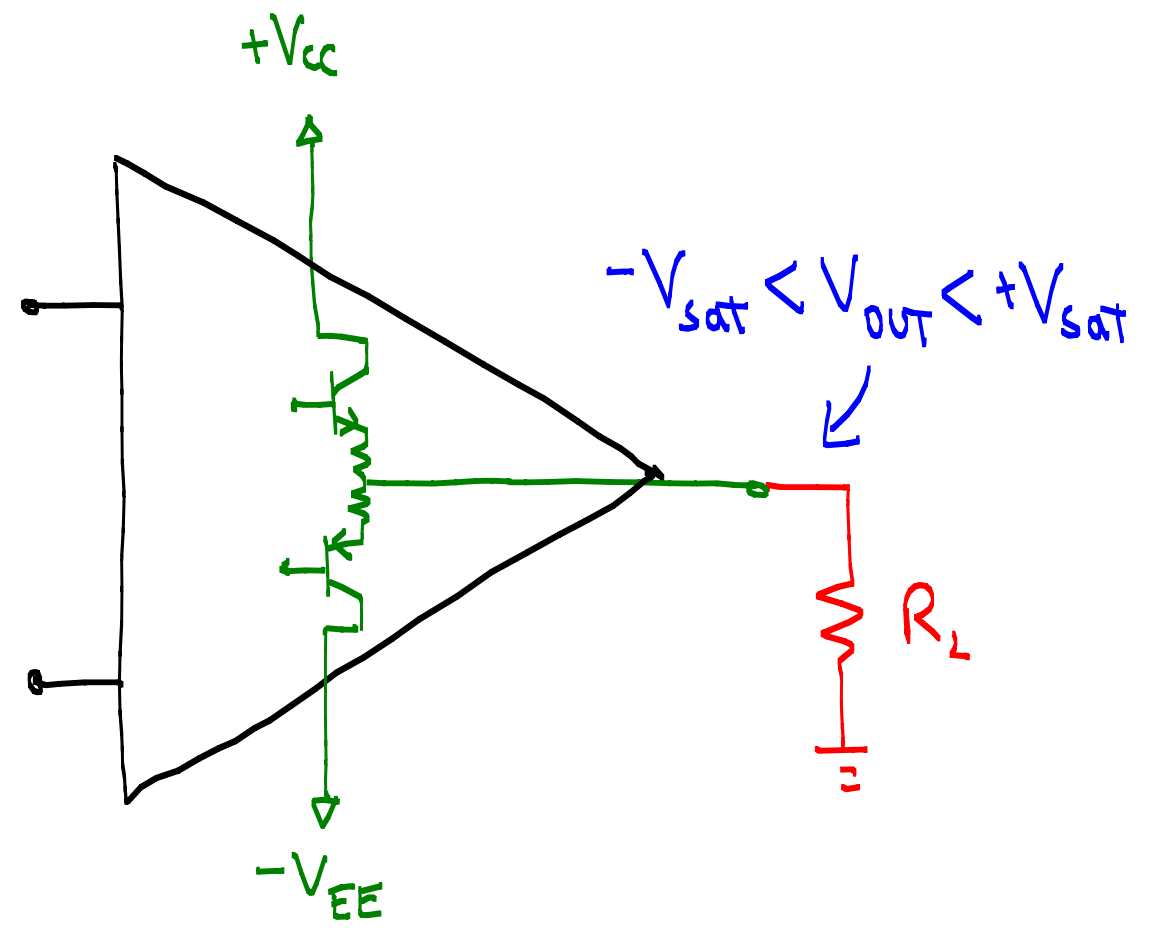
The LM111-N, LM211-N and LM311-N are voltage comparators that have input currents nearly a thousand times lower than devices like the LM106 or LM710. They are also designed to operate over a wider range of supply voltages: from standard  $\pm 15V$  op amp supplies down to the single 5V supply used for IC logic. Their output is compatible with RTL, DTL and TTL as well as MOS circuits. Further, they can drive lamps or relays, switching voltages up to 50V at currents as high as 50 mA.

• Open collector output

Comparators have "incomplete" output

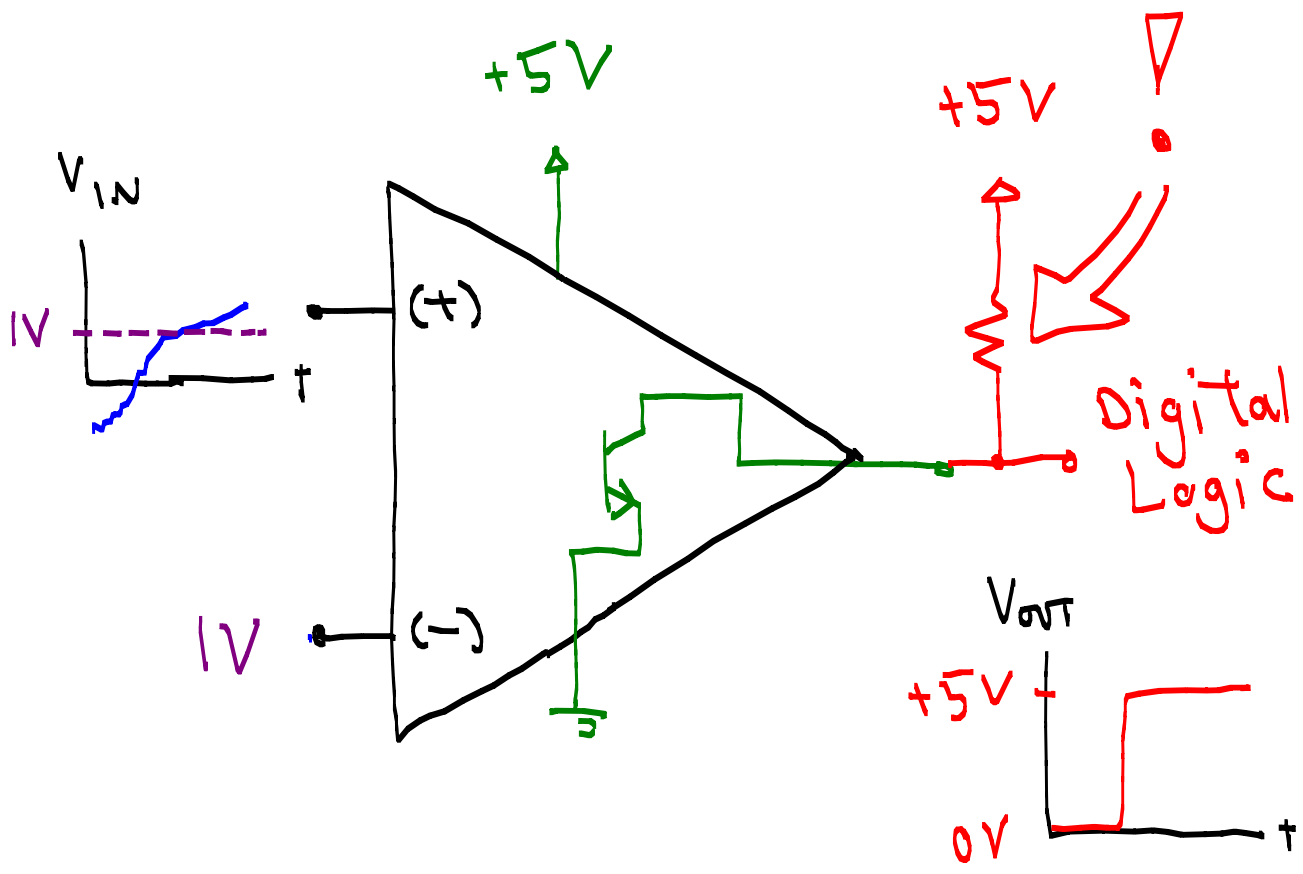


Op amps have push-pull output

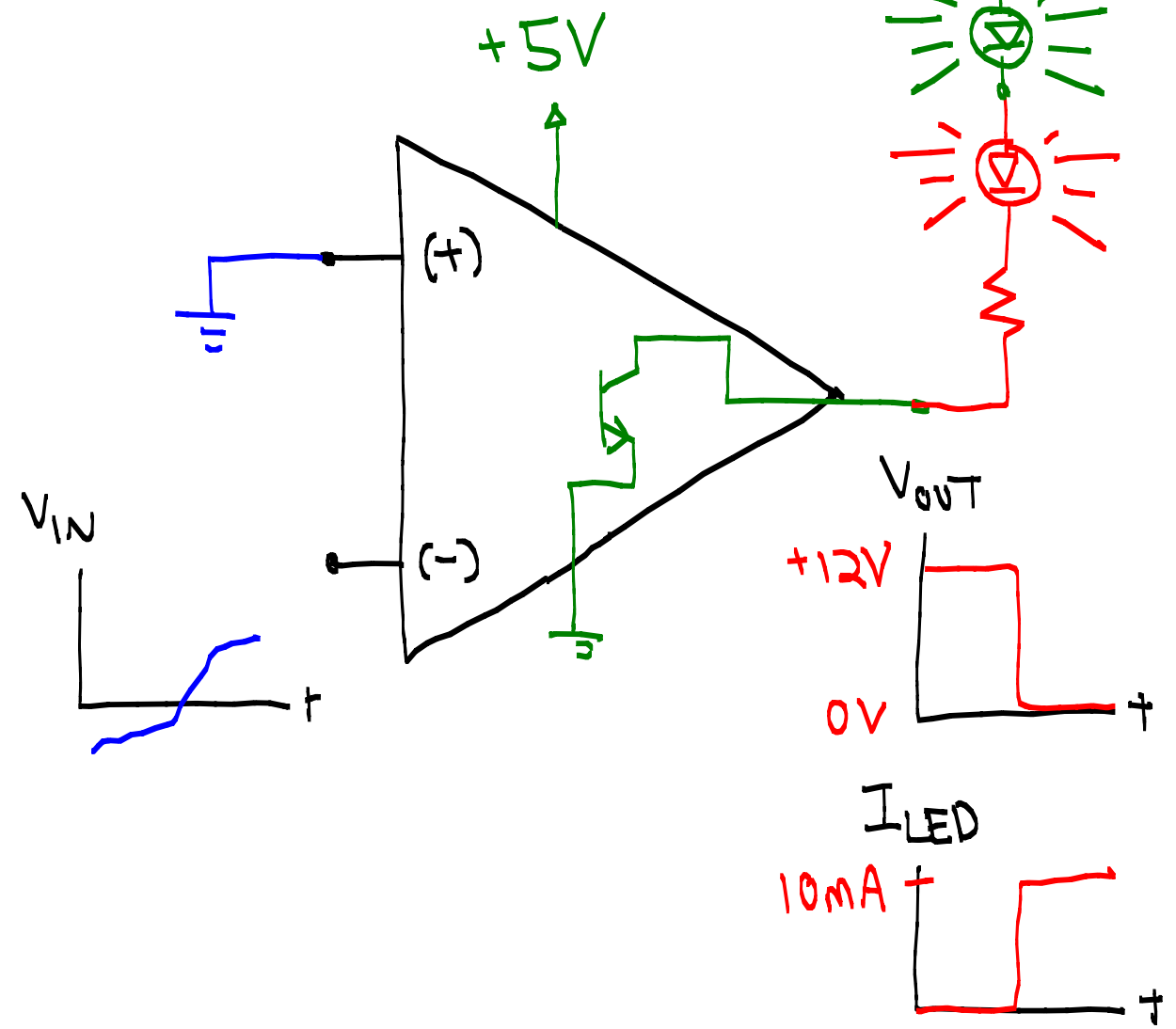


- Need a "pull up resistor" ( $\sim$  few  $k\Omega$ ) for proper operation.

**Example 1** Analog-to-TTL interface

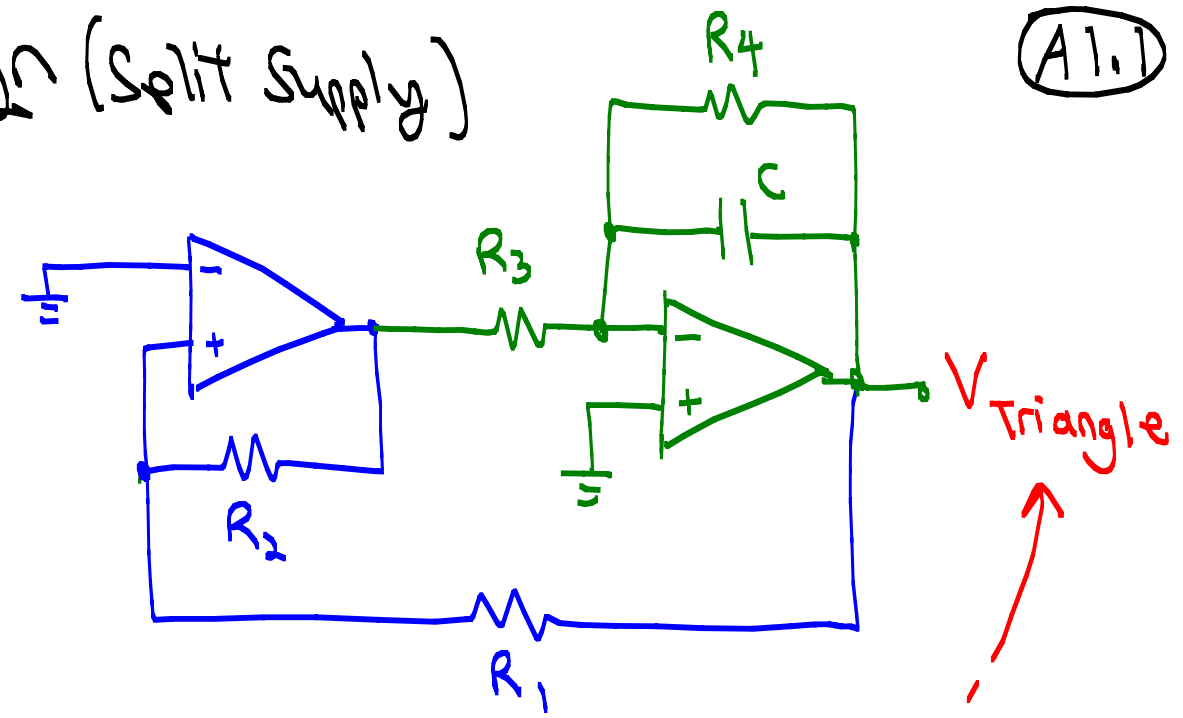


**Example 2** LED driver



# Appendix 1 : Triangle Wave Generator Design (Split Supply)

Example :  $f = 1 \text{ KHz}$  ,  $10 \text{ V}_{pp}$   
 $V_{cc} = 15\text{V}$      $+V_{sat} = V_{cc} - 1$   
 $-V_{EE} = -15\text{V}$      $-V_{sat} = -V_{EE} + 1$   
 use 5% resistor + 5% capacitors  
 →

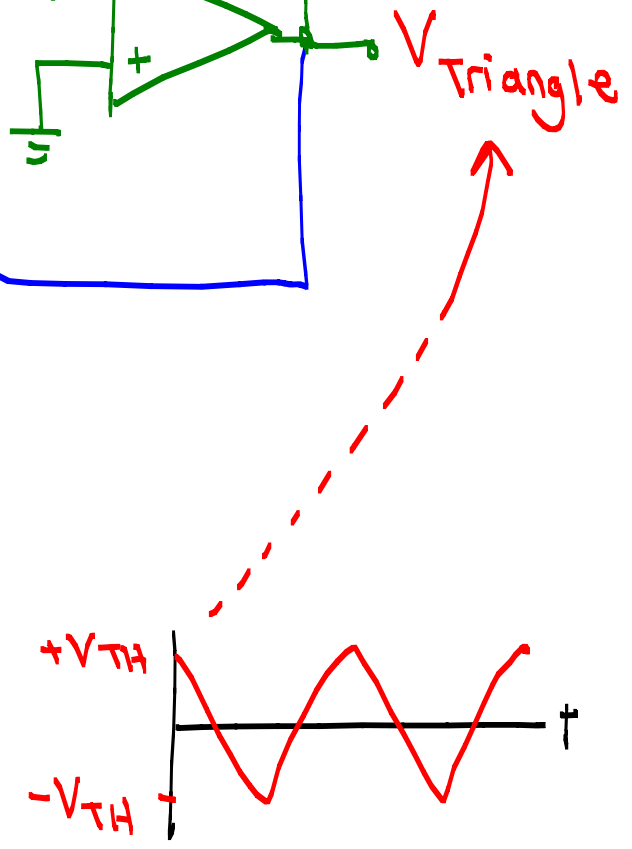


①  $V_{TH} = 5\text{V} = \frac{R_1}{R_1 + R_2} V_{sat}$     ← 14V

→  $\frac{R_1}{R_1 + R_2} = \frac{5}{14} = 0.357$

Typically,  $R_2 \sim 100 \text{ k}$  range

⇒ choose  $R_1 = 36 \text{ K}$   
 $R_2 = 100 \text{ K}$



$$\textcircled{2} \quad f = \frac{R_2}{4R_1 R_3 C} = \frac{100\text{K}}{4 \times 36\text{K} \times R_3 C} = 1000 \text{ Hz} \Rightarrow R_3 C = \underline{\underline{6.944 \times 10^{-4} \text{ s}}} \quad A1.2$$

Typically  $C < 0.1 \mu\text{F}$  and  $R_3 \sim 100\text{K}$ :

$R_3$	$C$	$C_{\pm 5\%}$	$\Delta C$
100K	6940 pF	6800 pF	140 pF
110K	6313	6200	113 ←
120K	5787	5600	187
130K	5341	5100	241

$$\frac{100\text{K}}{4 \times 36\text{K} \times (110\text{K})(6200\text{pF})} = 1018.3 \text{ Hz}$$

(within 1.8%)

③ Choose  $R_4 > 10R_3$  (or higher)

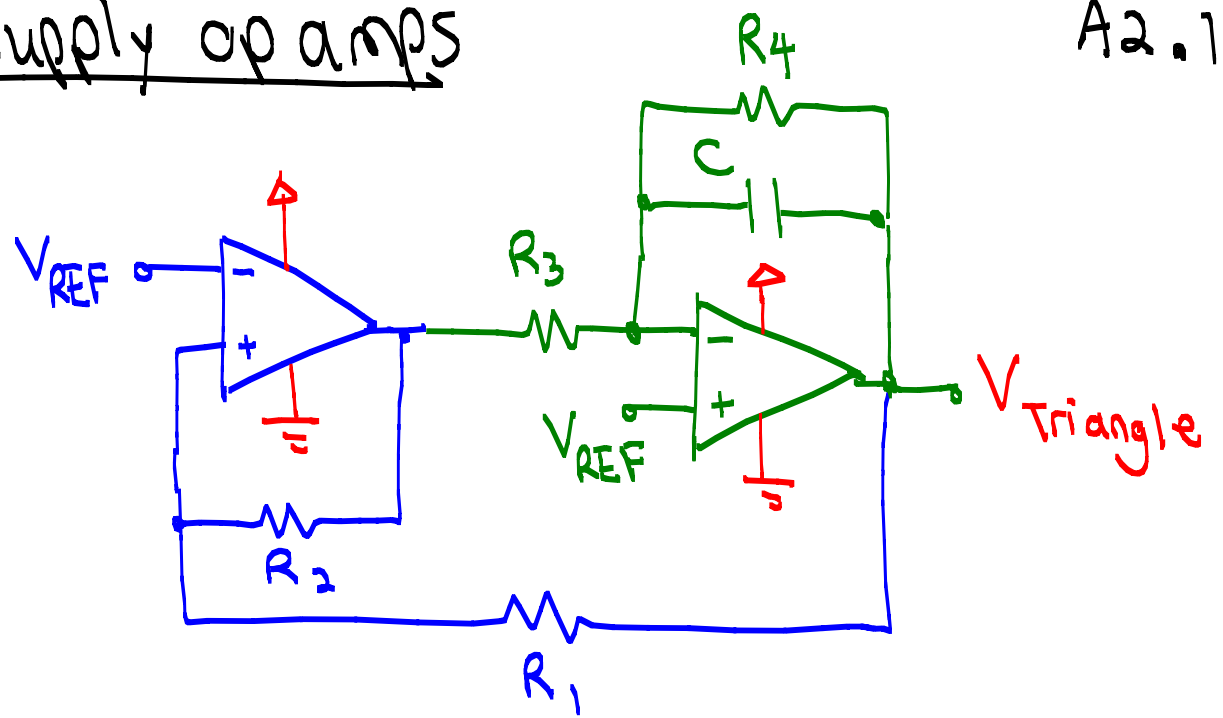
→  $R_4 = 1.5\text{M}$  (limit to few  $\text{M}\Omega$  or less)

# Appendix #2 • Triangle Wave w/ single-supply op amps

Example:  $f = 1 \text{ KHz}$ ,  $6 \text{ V}_{pp}$

$V_{CC} = 9\text{V}$	$+V_{sat} = V_{CC} - 1$
$-V_{EE} = 0\text{V}$	$-V_{sat} = 0$

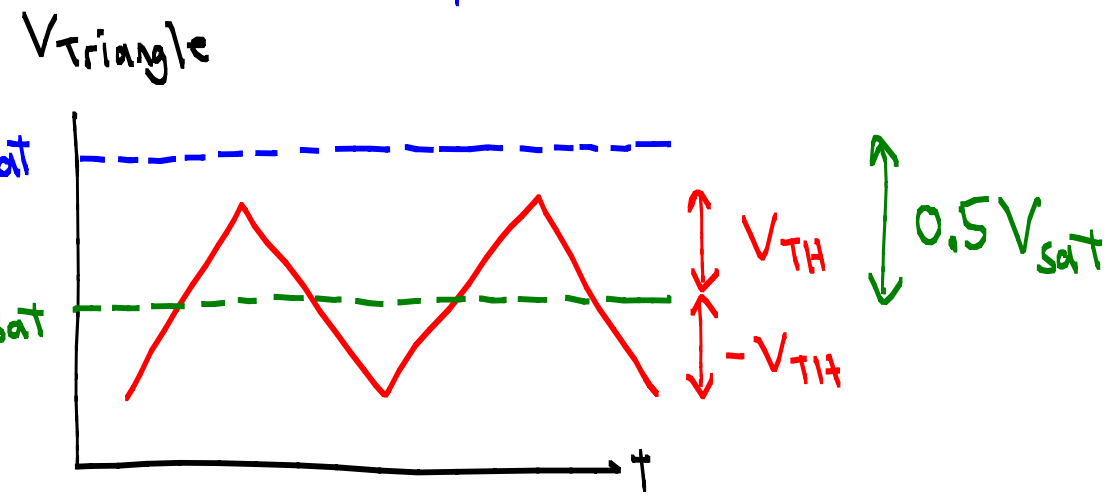
single supply op amp (e.g. LM358)



①  $V_{TH} = \frac{R_1}{R_2} \times 0.5 V_{sat} = 3\text{V}$

$\frac{9-1}{2} = 4\text{V}$

$V_{REF} = 0.5 V_{sat}$



$\frac{R_1}{R_2} = 0.75$

Typically,  $R_2 \sim 100 \text{ k}$  range

Choose  $R_1 = 75 \text{ K}$   
 $R_2 = 100 \text{ K}$



$$\textcircled{2} \quad f = \frac{R_2}{4R_1 R_3 C} = \frac{100\text{K}}{4 \times 75\text{K} \times R_3 C} = 1000\text{Hz} \rightarrow R_3 C = 3.333 \times 10^{-4} \text{ s}$$

A2.2

Typically  $C < 0.1 \mu\text{F}$  and  $R_3 \sim 100\text{K}$ :

$R_3$	$C$	$C_{5\%}$	$\Delta C$
100K	3333 pF	3300 pF	33 pF
110K	3030	3000	30 ←
120K	2778	2700	78
130K	2564	2400	164

$$\frac{100\text{K}}{4 \times 75\text{K} \times (110\text{K})(3000\text{pF})} = 1010.1 \text{ Hz}$$

(within 1%)

③ Choose  $R_4 > 10 R_3$  (or higher)

→  $R_4 = 1.5 \text{ M}$  (limit to few  $\text{M}\Omega$  or less)

$$\textcircled{4} \quad V_{REF} = 0.5 (V_{sat(+)} - V_{sat(-)})$$

$$= 0.5 (8 - 0) = \underline{\underline{4V}}$$

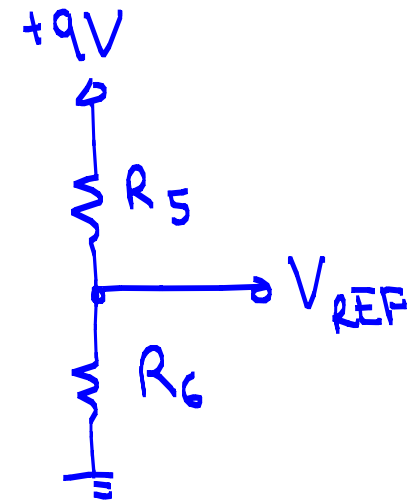
$$\rightarrow 9 \cdot \frac{R_6}{R_5 + R_6} = 4V$$

$$\frac{4}{9} R_6 = R_5 + R_6$$

$$\frac{4}{9} R_6 = 1.25 R_6 = R_5$$



Typically,  $R_6 \sim 100K$  :

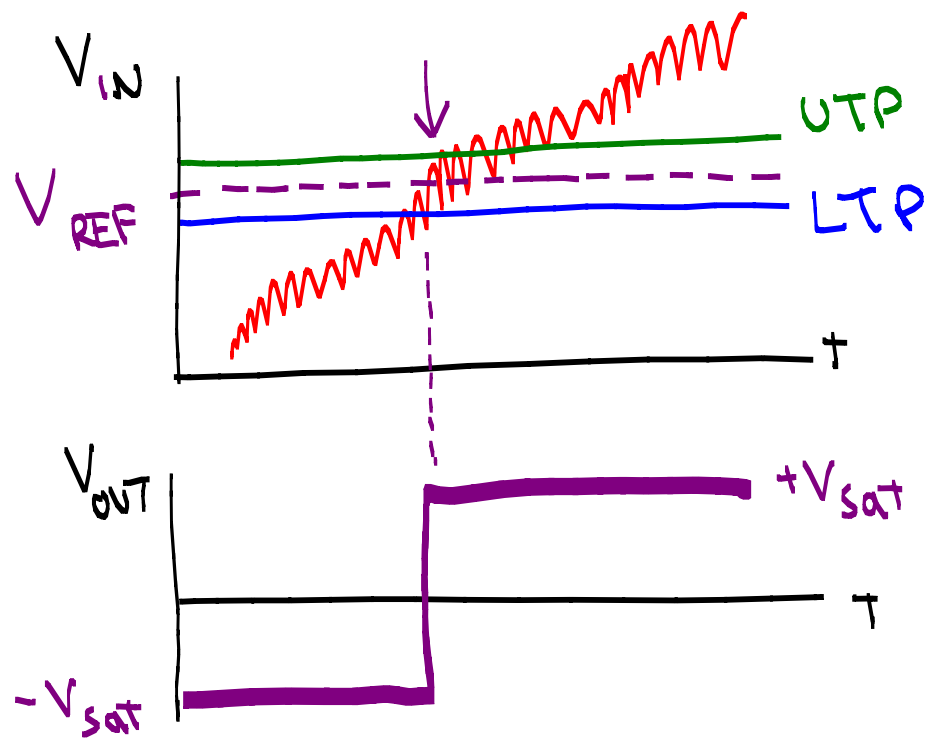


$R_6$	$R_5$
100K	125K
110K	137.5K
120K	150K



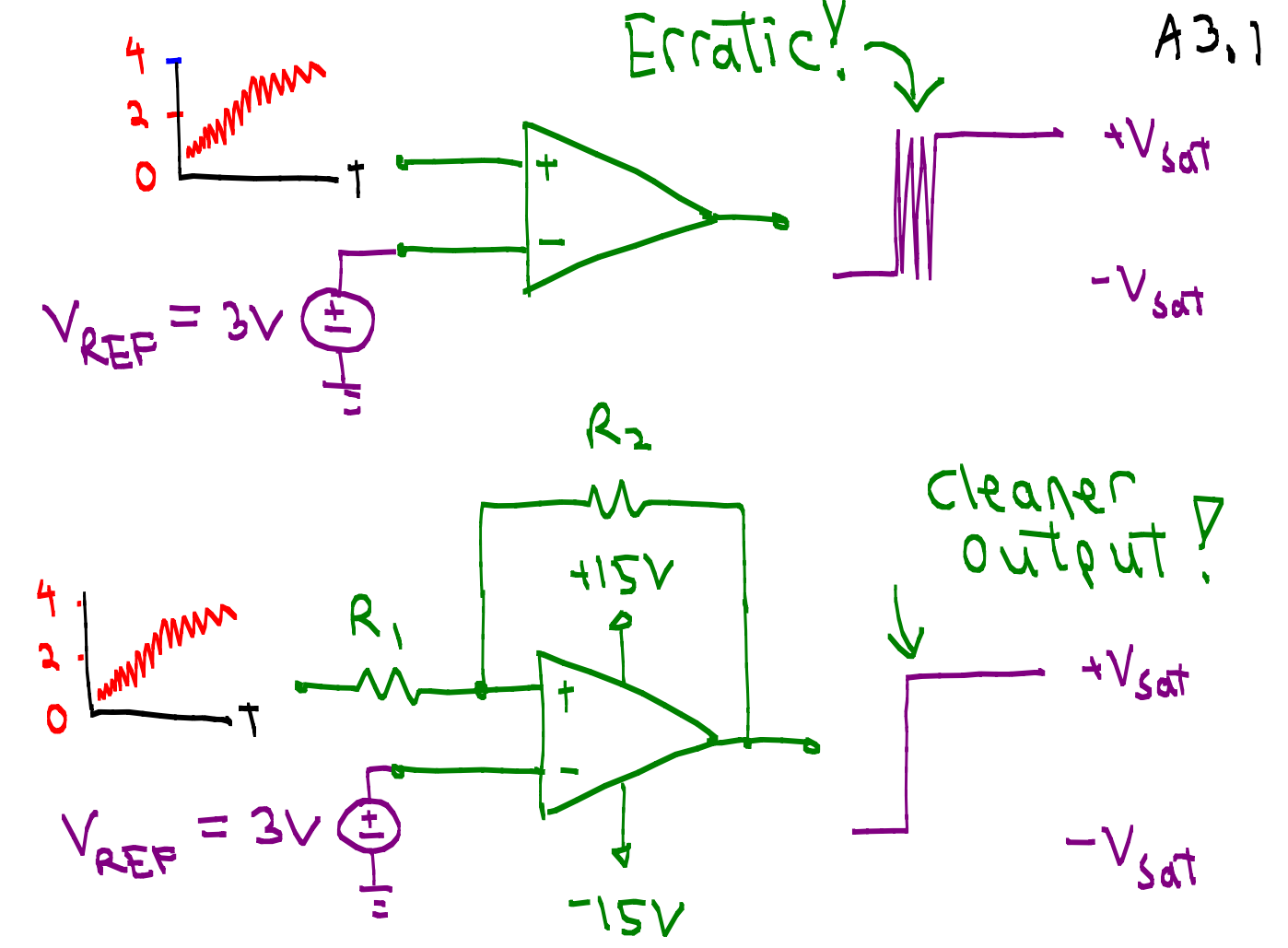
# Appendix # 3

## Comparator with hysteresis



UTP? 
$$\frac{UTP - V_{REF}}{R_1} = \frac{V_{REF} - (-V_{sat})}{R_2}$$

LTP? 
$$\frac{LTP - V_{REF}}{R_1} = \frac{V_{REF} - (V_{sat})}{R_2}$$



$$UTP = \left(1 + \frac{R_1}{R_2}\right) V_{REF} + \frac{R_1}{R_2} V_{sat}$$

$$LTP = \left(1 + \frac{R_1}{R_2}\right) V_{REF} - \frac{R_1}{R_2} V_{sat}$$