Waveshapping Circuits and Data Converters

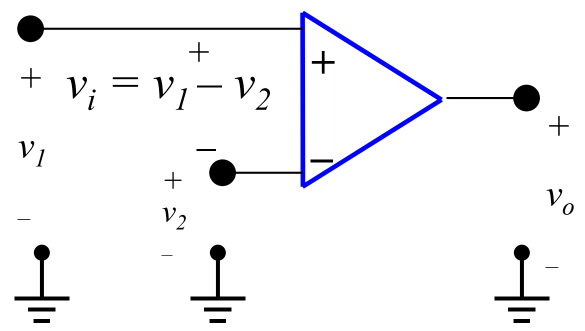
Lesson #17
Comparators and Schmitt Triggers
Section 12.1

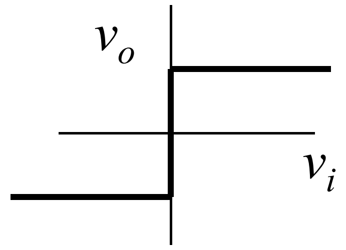
Waveshapping Circuits and Data Converters

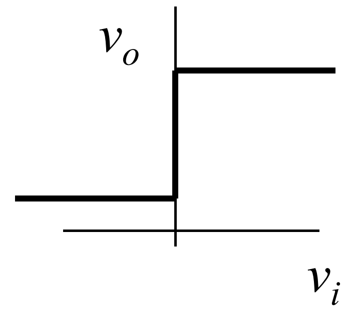
- Comparators and Schmitt Triggers
- Astable Multivibrators and Timers
- Rectifiers, Peak Detectors, Sample-and-Hold
- A/D and D/A Converters

Comparators

- Circuits which compare two input voltages, v_1 and v_2, and produces a logic output
  - E.g.
    - High if $v_1 > v_2$
    - Low if $v_1 < v_2$
  - Inputs:
    - Inverted and non-inverted
    - $v_i = v_1 - v_2$
  - Ideal Transfer Characteristics
    - Symmetrical or Unsymmetrical

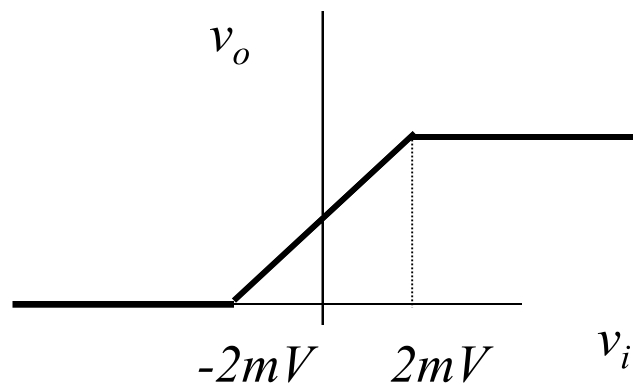






Real Comparators

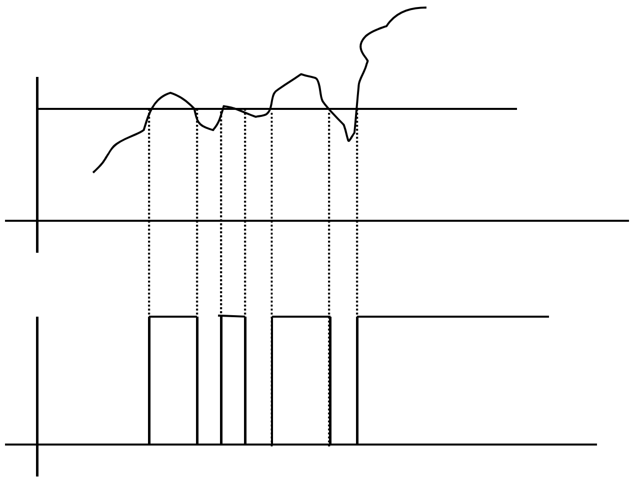
- Real Comparators have a gradual transistion
- $|v_i| > 0.2$ mV to cause a change in state.

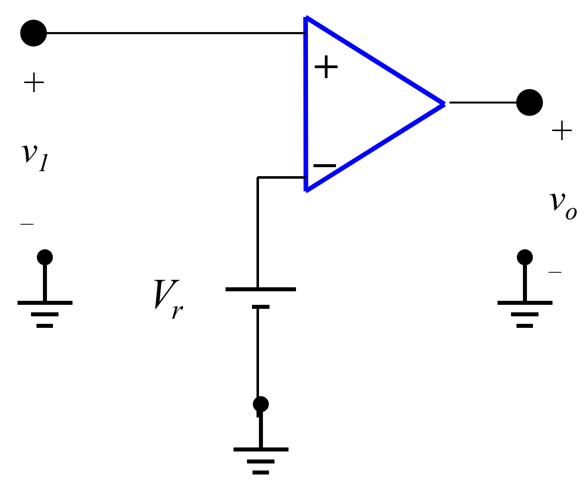


- Interface Analog to Digital signals and may have different voltage ranges
  - +15 to – 15 V on the analog side
  - +5 to 0 V on the digital side

Schmitt Triggers

- Noise on the input can cause undesirable transitions in the output of a comparator.
  - Example: comparing a noisy signal to a reference voltage.

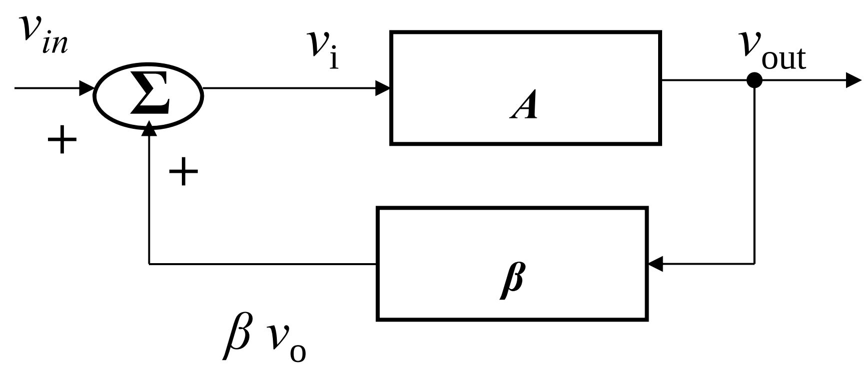




- Through the use of positive feedback to the comparator, this problem can be eliminated - The Schmitt Trigger

Effects of Positive Feedback

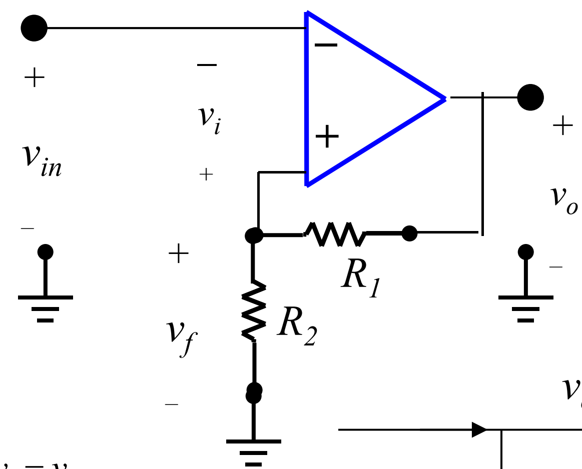
- From this circuit: $v_o = Av_i$ and $v_i = v_f - v_{in} = \beta v_o - v_{in}$
- Because of the positive feedback v_i is no longer equal to zero (not a virtual ground)
- So as v_i increases in the positive (negative) direction, increases in the positive (negative) direction.
- Because of the positive feedback, this will increase v_i in the positive direction (negative) which will further increase v_o which further increase v_i and so on.
- When will this stop?



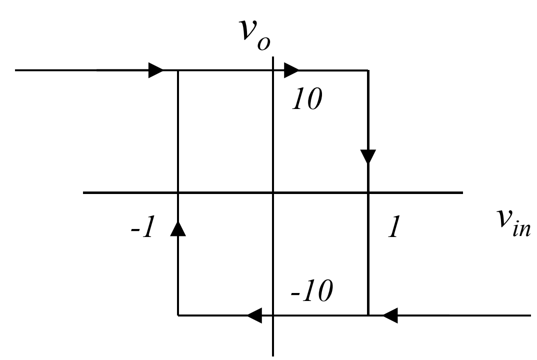
- If we had infinite power, then never.
- However, we have limited power which is given by the amplifier's DC voltage supplies: +A, -A.
- If v_i goes positive, then v_o "instantaneously" grows to +A volts
- And if v_i goes negative, then v_o "instantaneously" grows to -A volts

Hysteresis

- Assume that $\beta = R_2/(R_1+R_2) = 0.1$ and v_o levels are $+10$ (for $v_i > 0$) and $-10\ V$ (for $v_i < 0$).
- First, note that $v_i = v_f - v_{in}$. Now, let's assume $v_o = +10\ V$ and therefore $v_f = 1\ V$ then as long as v_{in} is less than $1\ V$, then $v_o = +10\ V$ (it's high state) since v_i, the input to the comparator, will be > 0. Once v_{in} surpasses 1, $v_i < 0$, and the output will switch to $-10\ V$.
- At this point, $v_f = -1\ V$ and as long as the $v_{in} > -1\ V$, the output will stay in its low state, $-10\ V$.
- Note that has the characteristic of being a flip-flop. If one pulses it with high (>1), then the output switches to a low and visa versa.



$$v_{in} + v_i = v_f$$
$$v_i = v_f - v_{in}$$
$$v_f = \beta v_o$$
$$v_i = 0.1 v_o - v_{in}$$
$$\text{For } v_i > 0; v_o = 10$$
$$v_i = 0.1 \times 10 - v_{in} > 0 \Rightarrow 1 - v_{in} > 0 \Rightarrow 1 > v_{in}$$
$$v_{in} < 1$$
$$\text{For } v_i < 0; v_o = -10$$
$$v_i = 0.1 v_o - v_{in} < 0 \Rightarrow -0.1 \times 10 - v_{in} < 0 \Rightarrow -1 < v_{in}$$
$$v_{in} > -1$$



This is characteristic is called **hysteresis**

Inverter

$v_{in} + v_i = v_f$

$v_i = v_f - v_{in}$

$v_f = \beta v_o$

$v_i = \beta v_o - v_{in}$

For $v_i > 0; v_o = A$

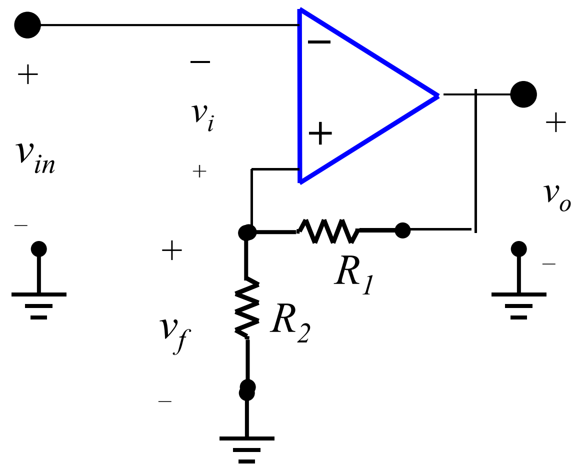
$v_i = \beta v_o - v_{in} > 0 \Rightarrow \beta A - v_{in} > 0 \Rightarrow \beta A > v_{in}$

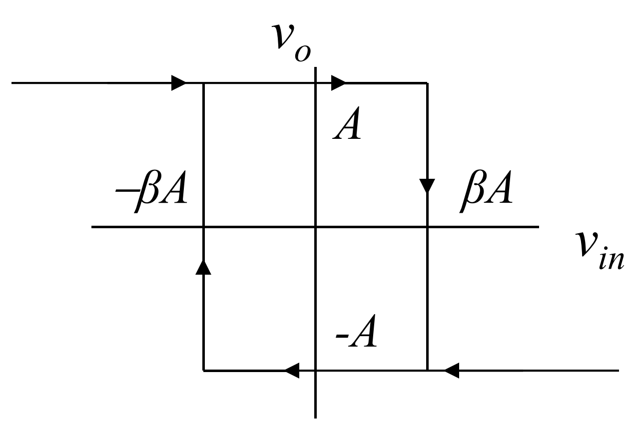
$v_{in} < \beta A$

For $v_i < 0; v_o = -A$

$v_i = \beta v_o - v_{in} < 0 \Rightarrow -\beta A - v_{in} < 0 \Rightarrow -\beta A < v_{in}$

$v_{in} > -\beta A$

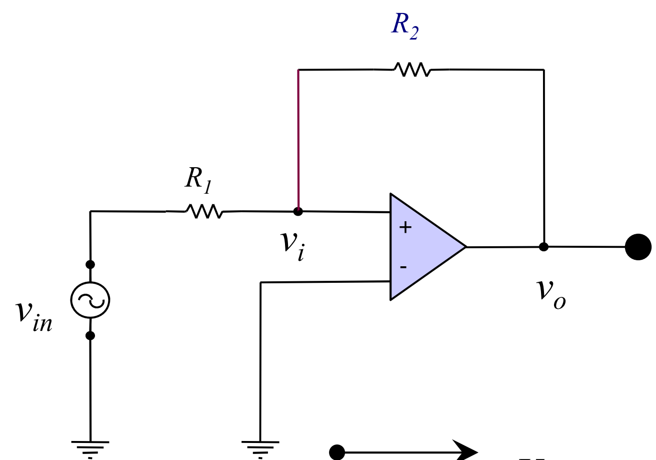




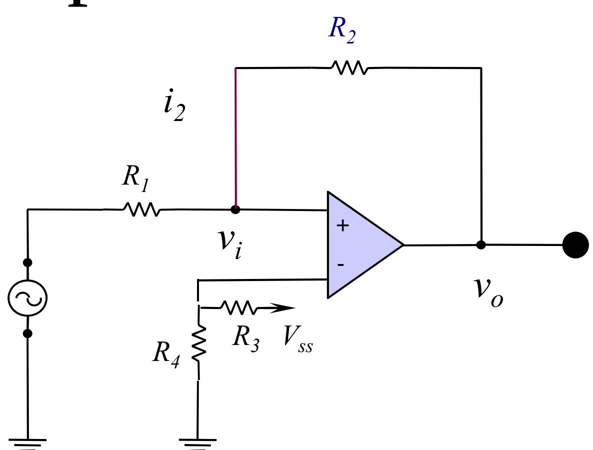
Note that $\pm \beta A$ volts are the thresholds for when the circuit switches states.

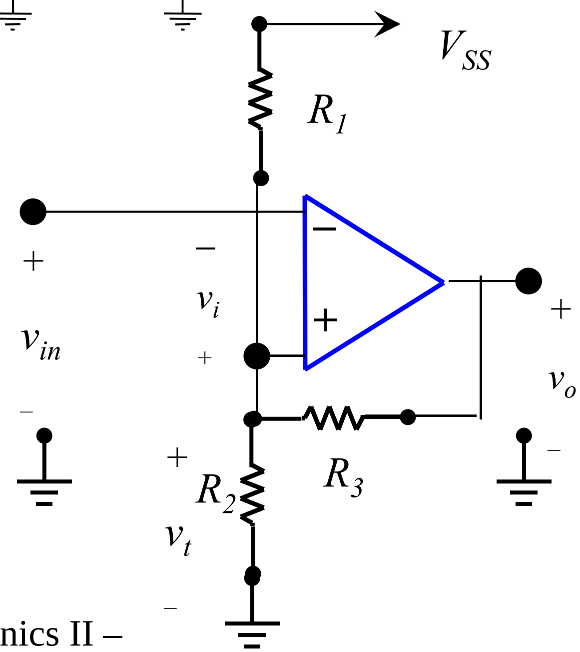
Other Forms of Schmitt Triggers

- Non-inverting types

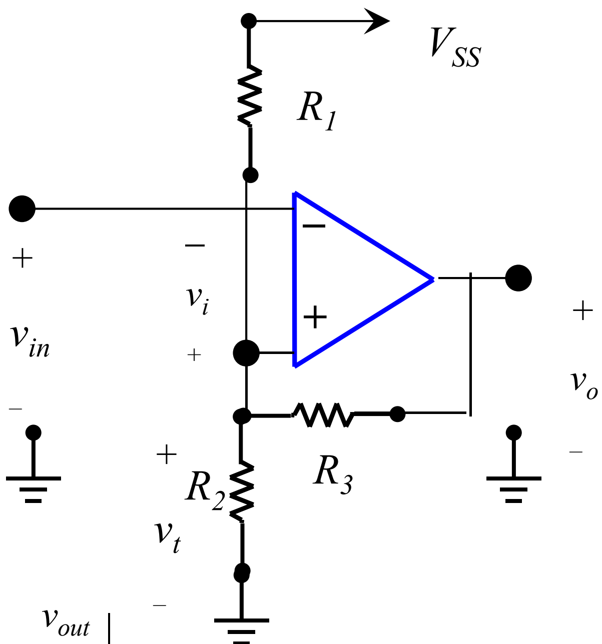


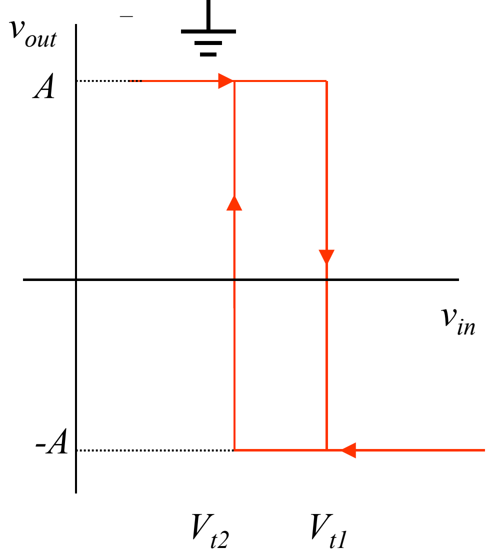
- Specified Thresholds





Specific Thresholds





$$v_i = v_t - v_{in}$$
$$v_i > 0; v_o = +A$$
$$v_i < 0; v_o = -A$$

From node at noninvering input:

$$\frac{v_t}{R_2} + \frac{v_t - v_o}{R_3} + \frac{v_t - V_{SS}}{R_1} = 0$$

$$v_t = \frac{\dfrac{v_o}{R_3} + \dfrac{V_{SS}}{R_1}}{\dfrac{1}{R_2} + \dfrac{1}{R_3} + \dfrac{1}{R_1}} = \frac{\dfrac{v_o}{R_3} + \dfrac{V_{SS}}{R_1}}{G_T} = \frac{v_o}{G_T R_3} + \frac{V_{SS}}{G_T R_1}$$

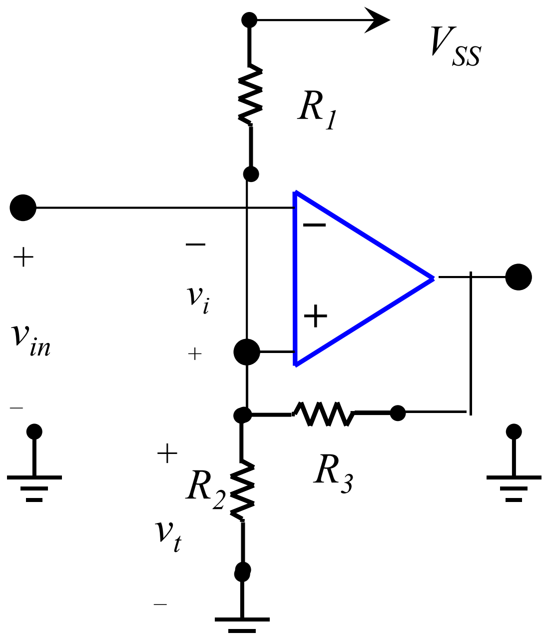
$$v_i = \frac{v_o}{G_T R_3} + \frac{V_{SS}}{G_T R_1} - v_{in}$$

$$v_i = \frac{A}{G_T R_3} + \frac{V_{SS}}{G_T R_1} - v_{in} > 0; v_{in} < V_{t1} = \frac{A}{G_T R_3} + \frac{V_{SS}}{G_T R_1}$$

$$v_i = \frac{-A}{G_T R_3} + \frac{V_{SS}}{G_T R_1} - v_{in} < 0; v_{in} > V_{t2} = \frac{-A}{G_T R_3} + \frac{V_{SS}}{G_T R_1}$$

An Example

- Choose the 3 resistors to provide thresholds of $5\pm 0.1\ V$ for output levels of $\pm 14.6\ V$.



At the non-inverting mode, we have:

$$\frac{V_t}{R_2}+\frac{V_t-V_{SS}}{R_1}+\frac{V_t-v_o}{R_3}=0$$

Using 15 V for V_{SS} and $V_t=5.1$ for $v_o=+14.6$, we have

$$\frac{5.1}{R_2}+\frac{5.1-15}{R_1}+\frac{5.1-14.6}{R_3}=\frac{5.1}{R_2}+\frac{9.9}{R_1}+\frac{9.5}{R_3}=0$$

Using $V_t=4.9$ for $v_o=$ -14.6, we have

$$\frac{4.9}{R_2}+\frac{4.9-15}{R_1}+\frac{4.9+14.6}{R_3}=\frac{4.9}{R_2}+\frac{10.1}{R_1}+\frac{19.5}{R_3}=0$$

- We need to chose one of the 3 resistors. If we choose $R_3= 1\ M$, then $R_1=20.55\ k$ and $R_2 = 10.38\ k$. If we chose resistors too small then may draw excessive amounts of current from our *15 V* supply and create a large power drain on the circuit.

Example contintued

$$v_i = v_t - v_{in}$$

when $v_i > 0; v_o = +14.6v$

therefore,

$$v_i = v_t - v_{in} > 0$$

$v_t > v_{in}$; or $v_{in} < 5.1$

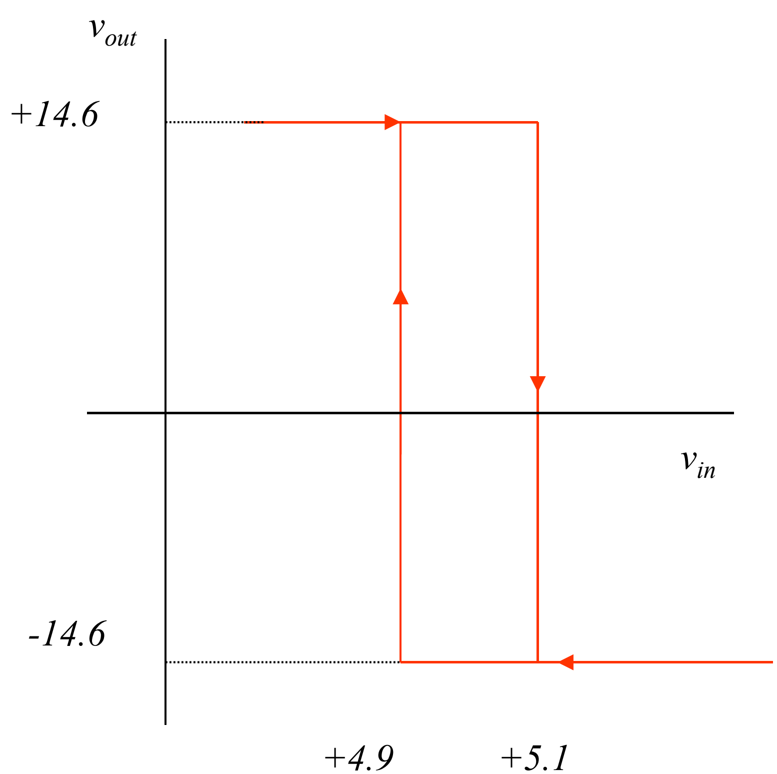
$$v_i = v_t - v_{in}$$

when $v_i < 0; v_o = -14.6v$

therefore,

$$v_i = v_t - v_{in} < 0$$

$v_t < v_{in}$; or $v_{in} > 4.9$



Another Example

- What are the transfer characteristics for this circuit if R_1=*1k* and R_2= *2k* and the thresholds levels are $\pm 10\ V$.

$$V_{in} = i(R_1 + R_2) + v_o$$

$$V_t = iR_1 = \frac{V_{in} - v_o}{R_1 + R_2} R_1$$

$$v_i = V_{in} - V_t = V_{in} - \frac{V_{in} - v_o}{R_1 + R_2} R_1$$

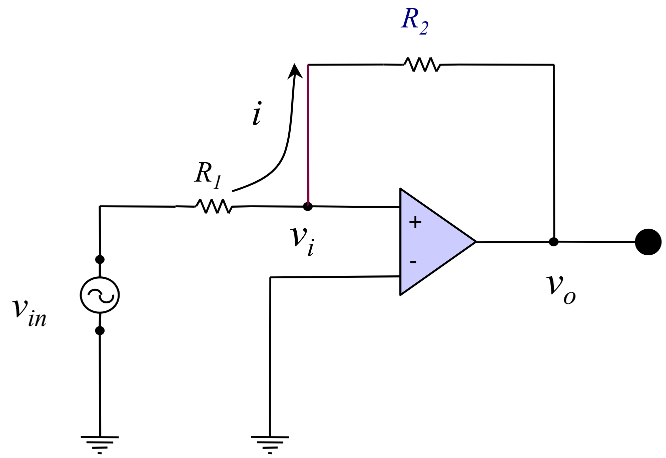
$$v_i = V_{in} - \frac{V_{in} - v_o}{3} = \frac{2}{3} V_{in} + \frac{v_o}{3}$$

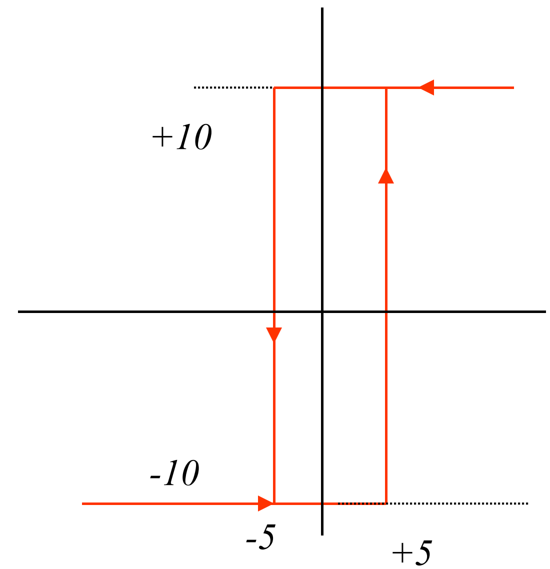
For $v_o = +10$ V, $v_i > 0$

$$v_i = \frac{2}{3} V_{in} + \frac{v_o}{3} > 0; \frac{2}{3} V_{in} > -\frac{v_o}{3}; V_{in} > -5$$

For $v_o = -10$ V, $v_i < 0$

$$v_i = \frac{2}{3} V_{in} + \frac{v_o}{3} < 0; \frac{2}{3} V_{in} < -\frac{v_o}{3}; V_{in} < 5$$





Homework

- Comparators and Schmitt Trigger Circuits
  - Problems: 12.8-9