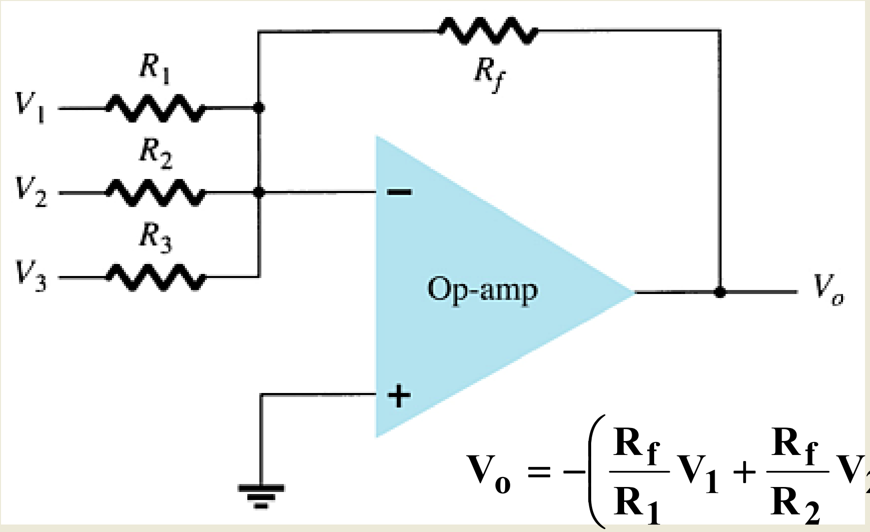
Chapter 11
Op-Amp Applications

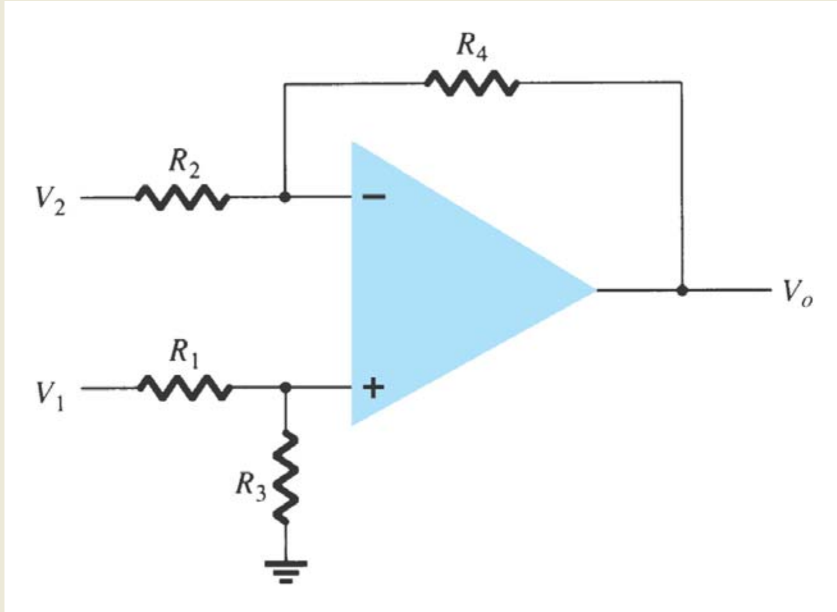
11.1 Operation Circuits

(1) Summing amplifier

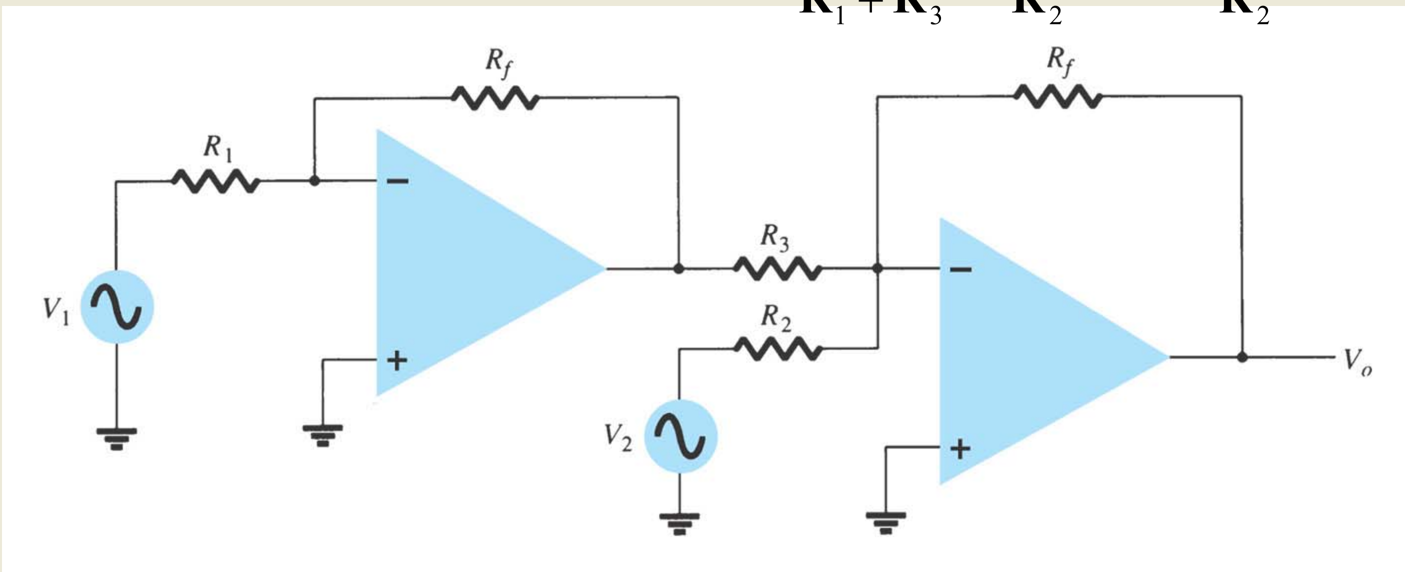


$$V_o = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$$

(2) Voltage Subtraction

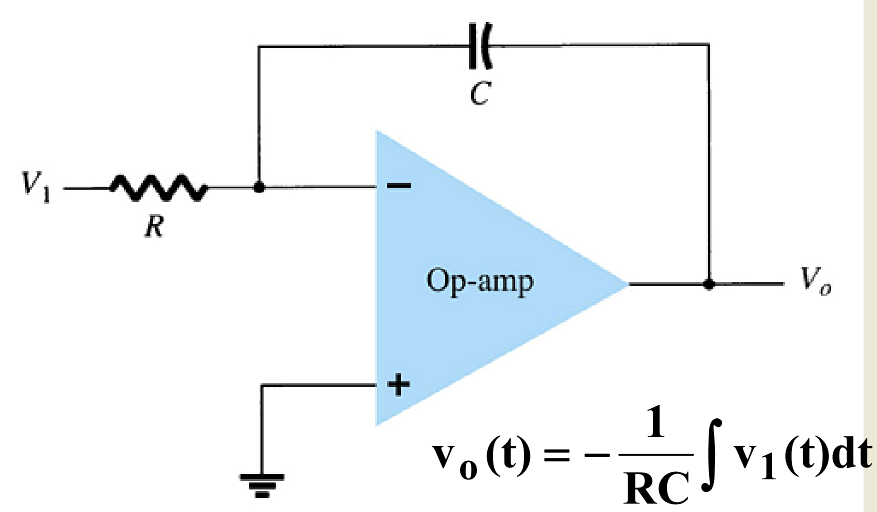


$$V_o = \frac{R_3}{R_1 + R_3}\,\frac{R_2 + R_4}{R_2}V_1 - \frac{R_4}{R_2}V_2$$



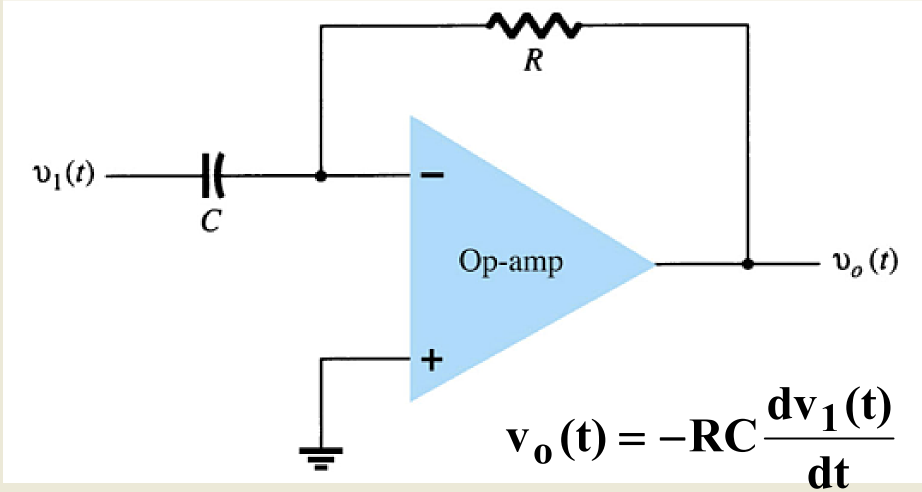
$$V_o = -\left(\frac{R_f}{R_2}V_2 - \frac{R_f}{R_3}\frac{R_f}{R_1}V_1\right)$$

(3) Integrator



$$v_o(t) = -\frac{1}{RC}\int v_1(t)dt$$

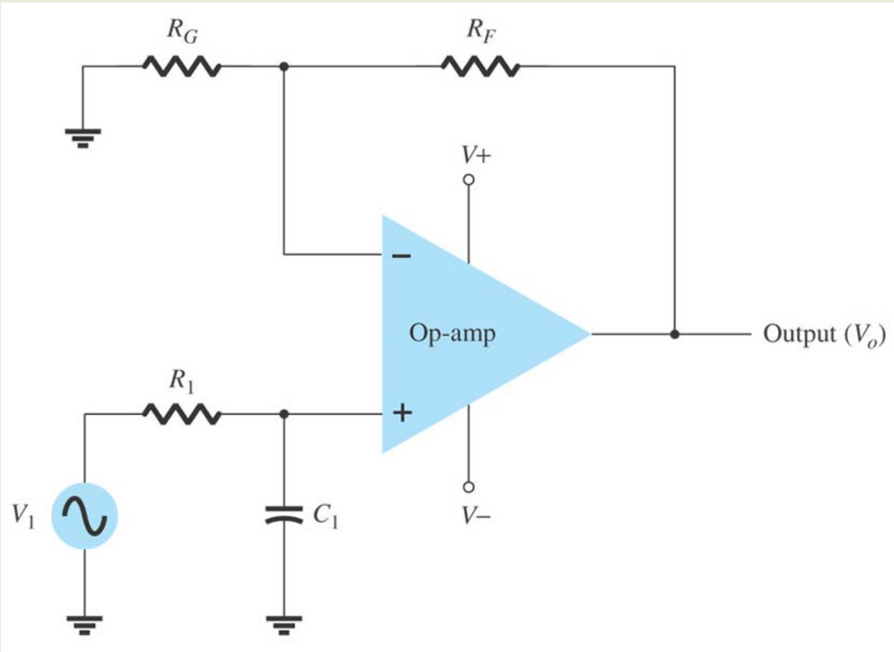
(4) Differentiator



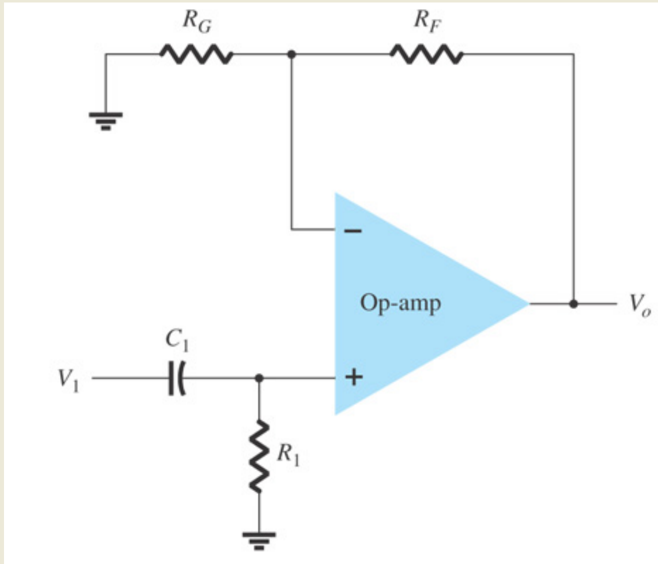
$$v_o(t) = -RC\frac{dv_1(t)}{dt}$$

11.2 Active Filter

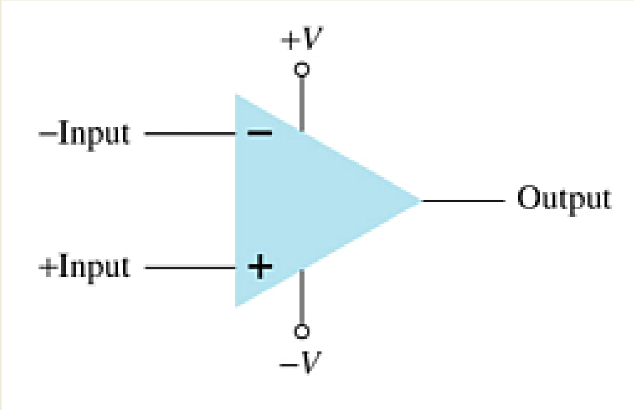
(1) First-order low-pass active filter

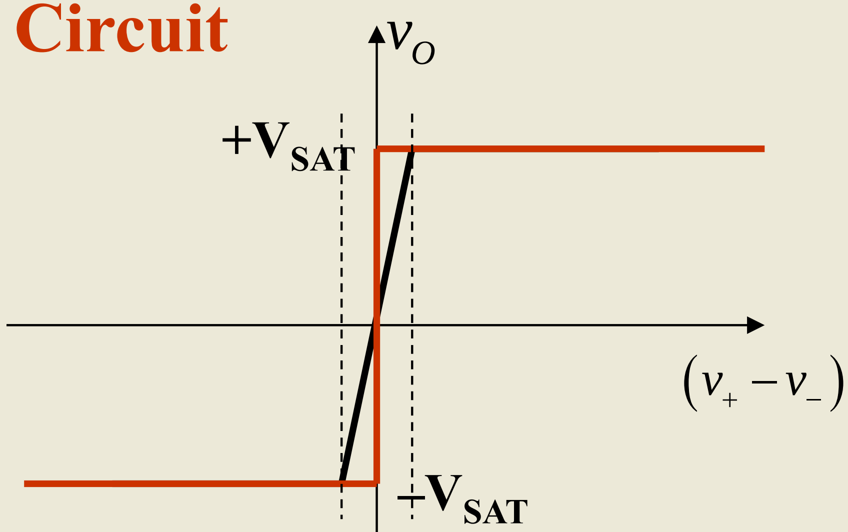


(2) First-order high-pass active filter



11.3 Comparator Circuit



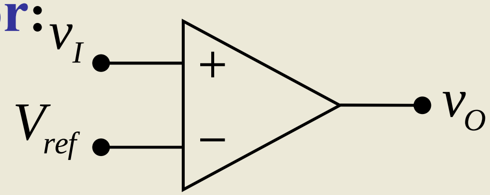


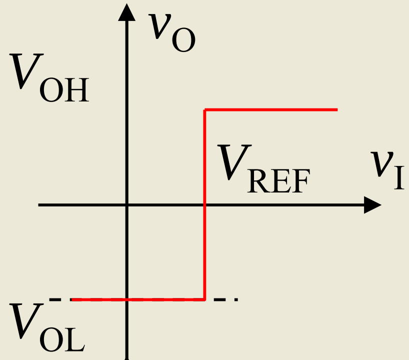
Open-loop Comparators and voltage transfer characteristics

The operation is a basic comparison. The output swings between its maximum and minimum voltage, depending upon whether one input (V_i) is greater or less than the other (V_{ref}).

For a noninverting op-amp comparator:

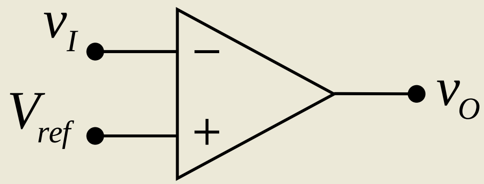
- $V_o = +V_{SAT}$ **when** $V_i > V_{ref}$.
- $V_o = -V_{SAT}$ **when** $V_i < V_{ref}$.

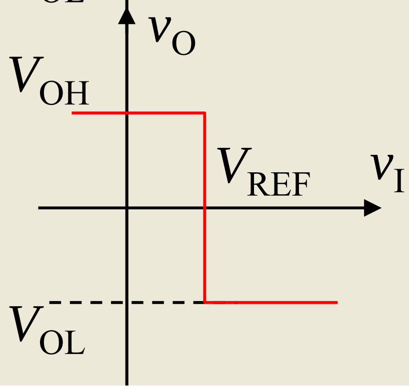




For a inverting op-amp comparator:

- $V_o = -V_{SAT}$ **when** $V_i > V_{ref}$.
- $V_o = +V_{SAT}$ **when** $V_i < V_{ref}$.

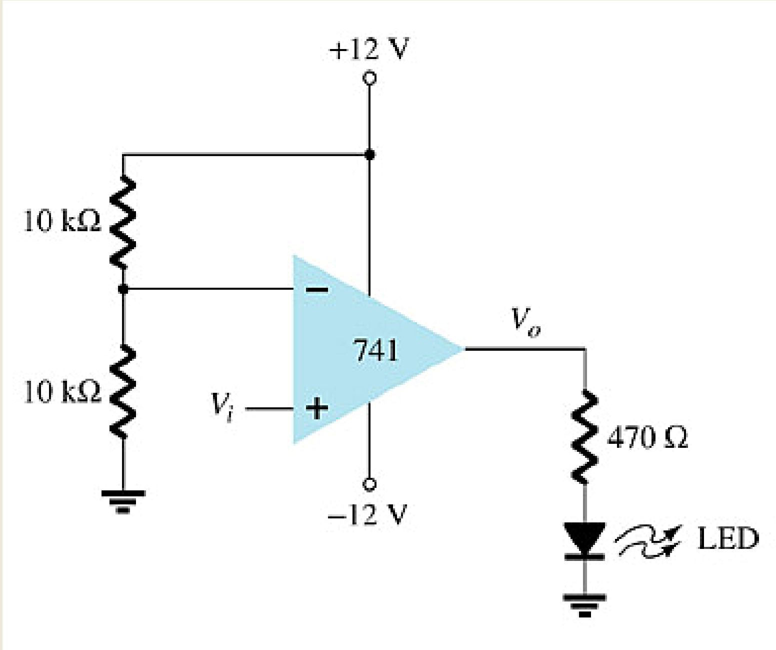




Use of Op-Amp as Comparator

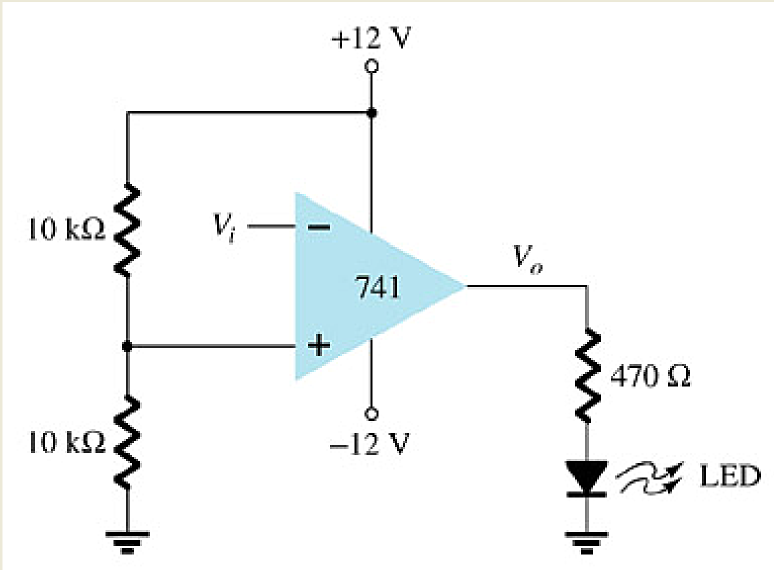
Example:

- V_{ref} in this circuit is +6V (from voltage divider)
- $+V_{SAT} = +V$, or +12V
- $-V_{SAT} = -V$ or –12V



When $V_i > +6V$ the output swings to +12V and the LED goes on.

When $V_i < +6V$ the output is at –12V and the LED goes off.



When $V_i < +6V$ the output swings to +12V and the LED goes on.

When $V_i > +6V$ the output is at –12V and the LED goes off.

Comparator ICs

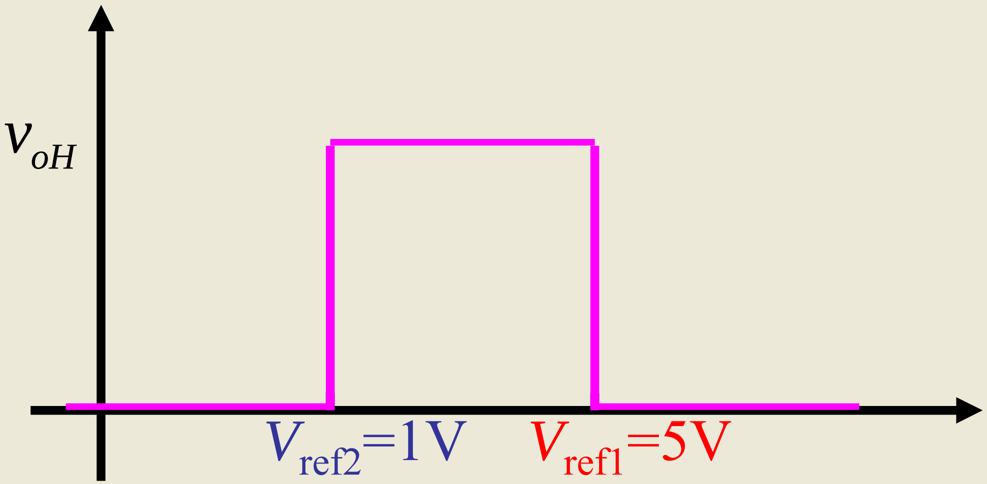
Advantages:

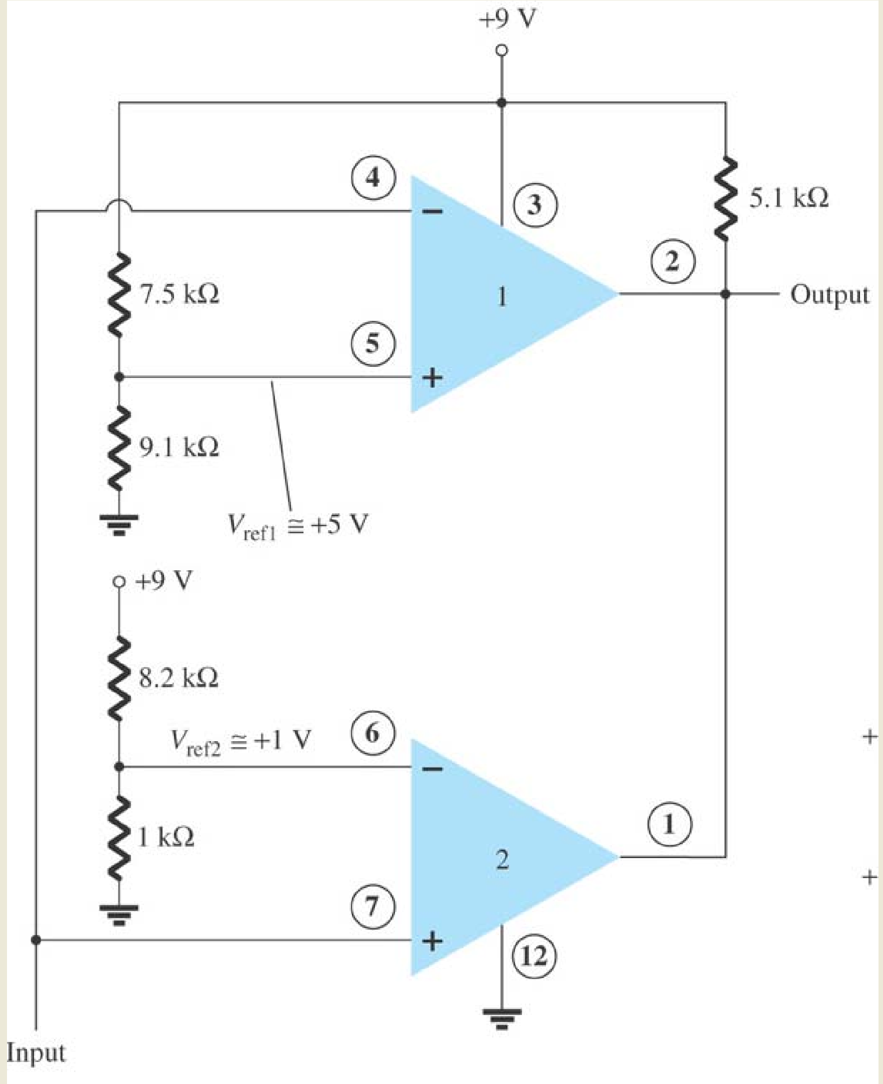
- **Faster switching**
- **Built-in noise immunity**
- **Outputs capable of directly driving loads**

Example of Comparator ICs

- **311**
- **339**

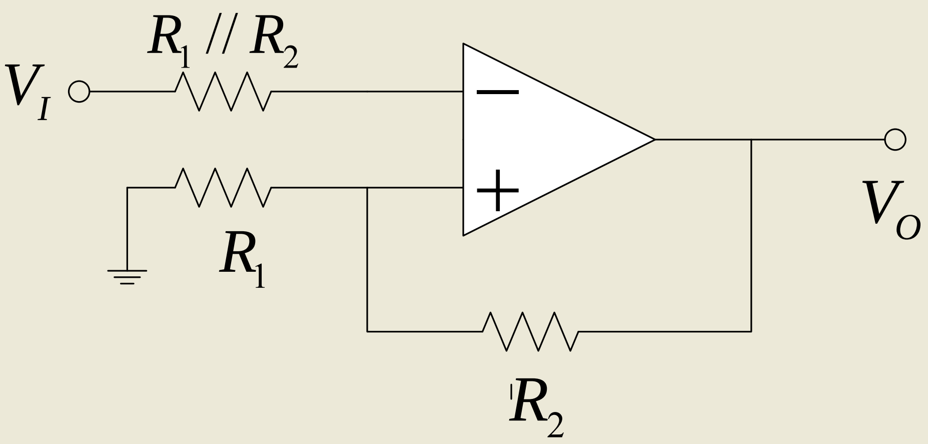
Voltage transfer characteristic





11.4 Schmitt Trigger

Basic inverting Schmitt Trigger



$$v_- = v_I \qquad v_+ = \frac{R_1}{R_1 + R_2} v_O$$

(1) when $v_O = V_{OH}$, high state

$$v_+ = \frac{R_1}{R_1 + R_2} V_{OH}$$

crossover occurs *when* $v_I = v_+$

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

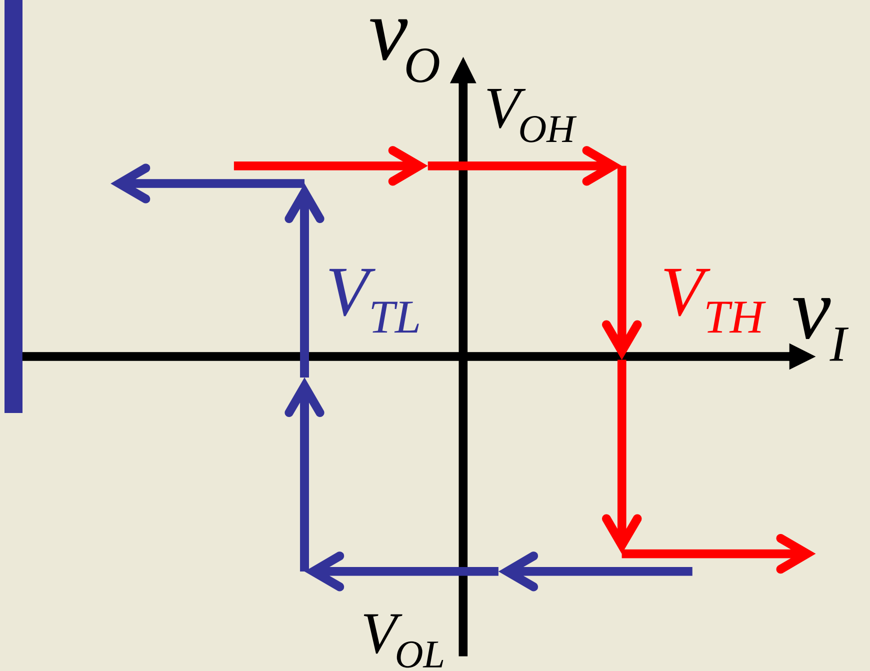
(2) when $v_O = V_{OL}$, low state

$$v_+ = \frac{R_1}{R_1 + R_2} V_{OL}$$

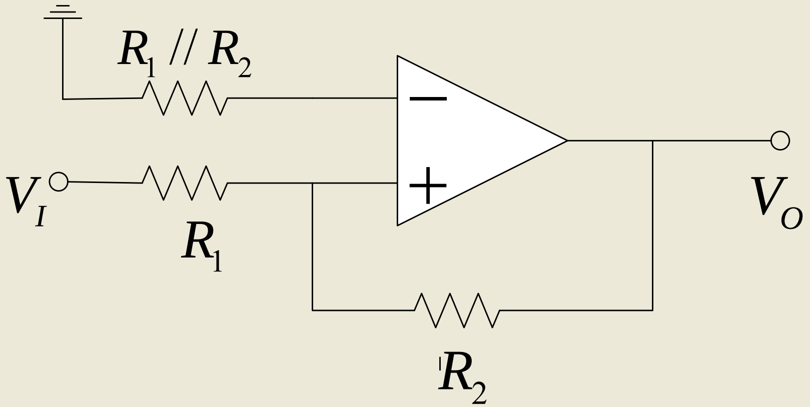
crossover occurs *when* $v_I = v_+$

$$V_{TL} = \frac{R_1}{R_1 + R_2} V_{OL}$$

voltage transfer characteristics



Noninverting Schmitt Trigger



$$v_- = 0 \qquad v_+ = \frac{R_2}{R_1+R_2} v_I + \frac{R_1}{R_1+R_2} v_O$$

(1) when $v_O = V_{OH}$, high state

$$v_+ = \frac{R_2}{R_1+R_2} v_I + \frac{R_1}{R_1+R_2} v_{OH}$$

crossover occurs *when* v_+=0

$$V_I = V_{TL} = -\frac{R_1}{R_2} V_{OH}$$

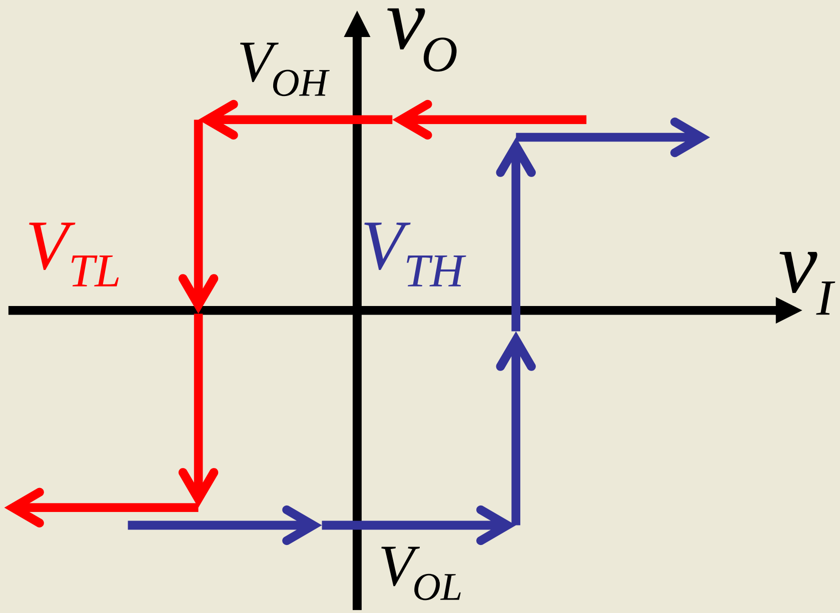
(2) when $v_O = V_{OL}$, low state

$$v_+ = \frac{R_2}{R_1+R_2} v_I + \frac{R_1}{R_1+R_2} v_{OL}$$

crossover occurs *when* v_+=0

$$V_I = V_{TH} = -\frac{R_1}{R_2} V_{OL}$$

voltage transfer characteristics



Additional Schmitt Trigger Configurations

-- With output limiters

-- With applied reference voltages

Summary of Chapter 11

- Linear Applications
  - 11.1 Operational Circuits
  - 11.2 Active Filter
- Nonlinear Applications
  - 11.3 Comparator
  - 11.4 Schmitt Trigger