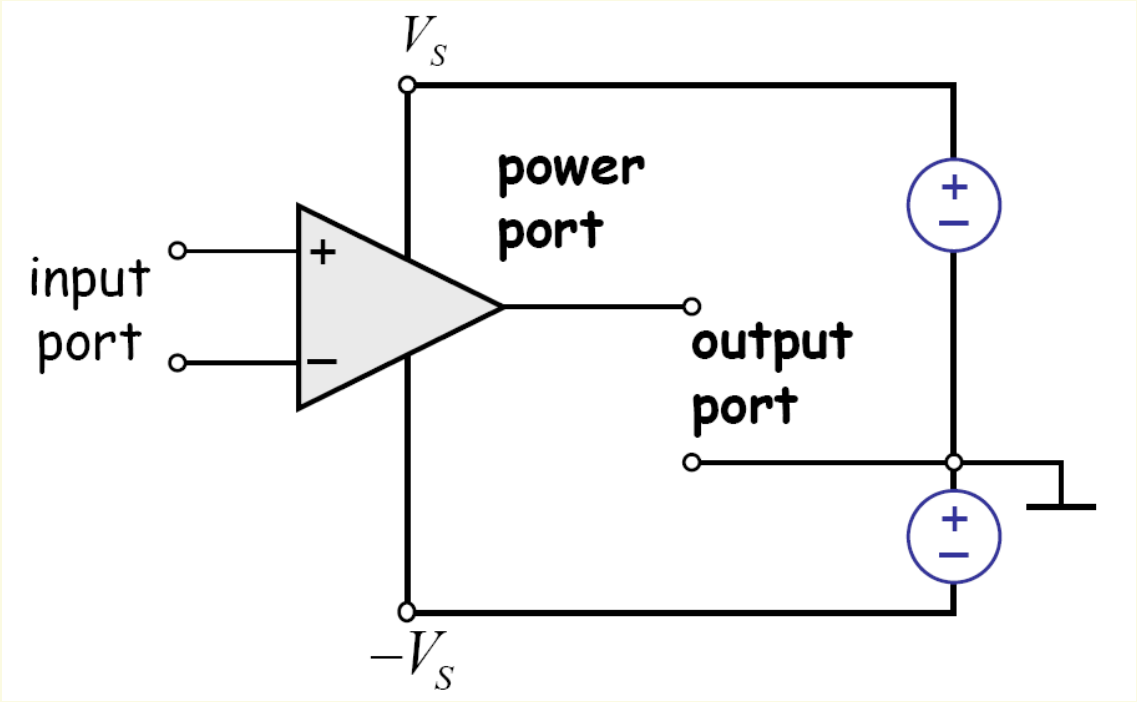
# Chap. 15 The Operational Amplifier Abstraction

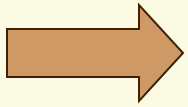
Device Properties of OP AMP

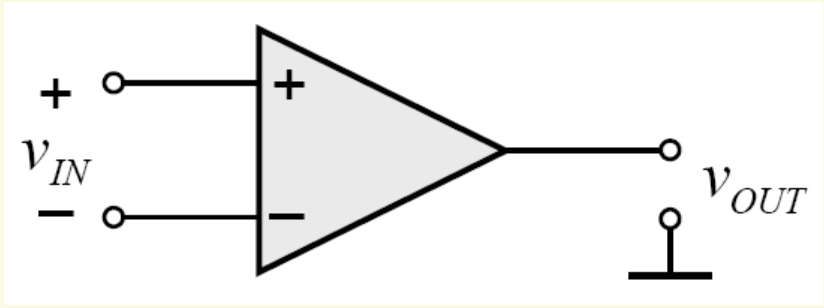
OP AMP Circuits

OP AMP RC Circuits

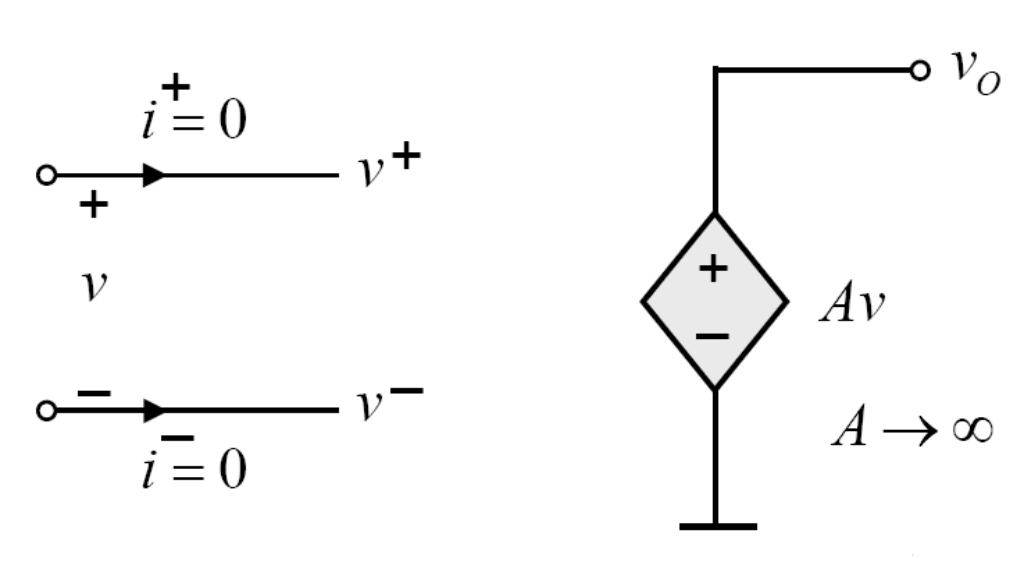
# Operational Amplifier (OP AMP) Abstraction

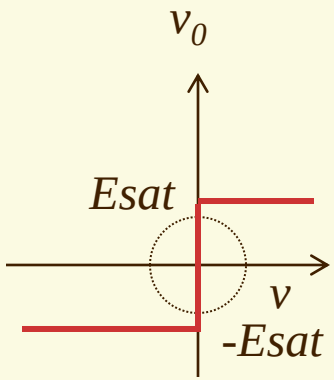


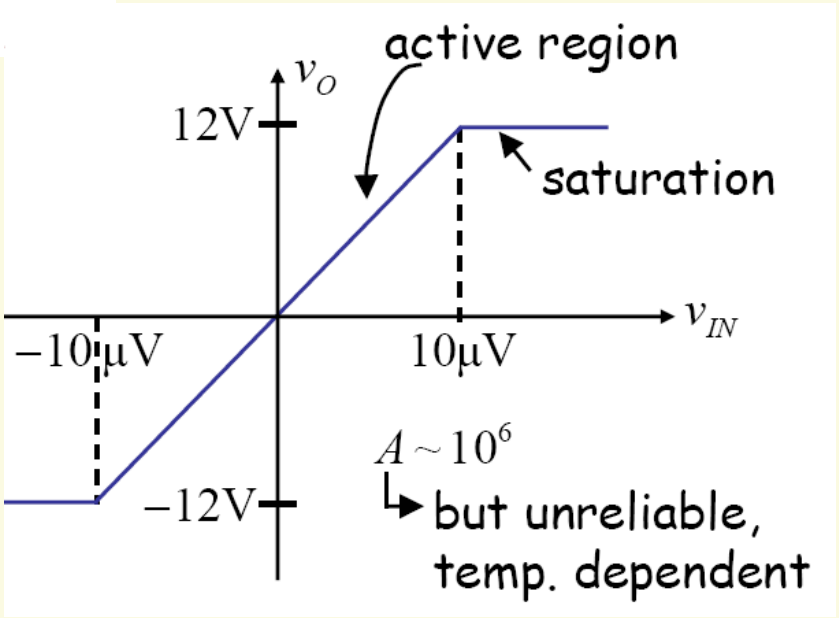


# Ideal Circuit Model of OP AMP

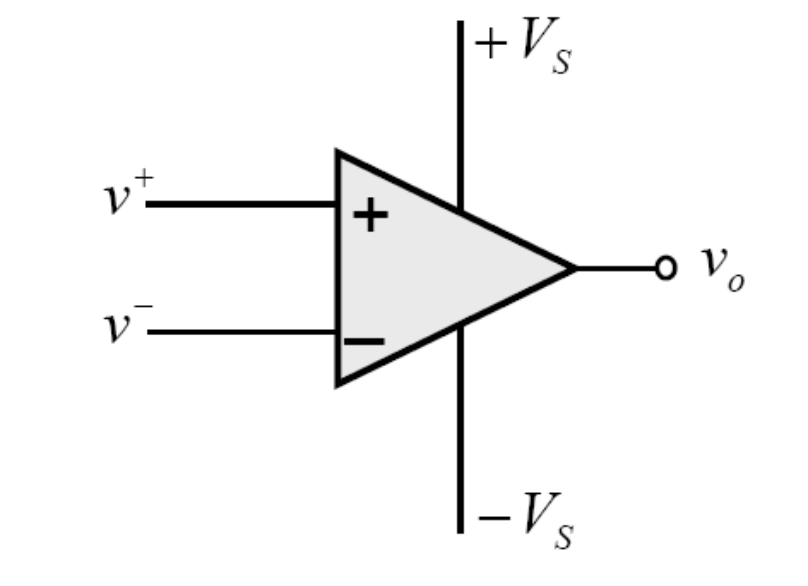


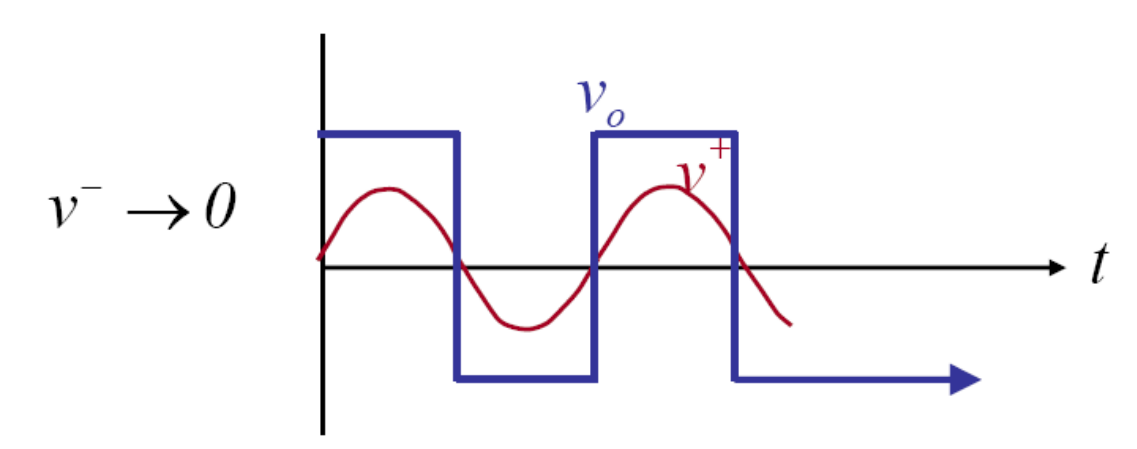




- Input resistance is infinite
- Output resistance is 0
- Infinite gain

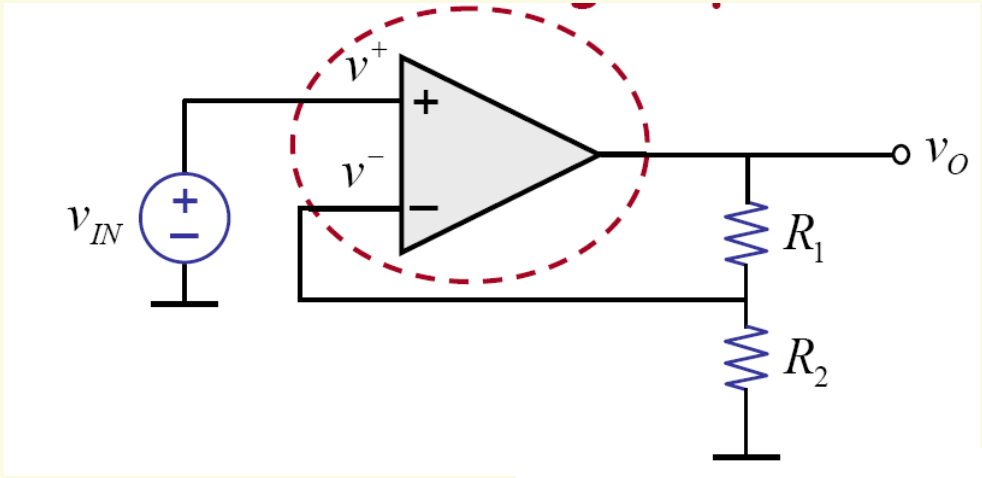


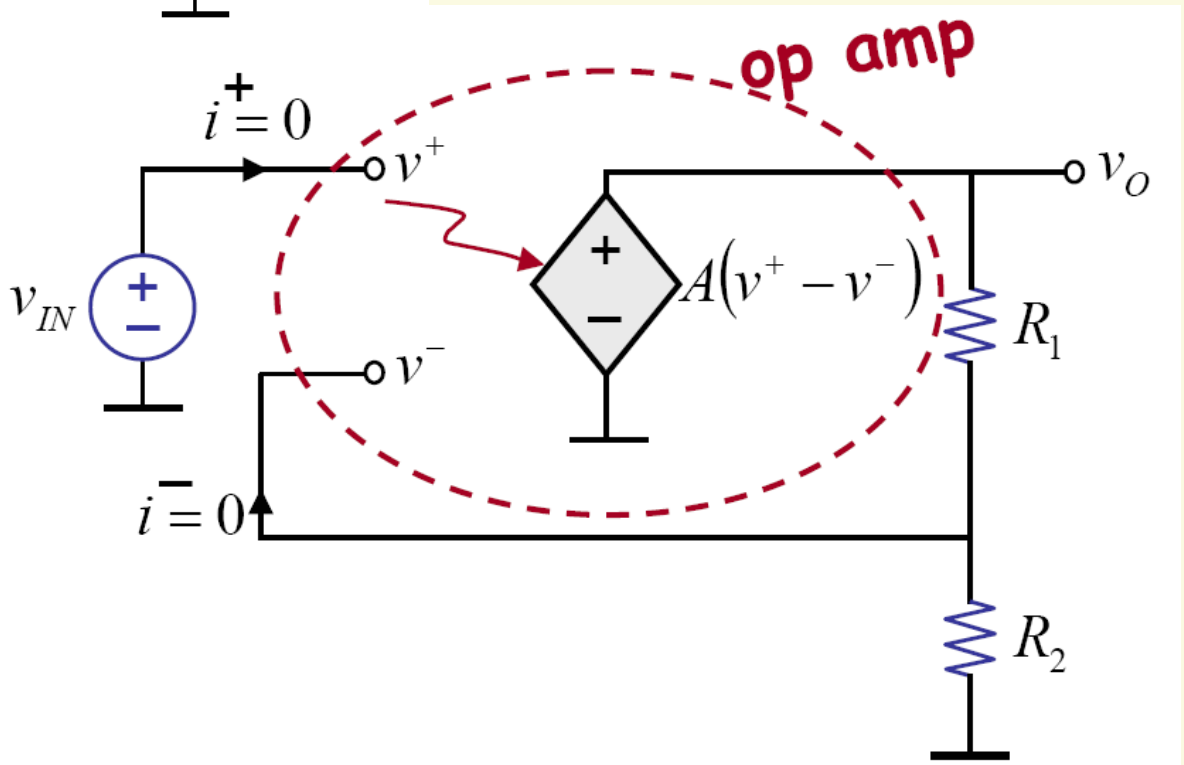
# Comparator (OP AMP in Saturation)



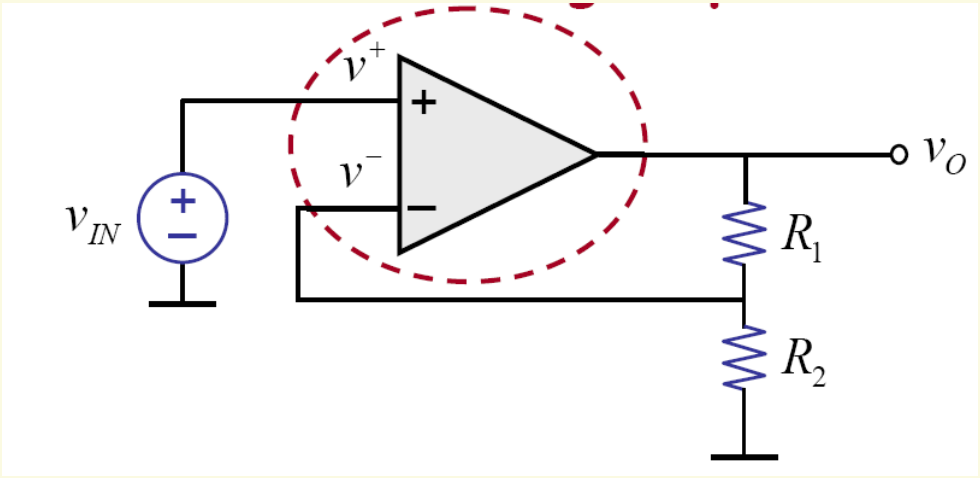



# Non-inverting Amplifier



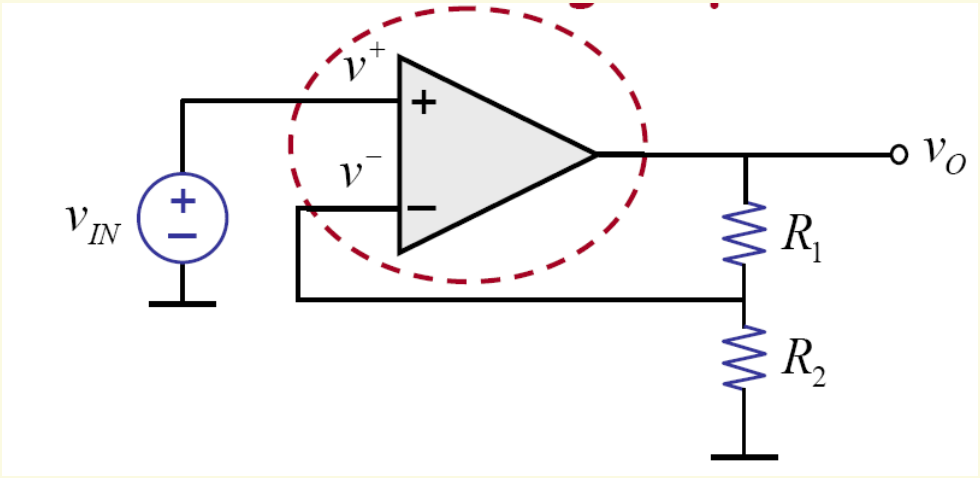
# Non-inverting Amplifier (2)




Show

$$v_O = \frac{Av_{IN}}{1 + \frac{AR_2}{R_1 + R_2}} \approx v_{IN} \underbrace{\frac{(R_1 + R_2)}{R_2}}_{\text{gain}}$$

# Negative Feedback

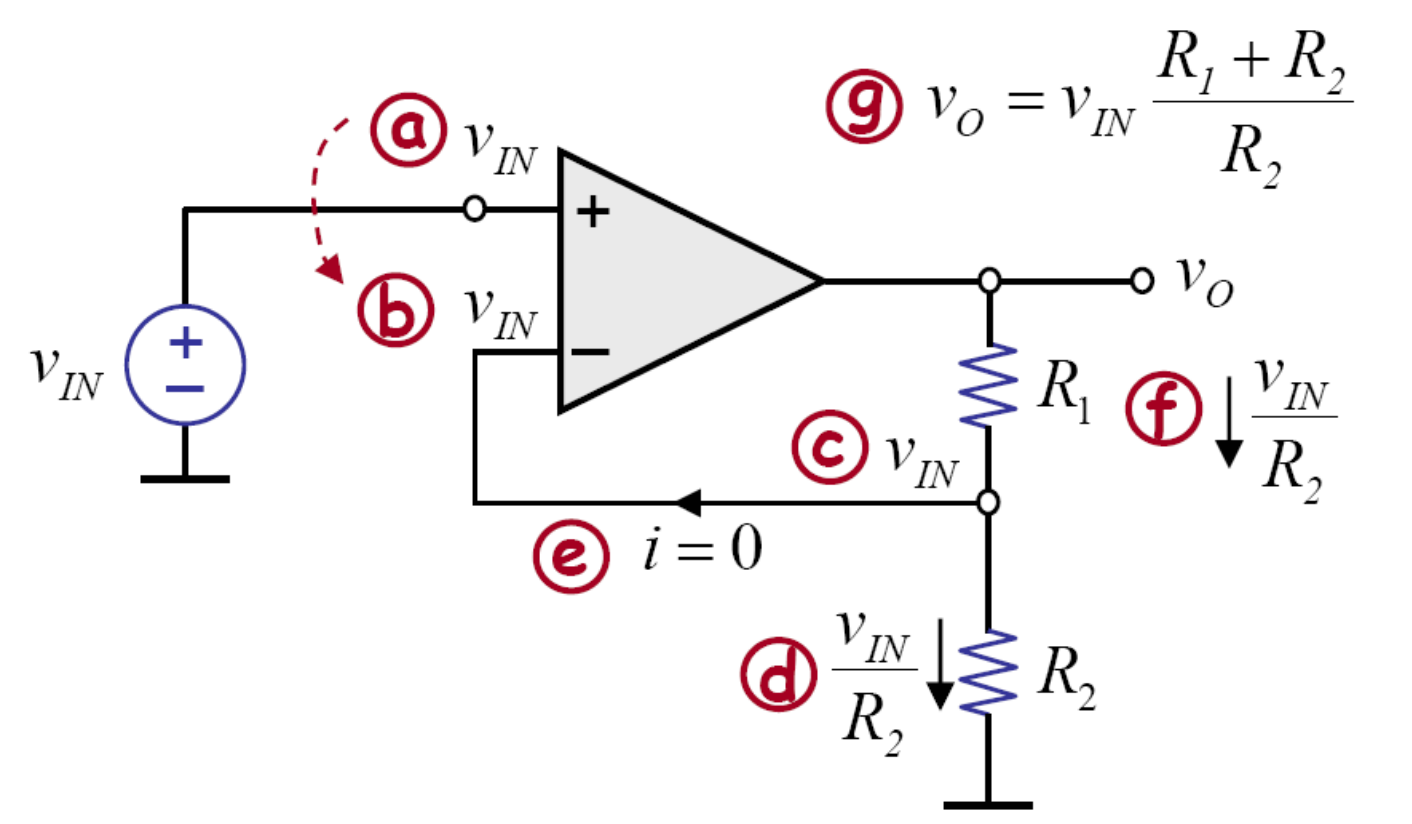



- Portion of output is fed back into the negative input
  - Stable state is reached without saturation
- Output is independent of OP AMP gain and temperature.

$$v^+ - v^- = \frac{v_O}{A} = \frac{\left(\frac{R_1 + R_2}{R_1}\right) v_{IN}}{A} \rightarrow 0$$

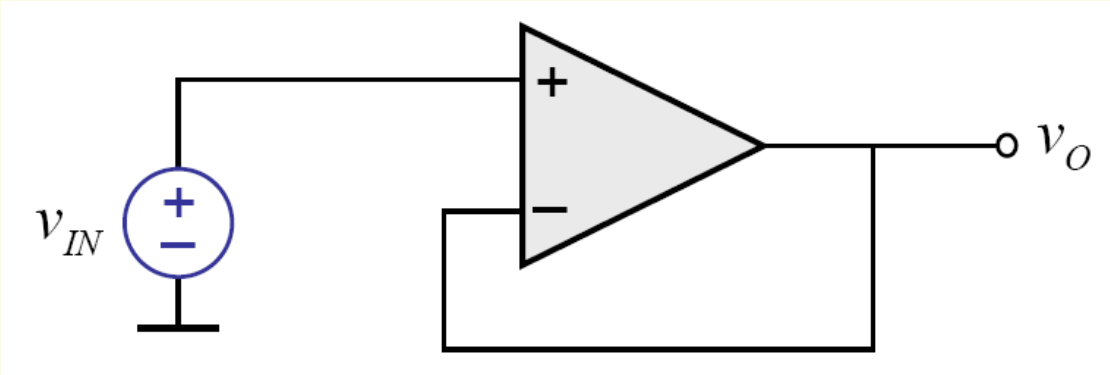
$$\Rightarrow \quad v^+ \approx v^-$$

# Easy Solution



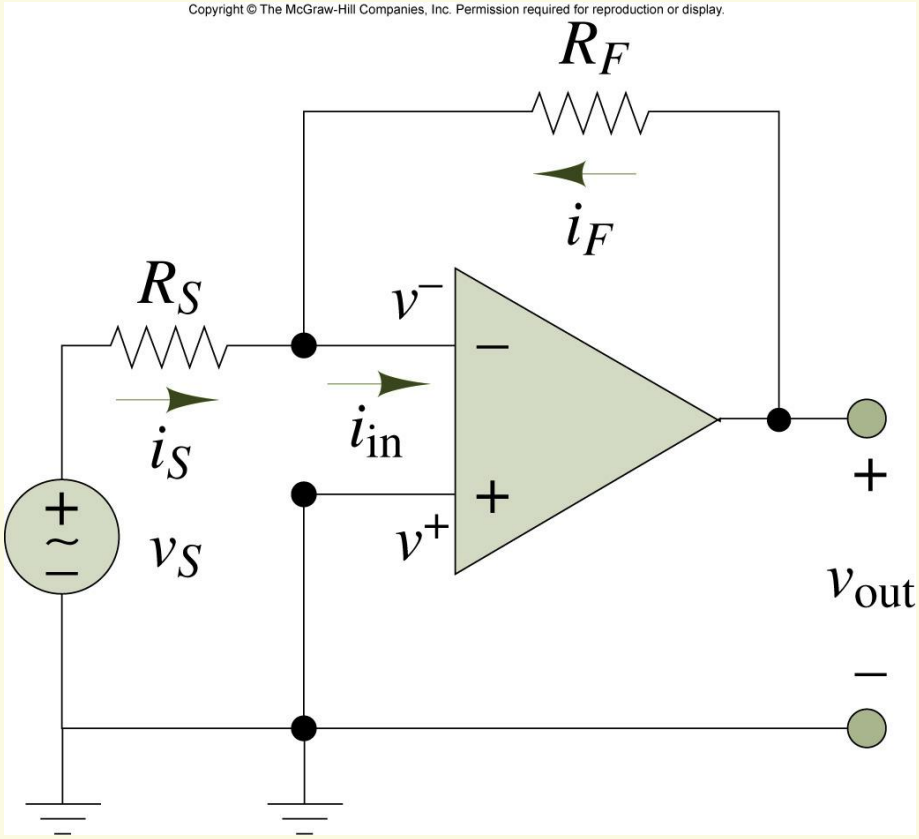

Node equation at the input ports !

# Voltage Follower

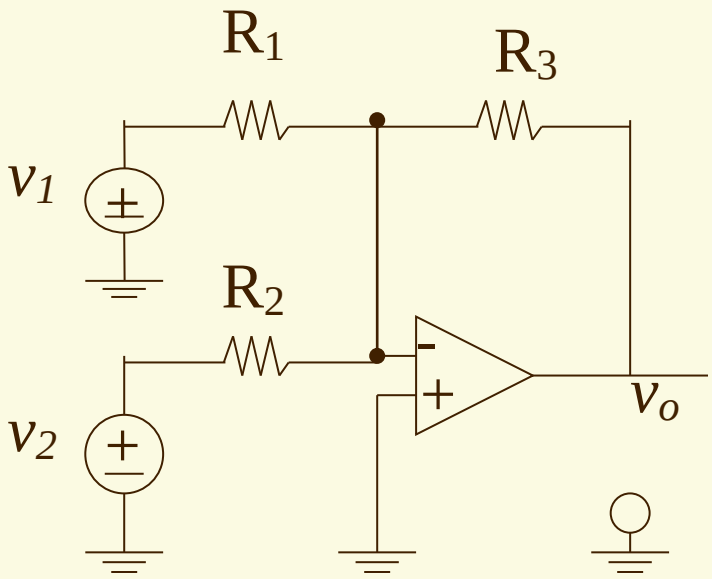



- Voltage gain = 1, current gain = infinite
- Buffer: isolate the input and the output circuits

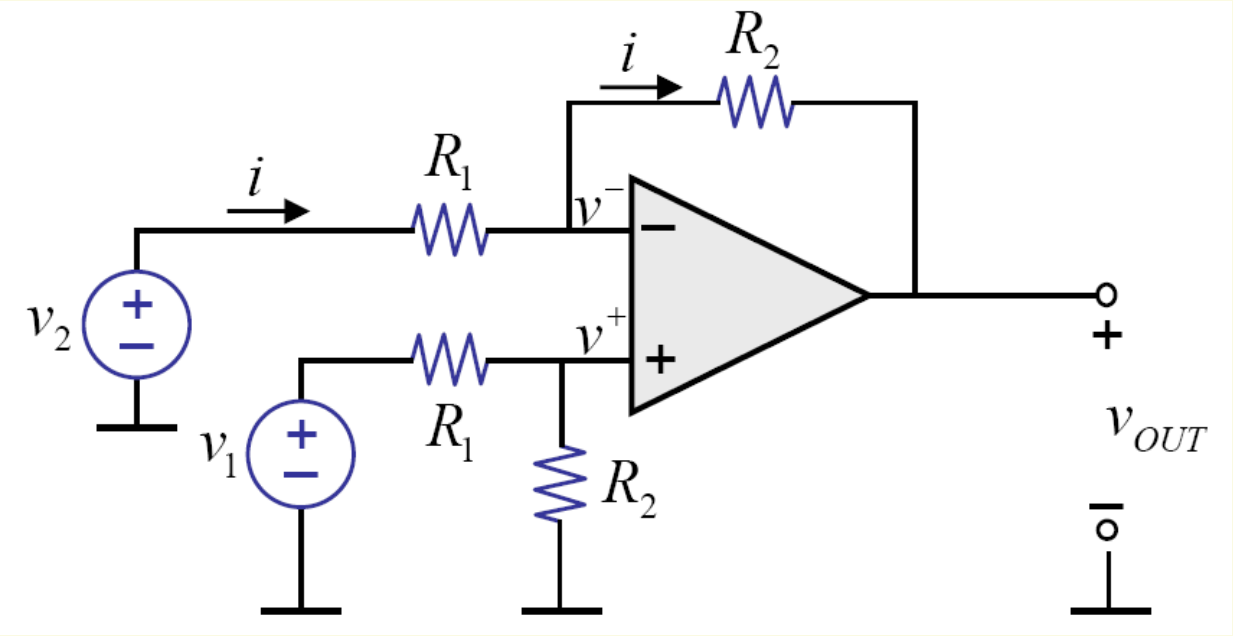
# Inverting OP AMP



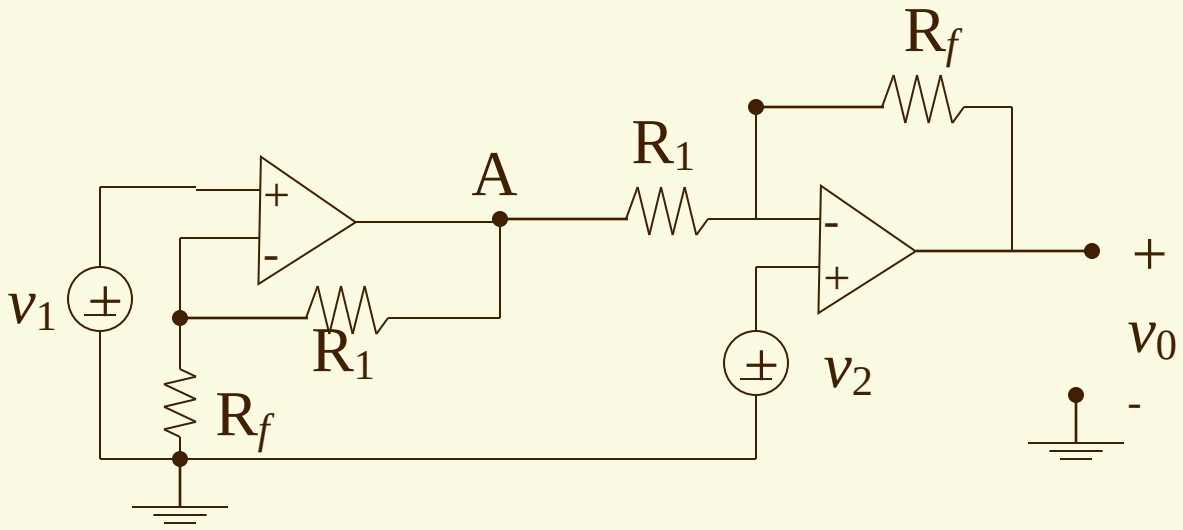
# Adder



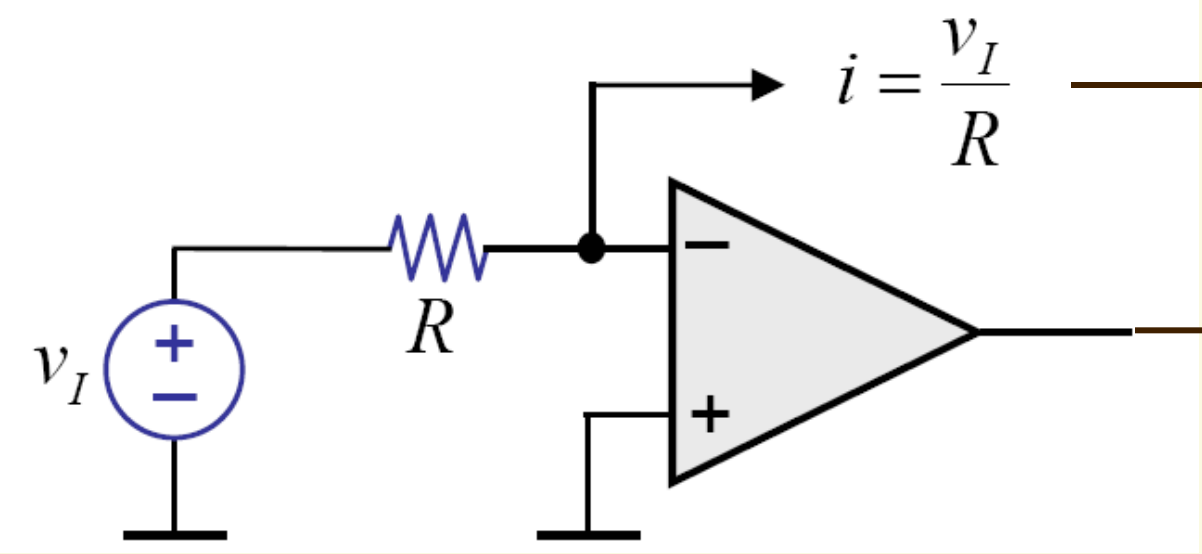
# Subtracter



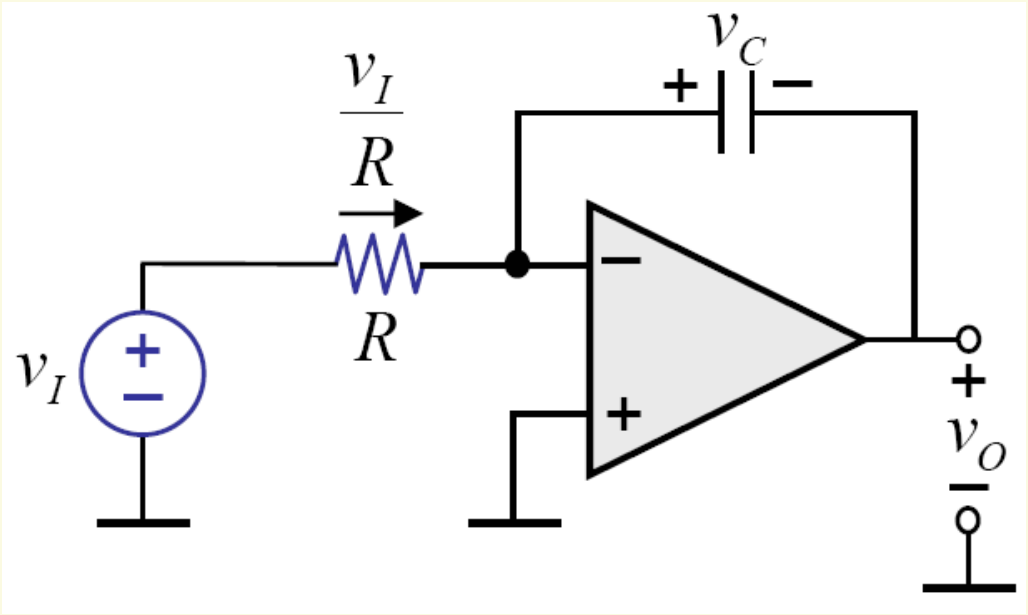
# Exercise



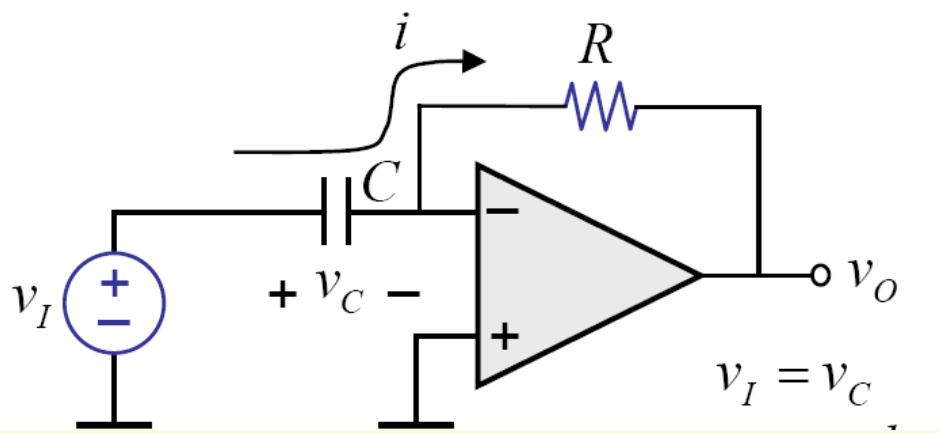
# Current Source from OP AMP



# OP AMP Integrator

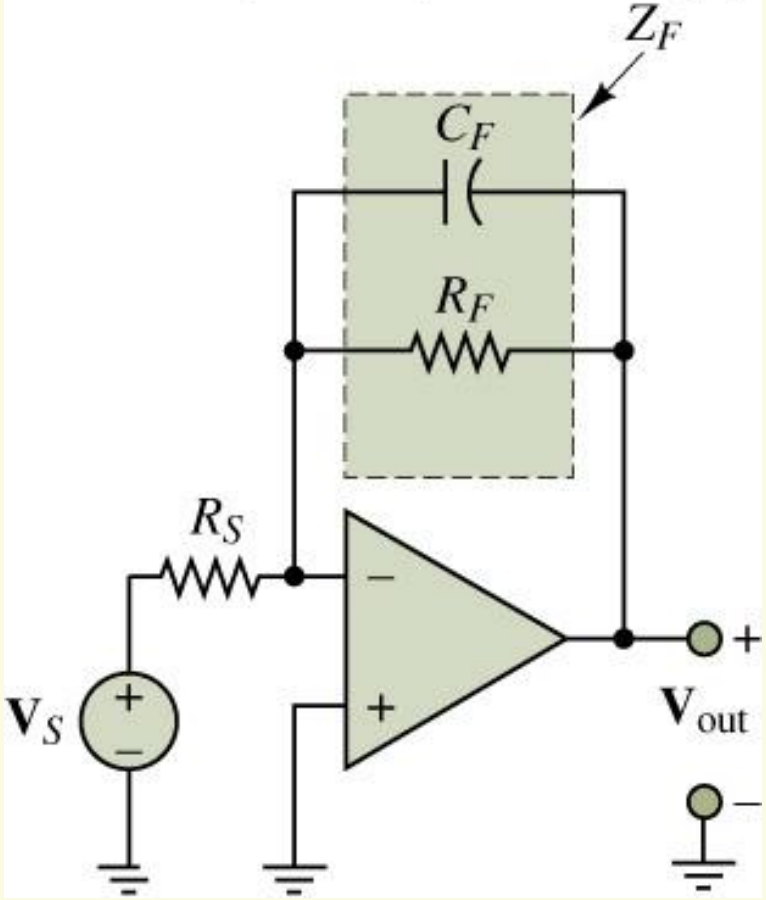


# OP AMP Differentiator

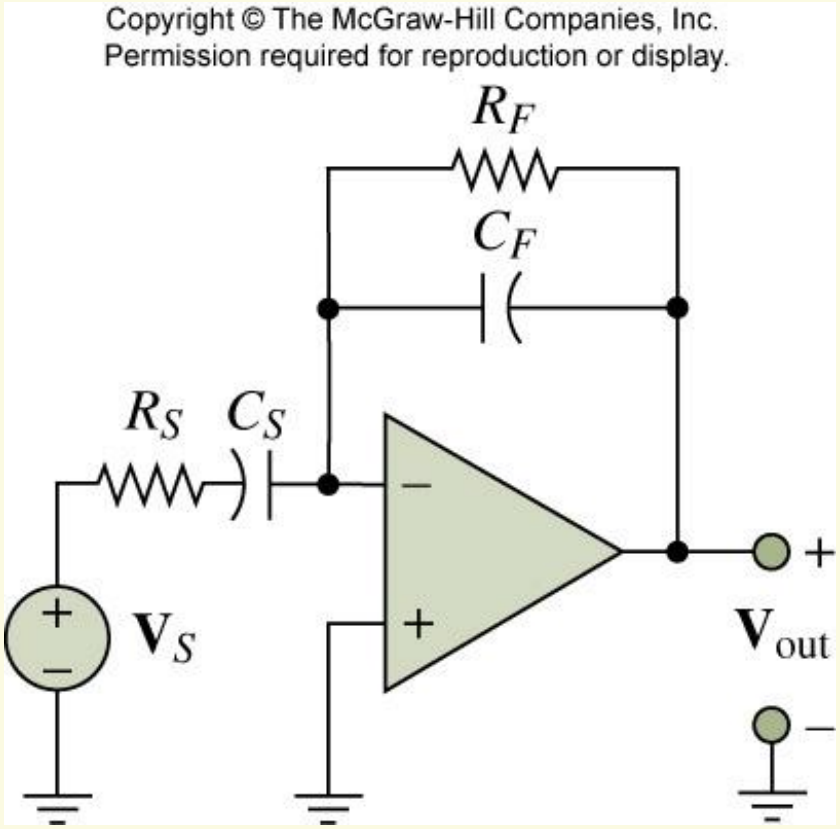


# OP AMP Active Filter





# Exercise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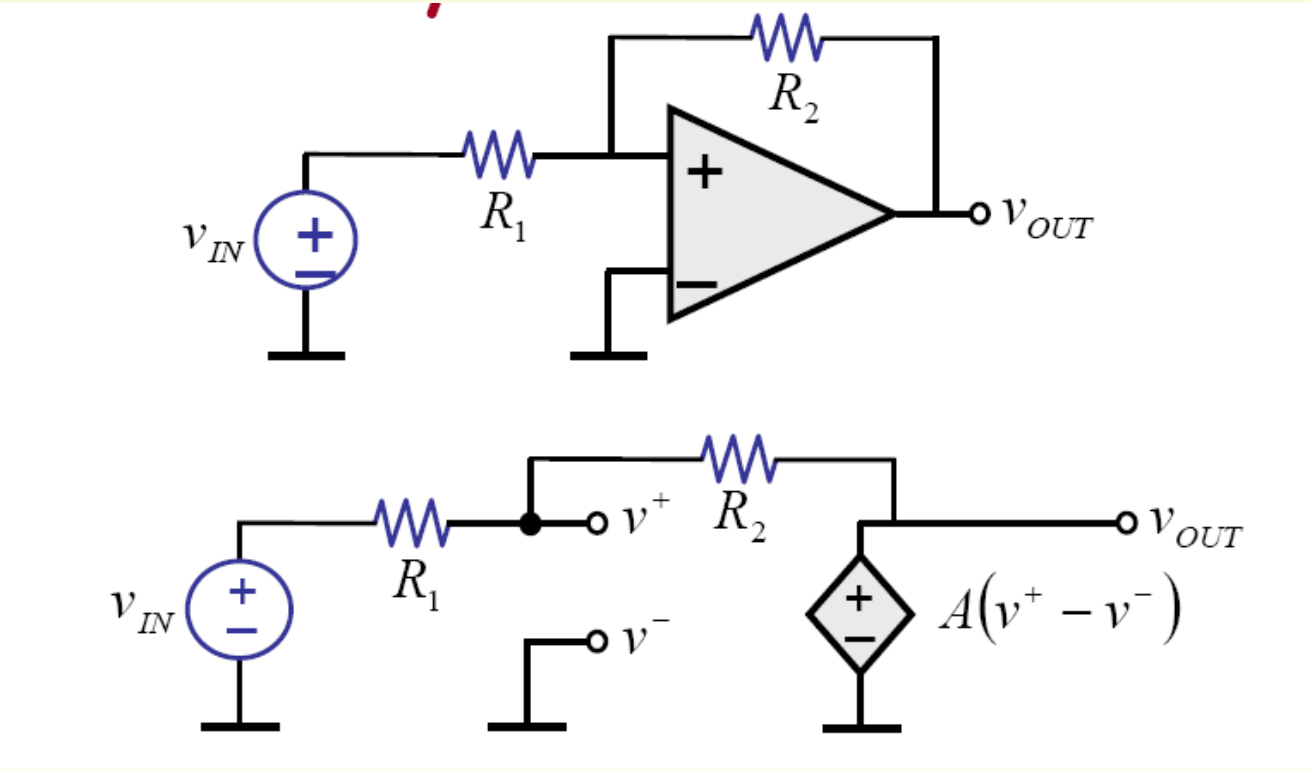
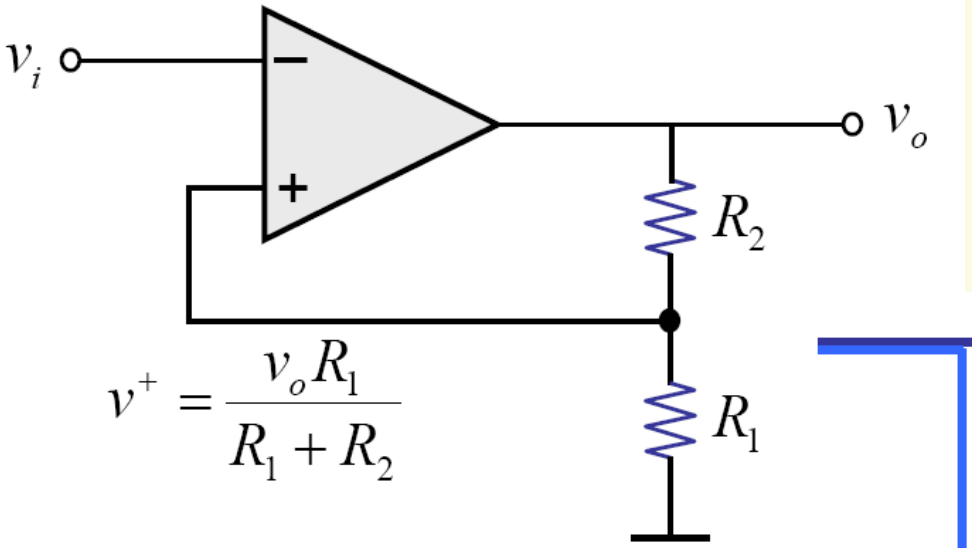
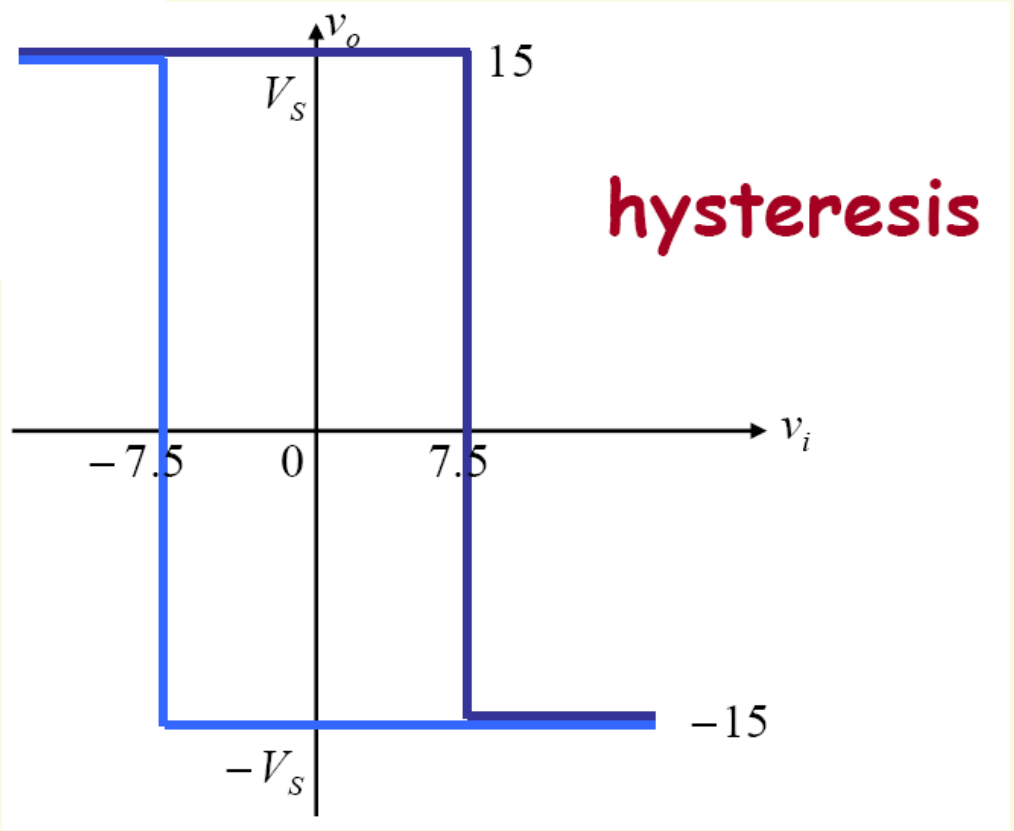
$R_F$
$C_F$
$R_S$
$C_S$
$\mathbf{V}_S$
$\mathbf{V}_{out}$

# Positive Feedback

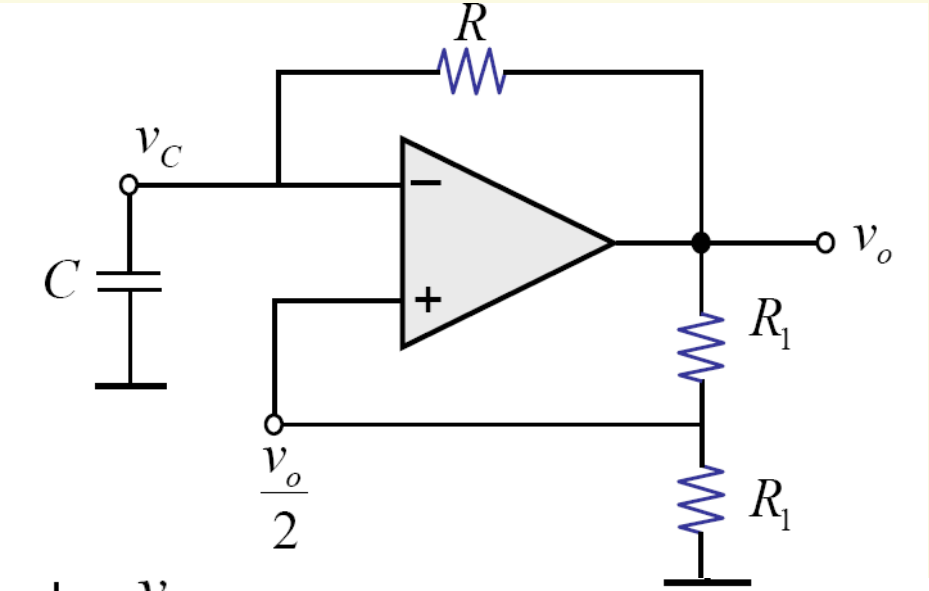


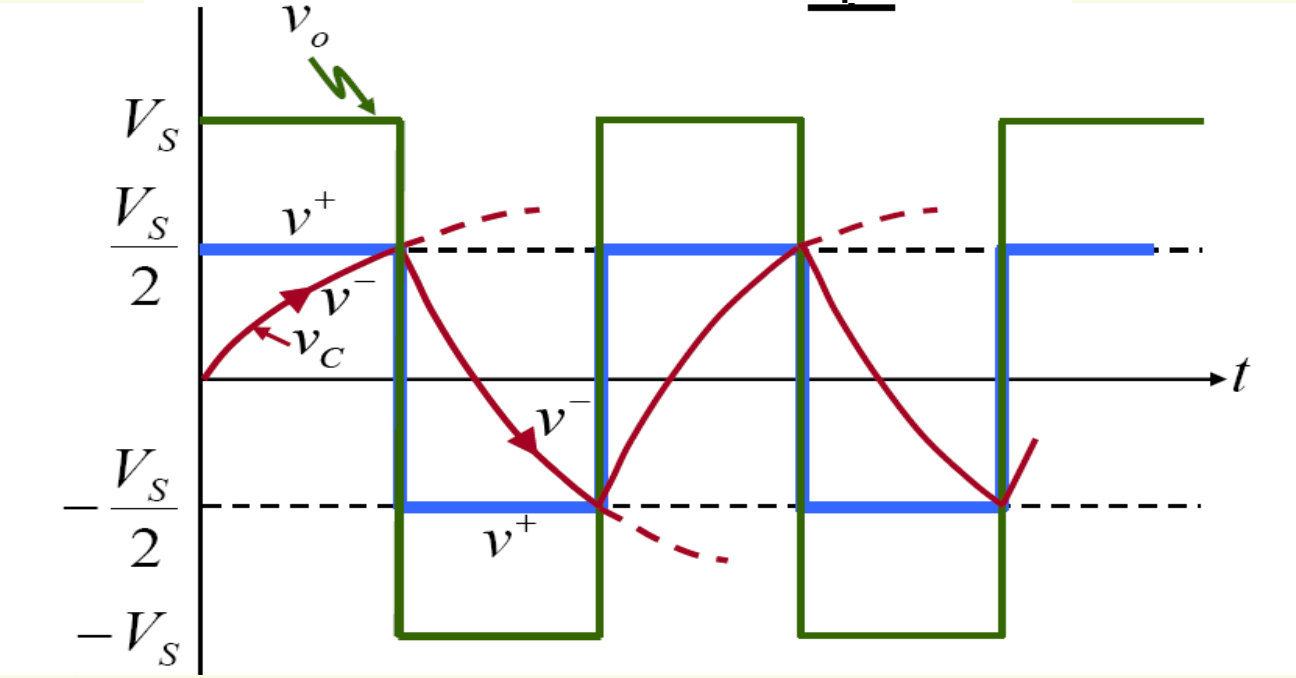
# Voltage Characteristic



# Oscillator



# Summary

- Ideal OP AMP
- Comparator: OP AMP in saturation
- Negative Feedback Circuits
- Active Filters
- Positive Feedback - oscillator

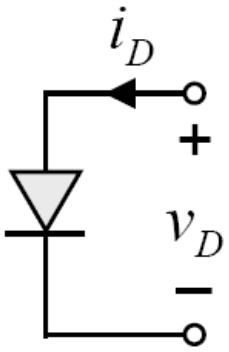
# Chap. 16 Diodes

Diode Characteristics

Peak Detector

Clamping Circuit

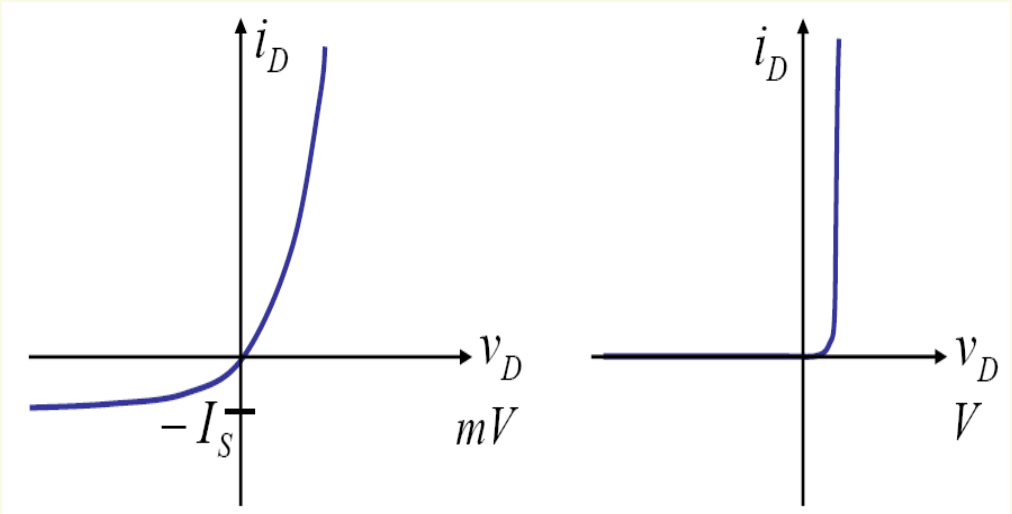
# Reminder: Diode Characteristics

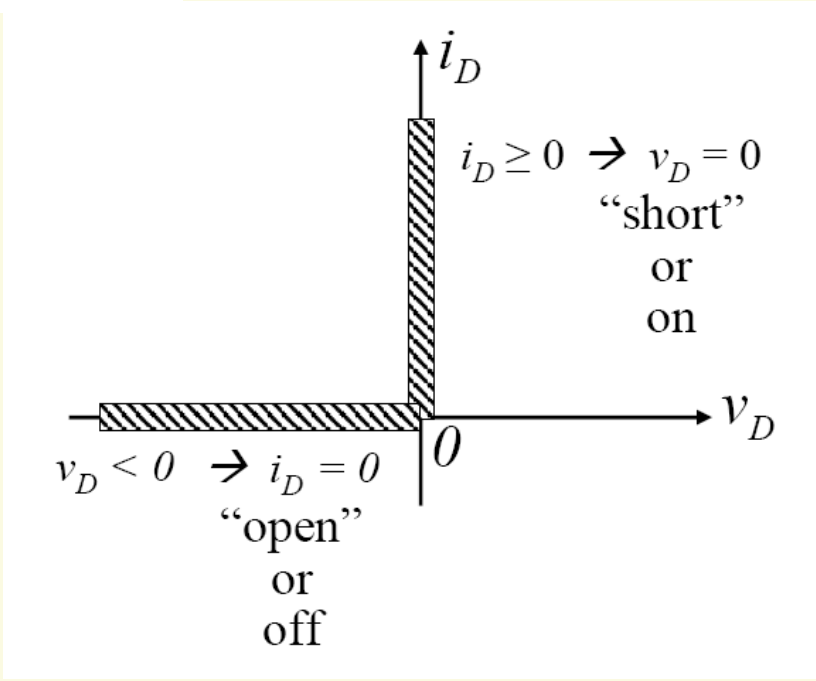



$$i_D = I_S\left(e^{\frac{v_D}{V_T}} - 1\right)$$

$$I_S = 10^{-12}\,A$$

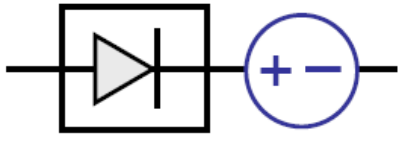
$$V_T = 0.025V$$

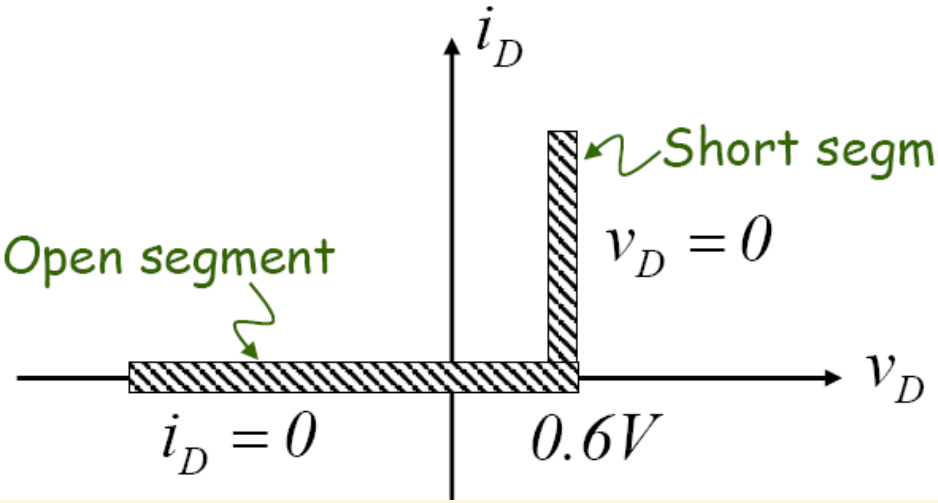


# Ideal Diode and Practical Diode

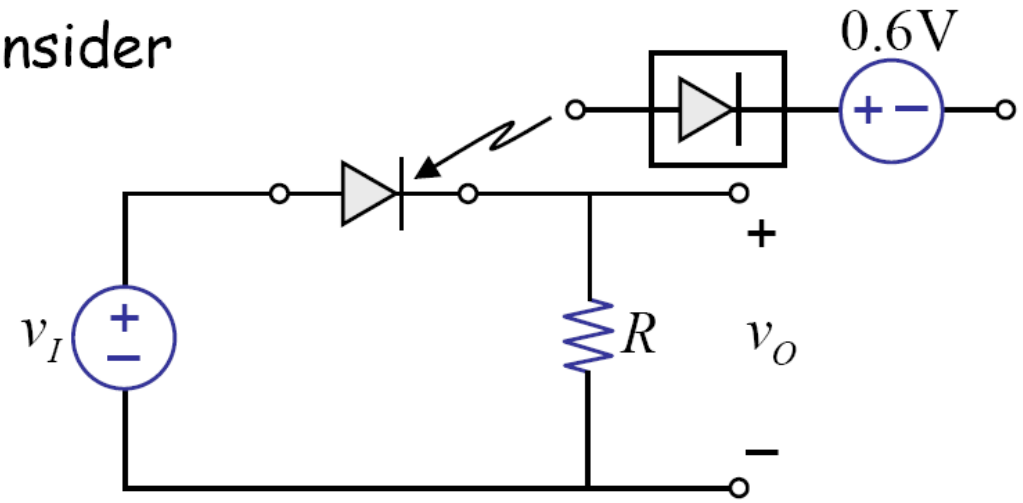
"Practical" diode model
ideal with offset



# Half Wave Rectifier

Consider

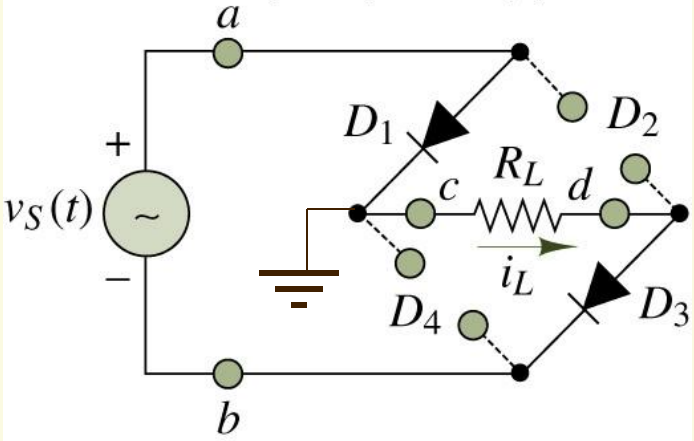



$v_I$ is a sine wave

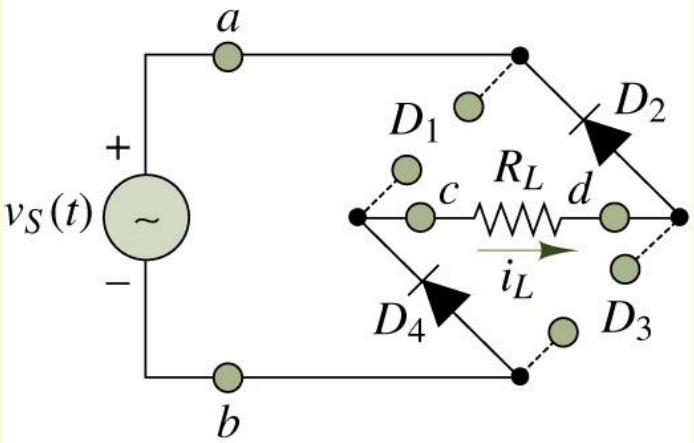
# Bridge Rectifier

- Do not need center-tapped transformer
- Smaller PIV



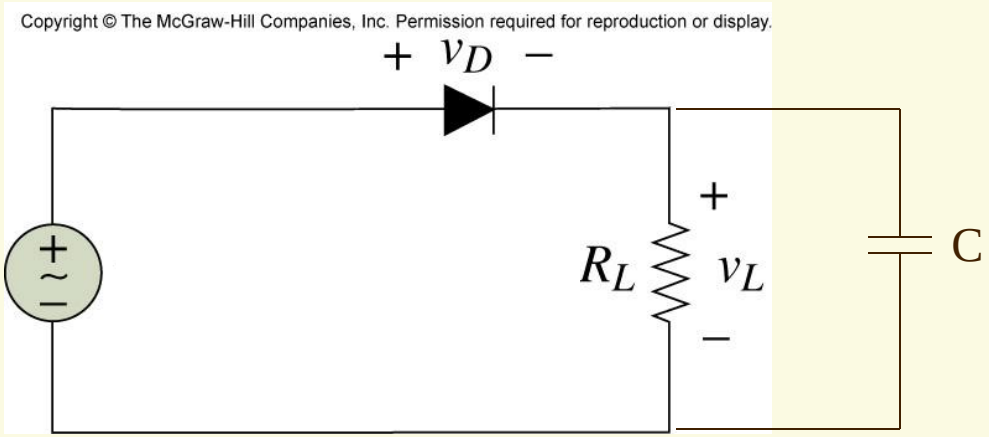



During the positive half-cycle of $v_S(t)$, $D_1$ and $D_3$ are forward-biased and $i_L = v_S(t)/R_L$ (ideal diodes).




During the negative half-cycle of $v_S(t)$, $D_2$ and $D_4$ are forward-biased and $i_L = -v_S(t)/R_L$ (ideal diodes).

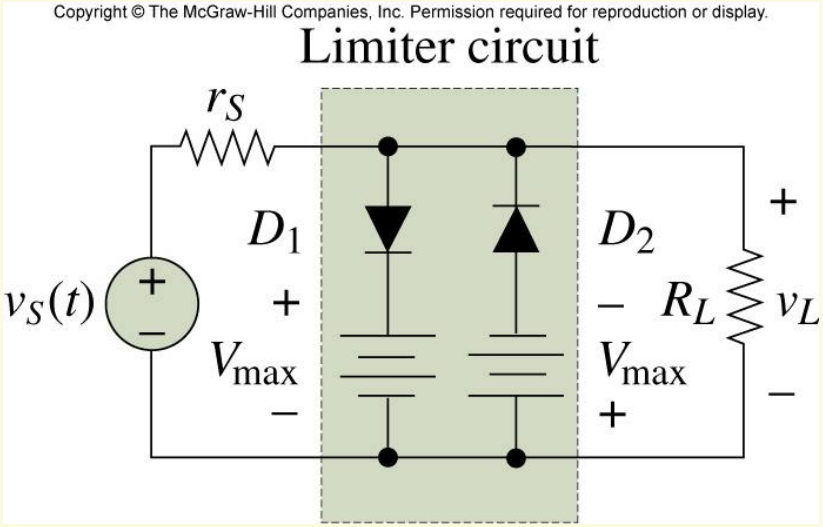
# Peak rectifier



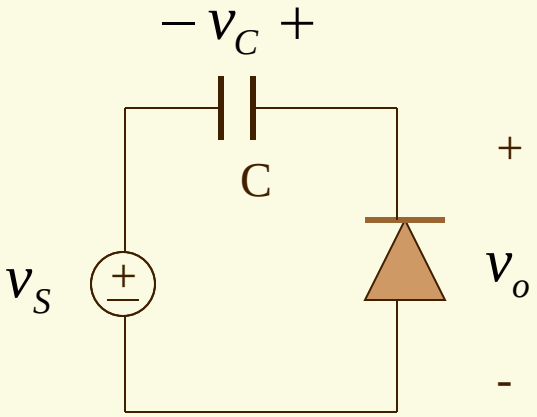

Ripple voltage $V_r = V_p(1 - e^{-\frac{T-\Delta t}{RC}}) \approx V_p \frac{T}{RC}$

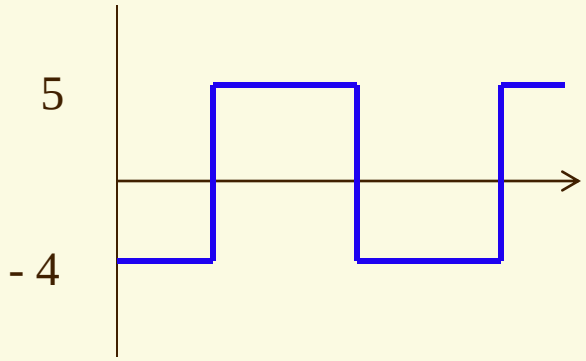
What is the ripple voltage for a Bridge rectifier?

# Exercise: Clipper or Limiter



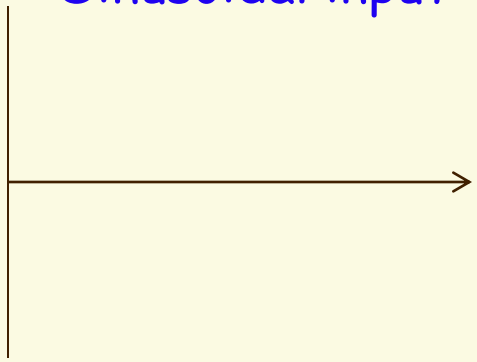
# Diode Claming Circuit



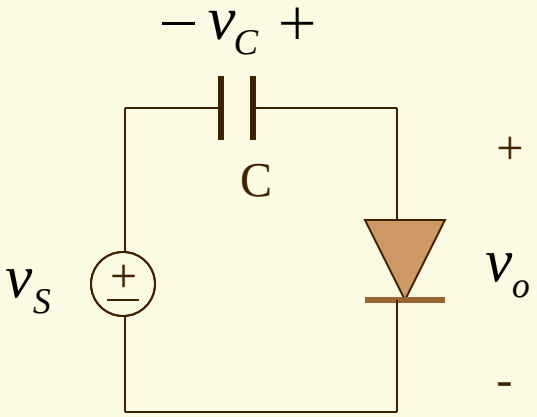



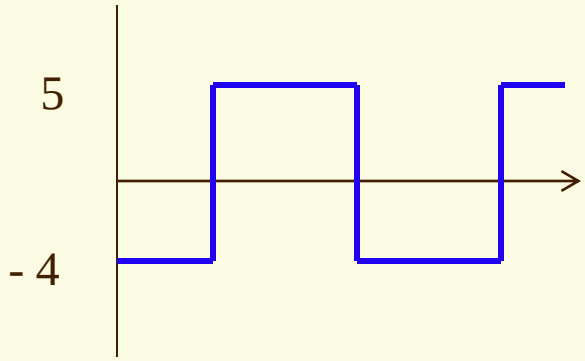

$$v_o = v_C + v_S$$

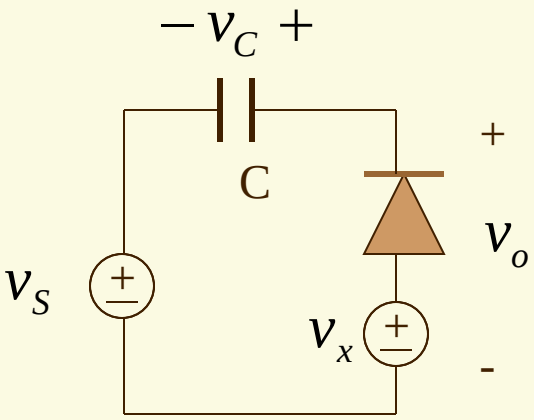
Sinusoidal input



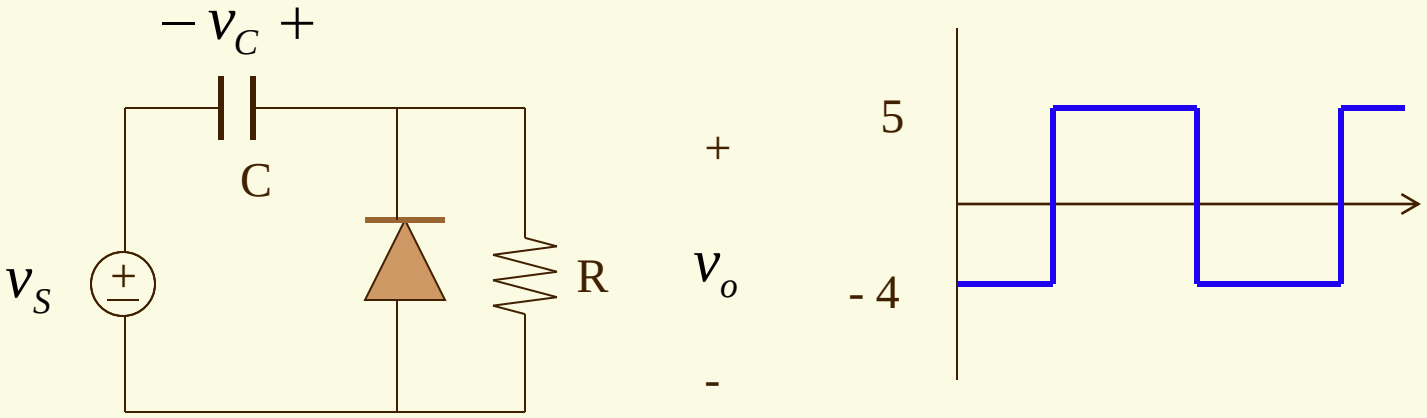
# More Diode Clamping Circuits



# Diode Clamp with Resister



# Summary: Diode Circuits

- Rectifier
- Peak Detector
- Limiter
- Clamping Circuits

# THE END...