

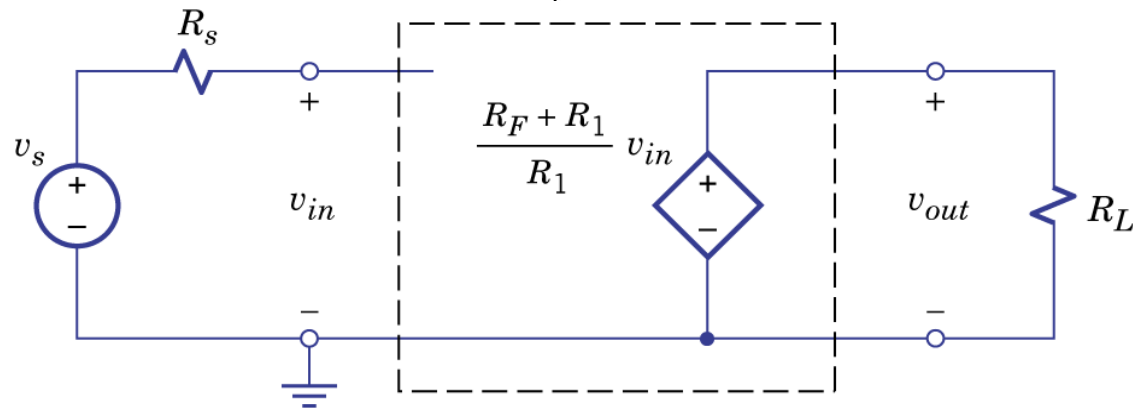
Chapter 3: Applications of Resistive Circuits

Chapter 3: Outline

Ideal Source vs. Real Source



Power Transfer to the Load



Amplifier Model



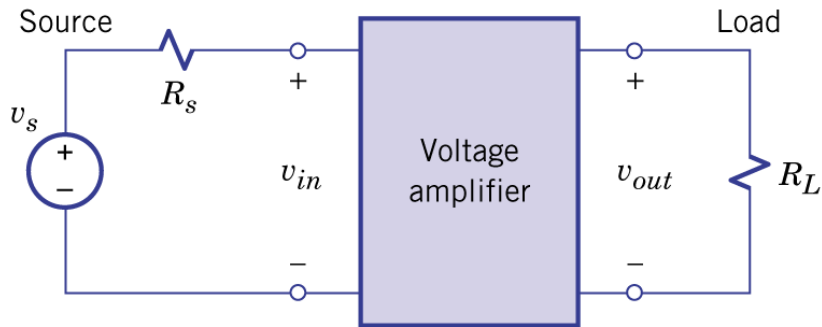
Op-Amps: Characteristics & Applications

Amplifier Models

Types of Amplifiers

- VCVS \rightarrow Voltage amplifier
- CCCS \rightarrow Current amplifier
- (VCCS, CCVS),...

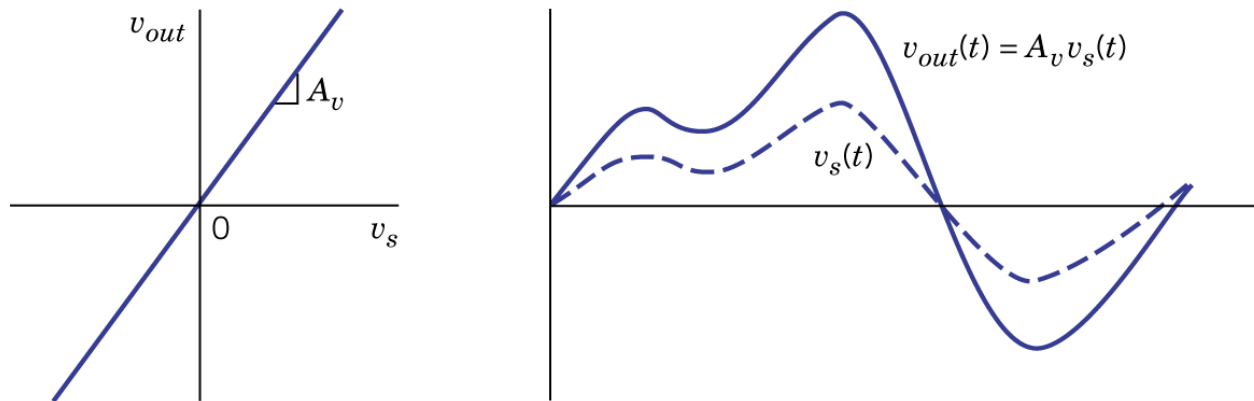
Voltage Amplifier



(a) Voltage amplifier with input source and output load

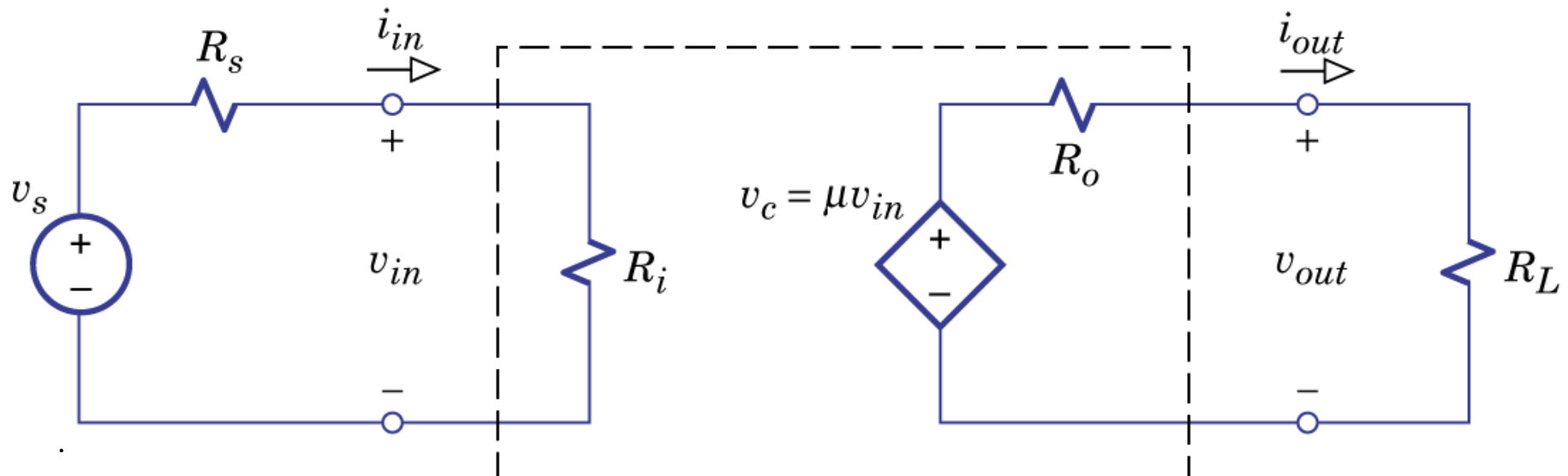
$$v_{out}(t) = A_v v_s(t)$$

A_v : overall voltage amplification



(b) Transfer curve and typical waveforms

Voltage Amplifier

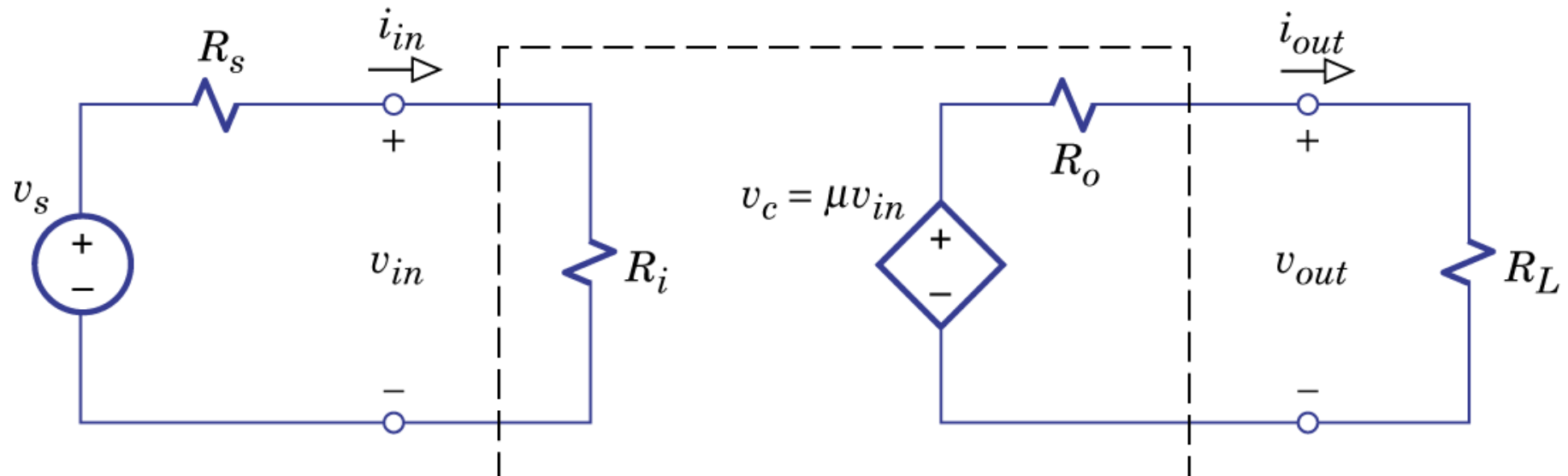


R_i : input resistance $R_i \equiv \frac{v_{in}}{i_{in}}$

$v_c = \mu v_{in}$: open-circuit output voltage

R_o : output resistance

Voltage Amplifier

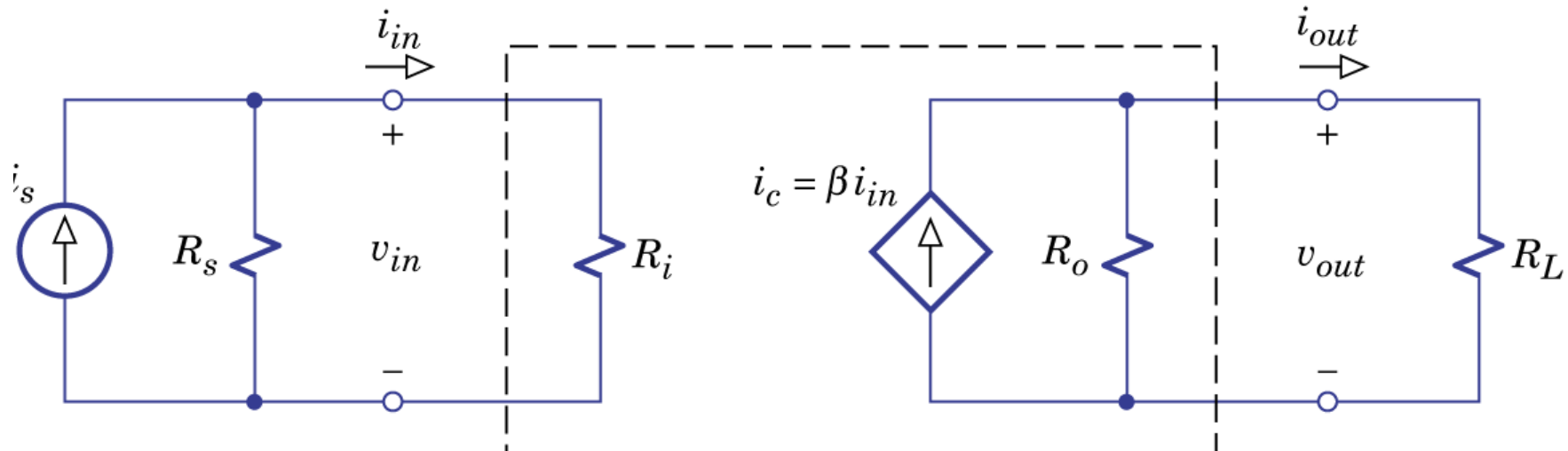


$$\frac{v_{out}}{v_s} = \frac{v_{in}}{v_s} \times \frac{v_c}{v_{in}} \times \frac{v_{out}}{v_c} = \frac{R_i}{R_s + R_i} \times \mathbf{m} \times \frac{R_L}{R_L + R_o}$$

- A good voltage amplifier has $R_i \gg R_s$ $R_o \ll R_L$
so that $A_v \approx \mathbf{m}$

$$i_c = \beta i_{in}$$

Current Amplifier



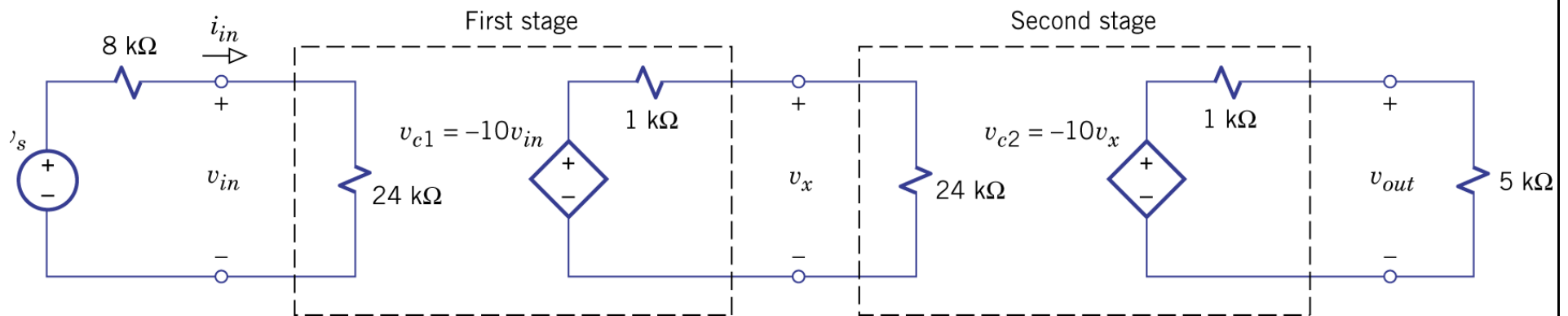
- Current amplifier with short-circuit output current:

$$i_c = \beta i_{in}$$

- A good current amplifier has $R_i \gg R_s$ $R_o \ll R_L$

so that $A_v \approx \mathbf{m}$

Example 3.4: Cascade Voltage Amplifier



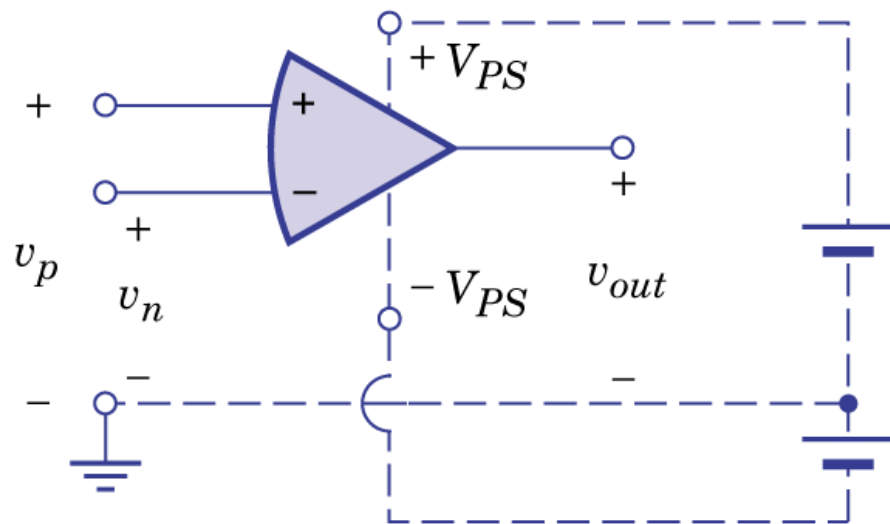
$$A_v = \frac{8}{8 + 24} (-10) \frac{1}{1 + 24} (-10) \frac{5}{1 + 5}$$

Operational Amplifiers (Op-Amps)

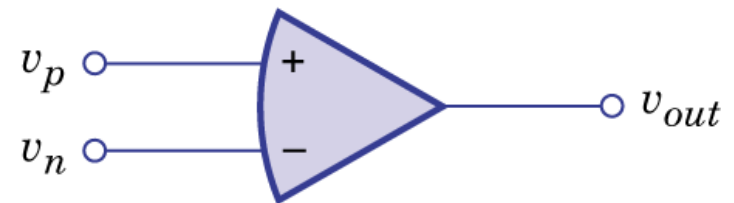
Amplifiers with very nice characteristics

Op-Amps

- Op-amps provide high-gain amplifications of the difference between two input voltages : $v_d = v_p - v_n$



(a) Schematic diagram of an op-amp with two power supplies



(b) Op-amp symbol

Op-Amps

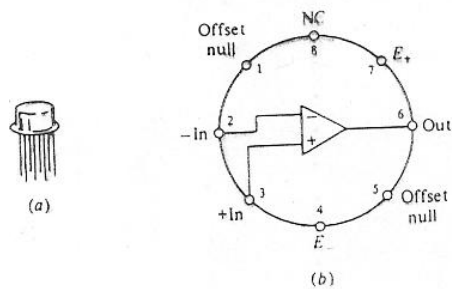


Figure 1.1 Eight-lead minipack view. (a) Side view. (b) Top view.

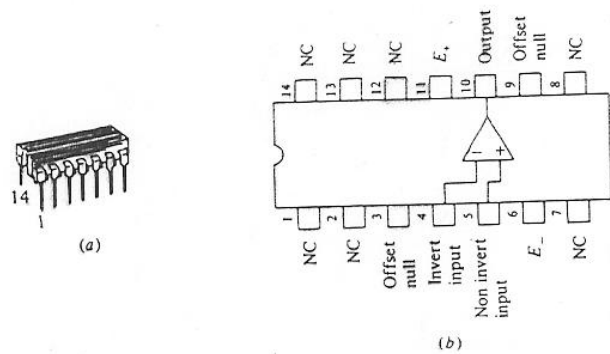


Figure 1.2 A 14-lead DIP (dual in-line package). (a) Side view (b) Top view

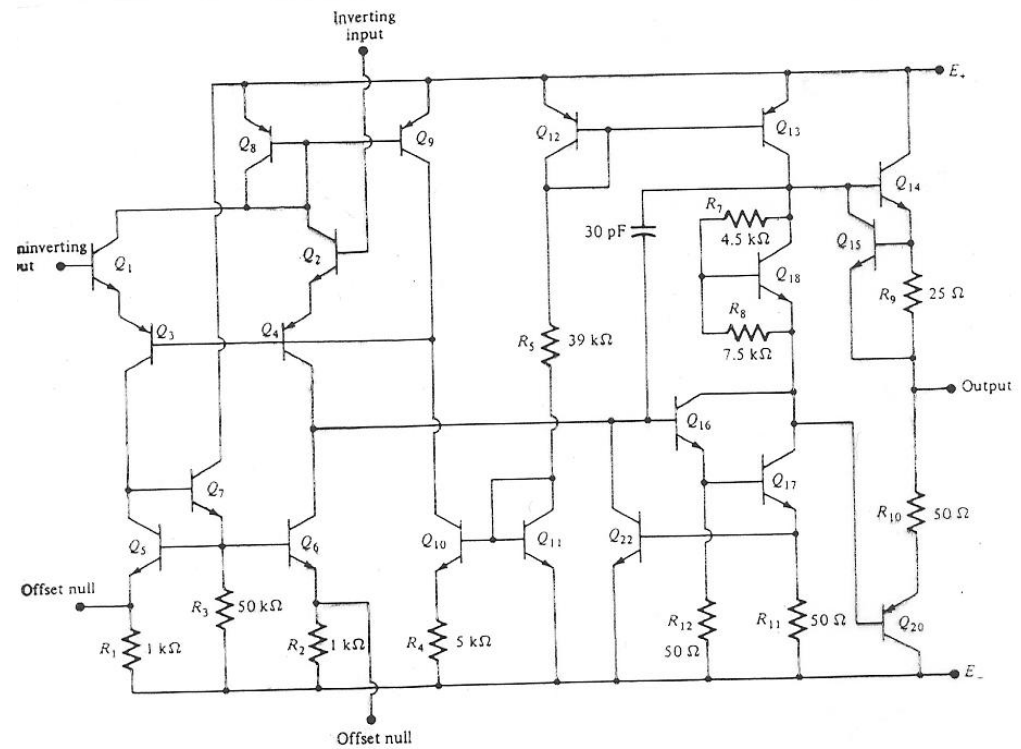
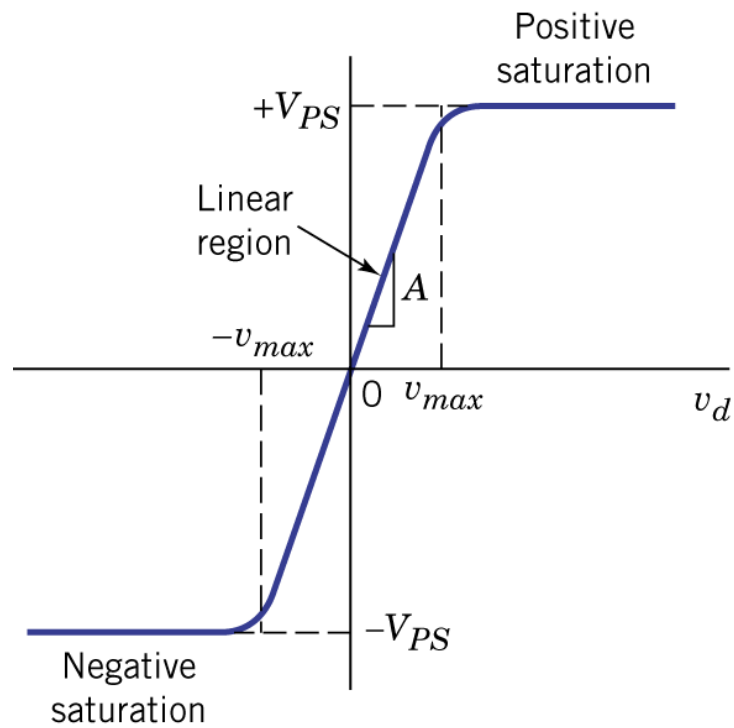
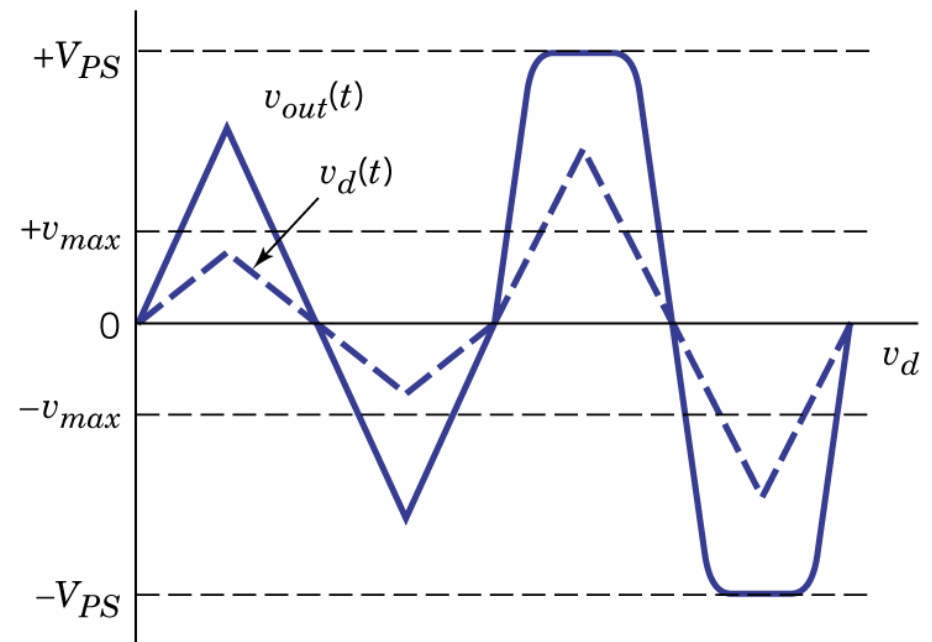


Figure 1.3 Schematic of the $\mu A741$ op amp.

Op-Amps

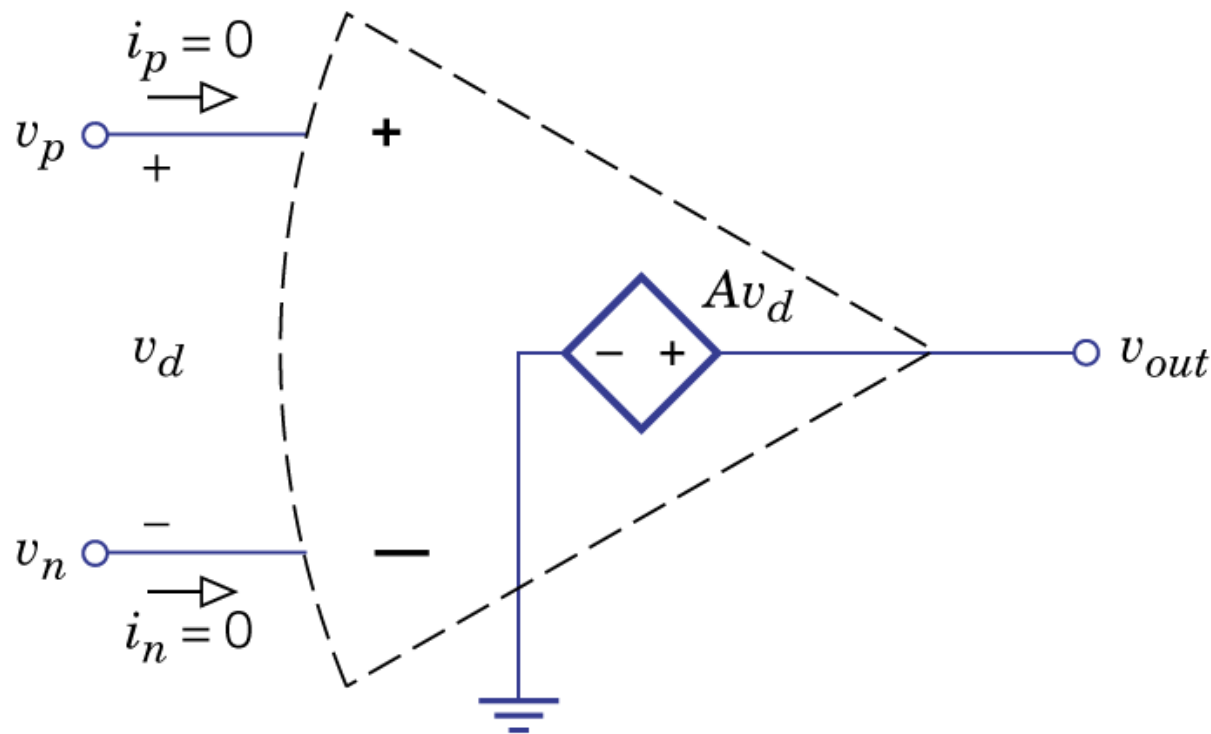


(a) Op-amp transfer curve



(b) Illustrative waveforms

Op-Amps: Linear Region



$$i_p = i_n = 0$$

$$v_{out} = Av_d = A(v_p - v_n)$$

$$\text{when } -v_{\max} < v_d < v_{\max}$$

$$\text{and } -V_{PS} < v_{out} < V_{PS}$$

$$v_{\max} \approx V_{PS} / A$$

$$v_{\max} \approx 0 \text{ for } A \rightarrow \infty$$

Op-Amps: Saturation Region

$$v_{out} \approx V_{PS} \text{ if } v_d > v_{\max}$$

$$v_{out} \approx -V_{PS} \text{ if } v_d < -v_{\max}$$

What is the equivalent circuit of an op-amp in the saturation region?

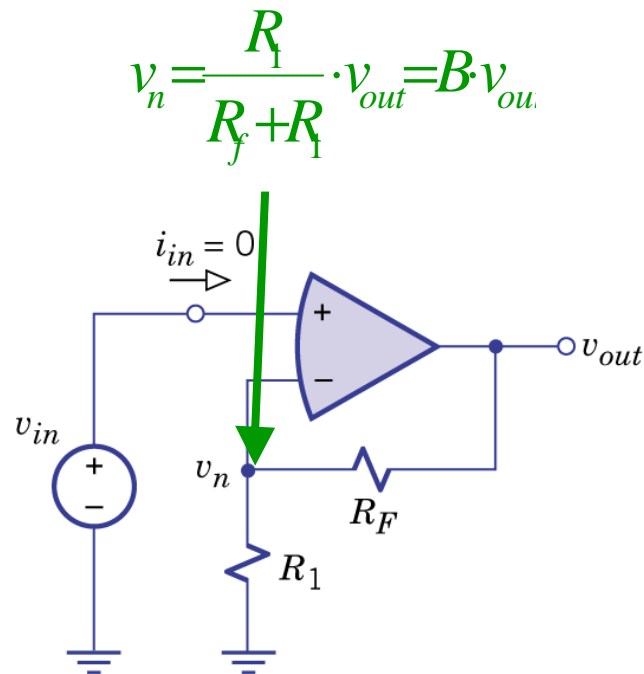
Op-Amps: Feedback Connection

- A stable op-amp requires negative feedback connection.

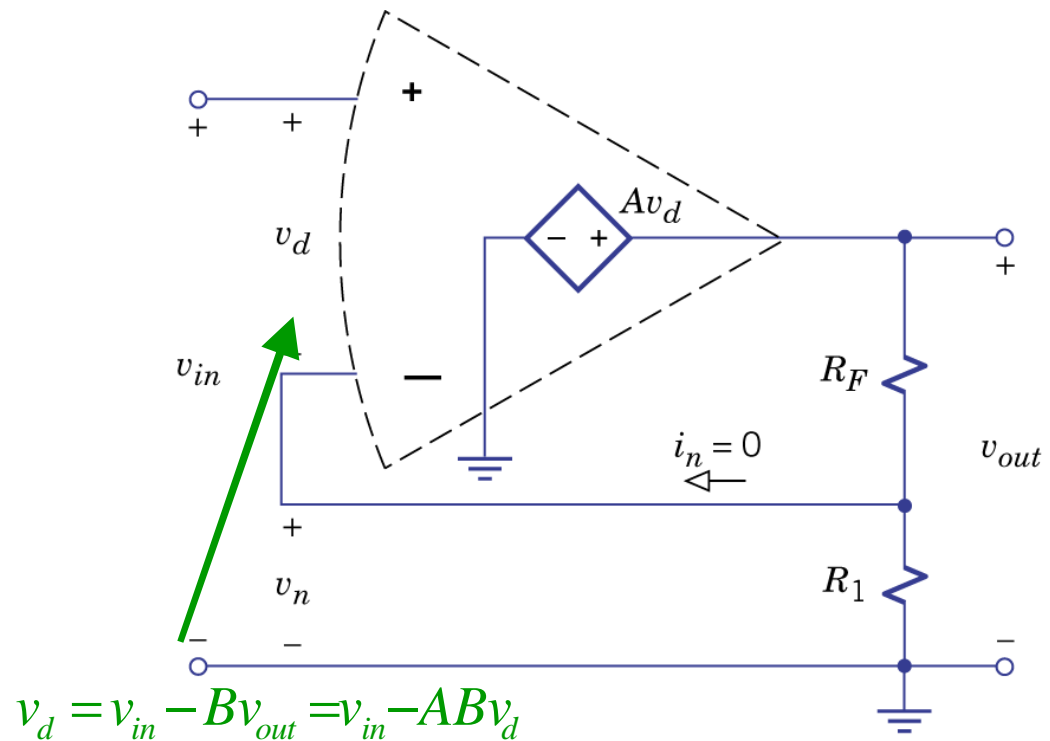
Various Op-Amp Circuits

- Non-inverting voltage amplifier
- Voltage follower (buffer)
- Inverting voltage amplifier
- Inverting summing amplifier
- Difference amplifier
- many more...

Non-inverting Voltage Amplifier



(a) Diagram of a noninverting voltage amplifier

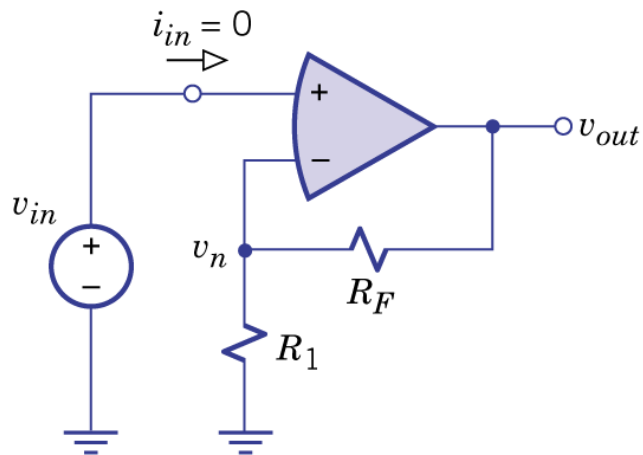


(b) Simplified circuit model

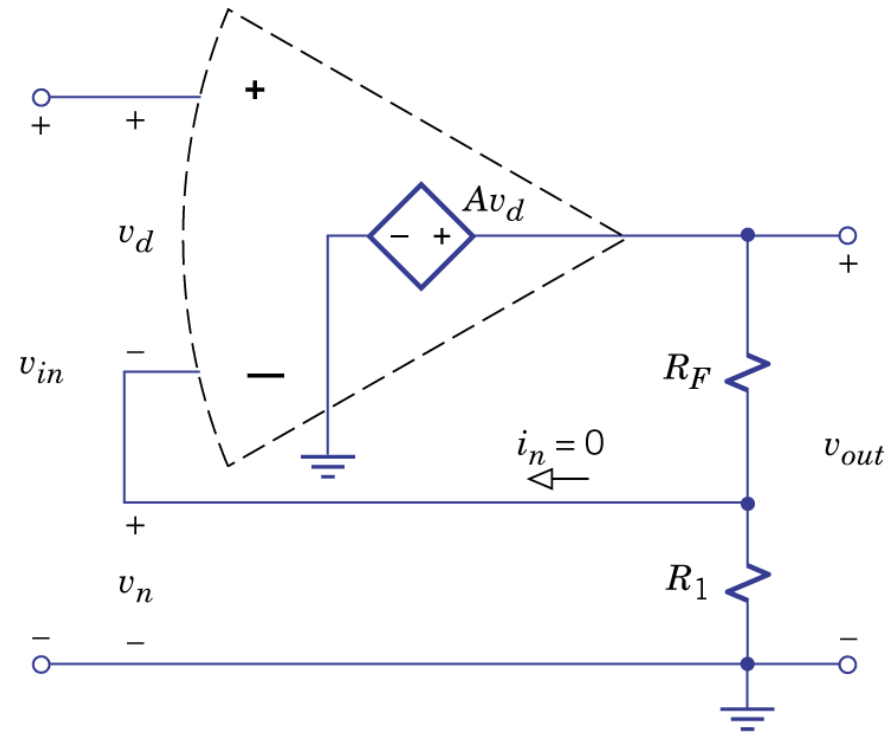
$$v_d = \frac{1}{1 + AB} v_{in} \qquad v_{out} = \frac{A}{1 + AB} v_{in}$$

Feedback factor B , loop gain AB , closed-loop gain $A/(1+AB)$.

Non-inverting Voltage Amplifier



(a) Diagram of a noninverting voltage amplifier

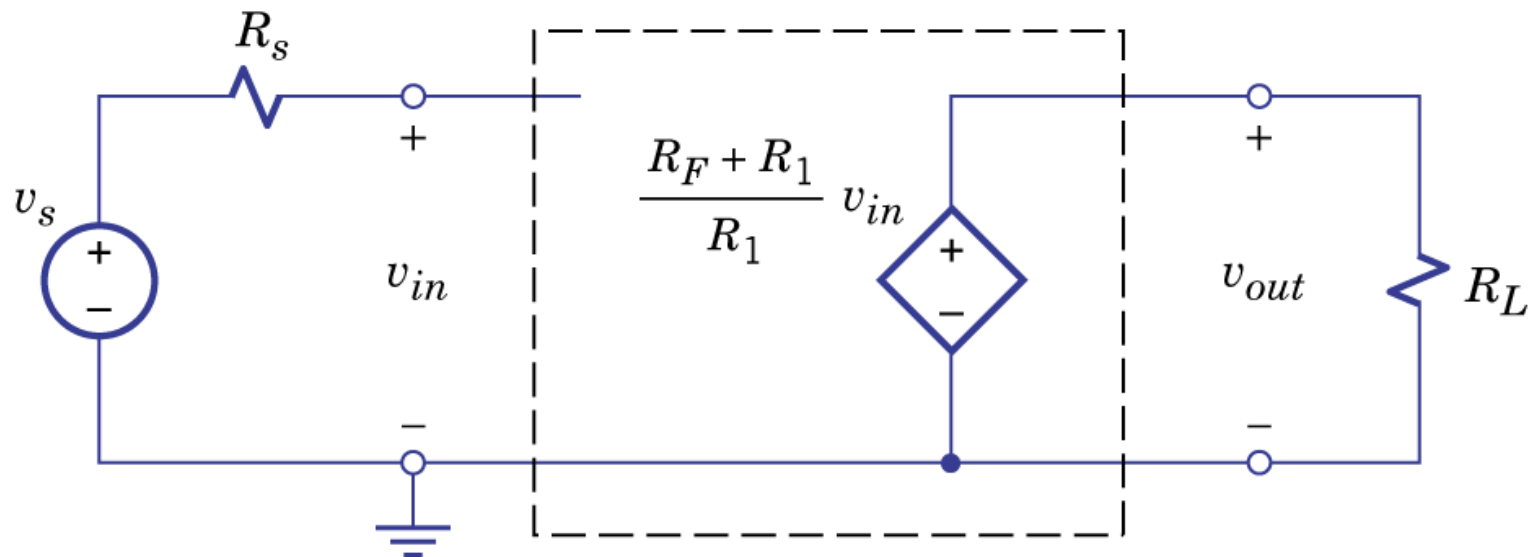


(b) Simplified circuit model

$$AB \gg 1, \quad v_{out} \approx \frac{1}{B} v_{in}, \quad |v_d| \ll |v_{in}|$$

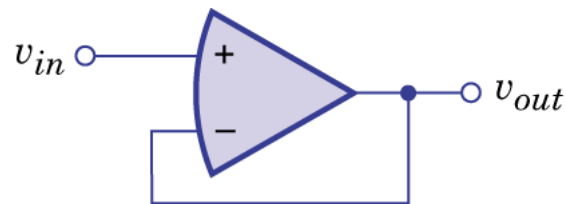
Non-inverting Voltage Amplifier

With a load and a real source

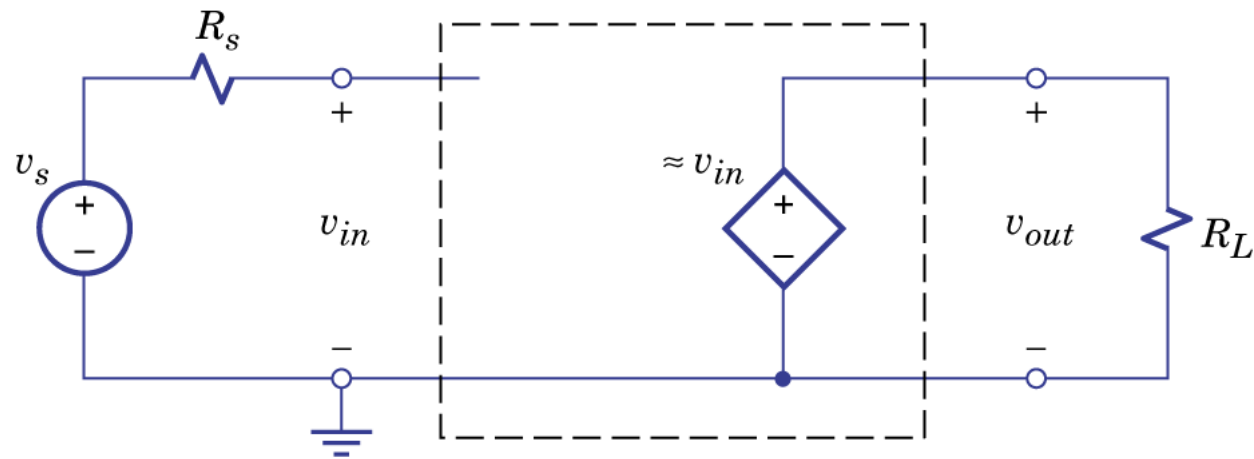


$$\frac{v_{out}}{v_s} = A_v = \frac{R_F + R_1}{R_1} = \frac{1}{B} \quad \rightarrow \text{No loading effects}$$

Voltage Follower (Buffer)



(a) Voltage follower

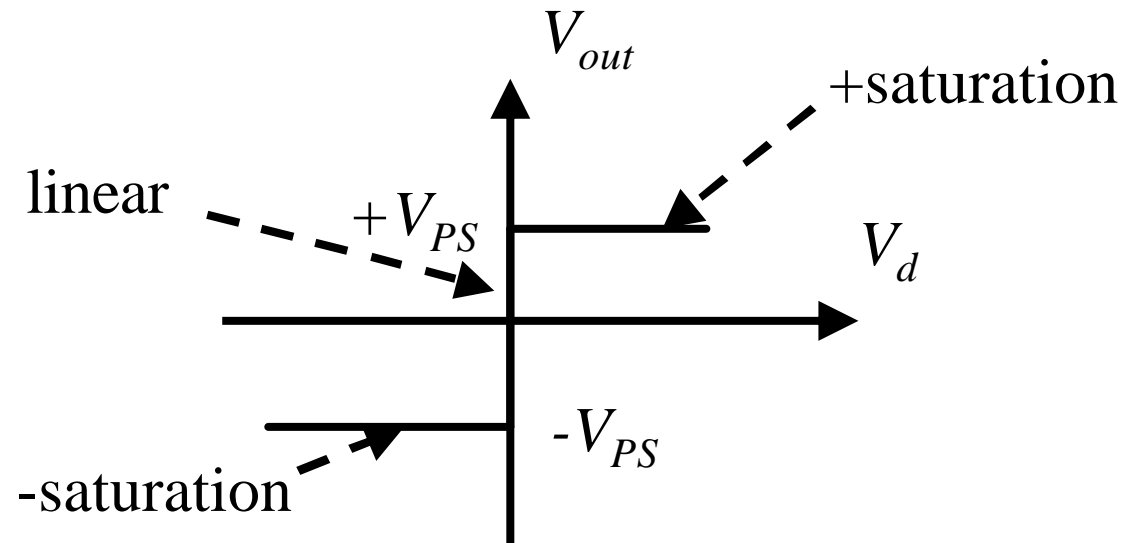
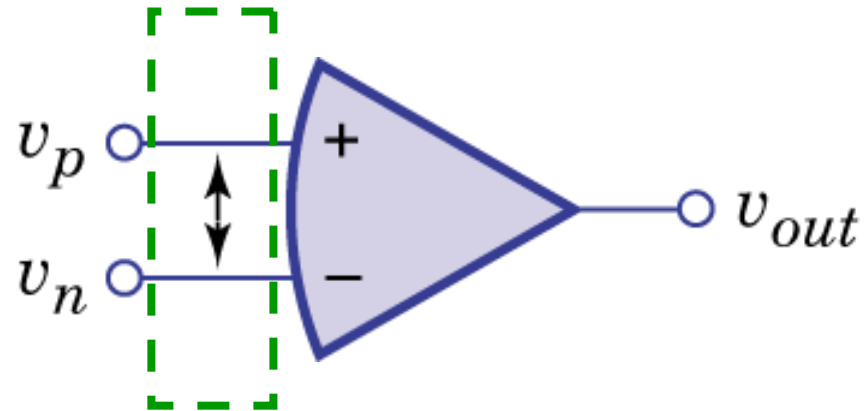


(b) Buffer between source and load

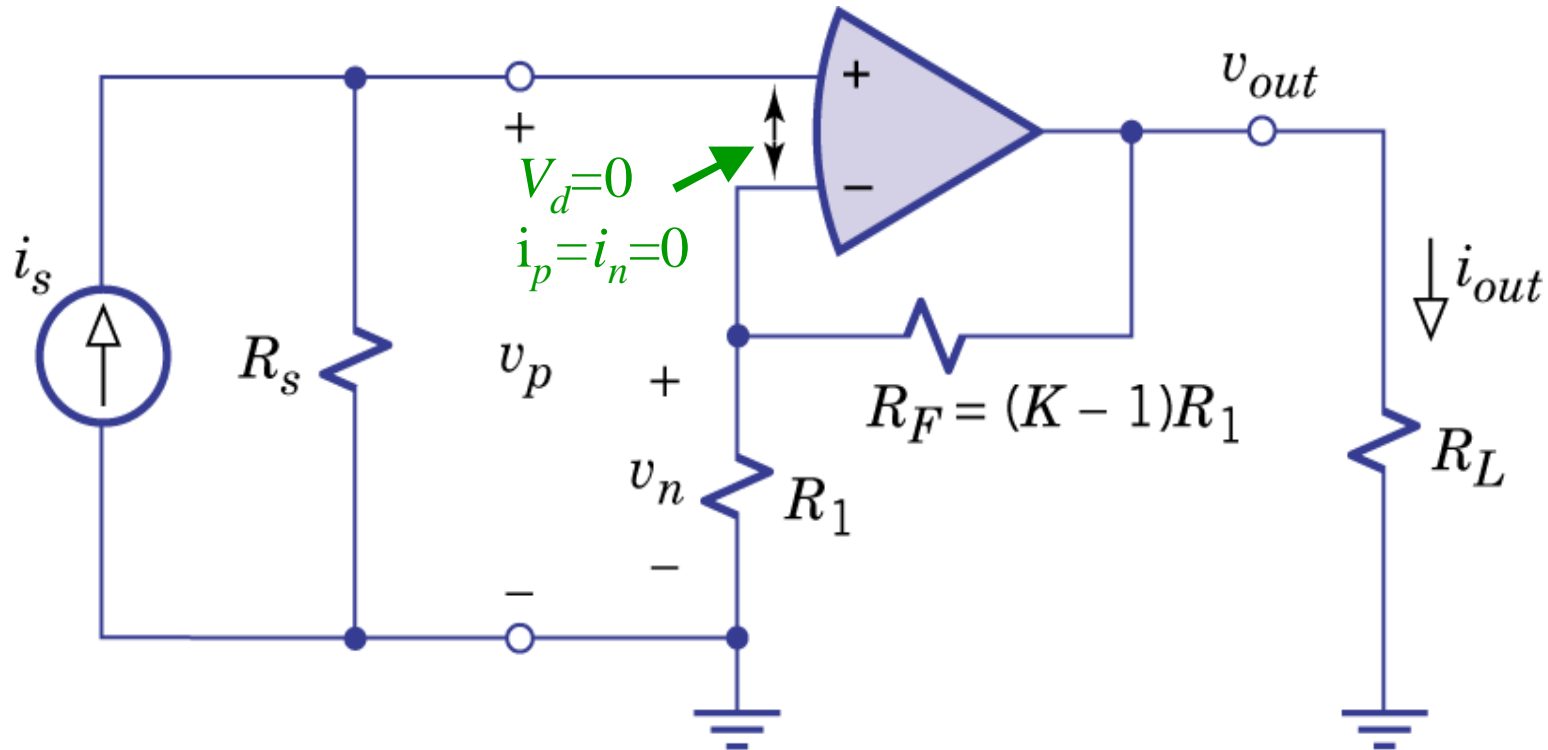
No loading effects, Input resistance $\rightarrow \infty$, Output resistance = 0

Ideal Op-Amps

- $A \rightarrow \infty$ (infinite gain)
- $V_d = 0$ (virtual short)
- $i_p = i_n = 0$ (no input current)
- Still in the linear region

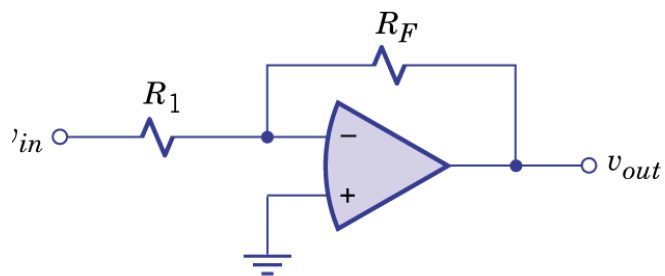


Example 3.6: A Non-inverting Current Amplifier

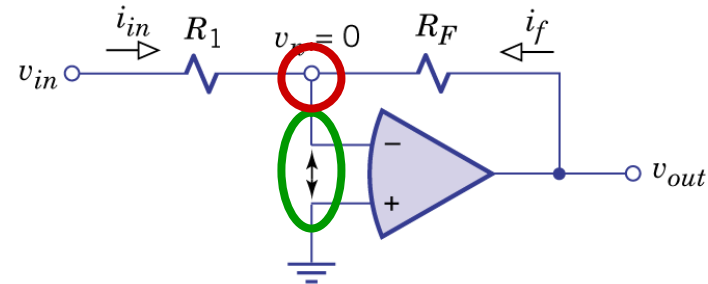


$$v_p = v_n = i_s R_s, \quad v_{out} = \frac{R_1 + R_F}{R_1} v_n = k v_n, \quad i_{out} = \frac{v_{out}}{R_L} = \frac{k R_s}{R_L} i_s$$

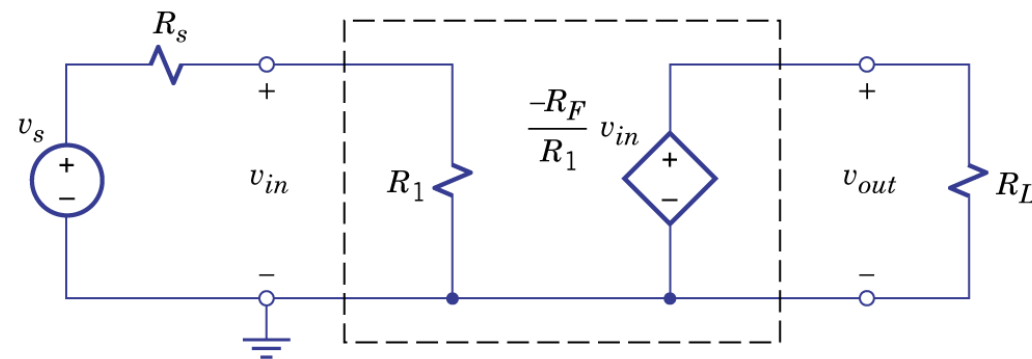
Inverting Voltage Amplifier



(a) Diagram of an inverting voltage amplifier



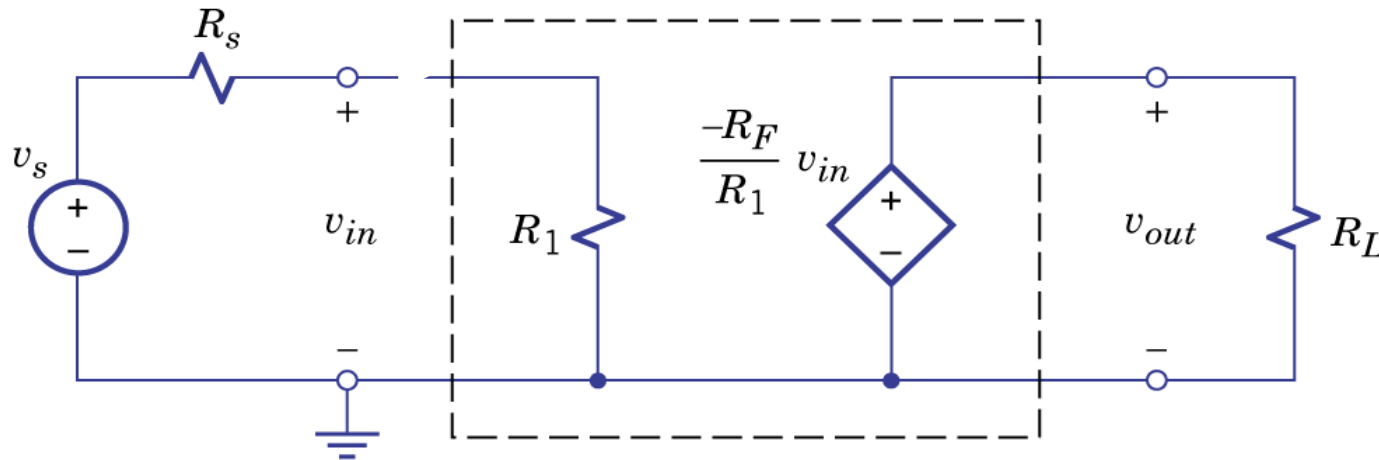
(b) Analysis using the virtual short



(c) Equivalent circuit

$$v_{out} = i_F R_F = -i_{in} R_F = -v_{in} \frac{R_F}{R_1} \quad R_F = R_1 \Rightarrow \text{unity gain inverter}$$

Inverting Voltage Amplifier



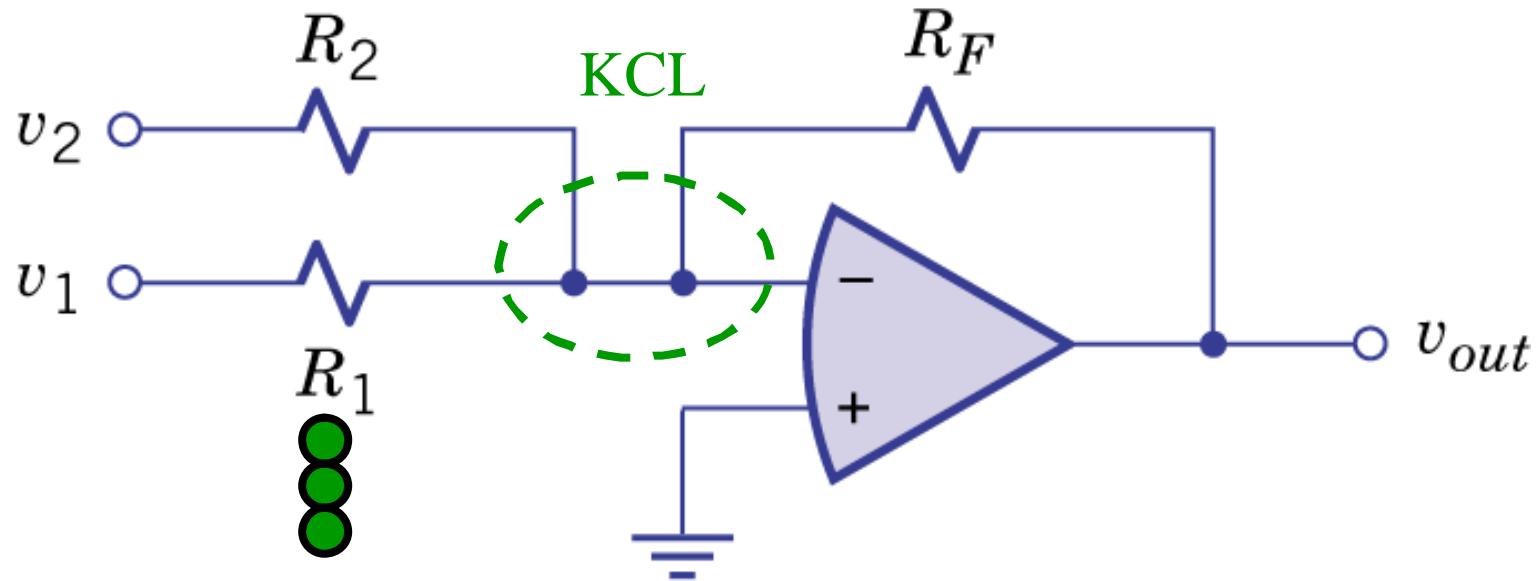
With source internal resistance R_{ss}

$$v_{in} = v_s \frac{R_1}{R_1 + R_s}, \quad A_v = \frac{v_{out}}{v_s} = -\frac{R_F}{R_s + R_1}$$

To minimize loading effects, $R_1 \gg R_s$, or add a voltage follower

- *Non-inverting voltage amplifier: loading effects*
- *Inverting voltage amplifier: loading effects*

Inverting Summing Amplifier



$$\frac{v_2}{R_2} + \frac{v_1}{R_1} = -\frac{v_{out}}{R_F}$$

$$v_{out} = -\left(\frac{R_F}{R_1}v_1 + \frac{R_F}{R_2}v_2\right) = -\frac{R_F}{R_1}(v_1 + v_2) \text{ if } R_1 = R_2$$

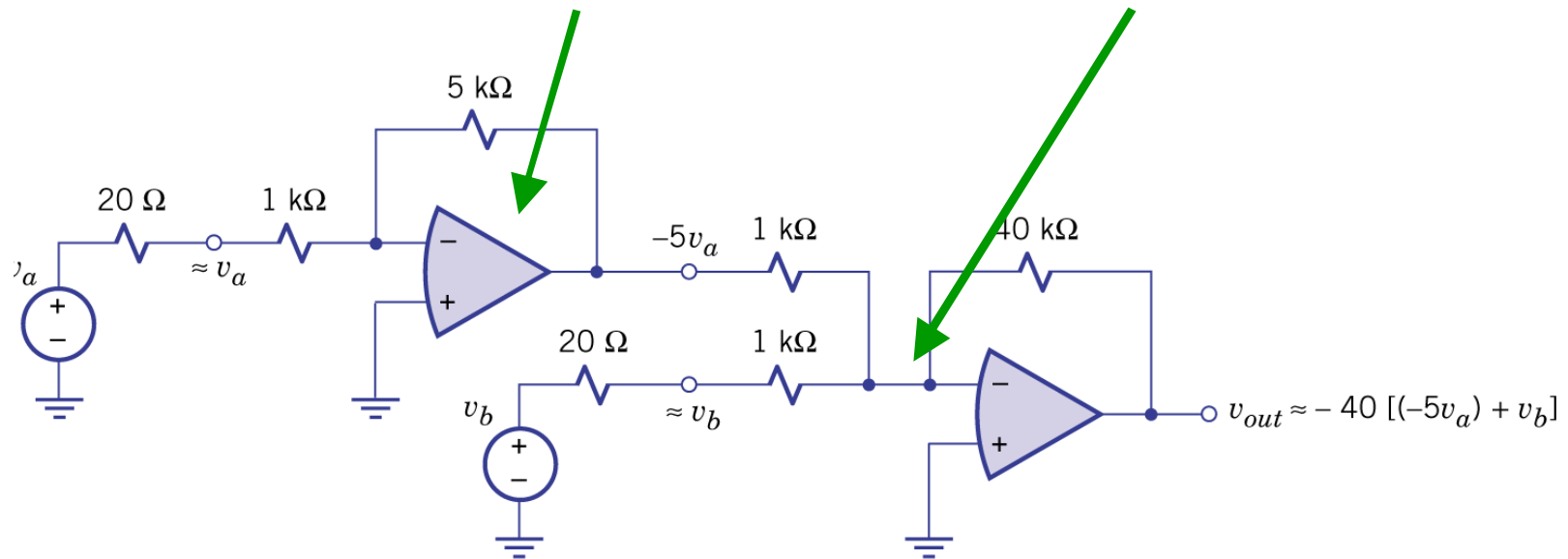
Example 3.7

Want to have: $v_{out}(t) \approx 200v_a(t) - 40v_b(t)$

$$v_{out} \approx -40((-5v_a) + v_b) = -40(v_1 + v_2)$$

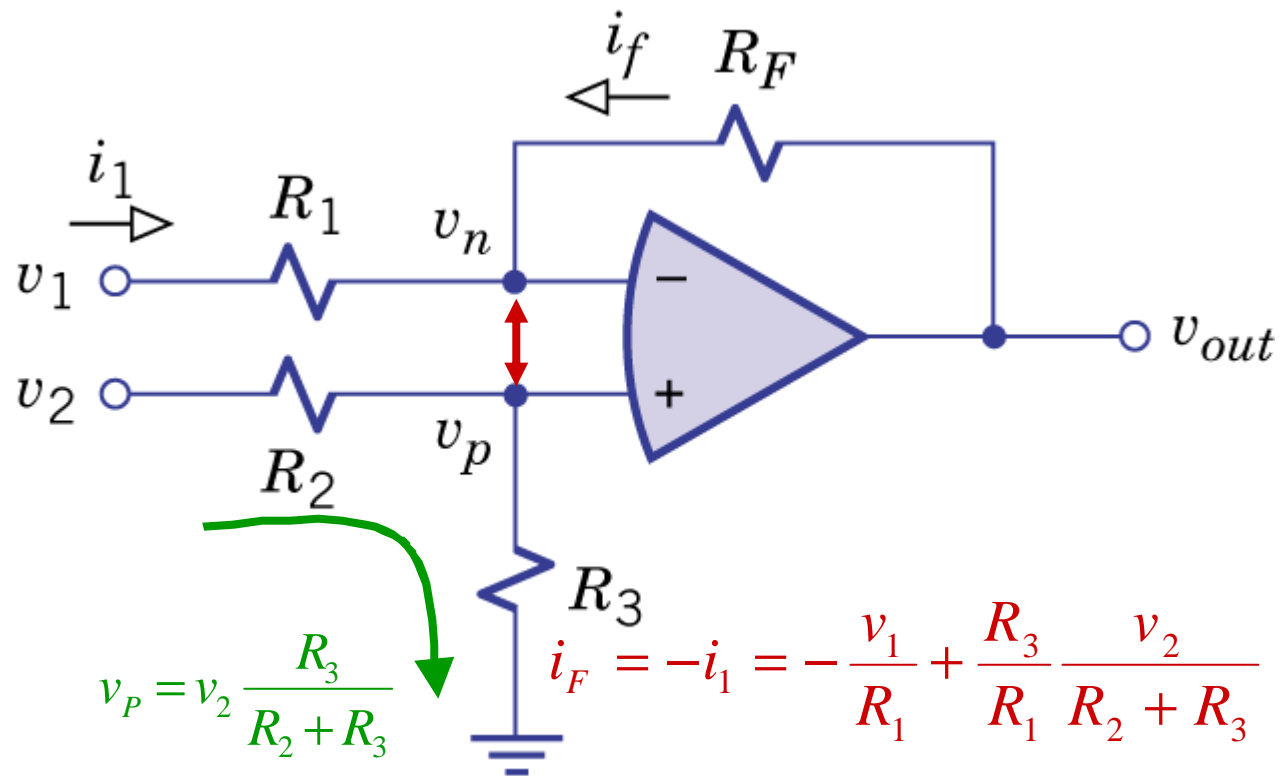
Inverting amplifier

Inverting summing amplifier



$$|v_{out}|_{\max} = 11V < V_{PS}$$

Example 3.8: Difference Amplifier



$$v_{out} = v_n + R_F i_f = \frac{R_F}{R_1} \frac{1 + R_1 / R_F}{1 + R_2 / R_3} v_2 - \frac{R_F}{R_1} v_1$$

$$\text{if } \frac{R_2}{R_3} = \frac{R_1}{R_F} \Rightarrow v_{out} = \frac{R_F}{R_1} (v_2 - v_1)$$

Chapter 3: Problem Set

- 14, 16, 20, 23, 25, 27, 29, 32, 36, 37, 39, 40, 45, 48