# INF3410/4411, Fall 2018

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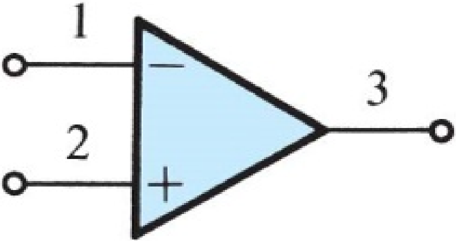
## Excerpt of Sedra/Smith Chapter 2: Basic Circuits with OpAmps

# Content

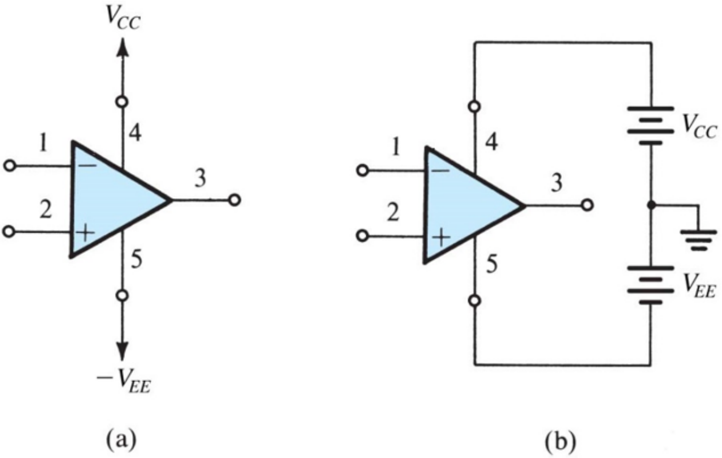
- The Ideal Opamp (book: 2.1)
- Some Circuits with OpAmps (book:2.2-2.5)
- DC Imperfections (book:2.6)
- Closed Loop Frequency Response (book:2.7)
- Large Signal (Non-Linear) Effects (book:2.8)

# Content

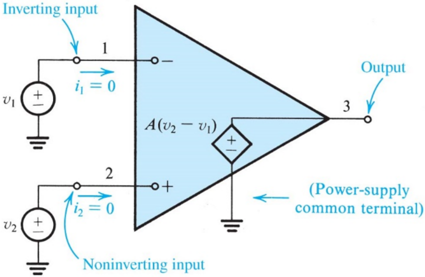
# Circuit Symbol



# Circuit Symbol with Supplies

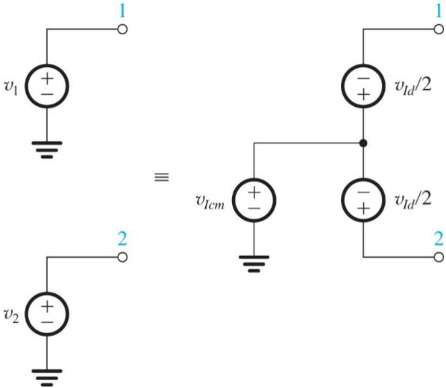


# Ideal Operational Amplifier



The *ideal* operational amplifier: Voltage mode (infinite input resistance/impedance, zero output resistance/impedance), single-ended-output, differential-input, zero common-mode gain, infinite open loop gain, infinite bandwidth.

# Differential- and Common-Mode Input



$$v_{Id} = v_2 - v_1 \quad (2.1)$$

$$v_{Icm} = \frac{v_2 + v_1}{2} \quad (2.2)$$

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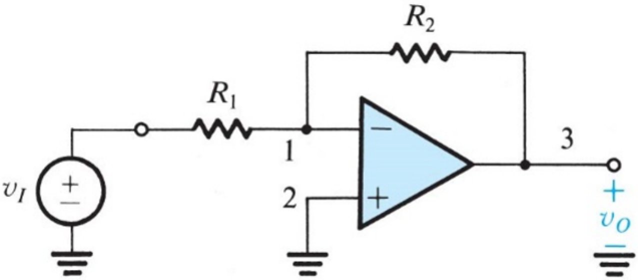
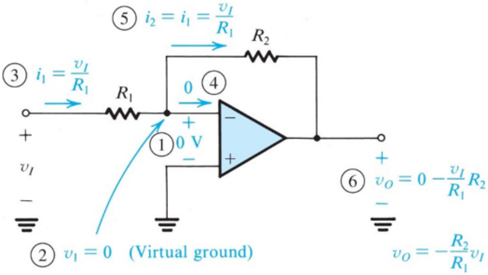
# Basic Inverting Amplifier



$$\frac{v_O}{v_I} = -\frac{R_2}{R_1} \quad \text{(page 101)}$$

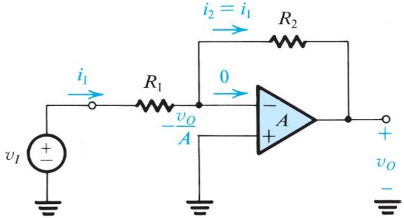
# Basic Inverting Amplifier Analysis



(b)

$$\frac{v_O}{v_I} = -\frac{R_2}{R_1} \quad (2.9)$$

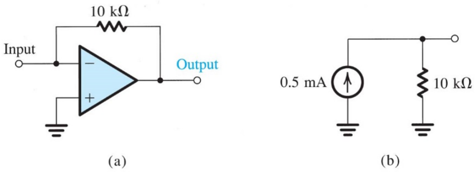
# Finite Open Loop Gain



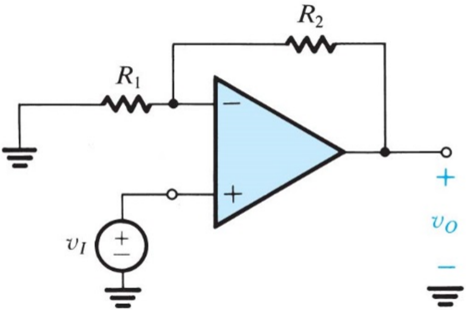
$$\frac{v_O}{v_I} = -\frac{R_2}{R_1} * \frac{1}{1 + (1 + R_2/R_1)/A} \quad (2.5)$$

For negligible *gain error*: $1 + R_2/R_1 << A$ (page 104)

# A Transresistance Amplifier

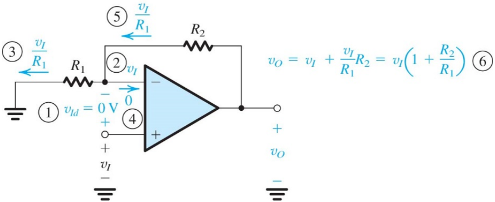


# Basic Non-Inverting Amplifier



$$\frac{v_O}{v_I} = 1 + \frac{R_2}{R_1} \quad (2.9)$$

# Analysis

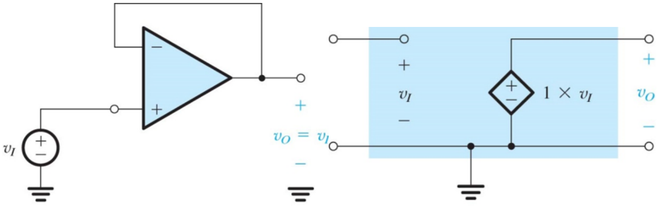

⑤ $\frac{v_I}{R_1}$
$R_2$
③ $\frac{v_I}{R_1}$
$R_1$
②
$v_I$
$v_O = v_I + \frac{v_I}{R_1}R_2 = v_I\left(1 + \frac{R_2}{R_1}\right)$ ⑥
−
0
① $v_{Id} = 0$ V
+
④
−
+
+
$v_I$
−
+
$v_O$
−

# Finite open loop gain

$$\frac{v_O}{v_I} = (1 + \frac{R_2}{R_1})\frac{1}{1 + (1 + R_2/R_1)/A} \quad (2.11)$$

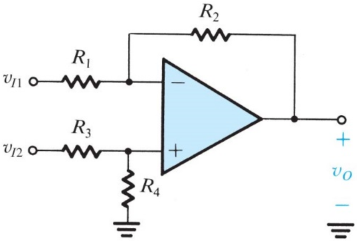
For negligible *gain error*: $1 + R_2/R_1 << A$ (page 111)

# Special Case: The Follower



(a) (b)

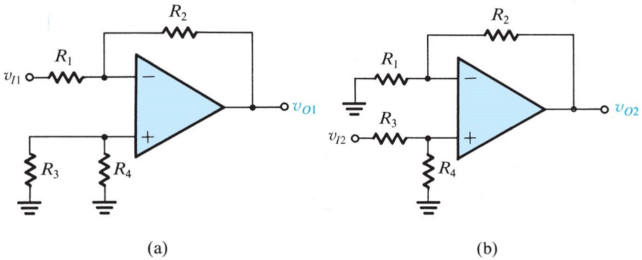
# Single OpAmp Differential Amplifier



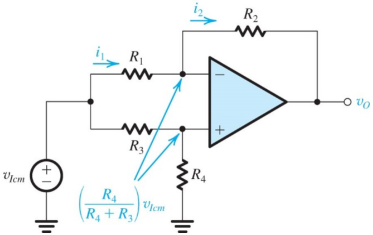
$$\frac{R_4}{R_3} = \frac{R_2}{R_1} = A_D \ ; (2.15, 2.17)$$

e.g. (and typically) $R_1 = R_3$ and $R_2 = R_4$

# Analysing Behaviour With One Input Constant



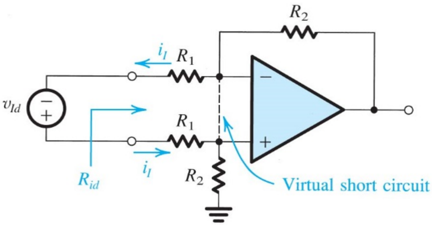
# Common Mode Gain



$$A_{cm} \equiv \frac{v_O}{v_{cm}} = \left(\frac{R_4}{R_4+R_3}\right)\left(1-\frac{R_2R_3}{R_1R_4}\right)$$

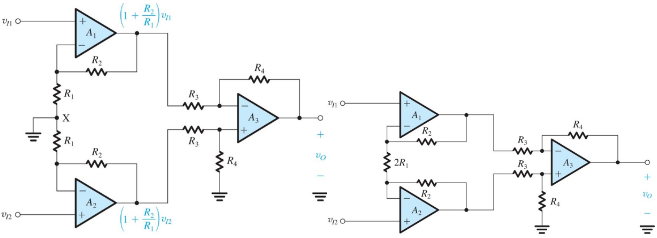
ATTENTION: impaired by resistor deviation from nominal value!

# Differential Input Resistance



Describing the I/V characteristics (i.e. the load seen) for a differential input source.

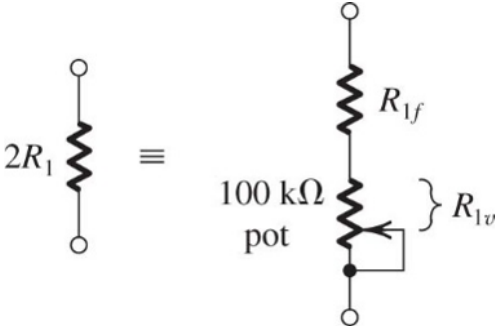
# Instrumentation amplifier



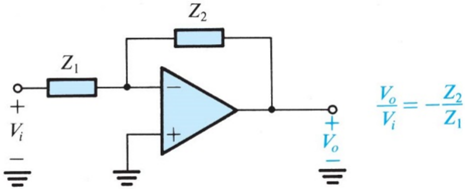
(a) (b)

$$A_d \equiv \frac{v_O}{v_{Id}} = \frac{R_4}{R_3}\left(1+\frac{R_2}{R_1}\right)$$

# Implementing a Variable Gain

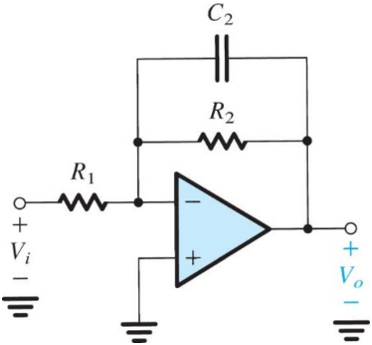


# Invering Amplifier with General Impedances



$$\frac{V_O(s)}{V_I(s)} = -\frac{Z_2(s)}{Z_1(s)}$$

# Low Pass Amplifier



$$\frac{V_O(s)}{V_I(s)} = -\frac{1}{\frac{R_1}{R_2} + sC_2R_1} = -R_2/R_1\frac{1}{1 + sC_2R_2} \quad \text{(page 125)}$$

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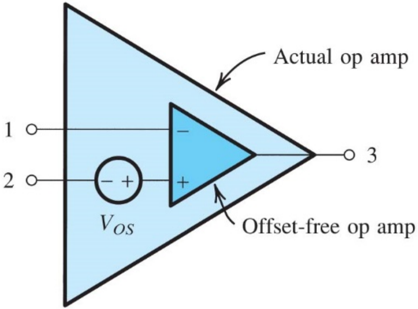
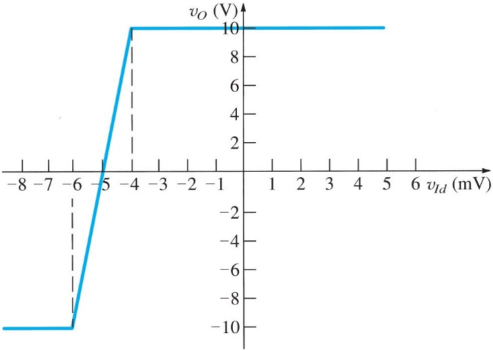
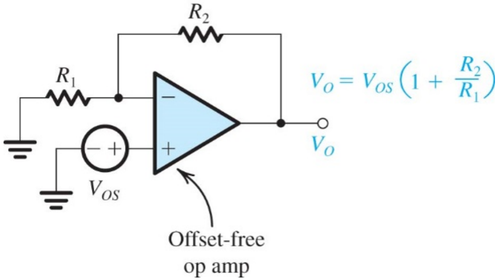
# Input Offset Voltage



# Input Offset Effect

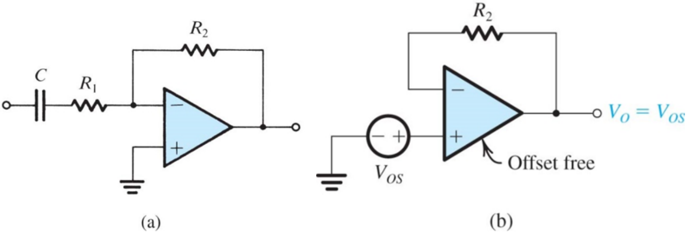


# Effect In Closed Loop Negative Amplifier



$$V_O = V_{OS}\left(1 + \frac{R_2}{R_1}\right)$$

# Offset Counter Measure: *AC Coupling*



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# General Concept

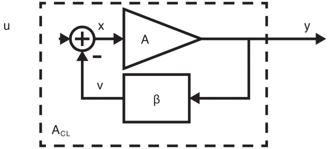


Figure 5.1

$$A_{CL} = \frac{y}{u} = \frac{A}{1 + A\beta} = \frac{A}{1 + L}$$

where $L := A\beta$

$$A_{CL} \approx \frac{1}{\beta} \quad \text{for large } L$$

# $\beta$ in inverting and non-inverting amp

non-inverting:

$$\beta = \frac{R_1}{R_1 + R_2}\ ,\ \frac{1}{\beta} = 1 + \frac{R_2}{R_1}$$

inverting:

$$\beta = \frac{R_1}{R_1 + R_2} / \frac{R_2}{R_1 + R_2}\ ,\ \frac{1}{\beta} = \frac{R_2}{R_1}$$

# Closed Loop Bandwidth Illustration

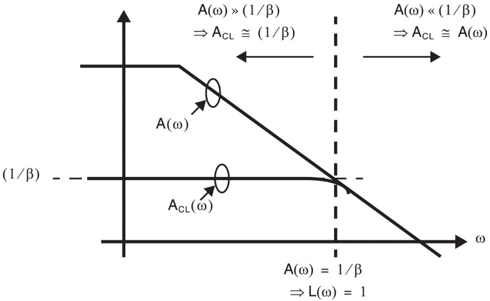
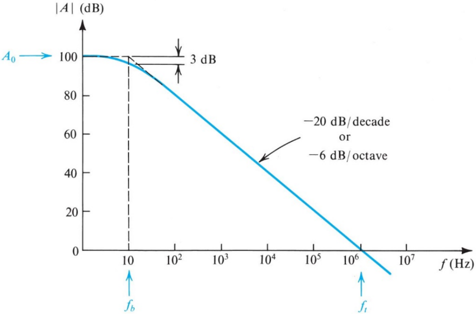


Figure 5.2

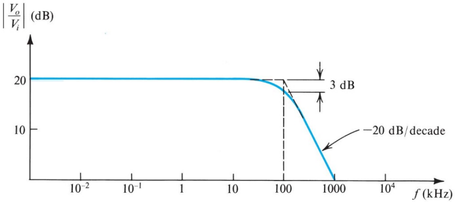
Provided the feedback loop is purely resistive, i.e. no time constant in the feedback loop.

# Example Open Loop Gain



# Non-Inverting Example

$$R_2/R_1 = 9\ ,\ \beta = 1/10 \Rightarrow \omega_{3\mathrm{dB}} = \frac{\omega_t}{\beta} = 100kHz$$

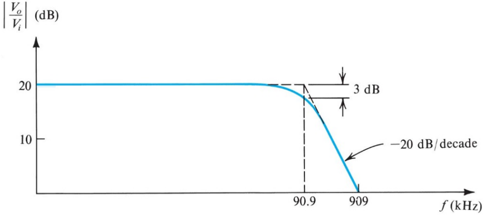


# Inverting Example

$$R_2/R_1 = 10\ ,\ \beta = 1/10 \Rightarrow \omega_{3\text{dB}} = \frac{\omega_t}{\beta} = 100kHz$$

However, the open loop gain with respect to $v_I$:

$$\omega_t' = \omega_t \left( \frac{1}{1 + R_1/R_2} \right)$$



Wait for chapter 10 for an explanation!

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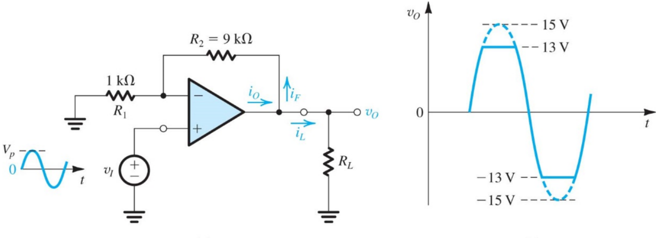
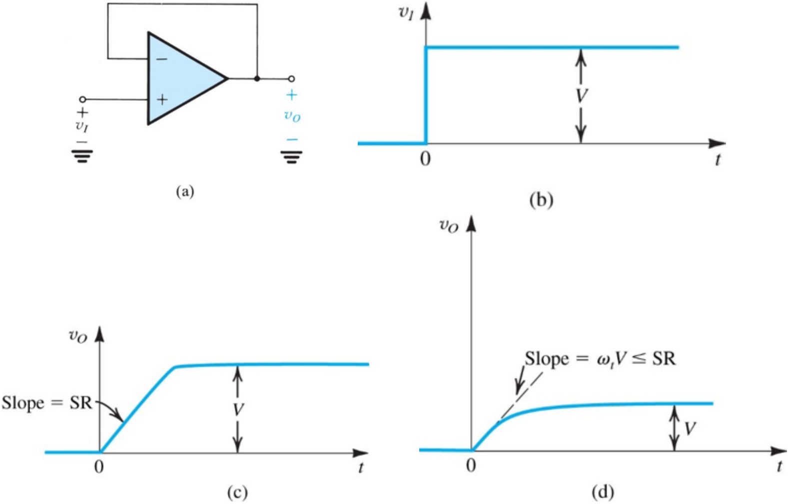
# Power Rail Clipping



(a) (b)

# Slew Rate Effect On Step



(similar effect by absolute output current limit)

# Slew Rate Effect On Sine