EE105 – Fall 2015
Microelectronic Devices and Circuits

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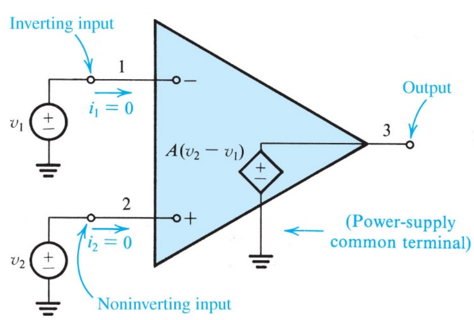
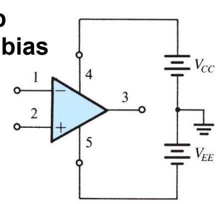
Ideal Op Amp



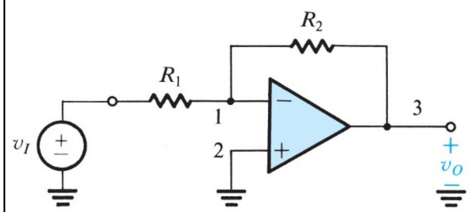
Op-Amp with dc bias



(b)

- **Infinite input impedance**
  - **No current goes in**
- **Zero output impedance**
- **Infinite open-loop gain, A**
  - **How is this possible?**
  - **Use feedback to define circuit gain**
- **Infinite bandwidth**
- **Infinite common-mode rejection**

Inverting Amplifier

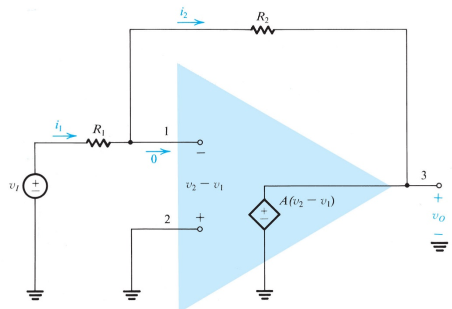


$$v_2 - v_1 = \frac{v_o}{A} = 0 \Rightarrow v_1 = v_2 = 0$$

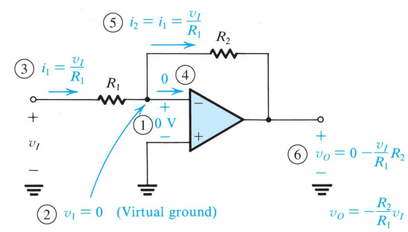
$$i_1 = \frac{v_I}{R_1} = i_2$$

$$v_0 = 0 - i_2 R_2 = -\frac{R_2}{R_1} v_I$$

Closed-loop gain: $G = \frac{v_o}{v_I} = -\frac{R_2}{R_1}$

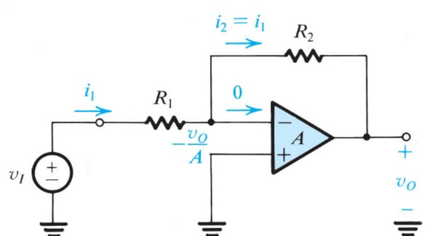


(a)



(b)

Inverting Amplifier with Finite Open-Loop Gain



- **Define gain by resistor ratio, much more controllable than open-loop gain**

$$v_2 - v_1 = \frac{v_o}{A} \neq 0 \Rightarrow v_1 = -\frac{v_o}{A}$$

$$i_1 = \frac{v_I - v_1}{R_1} = i_2$$

$$v_0 = -\frac{v_o}{A} - i_2 R_2 = -\frac{v_o}{A} - \frac{R_2}{R_1}\left(v_I + \frac{v_o}{A}\right)$$

Closed-loop gain:

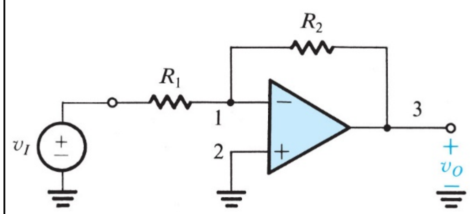
$$G = \frac{v_o}{v_I} = \left(-\frac{R_2}{R_1}\right)\frac{1}{1 + (1 + R_2/R_1)/A}$$

As $A \to \infty$, $G \to -\frac{R_2}{R_1}$

We should make $1 + \frac{R_2}{R_1} << A$

In other words, closed-loop gain should be much less than open-loop gain

Inverting Amplifier: Input and Output Resistances

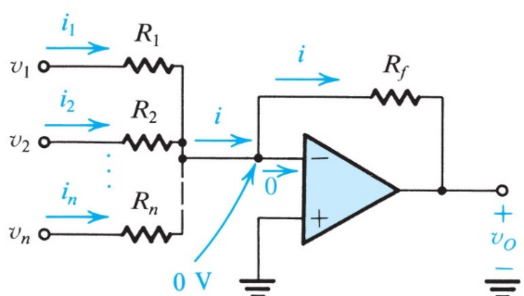


Since $v_1 = 0$,
the input resistance is simply
$R_i = R_1$

To find output resistance,
- Short-circuit the source,
- Apply a test source at the output, and find the impedance

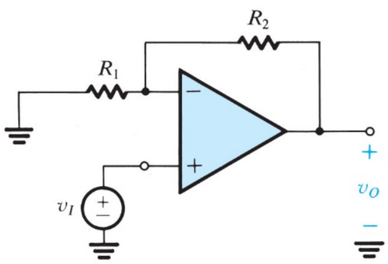
Since $v_o = A \cdot 0 = 0$
$R_o = 0$

Application of Inverting Amplifier: Weighted Summer



$$v_O = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \cdots + \frac{R_f}{R_n}v_n\right)$$

Non-Inverting Amplifier

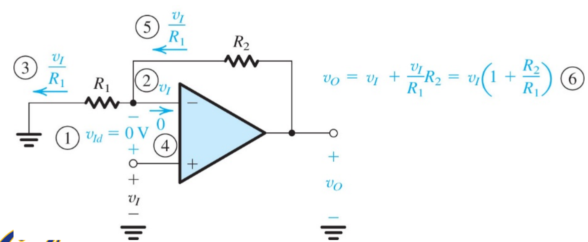


$$v_- = v_+ = v_I$$

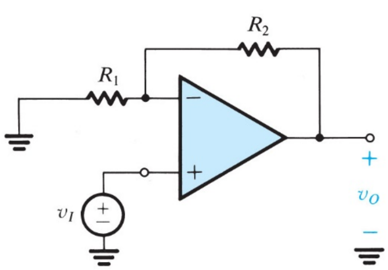
$$i_1 = \frac{v_I}{R_1} = i_2$$

$$v_0 = v_I + i_2 R_2 = \left(1 + \frac{R_2}{R_1}\right) v_I$$

Closed-loop gain: $G = \frac{v_o}{v_I} = 1 + \frac{R_2}{R_1}$



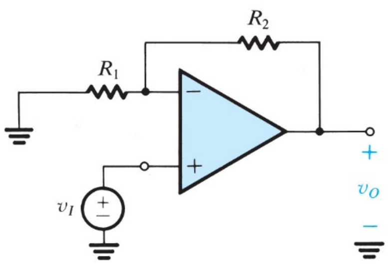
Non-Inverting Amplifier: Effect of Finite Open-Loop Gain



Follow similar analysis of interting amplifier, we can find the closed-loop gain with finite *A*:

$$G = \frac{v_o}{v_I} = \left(1 + \frac{R_2}{R_1}\right) \frac{1}{1 + \frac{1 + R_2 / R_1}{A}}$$

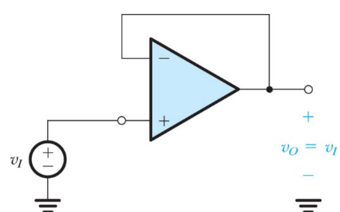
Non-Inverting Amplifier: Input and Output Resistances

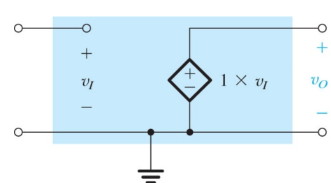


For ideal Op-Amp,
no current flows into the amplifier
$R_i = \infty$

To find output resistance,
replace v_I with short circuit.
This is identical to the
case of inverting amplifier.
$R_o = 0$

Voltage Follower: Unity Gain Amplifier





- **Unity voltage gain**
  - **But large power gain**
- **Purpose:**
  - **Provide impedance transformation:**
    - **A buffer stage that present infinite input impedance to the source, and zero output impedance to the load**
  - **Power amplifier**
    - **Boost drive current**