Ideal Op Amp

- 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 input

Noninverting input

Op-Amp with dc bias

(Power-supply common terminal)
Inverting Amplifier

\[ v_2 - v_1 = \frac{v_i}{A} = 0 \Rightarrow v_1 = v_2 = 0 \]

\[ i_1 = \frac{v_i}{R_1} = i_2 \]

\[ v_0 = 0 - i_2 R_2 = -\frac{R_2}{R_1} v_i \]

Closed-loop gain: \[ G = \frac{v_o}{v_i} = \frac{R_2}{R_1} \]

Inverting Amplifier with Finite Open-Loop Gain

\[ v_2 - v_1 = \frac{v_i}{A} \neq 0 \Rightarrow v_1 = -\frac{v_i}{A} \]

\[ i_1 = \frac{v_i - v_i}{R_1} = i_2 \]

\[ v_0 = \frac{v_i}{A} - i_2 R_2 = -\frac{v_i}{A} - \frac{R_2}{R_1} \left( v_i + \frac{v_i}{A} \right) \]

Closed-loop gain:

\[ G = \frac{v_o}{v_i} = \left( -\frac{R_2}{R_1} \right) \frac{1}{1 + \left( 1 + \frac{R_2}{R_1} \right) / A} \]

As \( A \to \infty \), \[ G \to -\frac{R_2}{R_1} \]

We should make \( 1 + \frac{R_2}{R_1} \ll A \)

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

• Define gain by resistor ratio, much more controllable than open-loop gain
Inverting Amplifier: Input and Output Resistances

Since $v_i = 0$,
the input resistance is simply
$R_i = R_i$

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

\[ v_+ = v_+ = v_i \]
\[ i_i = \frac{v_i}{R_i} = i_i \]
\[ v_o = v_i + i_i R_2 = \left(1 + \frac{R_2}{R_1}\right) v_i \]

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 interverting amplifier, we can find the closed-loop gain with finite \( A \):

\[ G = \frac{v_o}{v_i} = \left(1 + \frac{R_2}{R_1}\right) \frac{1}{1 + \frac{R_2}{R_1} \frac{A}{1}} \]
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 presents infinite input impedance to the source, and zero output impedance to the load
  - Power amplifier
    - Boost drive current