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EE115 Analog Circuits
Ideal Op Amp

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Outline

- Operational Amplifiers
  - Ideal Op Amp
  - Inverting Configuration
  - Noninverting Configuration
  - Difference Amplifiers
- Reading: SEDTRA/SMITH book pages 58-82

Ideal Op Amp

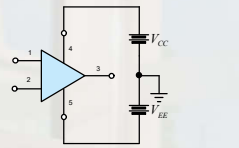


Fig. Op amp shown connected to dc power supplies.

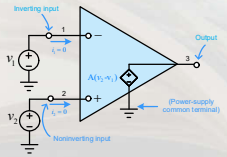


Fig. Equivalent circuit of the ideal op amp.

- Infinite input impedance
  - **No current goes in, virtual open**
- Zero output impedance
- Infinite open-loop gain, A
  - How is this possible?
  - Use feedback to define circuit gain
  - **$v_1 = v_2$, virtual short**
- Infinite bandwidth
- Infinite common-mode rejection

Inverting Amplifier

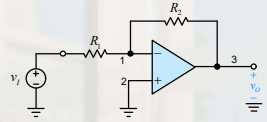


Fig. Inverting closed-loop configuration.

$$\frac{v_o}{v_I} = -\frac{R_2}{R_1}$$

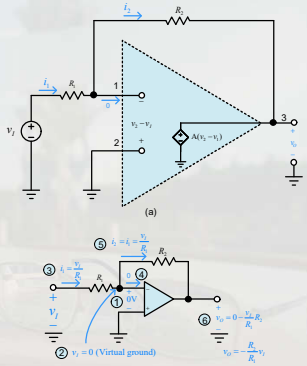


Fig. Analysis of the inverting configuration.

Inverting Amplifier with Finite Open-Loop Gain

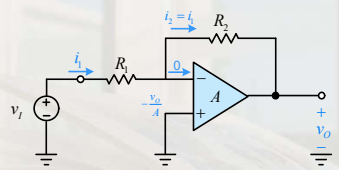


Figure 2.7 Analysis of the inverting configuration taking into account the finite open-loop gain of the op amp.

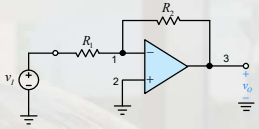
$$i_1 = \frac{v_I - (-v_O/A)}{R_1} = \frac{v_I + v_O/A}{R_1}$$

$$v_O = -\frac{v_O}{A} - i_1 R_2 = -\frac{v_O}{A} - \left(\frac{v_I + \frac{v_O}{A}}{R_1}\right) R_2$$

$$G \equiv \frac{v_O}{v_I} = \frac{-R_2/R_1}{1 + (1 + R_2/R_1)/A}$$

Inverting Amplifier: Input and Output Resistances

- Since $v_1 = 0$
  - The input resistance is simply $R_i = R_1$



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

Application of Inverting AMP: Weighted Summer

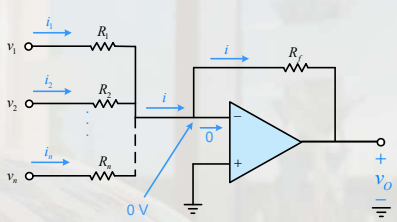


Fig. A weighted summer.

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

Non-Inverting Amplifier

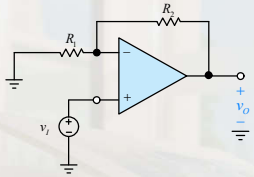


Fig. The noninverting configuration.

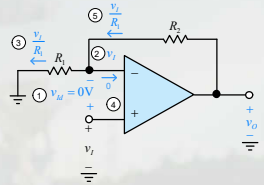


Fig. Analysis of the noninverting circuit.

$$\frac{v_O}{v_I} = 1 + \frac{R_2}{R_1}$$

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

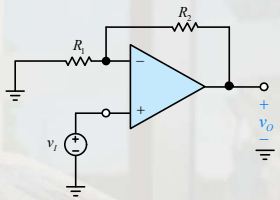


Fig. Noninverting configuration.

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

Non-Inverting AMP Input and Output R

- For ideal Op-Amp
- No current flows into the amplifier
- $R_i = \infty$
- To find output resistance
  - Replace v_I with short circuit
- $R_o = 0$

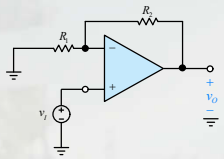


Fig. Noninverting configuration.

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

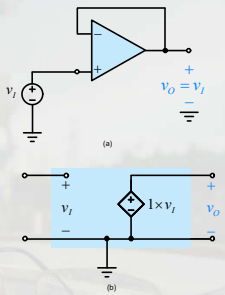


Fig. (a) The unity-gain buffer or follower amplifier. **(b)** Its equivalent circuit model.

Differential Amplifier

- A differential amplifier is one that **responds to the difference** between the two signals applied at its input and ideally **rejects** signals that are **common** to the two inputs.

$$v_o = A_d v_{Id} + A_{cm} v_{Icm}$$

- Common-mode rejection ratio (CMRR)
- CMRR = $20\log(|A_d|/|A_{cm}|)$

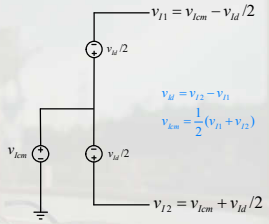


Fig. Representing the input signals to a differential amplifier in terms of their differential and common-mode components.

Differential Amplifier: Differential gain

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- Apply superposition method

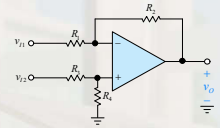

Fig. A difference amplifier.

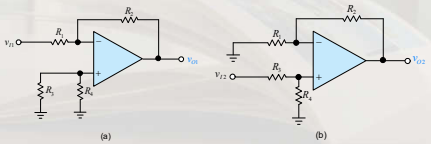

Fig. Superposition analysis

$$v_{O1} = -\frac{R_2}{R_1} v_{I1} \quad \textit{Condition:} \quad \frac{R_4}{R_3} = \frac{R_2}{R_1}$$

$$v_{O2} = \left(\frac{R_4}{R_3 + R_4}\right)\left(1 + \frac{R_2}{R_1}\right) v_{I2} = \frac{R_2}{R_1} v_{I2}$$

- Differential gain

$$v_O = \frac{R_2}{R_1}(v_{I2} - v_{I1}) = \frac{R_2}{R_1} v_{Id}$$

$$A_d = \frac{R_2}{R_1}$$

Differential Amplifier: common mode gain

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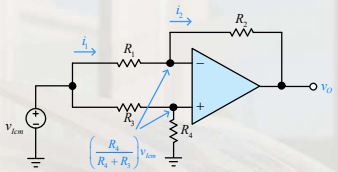

Fig. Analysis of the difference amplifier to determine its common-mode gain $A_{cm} = v_o/v_{cm}$

$$A_{cm} \equiv \frac{v_O}{v_{Icm}} = \left(\frac{R_4}{R_3 + R_4}\right)\left(1 - \frac{R_2}{R_1}\frac{R_3}{R_4}\right)$$

Condition: $\frac{R_4}{R_3} = \frac{R_2}{R_1}$

$$A_{cm} = 0$$

Differential Amplifier: input resistance

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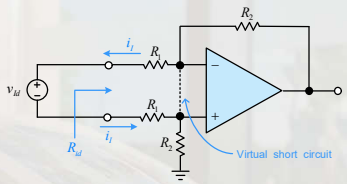

Fig. Finding the input resistance of the difference amplifier for the case $R_3 = R_1$ and $R_4 = R_2$.

$$R_{id} = 2R_1$$