Operational Amplifier Configurations

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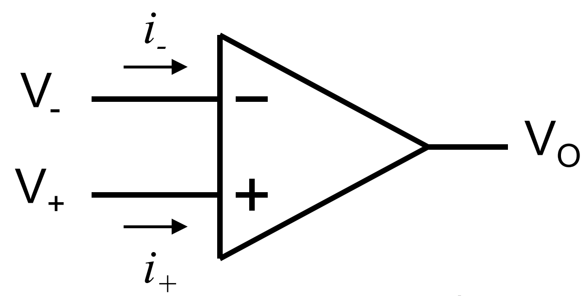
Ideal Op-Amp

- infinite voltage gain ($A = \infty$, $V_- = V_+$ for finite V_O)
- infinite input impedance ($i_- = i_+ = 0$)
- zero output impedance
- infinite bandwidth
- zero input offset



$V_O = A(V_+ - V_-)$

Ideal Op-Amp

- Inverting Amplifier Configuration

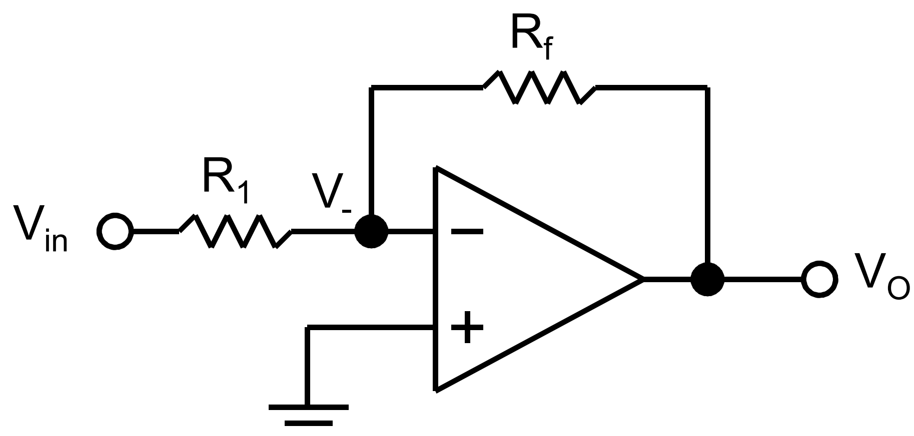
  - current through R_1 = current through R_f ($\because i_- = i_+ = 0$)

    $(V_{in}-V_1) / R_1 = (V_- - V_O) / R_f$

  - and

    $V_- = V_+ = 0$

  - $V_O = -(R_f / R_1) \cdot V_{in}$



Ideal Op-Amp

- Non-Inverting Amplifier Configuration

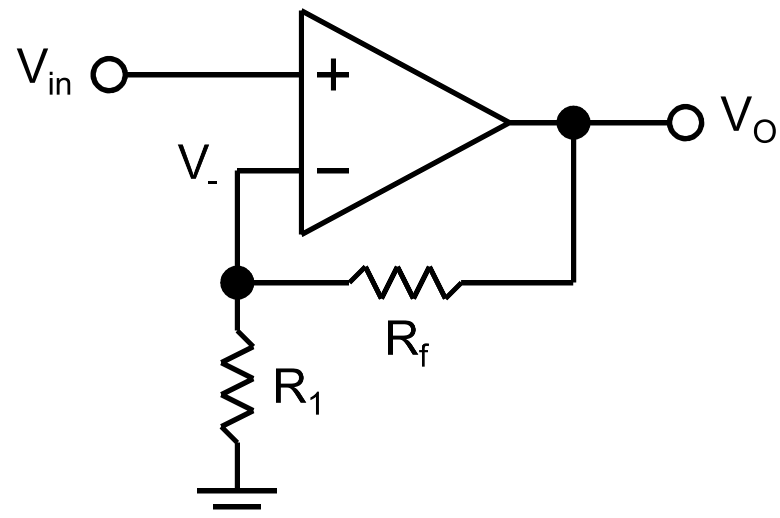
  - current through R_1 = current through R_f ($\because i_- = i_+ = 0$)

    $(V_O - V_-) / R_f = V_- / R_1$

  - and

    $V_- = V_+ = V_{in}$

  - $V_O = (1 + R_f / R_1) \cdot V_{in}$

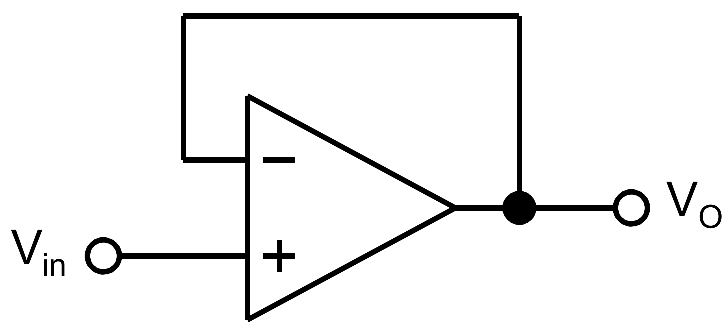


Ideal Op-Amp

- Voltage Follower (Unit Gain Buffer)

  - unit-gain non-inverting amplifier

  - $V_O = V_{in}$



Non-Ideal Op-Amp

- Real World

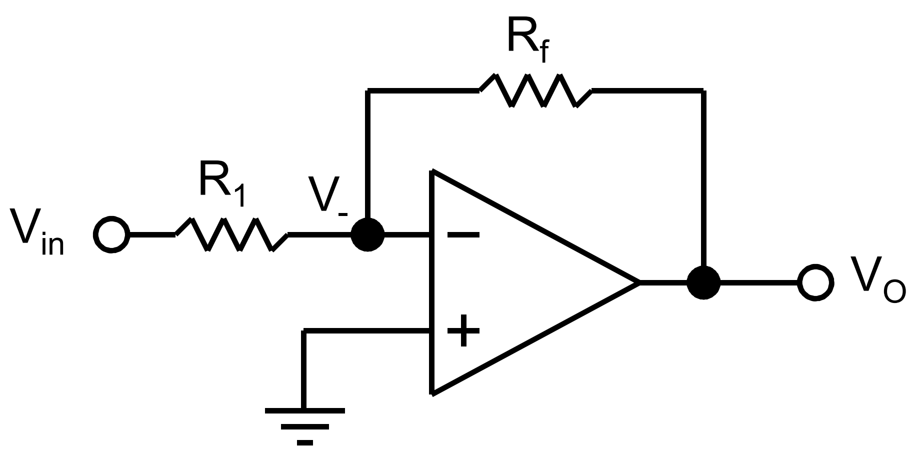
  - gain is not infinite
    → $V_- \neq V_+$

  - gate current
    → $i_+ \neq 0$, $i_- \neq 0$ (but still negligible)

  - finite bandwidth
    → requires frequency compensation

Non-Ideal Op-Amp

- Inverting Amplifier Configuration



$$V_O = A(V_+ - V_-) \rightarrow V_- = -V_O / A$$

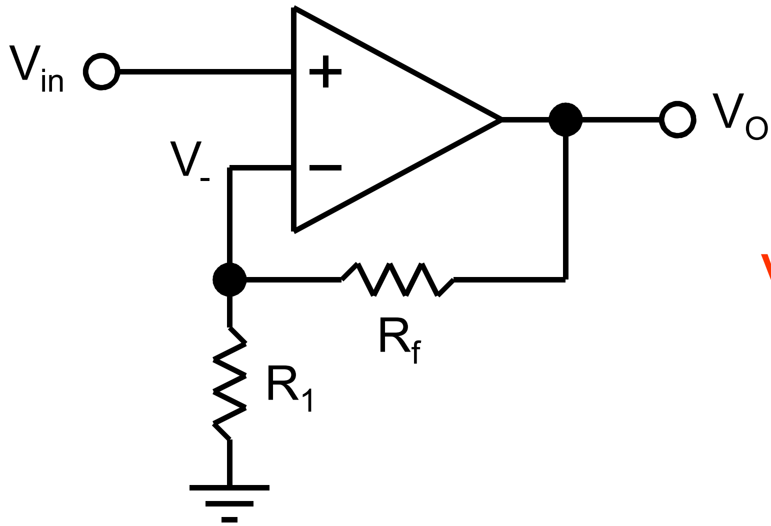
$$(V_{in} - V_-) / R_1 = (V_- - V_O) / R_f$$

$$V_O = \frac{-R_f/R_1}{1+(1+R_f/R_1)/A} V_{in}$$

note that if $A \rightarrow \infty$, $V_O \rightarrow -(R_f / R_1)V_{in}$

Non-Ideal Op-Amp

- Non-Inverting Amplifier Configuration

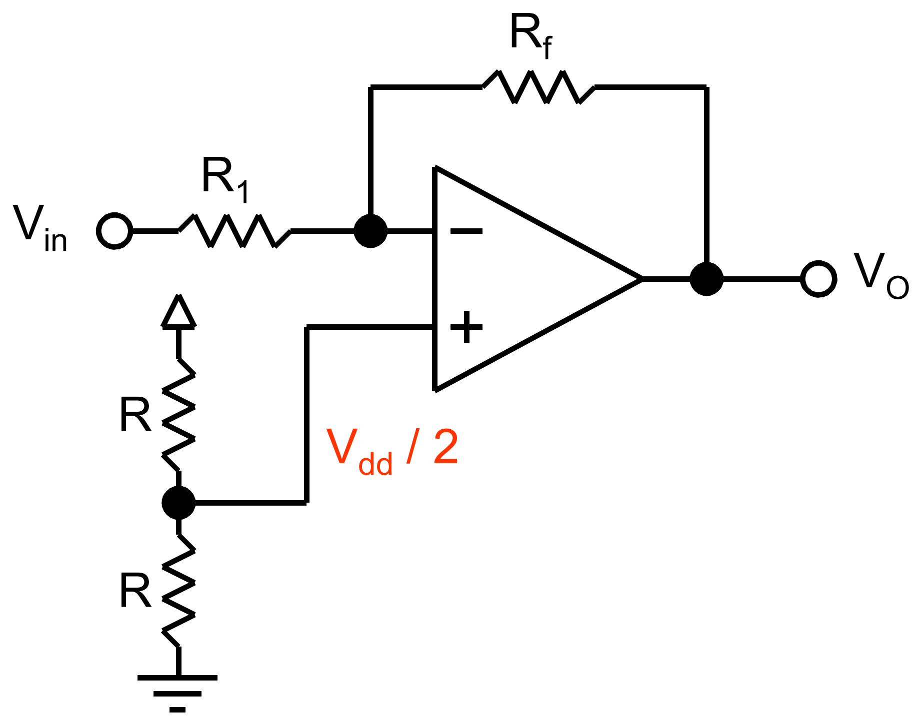


$$V_O = \frac{A}{1 + \frac{R_1}{R_1+R_f}A} V_{in}$$

note that if $A \rightarrow \infty$, $V_O \rightarrow (1+R_f / R_1)V_{in}$

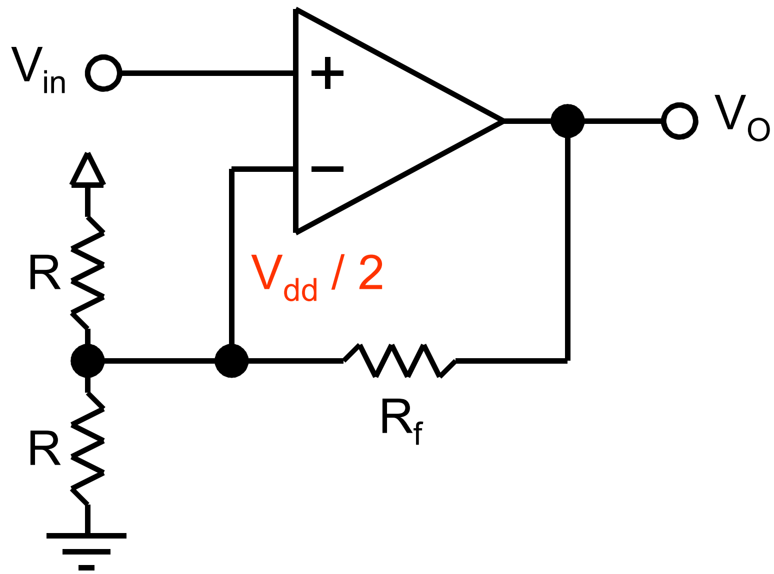
Op-Amp with Single Supply

- Inverting Amplifier Configuration



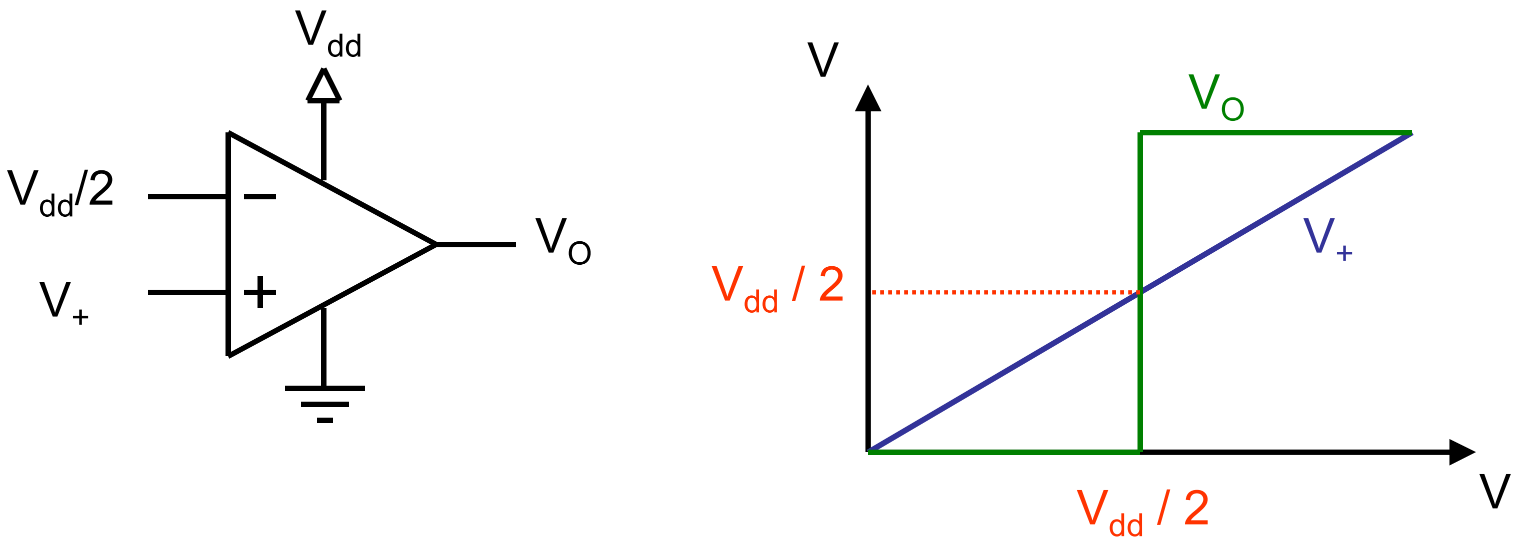
Op-Amp with Single Supply

- Non-Inverting Amplifier Configuration



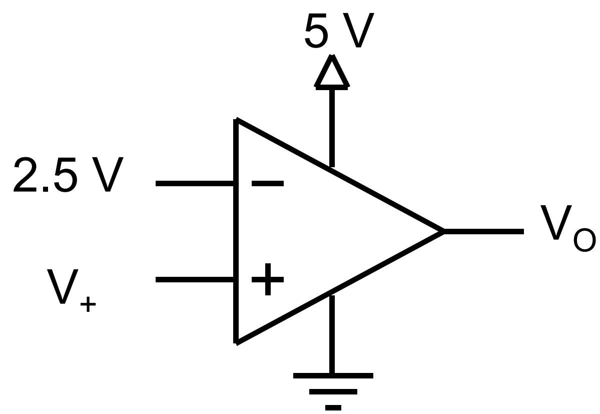
Op-Amp with Single Supply

- Amplifier Design
  - well-designed amplifier should have a transition point centered at V_{dd} / 2



Op-Amp with Single Supply

- Examples from Last Class



  - voltage comparator

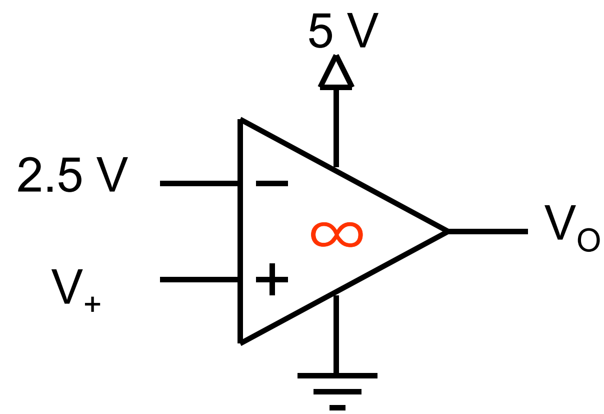
    – $V_+ = 2.5$ V → $V_O = ?$

    – $V_+ = 2.501$ V → $V_O = ?$

    – $V_+ = 2.499$ V → $V_O = ?$

Op-Amp with Single Supply

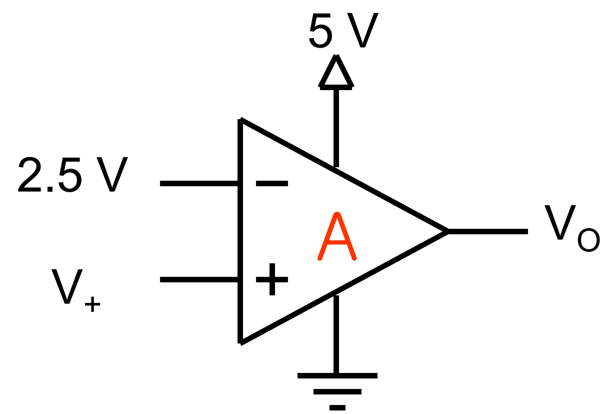
- Examples from Last Class



  - ideal case (gain = ∞)
  - $V_+ = 2.5$ V → $V_O = 2.5$ V
    ($V_+ = V_-$ for finite V_O and V_O centered at 2.5 V)
  - $V_+ = 2.501$ V → $V_O = 2.5 + A(V_+ - V_-) = \infty$
    → $V_O = 5$ V (limited to supply)
  - V+ = 2.449 V → $V_O = 2.5 + A(V_+ - V_-) = -\infty$
    → $V_O = 0$ V (limited to supply)

Op-Amp with Single Supply

- Examples from Last Class



  - gain A = 1000

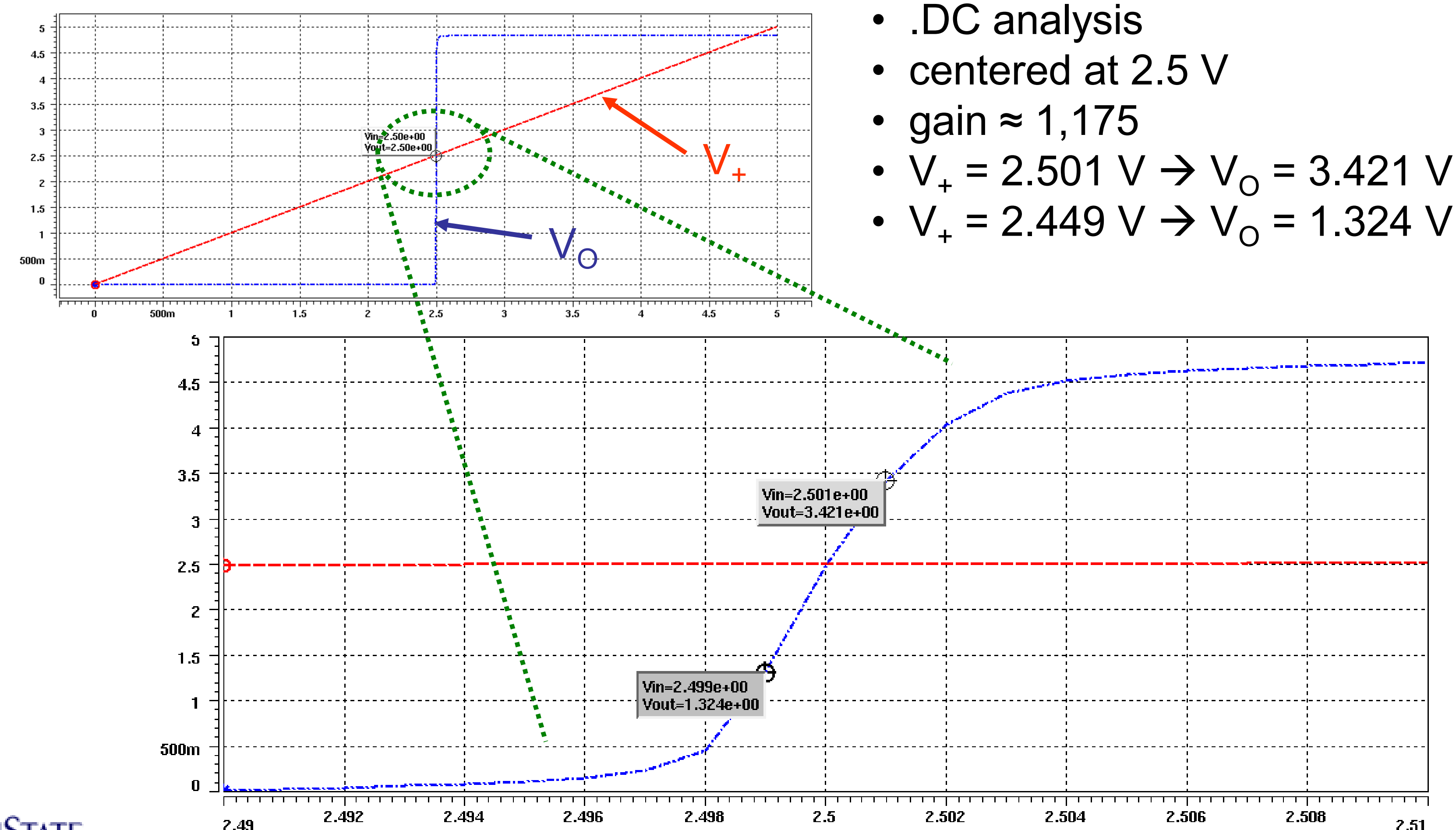
  - $V_+ = 2.5$ V → $V_O = 2.5$ V   (V_O centered at 2.5 V)

  - $V_+ = 2.501$ V → $V_O = 2.5 + 1000(V_+ - V_-) = 3.5$ V

  - V+ = 2.449 V → $V_O = 2.5 + 1000(V_+ - V_-) = 1.5$ V

Op-Amp with Single Supply

- HSpice Simulation



- .DC analysis
- centered at 2.5 V
- gain ≈ 1,175
- V_+ = 2.501 V → V_O = 3.421 V
- V_+ = 2.449 V → V_O = 1.324 V