ECE/ENGRD 2100

Introduction to Circuits for ECE

Lecture 13

Op-Amps and Op-Amp Amplifiers

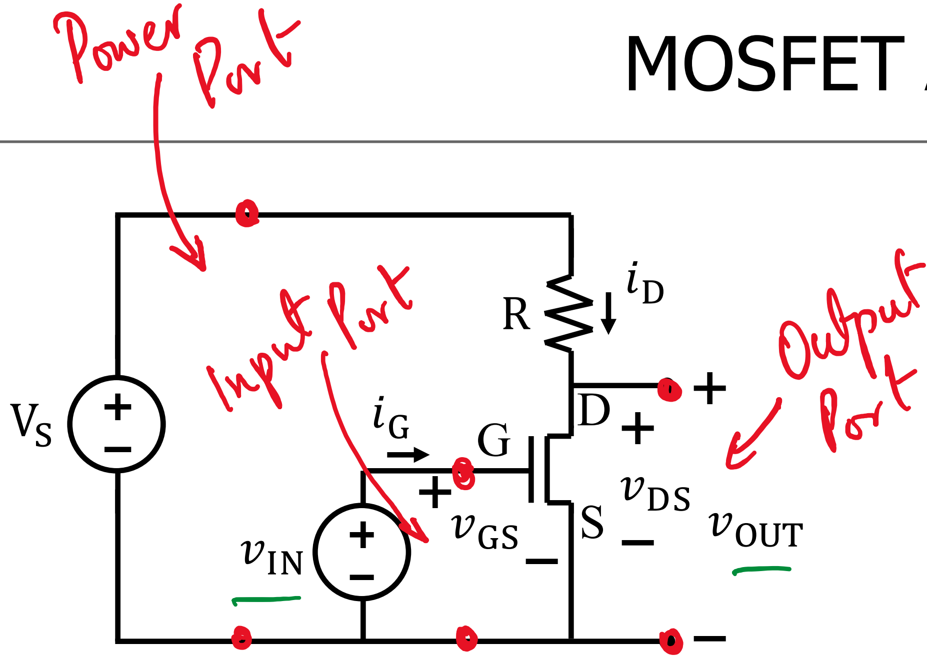
Announcements

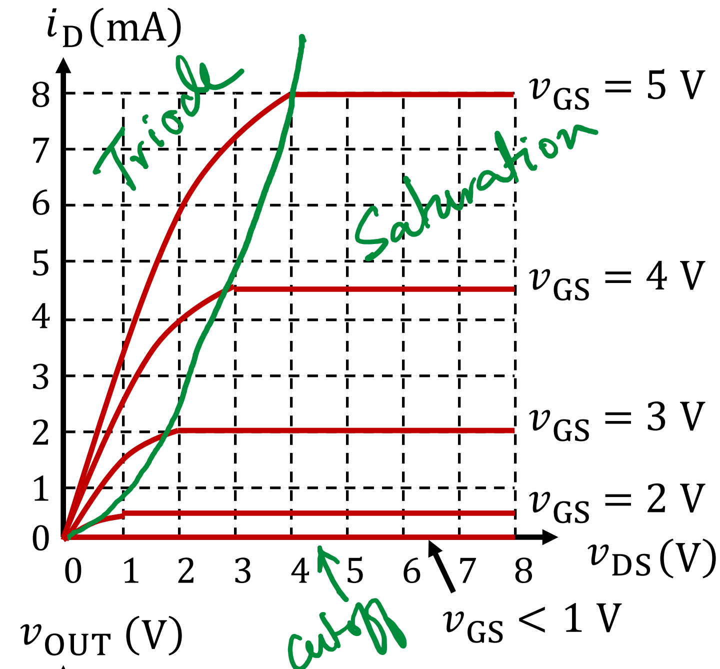
- Recommended Reading:
  - Textbook Chapter 5

- Upcoming due dates:
  - Lab report 2 due by 11:59 pm on Wednesday 27, 2019

- Prelim 1 on Thursday February 21, 2019 from 7:30 – 9 pm in 203 Phillips
  - Email afridi@cornell.edu if have conflict
  - Make up exams on same day (Thursday February 21):
    - 10 – 11:30 am in 307 Phillips
    - 2:30 – 4 pm in 310 Rhodes (room has changed)
  - Will cover material through Lecture 11
  - Prelim is closed-book and closed-notes
  - One double-sided page formula sheet is allowed
  - Bring a calculator

MOSFET Amplifier



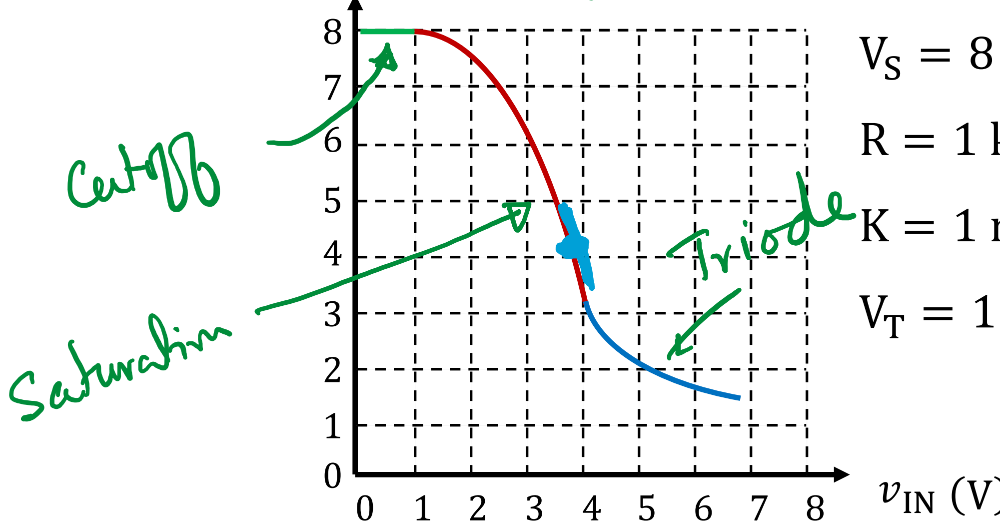


Large-Signal Response

$$v_{OUT} = V_S - \frac{RK}{2}(v_{IN} - V_T)^2$$

Small-Signal Response

$$v_{out} = -RK(V_{IN} - V_T) \cdot v_{in}$$



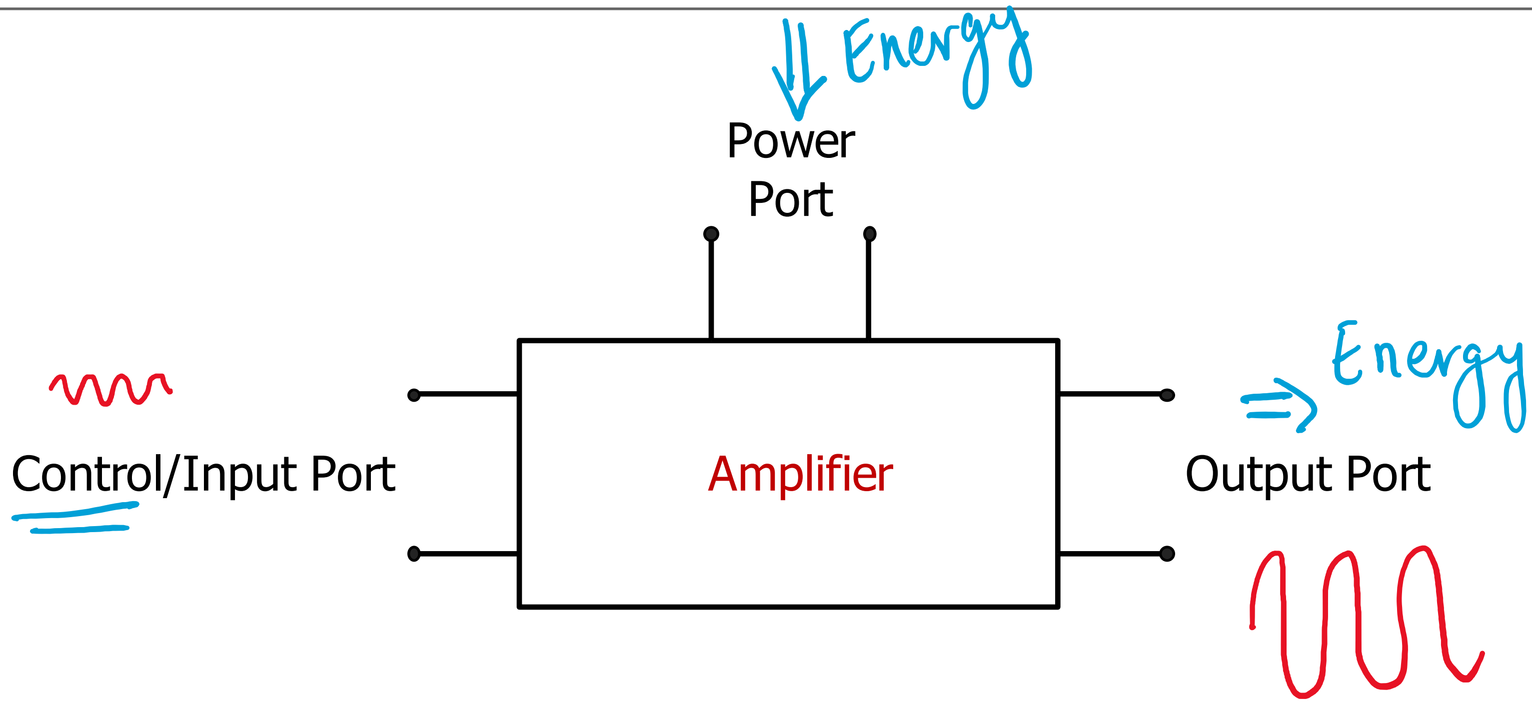
$V_S = 8$ V

$R = 1$ kΩ

$K = 1$ mA/V^2

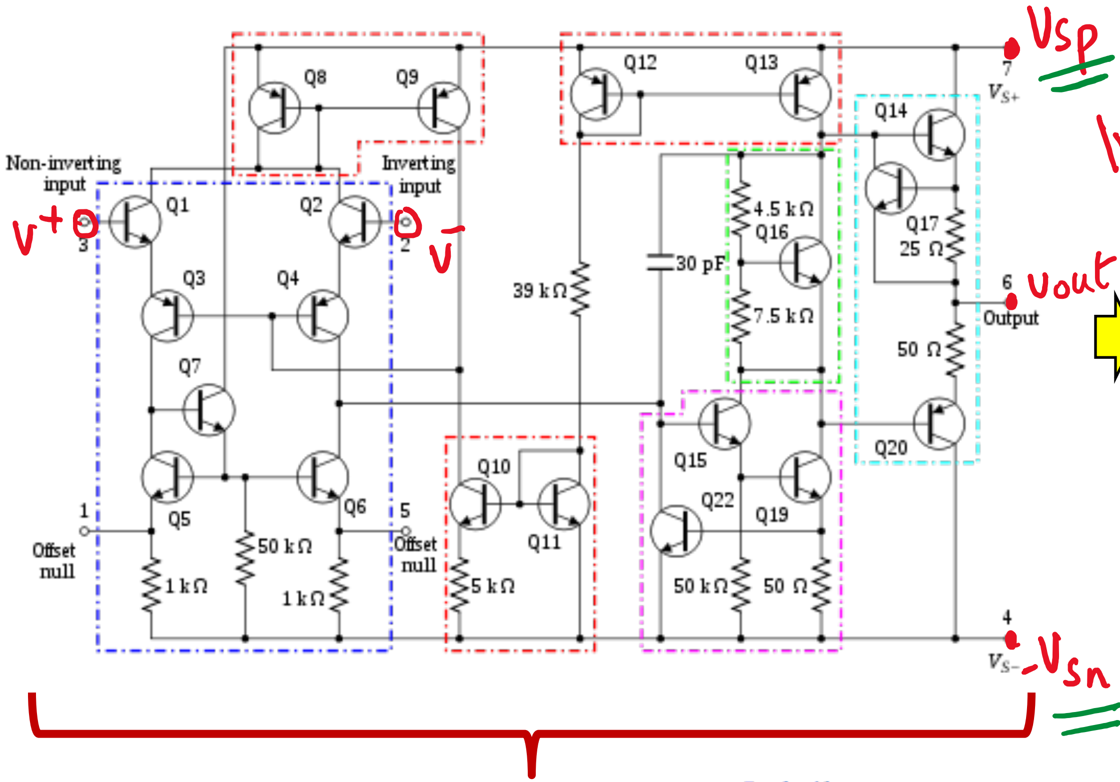
$V_T = 1$ V

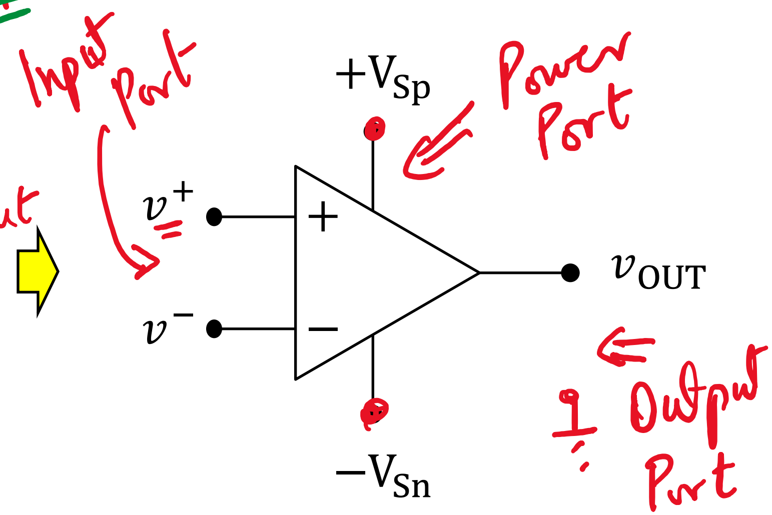
Amplifiers



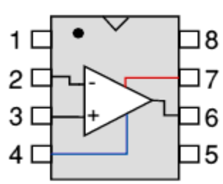
- Amplifier is a three port device
- Provides power gain (voltage gain, current gain or both)
- Fundamental building block in analog signal processing systems, such as audio and video communications, instrumentation and control, etc.

Operational Amplifier (Op-Amp)

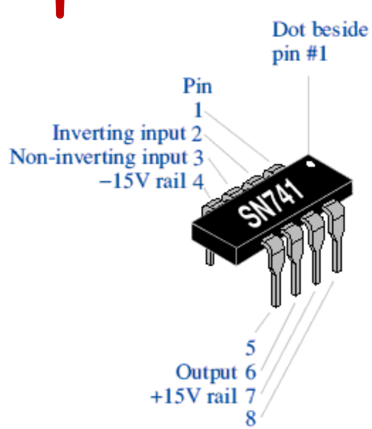




741 Op Amp
8-pin DIP



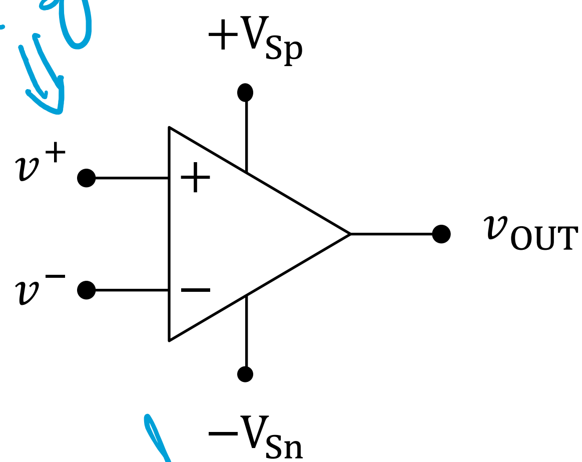
Top view



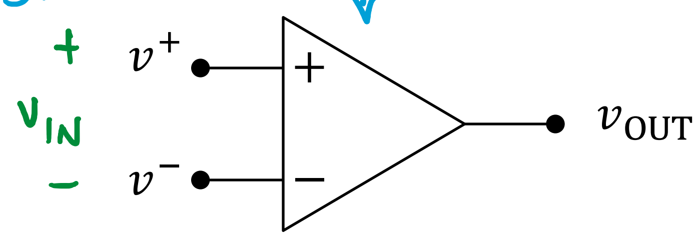
741 Op Amp

Simple Op-Amp Model

Full Symbol



Short-hand notation



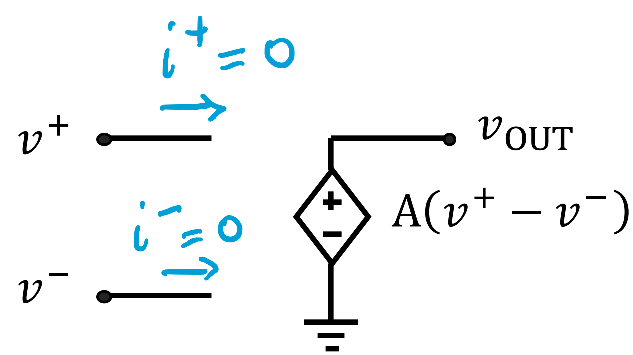
Typically do not show power supply terminals

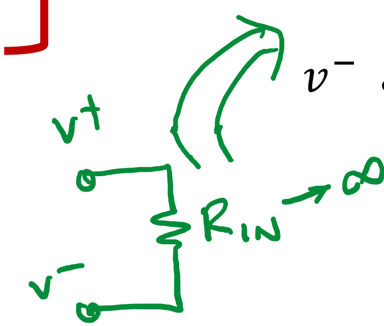
$$v_{OUT} = A(v^+ - v^-)$$

$v_{OUT} = A v_{IN}$

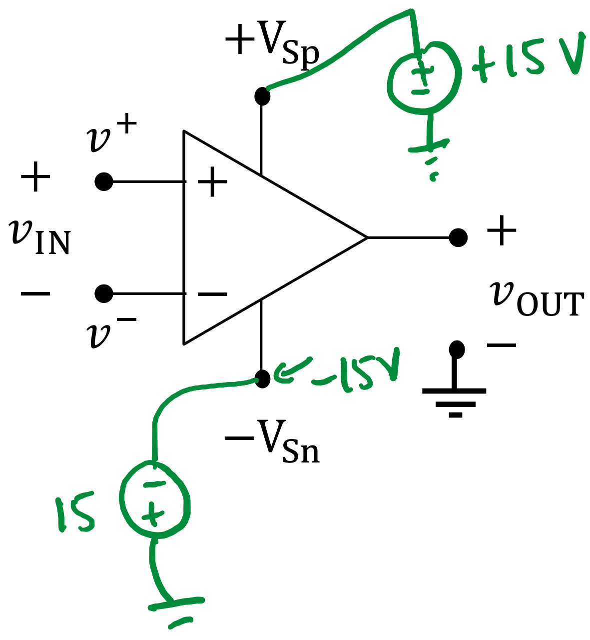
Ideal Op Amp has:

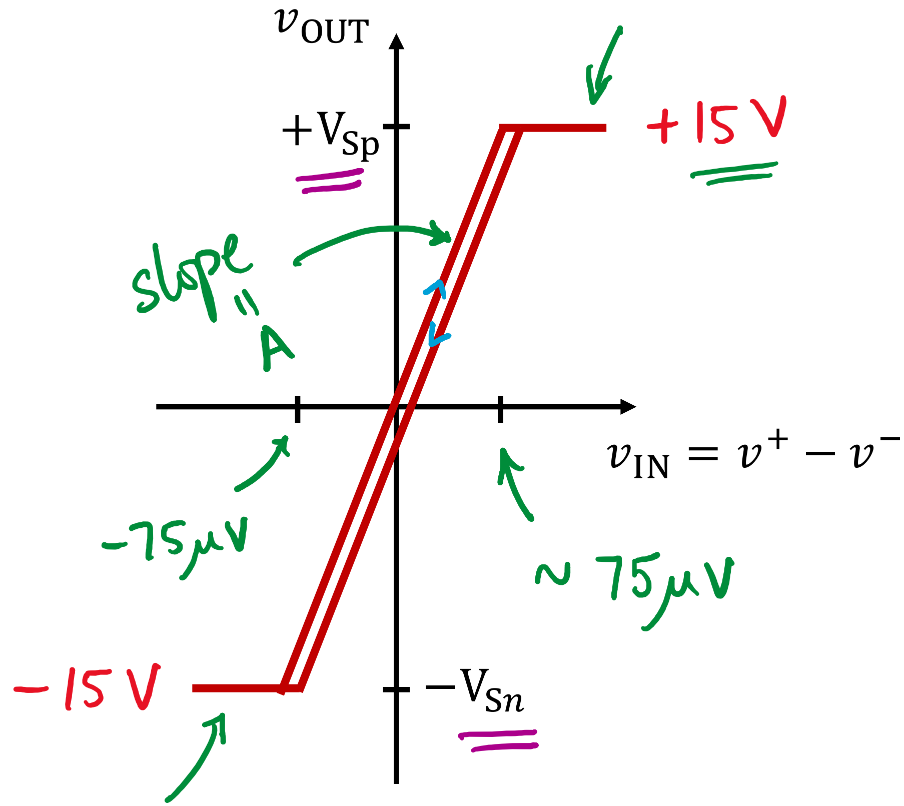
- Infinite Gain, i.e., $A \to \infty$
- Infinite Input Resistance ←
- Output v_{OUT} can take any value ←





Real Op-Amp Behavior

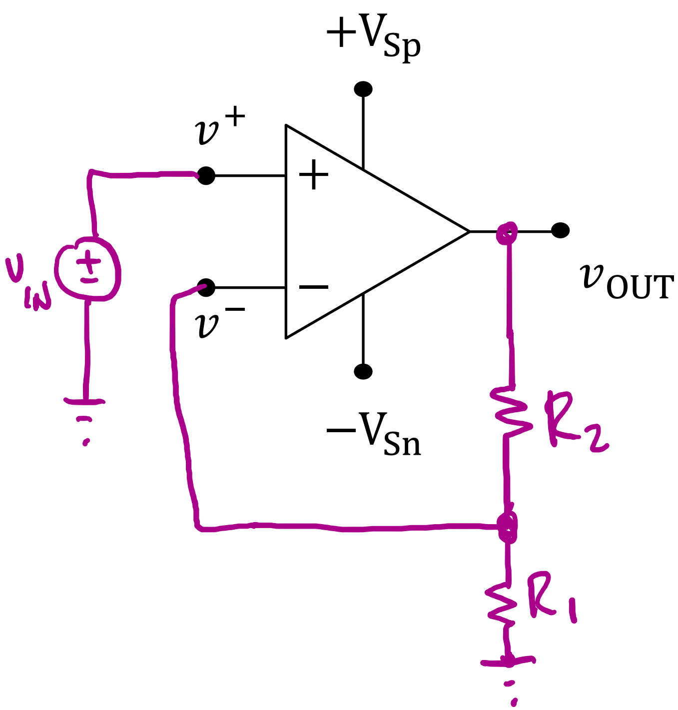


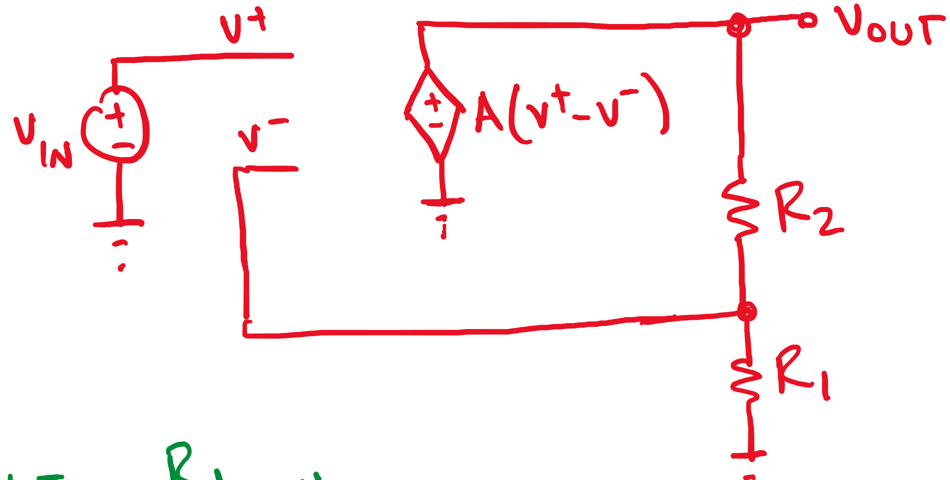


- Voltage gain, $A \equiv \frac{v_{OUT}}{v_{IN}} \approx 200{,}000$
- Non-linear
- Temperature dependent

} Non-idealities

Practical Amplifier Design





$$v^- = \frac{R_1}{R_1+R_2} v_{OUT}$$

$$v_{OUT} = A(v^+ - v^-) = A\left(v_{IN} - \frac{R_1}{R_1+R_2} v_{OUT}\right)$$

$$\Rightarrow v_{OUT}\left(1+\frac{R_1 A}{R_1+R_2}\right) = A v_{IN} \Rightarrow v_{OUT} = \frac{A v_{IN}}{1+\frac{R_1 A}{R_1+R_2}}$$

$$\left(1+\frac{R_2}{R_1}\right)v_{IN}$$

$$\Rightarrow v_{OUT} = \frac{v_{IN}}{\frac{1}{A}+\frac{R_1}{R_1+R_2}}$$

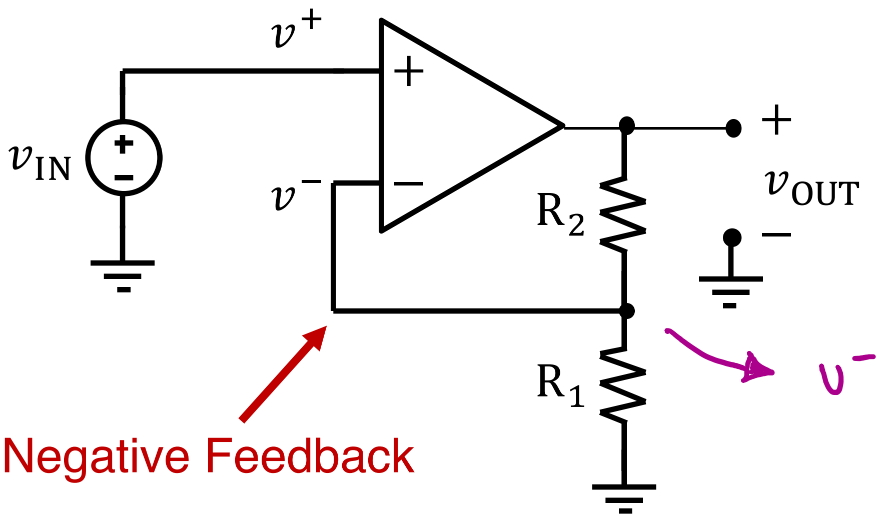
Use A is very large

$$A \gg \frac{R_1+R_2}{R_1}$$

$$\Rightarrow \boxed{v_{OUT} = \frac{R_1+R_2}{R_1} v_{IN}}$$

new gain

Non-Inverting Amplifier



$$v_{OUT} = \frac{v_{IN}}{\frac{1}{A} + \frac{R_1}{R_1+R_2}}$$

$$v^- = \frac{R_1}{R_1+R_2} v_{OUT} = \frac{\frac{R_1}{R_1+R_2}}{\frac{1}{A} + \frac{R_1}{R_1+R_2}} \cdot v_{IN}$$

$\Rightarrow$ $v^- = v_{IN}$ as $A \to \infty$

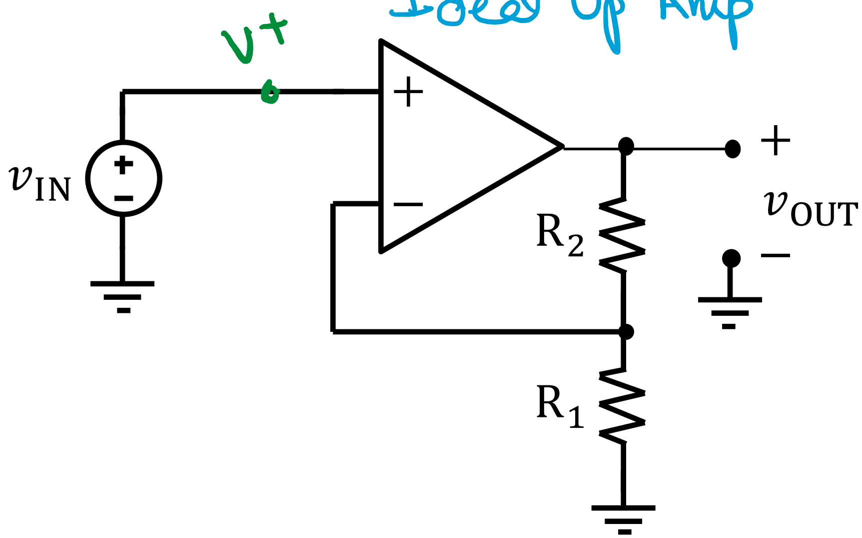
$v^+ = v_{IN}$

$v^- = v^+$ as $A \to \infty$

$v^- \approx v^+$ under negative feedback & very large A

Shortcut Analysis of Op Amps with Negative Feedback

Ideal Op Amp



Under negative feedback

$v^- \approx v^+$

$v^+ = v_{IN} \Rightarrow v^- \approx v_{IN}$

$$v^- = \frac{R_1}{R_1+R_2} v_{OUT} = v_{IN}$$

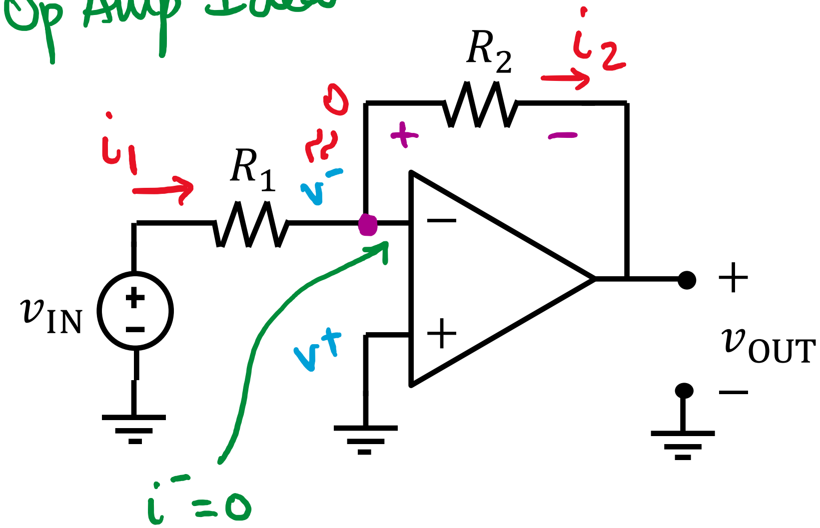
$$\Rightarrow \boxed{v_{OUT} = \frac{R_1+R_2}{R_1} v_{IN}}$$

Same as before

Non-Inverting Amplifier

Inverting Amplifier

Op Amp Ideal



Have negative feedback

$v^- \approx v^+$

$v^- \approx 0\ V$

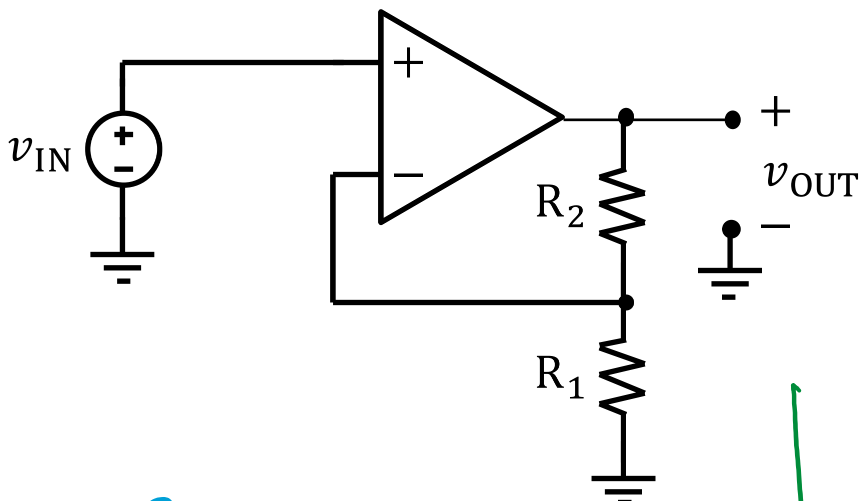
$$i_1 = \frac{v_{IN}}{R_1}$$

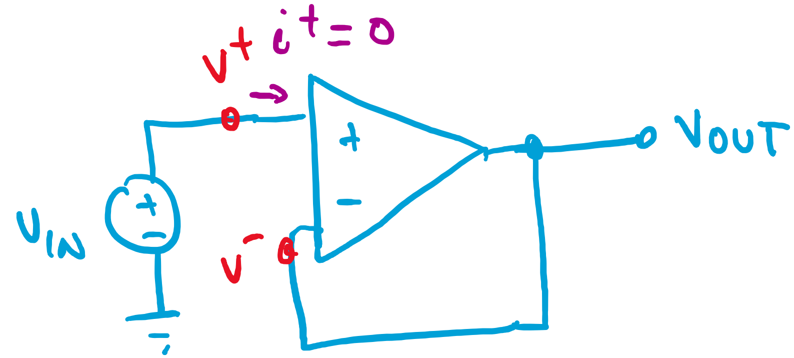
$$i_2 = i_1 = \frac{v_{IN}}{R_1}$$

$$v_{OUT} = 0 - R_2 i_2 \Rightarrow \boxed{v_{OUT} = -\frac{R_2}{R_1} v_{IN}}$$

Inverting Amplifier

Voltage Buffer





$R_2 = 0$

$R_1 \rightarrow \infty$

$$v_{OUT} = \frac{R_1 + R_2}{R_1} v_{IN}$$

$$= \left(1 + \frac{R_2}{R_1}\right) v_{IN} = v_{IN}$$

$v^- = v_{OUT}$

Negative Feedback

$v^- \approx v^+ = v_{IN}$

$\Rightarrow v_{OUT} = v_{IN}$