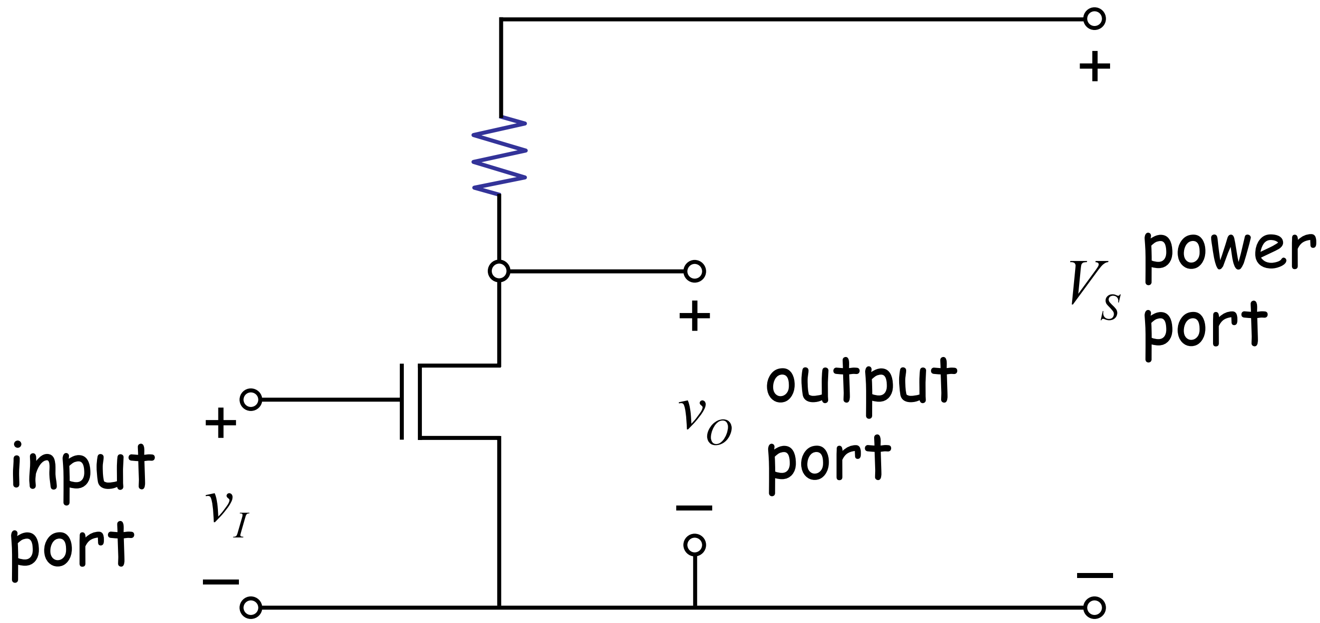
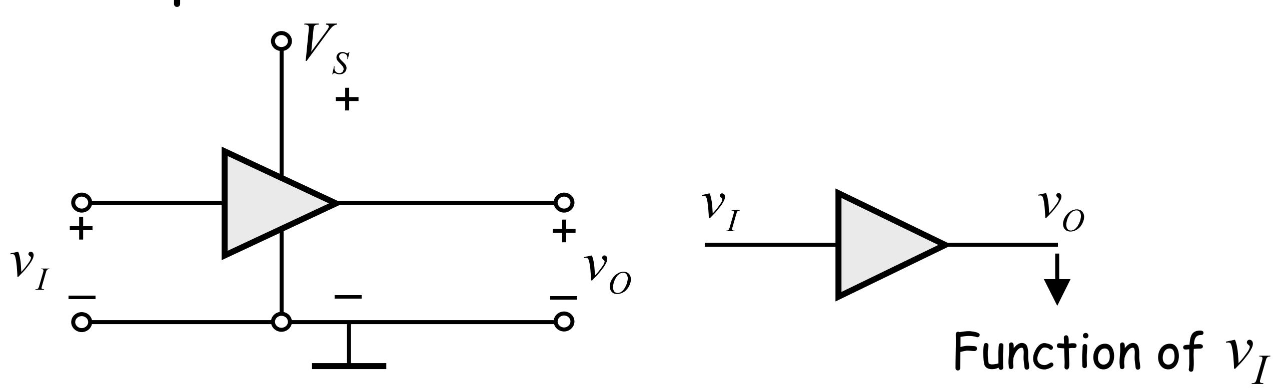
The Operational Amplifier Abstraction

Review

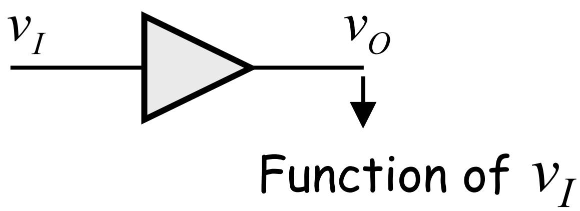
- MOSFET amplifier — 3 ports



- Amplifier abstraction



Review

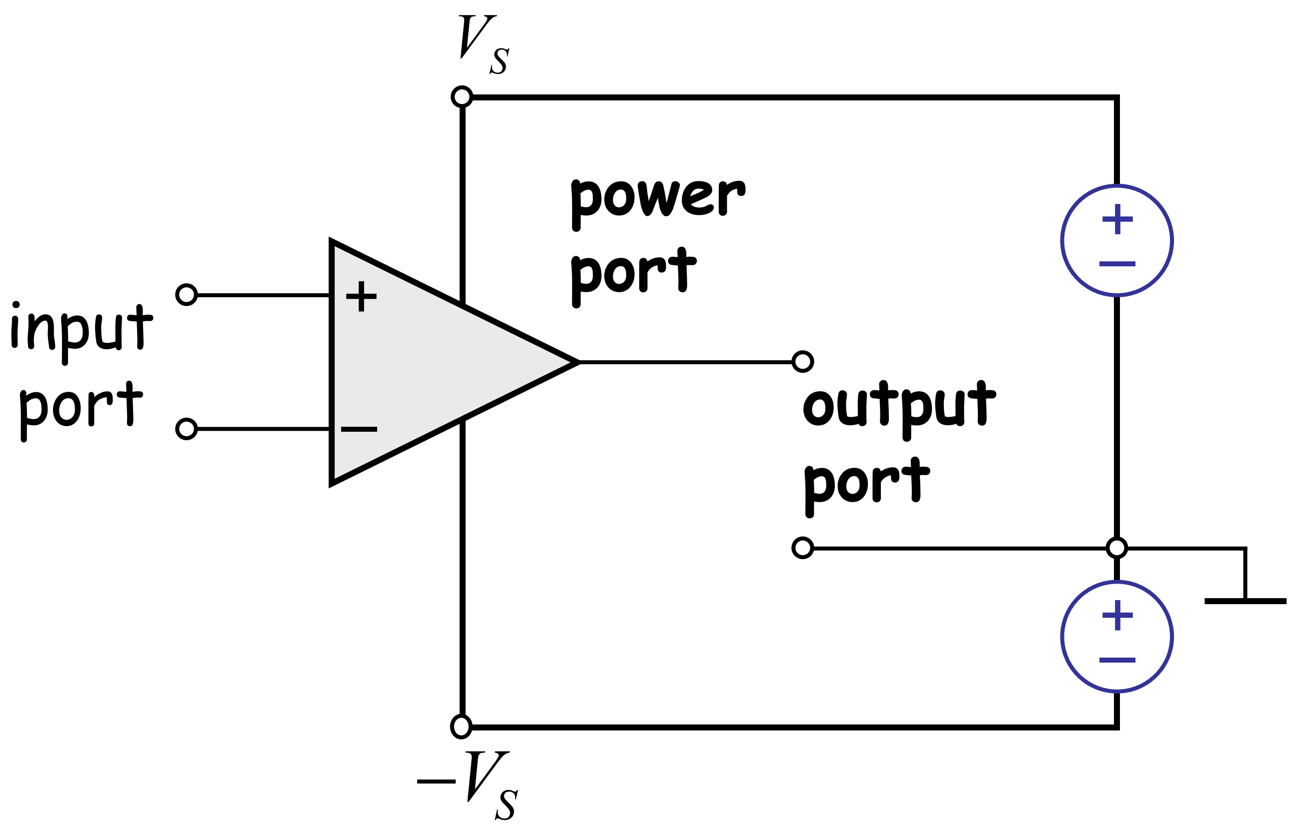


- Can use as an abstract building block for more complex circuits (of course, need to be careful about input and output).
- **Today**

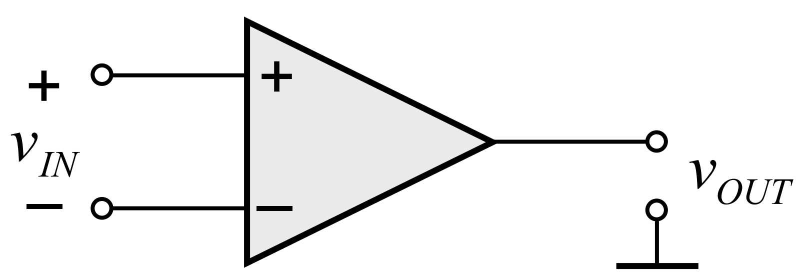
  Introduce a more powerful amplifier abstraction and use it to build more complex circuits.

Reading: Chapter 15 from A & L.

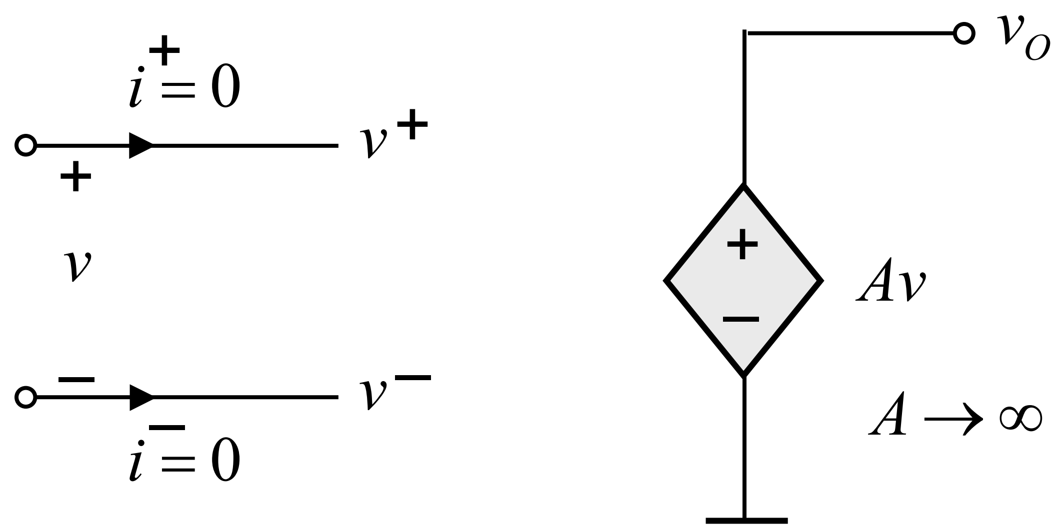
Operational Amplifier
Op Amp



More abstract representation:

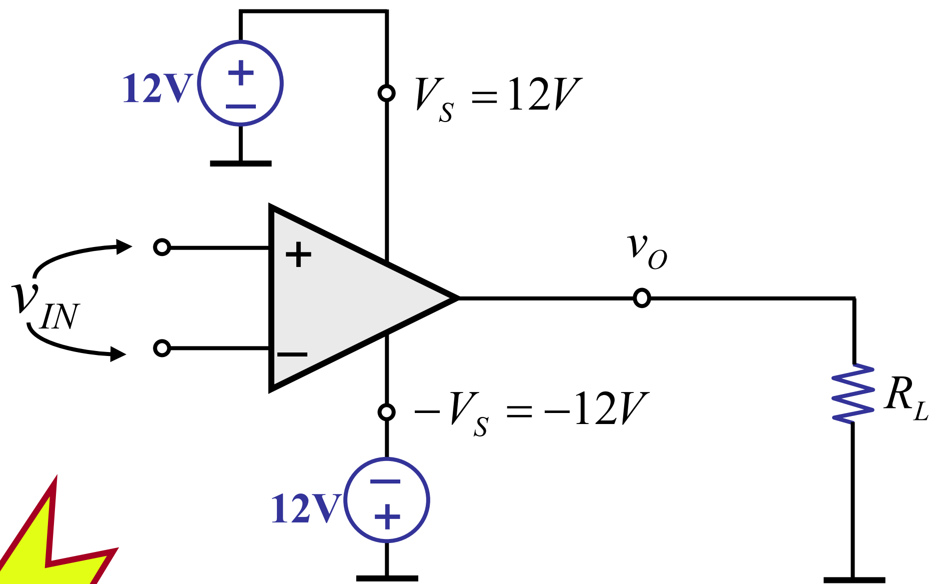


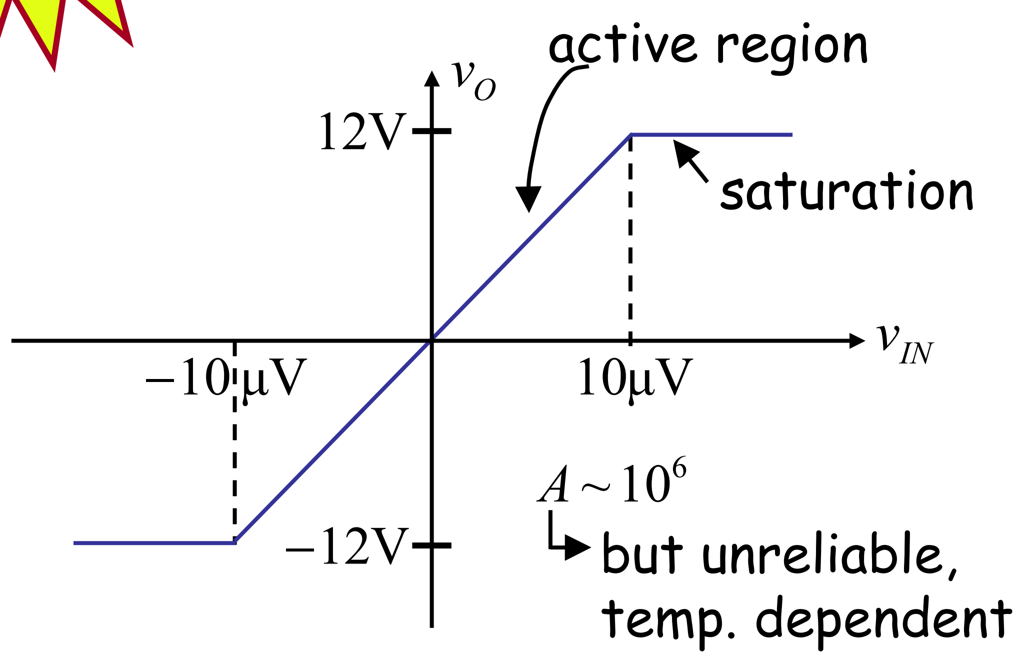
Circuit model (ideal):



i.e.
- ♦ ∞ input resistance
- ♦ *0* output resistance
- ♦ "*A*" virtually ∞
- ♦ No saturation

Using it…

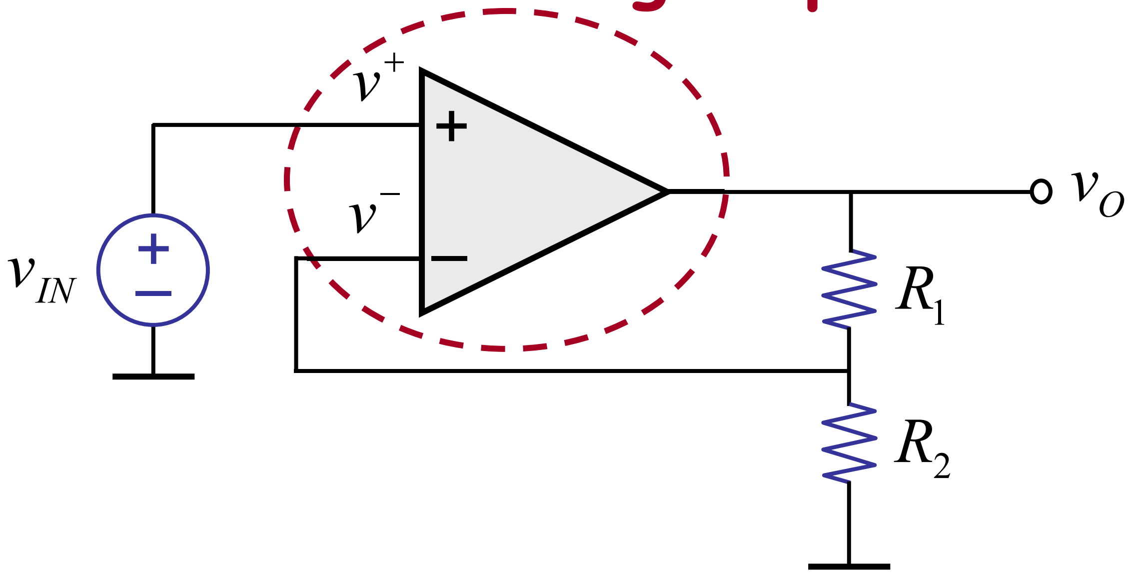




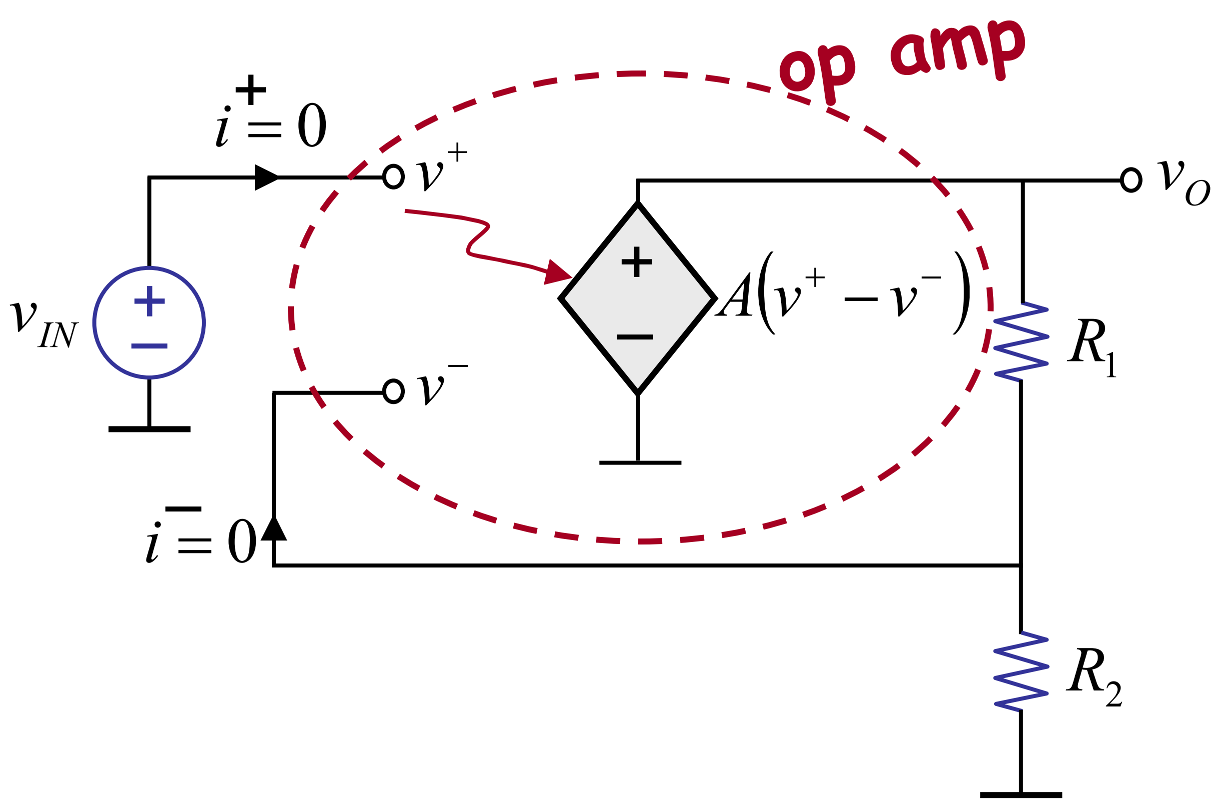
(Note: possible confusion with MOSFET saturation!)

Let us build a circuit…

Circuit: noninverting amplifier



Equivalent circuit model



Let us analyze the circuit:

Find v_O in terms of v_{IN}, etc.

$$v_O = A\left(v^+ - v^-\right)$$

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

$$v_O\left(1 + \frac{AR_2}{R_1 + R_2}\right) = Av_{IN}$$

$$v_O = \frac{Av_{IN}}{1 + \frac{AR_2}{R_1 + R_2}}$$

What happens when "A" is very large?

Let's see… When A is large

$$v_O = \frac{A v_{IN}}{\cancel{1} + \dfrac{A R_2}{R_1 + R_2}} \approx \frac{\cancel{A} v_{IN}}{\dfrac{\cancel{A} R_2}{R_1 + R_2}}$$

$$\approx v_{IN} \underbrace{\frac{(R_1 + R_2)}{R_2}}_{\text{gain}}$$

Suppose

$$A = 10^6$$
$$R_1 = 9R$$
$$R_2 = R$$

$$v_O = \frac{10^6 \cdot v_{IN}}{1 + \dfrac{10^6 R}{9R + R}}$$

$$= \frac{\cancel{10^6} \cdot v_{IN}}{\cancel{1} + \cancel{10^6} \cdot \dfrac{1}{10}}$$

Demo

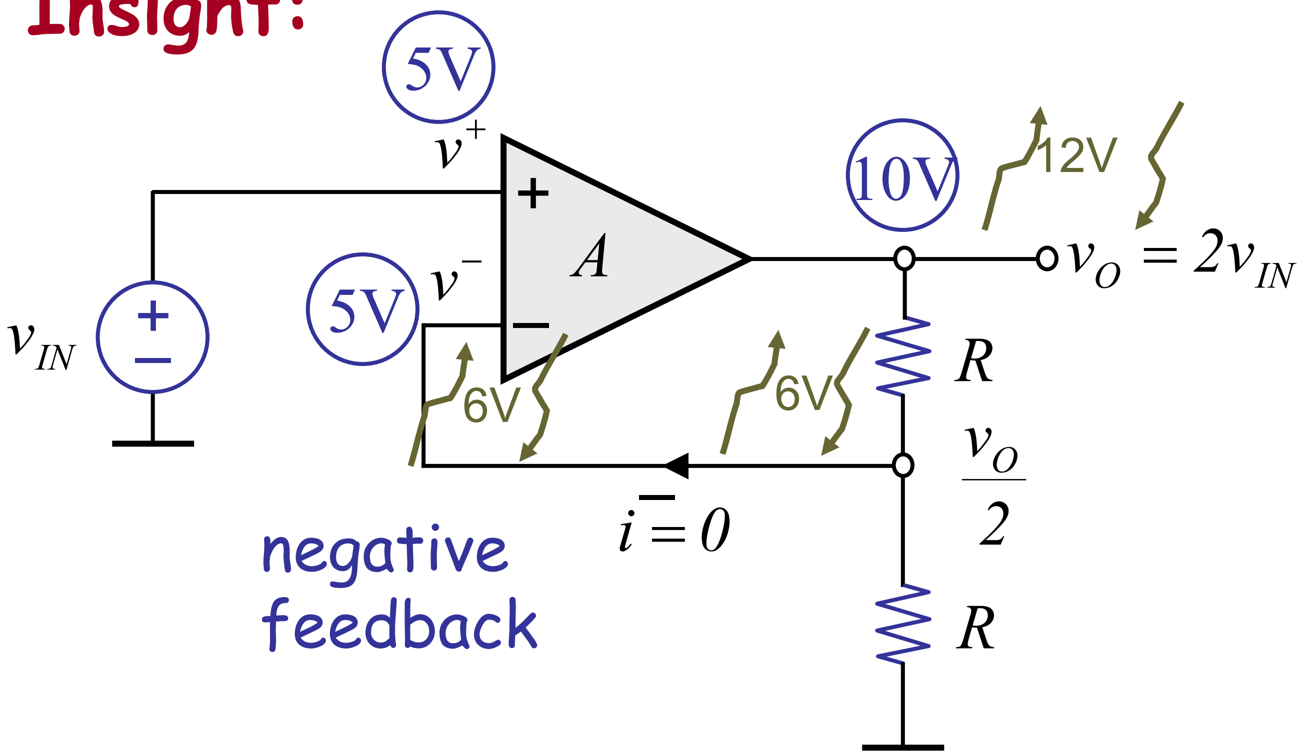
$$v_O \approx v_{IN} \cdot 10$$

Gain:

- determined by resistor ratio
- insensitive to A, temperature, fab variations

Why did this happen?

Insight:



e.g. $v_{IN} = 5V$

Suppose I perturb the circuit…

(e.g., force v_O momentarily to $12V$ somehow).

Stable point is when $v^+ \approx v^-$.

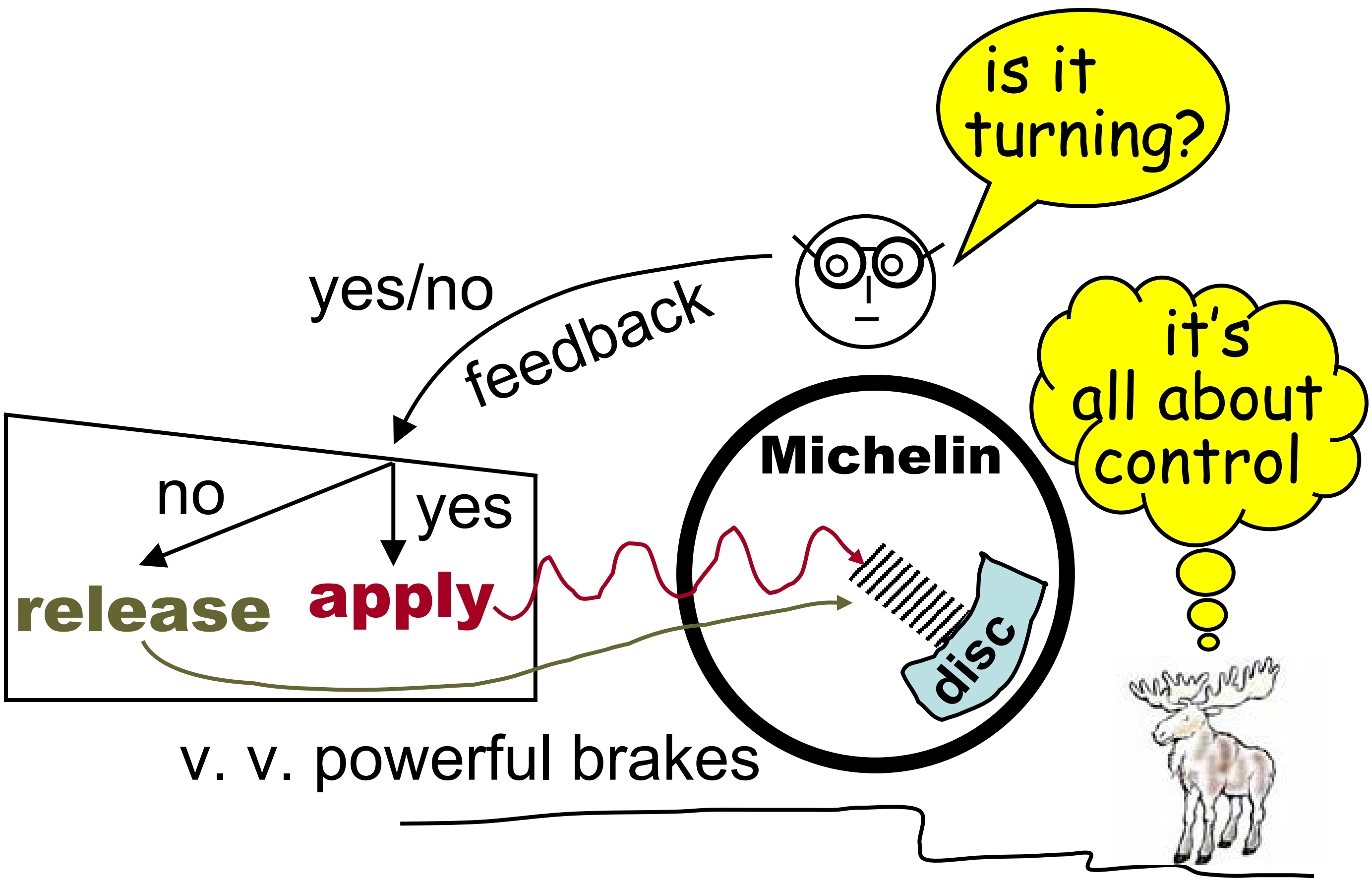
Key: negative feedback → portion of output fed to $-ve$ input.

e.g. Car antilock brakes

→ small corrections.

Question: How to control a high-strung device?

Antilock brakes



More op amp insights:

Observe, under negative feedback,

$$v^+ - v^- = \frac{v_O}{A} = \frac{\left(\frac{R_1 + R_2}{R_1}\right) v_{IN}}{A} \rightarrow 0$$

$$\boxed{v^+ \approx v^-}$$

We also know

$$\boxed{\begin{array}{l} i^+ \approx 0 \\ i^- \approx 0 \end{array}}$$

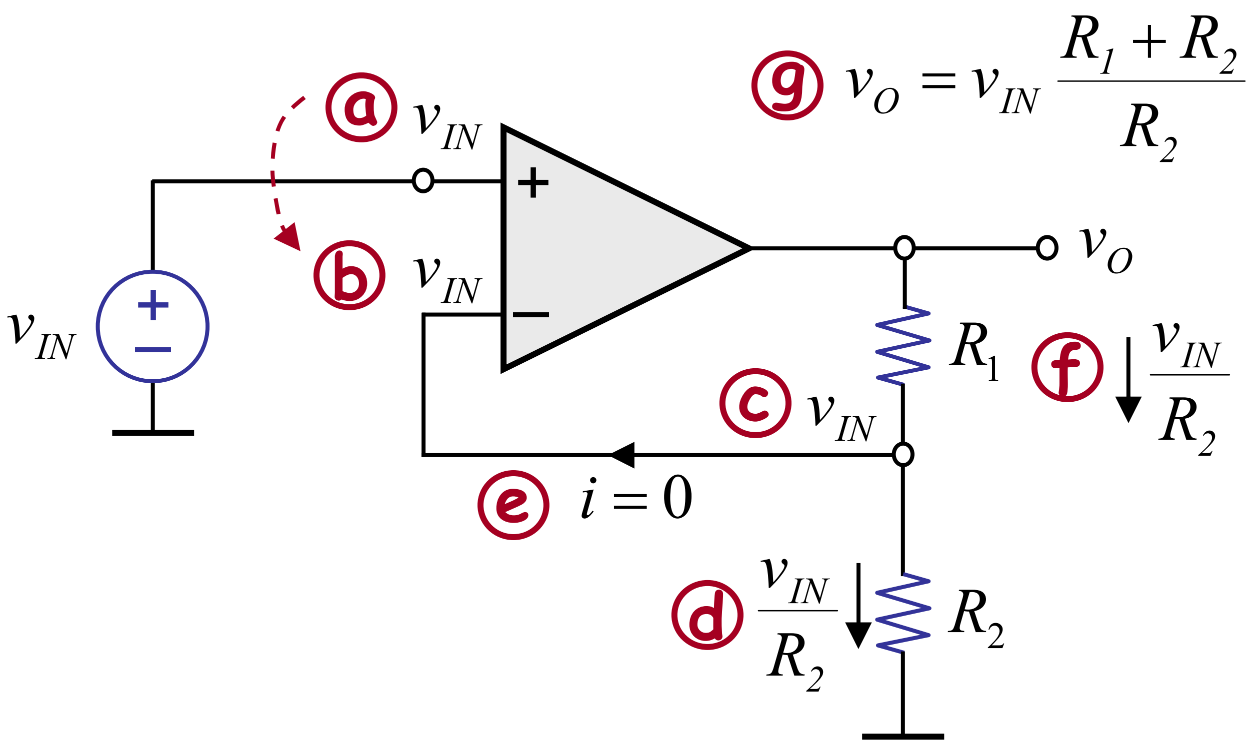
→yields an easier analysis method (under negative feedback).

Insightful analysis method under negative feedback

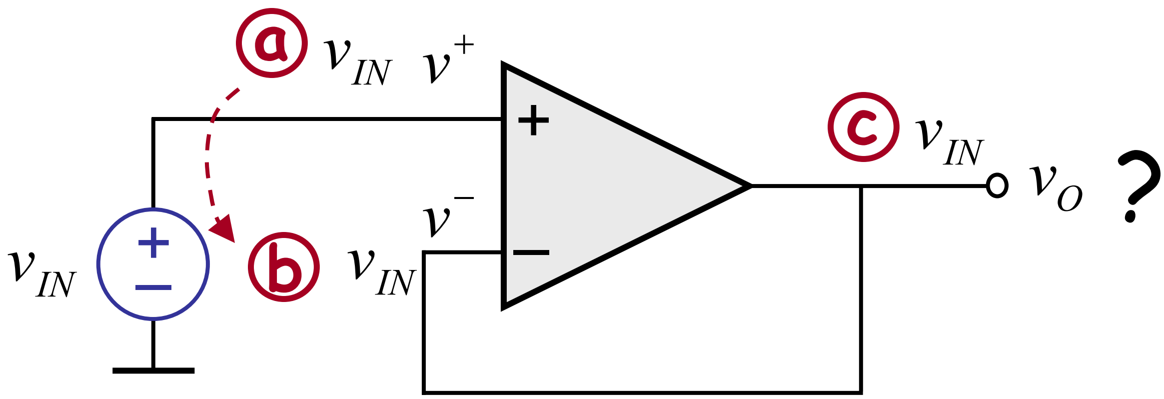
$$v^{+} \approx v^{-}$$

$$i^{+} \approx 0$$

$$i^{-} \approx 0$$



Question:



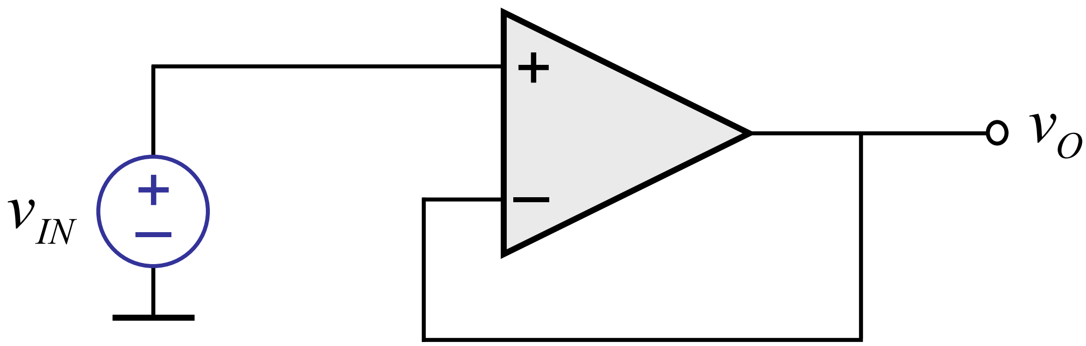
$$v_O \approx v_{IN}$$

or $$v_O = v_{IN} \frac{R_1 + R_2}{R_2}$$

with $R_1 = 0$

$R_2 = \infty$

Why is this circuit useful?



$$v_O \approx v_{IN}$$

Buffer

voltage gain = *1*

input impedance = ∞

output impedance = *0*

current gain = ∞

power gain = ∞