The Operational Amplifier Abstraction
Review

- MOSFET amplifier — 3 ports

   + -- +
   v_i   v_o

   power port

   + -- +
   v_s

   output port

   -

   input port

- Amplifier abstraction

   + -- +
   v_i

   Function of v_i

   -

   v_o

   -

   -

   -

   + -- +
   v_i

   Function of v_i

   -

   -
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:

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Circuit model (ideal):

\[ i = 0 \]
\[ v^+ \]
\[ v \]
\[ v^- \]
\[ i = 0 \]

\[ A \rightarrow \infty \]

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
Let us analyze the circuit:

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

\[
v_O = A(v^+ - v^-)
\]

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

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

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

What happens when “\( A \)” is very large?
Let’s see... When $A$ is large

$$v_O = \frac{Av_{IN}}{I + \frac{AR_2}{R_1 + R_2}} \approx \frac{Av_{IN}}{AR_2} \approx v_{IN} \frac{(R_1 + R_2)}{R_2}$$

Suppose

$A = 10^6$

$R_1 = 9R$

$R_2 = R$

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

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

Gain:

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

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Why did this happen?

Insight:

e.g. \( v_{IN} = 5\text{V} \)

Suppose I perturb the circuit...
(e.g., force \( v_O \) momentarily to 12V somehow).

Stable point is when \( v^+ \approx v^- \).

Key: negative feedback \( \rightarrow \) portion of output fed to \(-ve\) input.
   e.g. Car antilock brakes
   \( \rightarrow \) small corrections.
Question: How to control a high-strung device?

Antilock brakes

is it turning?

it's all about control

yes/no feedback

no yes

release apply

v. v. powerful brakes

Michelin disc

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More op amp insights:

Observe, under negative feedback,

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

\[ v^+ \approx v^- \]

We also know

\[ i^+ \approx 0 \]
\[ i^- \approx 0 \]

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

\[ v^+ \approx v^- \]
\[ i^+ \approx 0 \]
\[ i^- \approx 0 \]

\[ v_O = v_{IN} \frac{R_1 + R_2}{R_2} \]

\[ v = \frac{v_{IN}}{R_2} \]

\[ i = 0 \]

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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?

Buffer

\[ v_O \approx v_{IN} \]

- Voltage gain = 1
- Input impedance = \( \infty \)
- Output impedance = 0
- Current gain = \( \infty \)
- Power gain = \( \infty \)