The Operational Amplifier

- The **operational amplifier** ("op amp") is a basic building block used in circuits.
  - Its behavior is modeled using a dependent source.
  - When combined with resistors, capacitors, and inductors, it can perform various useful functions:
    - **amplification/scaling** of an input signal
    - **sign changing** (inversion) of an input signal
    - **addition** of multiple input signals
    - **subtraction** of one input signal from another
    - **integration** (over time) of an input signal
    - **differentiation** (with respect to time) of an input signal
    - **analog filtering**
    - **nonlinear functions** like exponential, log, sqrt, etc
  - Isolate input from output; allow cascading
Op Amp Terminals

- 3 signal terminals: 2 inputs and 1 output
- IC op amps have 2 additional terminals for DC power supplies
- Common-mode signal = \((v_1 + v_2)/2\)
- Differential signal = \(v_1 - v_2\)

![Op Amp Diagram]

- **Inverting input** \(v_2\)
- **Non-inverting input** \(v_1\)
- **Positive power supply**
- **Negative power supply**
- **Output** \(v_0\)
Model for Internal Operation

- $A$ (or $A_d$ or $A_{OL}$) is differential gain or open loop gain
- Ideal op amp
  
  \[ A \to \infty \]
  \[ R_i \to \infty \]
  \[ R_o = 0 \]
  
  - Common mode gain = 0

  \[
  v_{cm} = \frac{(v_1 + v_2)}{2}, v_d = v_1 - v_2
  \]
  \[
  v_o = A_{cm} v_{cm} + A_d v_d
  \]
  \[
  Since \ v_o = A(v_1 - v_2), A_{cm} = 0
  \]
Model and Feedback

- Negative feedback
  - connecting the output port to the negative input (port 2)
- Positive feedback
  - connecting the output port to the positive input (port 1)
- Input impedance: $R_i$ looking into the input terminals
- Output impedance: Impedance in series with the output terminals

Circuit Model

\[ A(v_1 - v_2) \]
Op-Amp and Use of Feedback

A very high-gain differential amplifier can function in an extremely linear fashion as an operational amplifier by using negative feedback.

\[ V_0 \approx V_{IN} \cdot \frac{R_1 + R_2}{R_1} \]

We can show that for \( A \to \infty \) and \( R_i \to \infty \),

\[ V_0 \approx V_{IN} \cdot \frac{R_1 + R_2}{R_1} \]

Stable, finite, and independent of the properties of the OP AMP!
Summing-Point Constraint

- Check if we are under negative feedback
  - Small $v_i$ result in large $v_o$
  - Output $v_o$ is connected to the inverting input to reduce $v_i$
  - Resulting in $v_i=0$
- Summing-point constraint
  - $v_1 = v_2$
  - $i_1 = i_2 = 0$
- Virtual short circuit
  - Not only voltage drop is 0 (which is short circuit), input current is 0
  - This is different from short circuit, hence called "virtual" short circuit.
Ideal Op-Amp Analysis Technique

Applies only when Negative Feedback is present in circuit!

Assumption 1: The potential between the op-amp input terminals, $v_{(+)} - v_{(-)}$, equals zero.

Assumption 2: The currents flowing into the op-amp’s two input terminals both equal zero.

EXAMPLE

No Potential Difference

No Currents

Vin → Op-Amp → Vo
Voltage Follower

\[ R_2 = 0 \]
\[ R_1 \to \infty \]

\[ i = \frac{(v_0 - v_2)}{R_2} = \frac{(v_2 - 0)}{R_1} \]

\[ A = \frac{v_o}{v_{in}} = \frac{(R_1 + R_2)}{R_1} = 1 + \frac{R_2}{R_1} = 1 \]