EE40
Lecture 23
Venkat Anantharam

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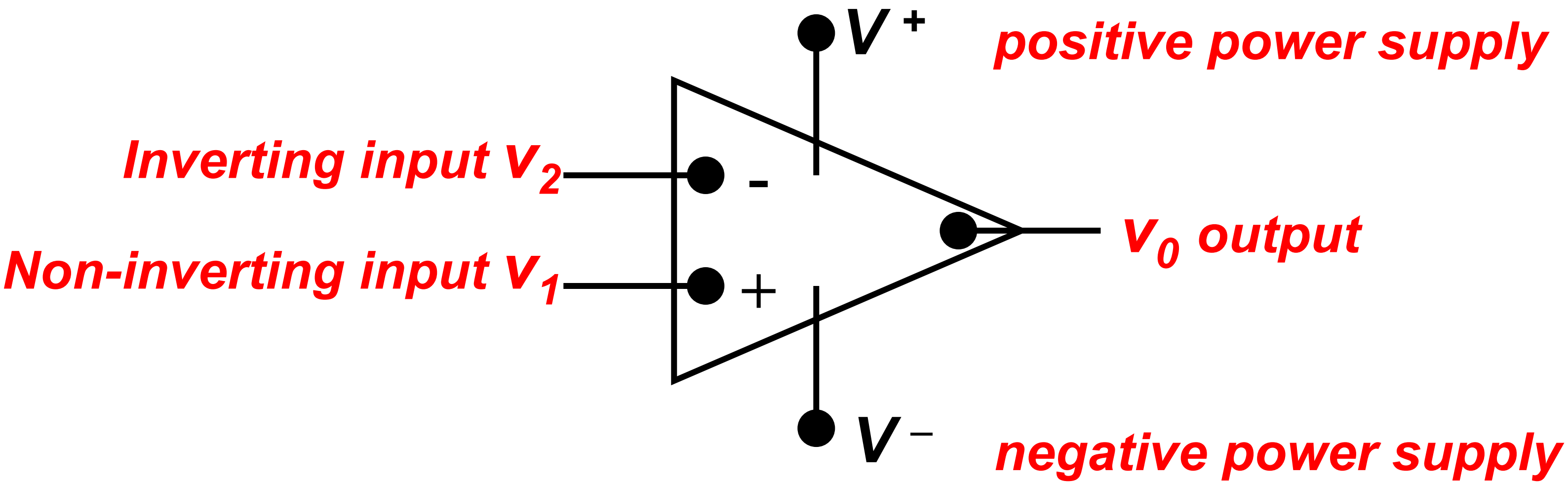
Reading: Chap. 14: Operational Amplifiers.

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



Model for Internal Operation

- A (or A_d or A_{OL}) is differential gain or open loop gain
- Ideal op amp

$$A \to \infty$$

$$R_i \to \infty$$

$$R_o = 0$$

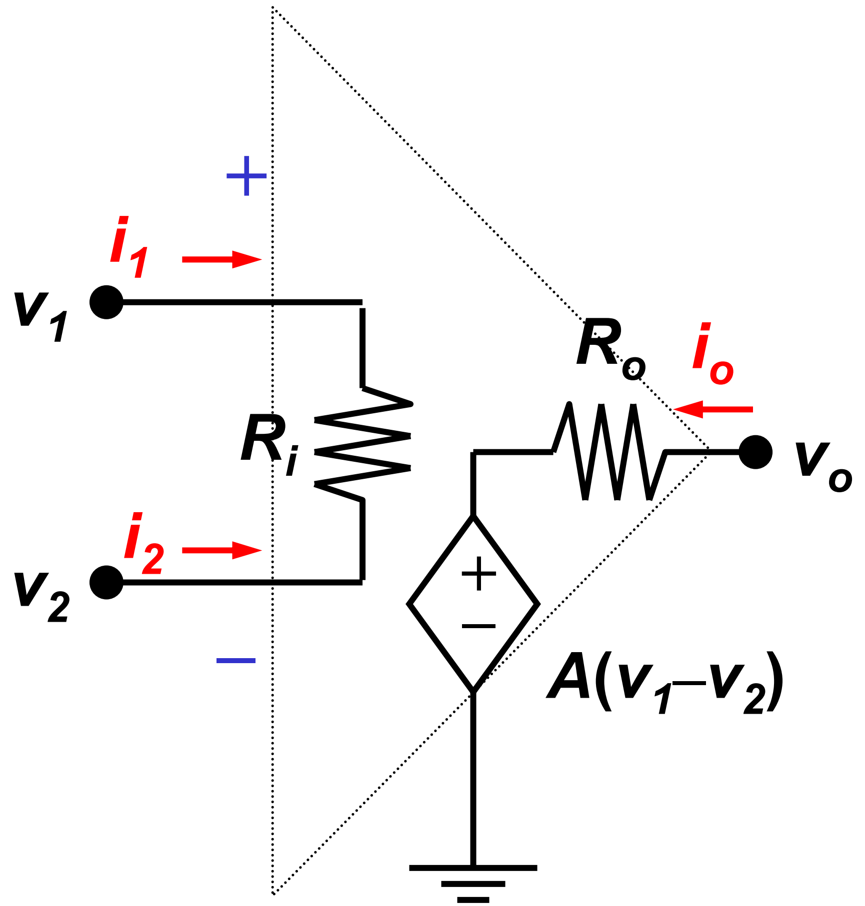
  – Common mode gain = 0

$$v_{cm} = \frac{(v_1 + v_2)}{2} \quad , v_d = v_1 - v_2$$

$$v_o = A_{cm} v_{cm} + A_d v_d$$

$$Since \quad v_o = A(v_1 - v_2) \quad , A_{cm} = 0$$

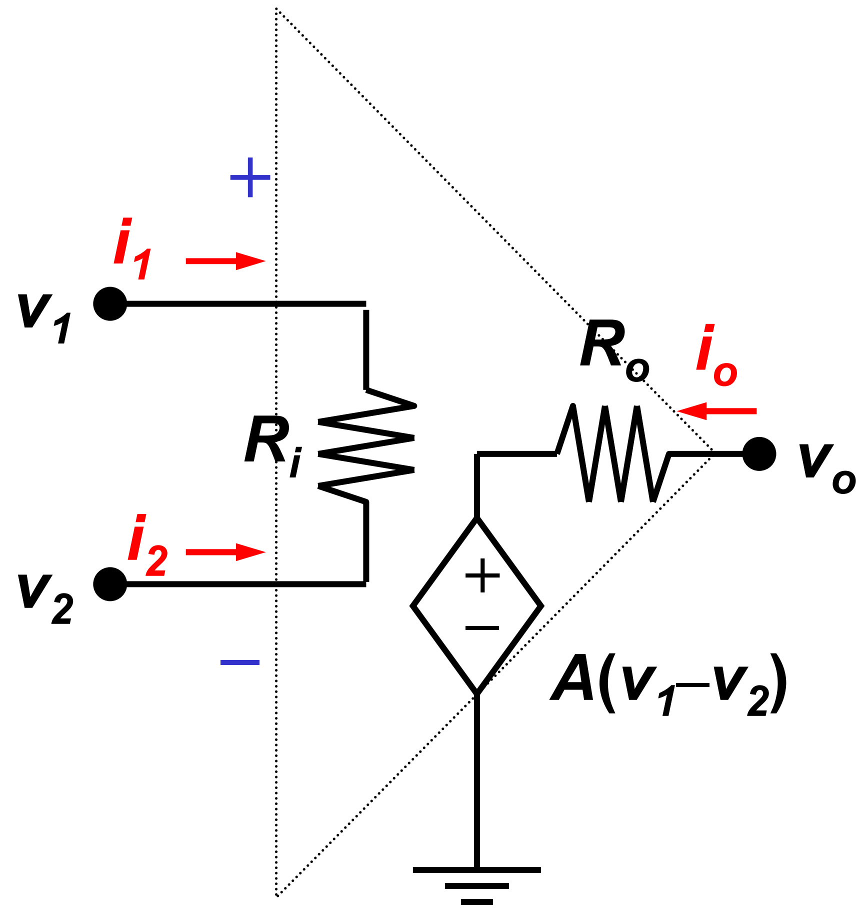
- Circuit Model



Model and Feedback

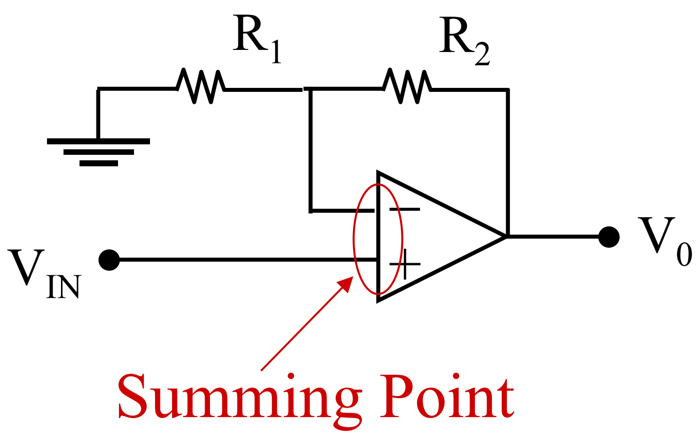
- Negative feedback
  - connecting the output port to the negative input (port 2)
- Positive feedback
  - connecting the output port to the positive input (port 1)
- Input impedance: R looking into the input terminals
- Output impedance: Impedance in series with the output terminals

- Circuit Model



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.



Negative feedback $\Rightarrow$ **Stabilizes** the output

We can show that that for $A \rightarrow \infty$ and $R_i \rightarrow \infty$,

$$V_0 \cong V_{IN} \cdot \frac{R_1 + R_2}{R_1}$$

Stable, finite, and independent of the properties of the OP AMP !

Summing-Point Constraint

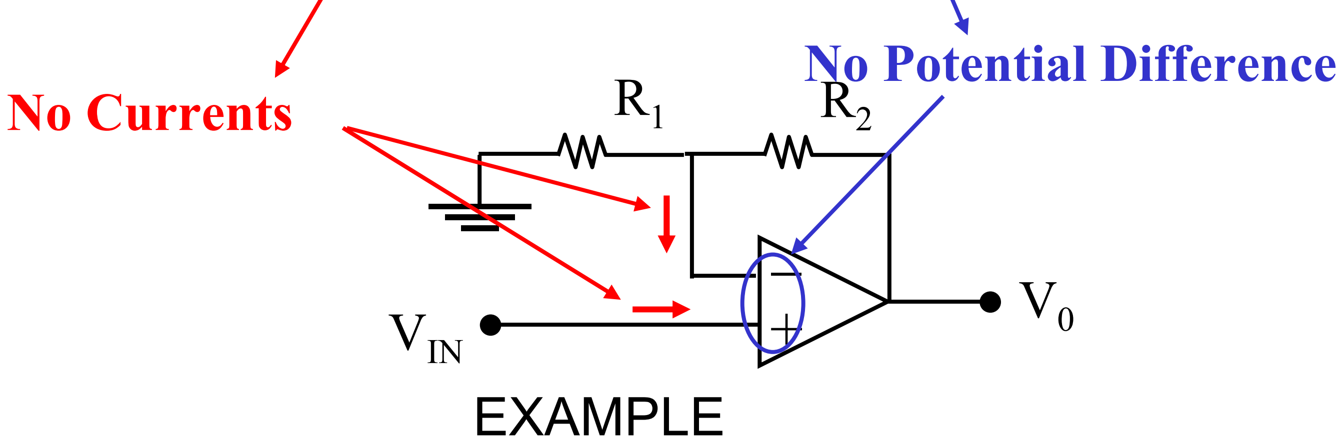
- Check if we are under negative feedback
  - Small v_i result in large v_o
  - Output v_o is connected to the inverting input to reduce v_i
  - Resulting in $v_i=0$
- Summing-point constraint
  - $v_1 = v_2$
  - $i_1 = i_2 = 0$
- Virtual short circuit
  - Not only voltage drop is 0 (which is short circuit),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

Ideal Op-Amp Analysis Technique

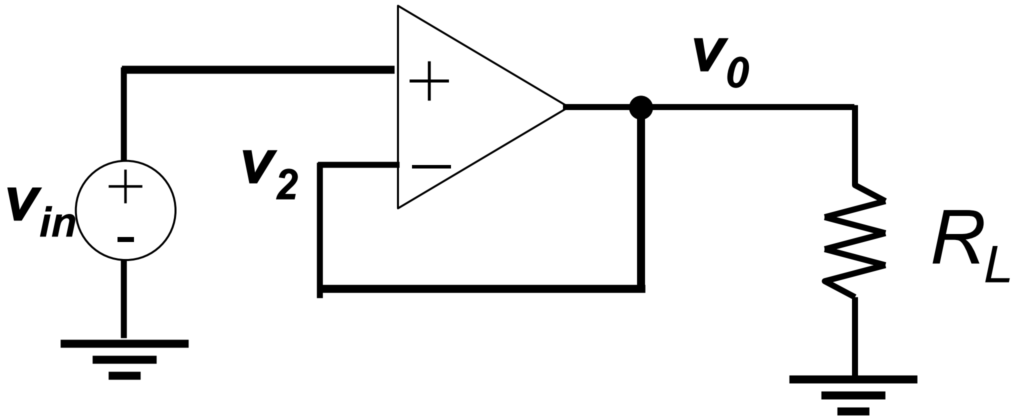
Applies only when Negative Feedback is present in circuit!

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.



Voltage Follower



$$R_2 = 0$$

$$R_1 \to \infty$$

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

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