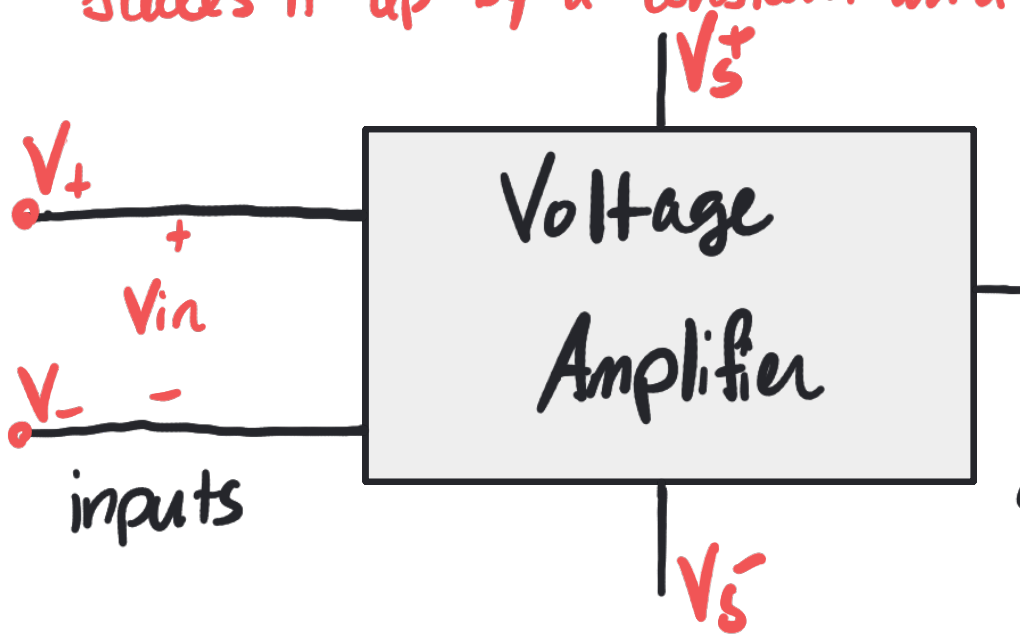
Intro to ECSE Class 14: Operational Amplifiers Pt.1

I] Operational Amplifier (op-amp) Basics

- what is an operational amplifier?
  - Voltage amplifier: takes an input voltage, scales it up by a constant and outputs it



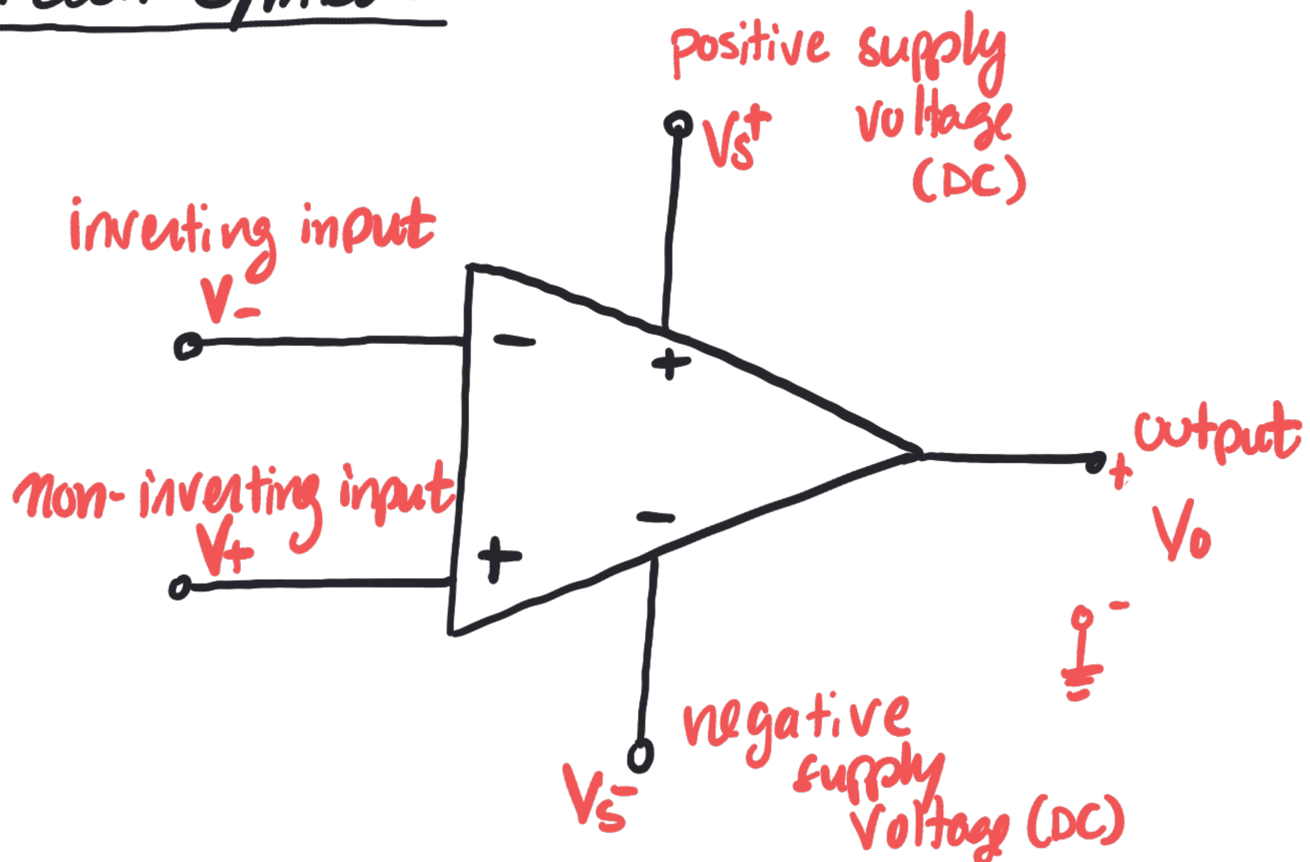
$V_{in} = V_+ - V_-$

$V_{out} = A\ V_{in} = A(V_+ - V_-)$ (A ↑ gain)

$A = \frac{V_{out}}{V_{in}} = \text{gain}$

- V_s^+ and V_s^-: Supply voltages: give the op-amp the power it needs to amplify a signal
  - you must power your op-amp for it to work (V_s^+ and V_s^- must be connected)

Circuit Symbol



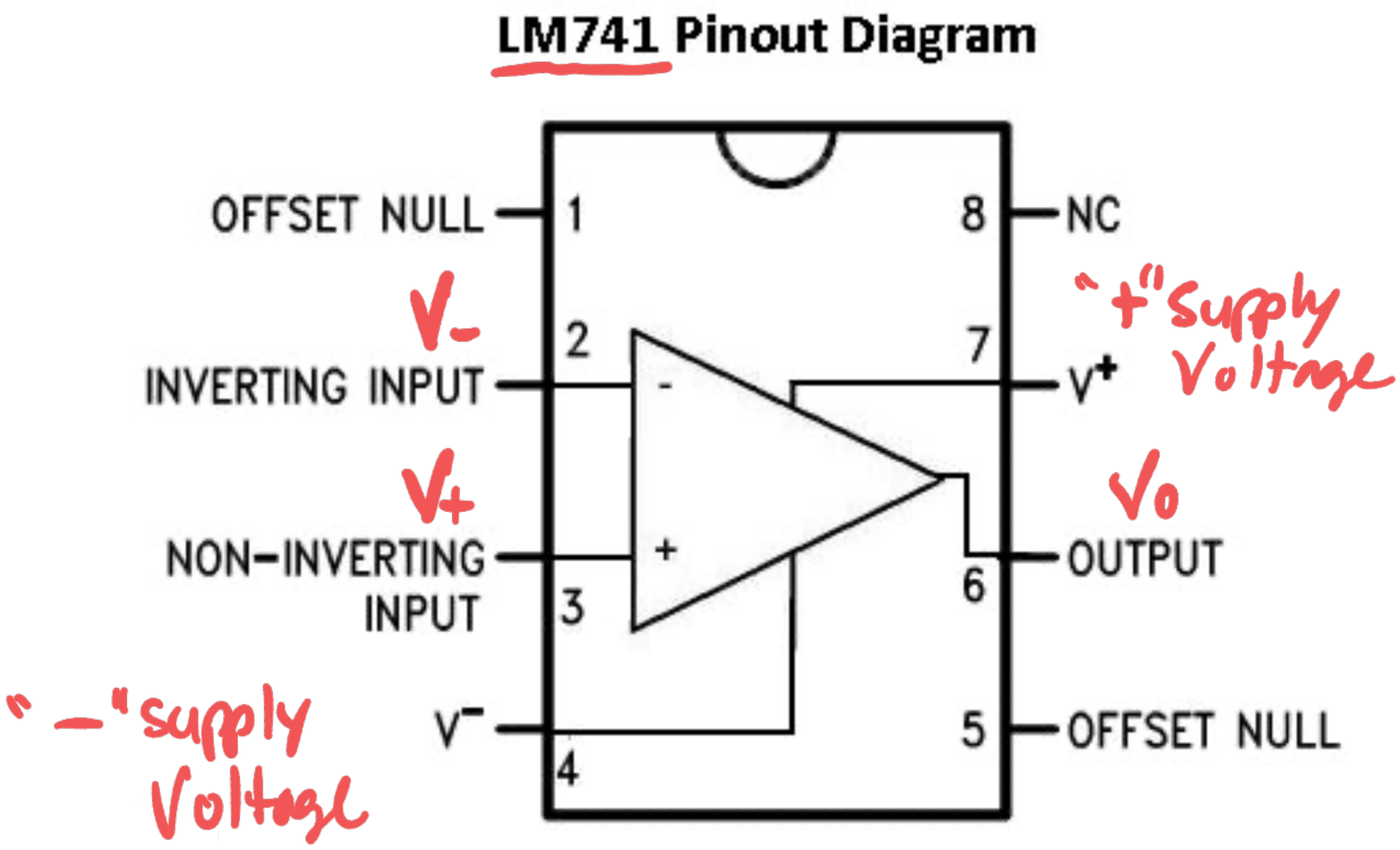
- Inputs/Output: $V_{in} = V_+ - V_- \rightarrow V_o = A V_{in}$
  Input signal at V_+ and V_- and measure V_o as the output

- Voltage/Power Supply: typically $V_S^- = -V_S^+$ ($V_S^+ = +5V, +9V$; $V_S^- = -5V, -9V$)
  - some op-amps will allow $V_S^- = 0V$, but you need to check the datasheet

- LTspice: use UniversalOpAmp2 → it causes fewer problems

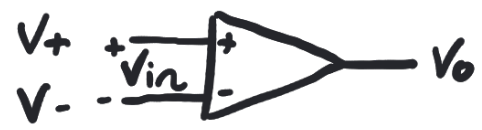
Pinout Diagram

- Specifies which IC (integrated circuit) pins correspond to which terminals on the circuit symbol. Not the same for all op-amps - check the datasheet

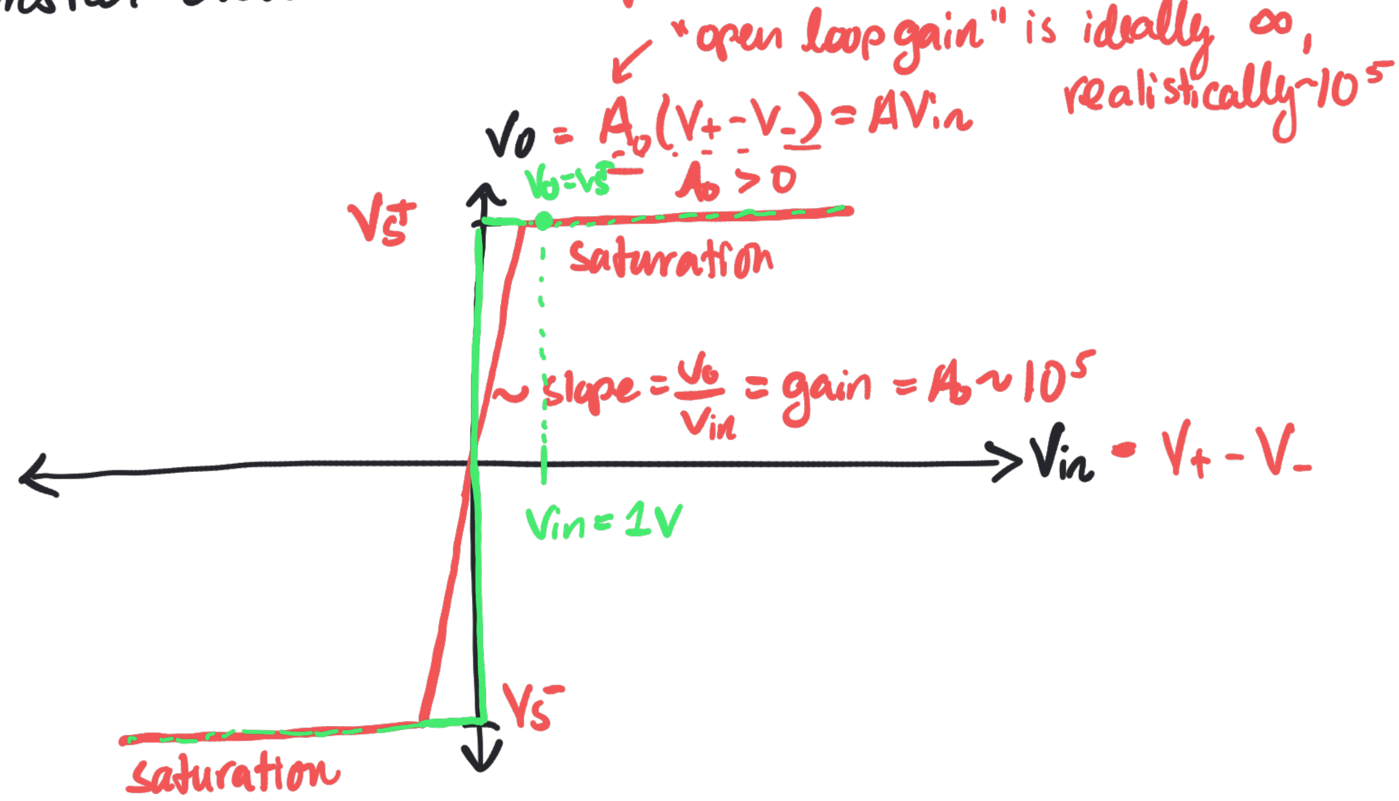


Transfer Characteristic of an open-loop op-amp

- open-loop: no feedback loop

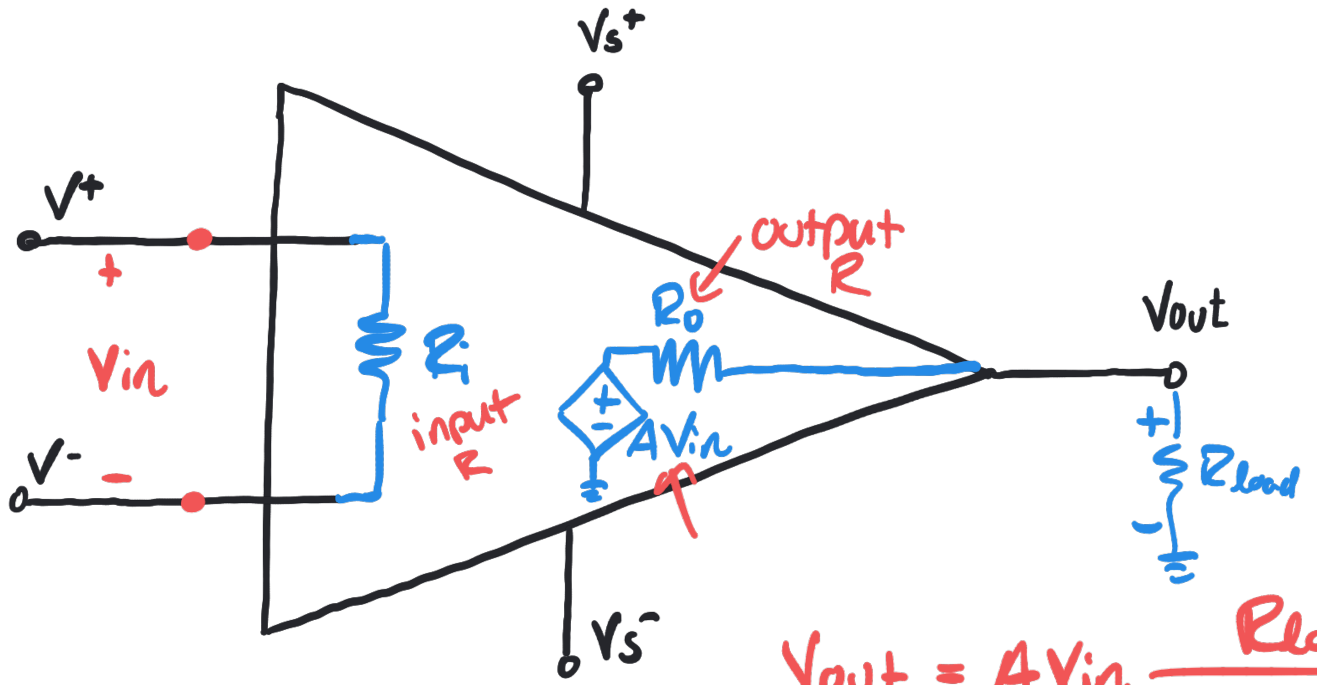


- Transfer characteristic: plots Vout vs. Vin



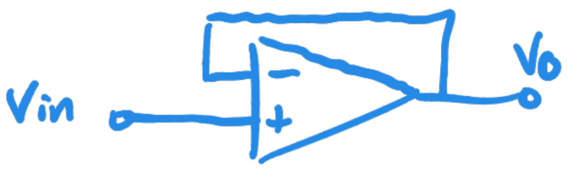
- Output follows $A_0 \times V_{in}$ until we reach V_s^+ or V_s^-, then we say the op-amp "saturates"
- Saturation: we cannot output voltages larger than V_s^+ or smaller than V_s^-
- What is the function of an open-loop op-amp?
  - it functions as a zero-crossing detector (comparator)
  - it compares V_+ to V_- (recall $V_{in} = V_+ - V_-$)
    - if $V_+ > V_-$, $V_{in} > 0$, $V_o = AV_{in} \rightarrow V_s^+$ (saturation)
    - if $V_+ < V_-$, $V_{in} < 0$, $V_o = AV_{in} \rightarrow V_s^-$ (saturation)
  - This is a decision-making circuit

The Ideal Op-Amp Model

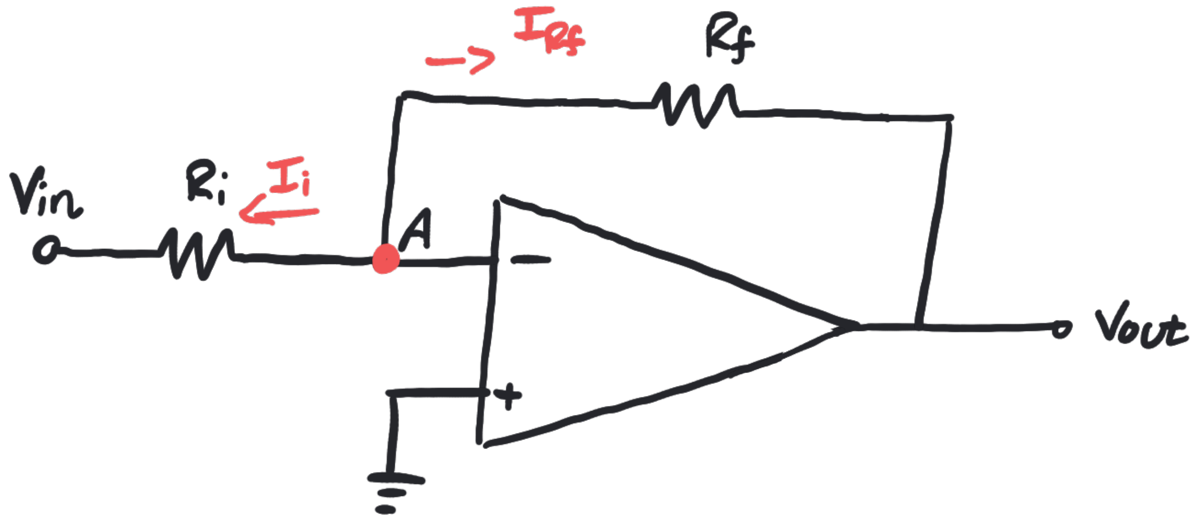


$$V_{out} = A V_{in} \frac{R_{load}}{R_o + R_{load}}$$

- Input Resistance (R_i): resistance that Vin "sees"
  - Ideally: $R_i = \infty$
  - Consequence: Golden Rule #1: no current ever flows into the "+" or "−" terminals
  - In Reality: $R_i \sim 2M\Omega$ (check the data sheet)
- Output Resistance (R_o): resistance that output terminal "sees"
  - Ideally: $R_o = 0$
  - In Reality: $3\Omega < R_o < 35\Omega$ (check datasheet)
- Open-loop gain (A_o): Voltage gain of an open-loop op-amp
  - Ideally: $A_o = \infty$
  - Consequence: Golden Rule #2: when an op-amp is configured with negative feedback, $V_+ = V_-$
  - In Reality: $A_o \sim 10^5$ good enough for Golden Rule #2 to hold
- Negative feedback: when you connect V_o to V_-: stabilizes the circuit



Example: Using the properties of an ideal op-amp, determine Vout in terms of Vin



- Assume the op-amp is powered
- Hint #1: the op-amp is configured in a negative feedback loop (can use Golden Rule #2)
- Hint #2: Use KCL at node A

KCL @ A: $I_i + I_{Rf} = 0$ ← Golden Rule #2

$$I_i = \frac{V_A - V_{in}}{R_i} = -\frac{V_{in}}{R_i}, \quad V_A \to 0$$

$$I_{Rf} = \frac{V_A - V_o}{R_f} = -\frac{V_o}{R_f}$$

$$-\frac{V_{in}}{R_i} - \frac{V_o}{R_f} = 0$$

$$V_o = -\frac{R_f}{R_i} V_{in}$$

inverting amplifier

- #1: what is $\left(-\frac{R_f}{R_i}\right)$? the gain
- #2: we reduced the gain from $A_0 = 10^5$ to $-\frac{R_f}{R_i}$ by using negative feedback

Upcoming Assignment Due Dates

1. Mid-Semester Survey — Late Due Date 10/19
2. Lab 02 Parts A & B — Due Date 10/19
3. Problem Set 06 — Due Date 10/19