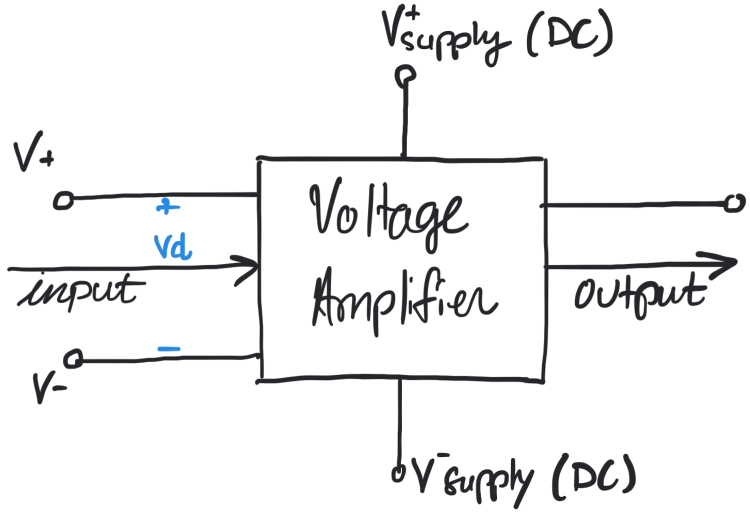
Intro to ECSE : Operational Amplifiers (op-amps)

1) What is a voltage amplifier?

- for this class, a "black box" that takes an input voltage and scales it up, then outputs it.

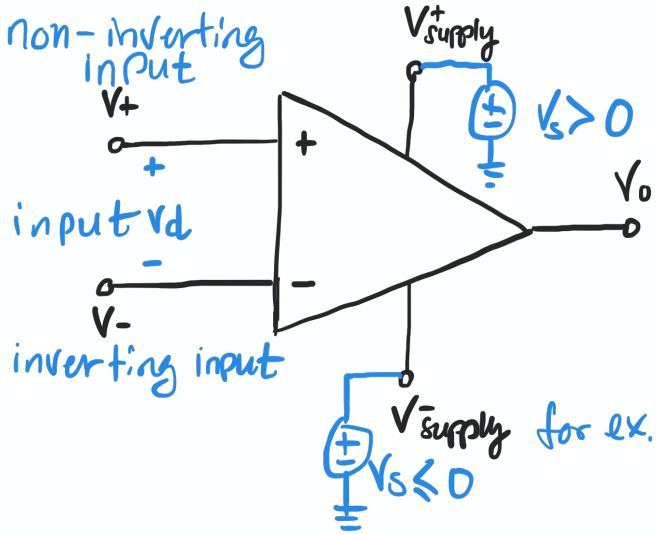


$V_o = A(V_+ - V_-) = AV_d$

$A = V_o / V_d$

+ The supply voltages provide the power needed to amplify the signal.

2) Circuit Symbol

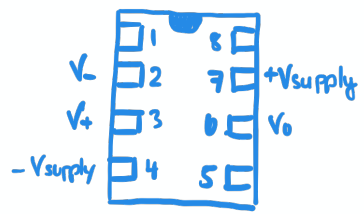


★ In LTspice: use Universal op-amp2 (causes fewest problems)

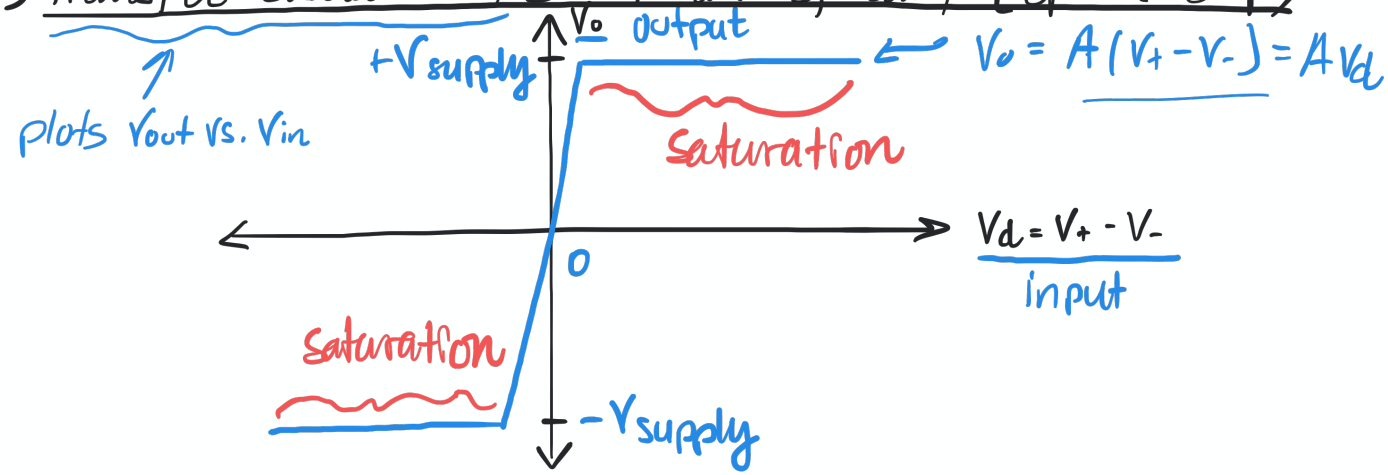
3) Pinout Diagram – in the data sheet

- specifies which IC pins correspond to the op-amp terminals

uA741 Pinout diagram



4) Transfer Characteristic of an op-amp (open loop)



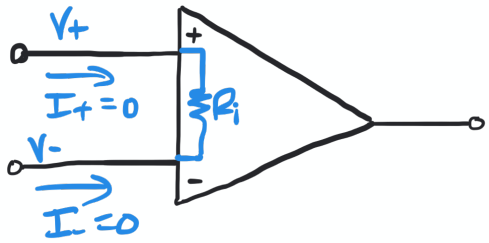
$V_o = A(V_+ - V_-) = A V_d$

- Saturation: V_o cannot be larger than $+V_{supply}$ or more negative than $-V_{supply}$: $-V_{supply} \leq V_o \leq +V_{supply}$
- What is the function of an open-loop op-amp?
  - comparator: compares V_+ to V_- : if $V_+ > V_- \rightarrow V_o = +V_{supply}$
  - decision-making circuit — $V_+ < V_- \rightarrow V_o = -V_{supply}$
  - no feedback loop

5) Characteristics of an ideal op-amp

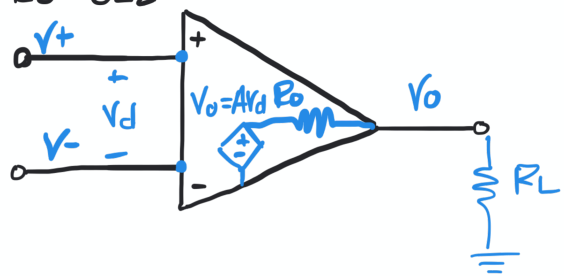
a) input resistance: ideally $R_i = \infty$

- no current even flows into the "+" or "−" terminal
- in reality: $R_i \sim 2M\Omega$



b) output resistance: ideally $R_o = 0\Omega$

- in reality: $3\Omega < R_o < 35\Omega$



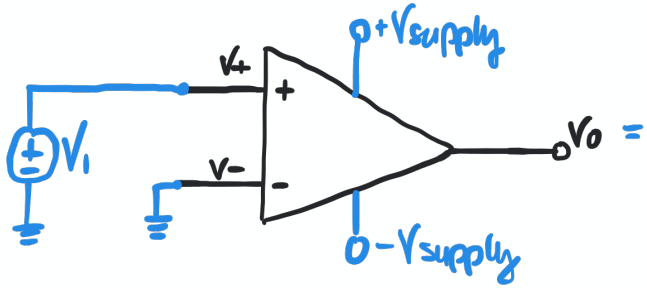
c) open loop gain: ideally $A_o = \infty$

- in reality $A_o \sim 10^5$
- $V_o = A_o(V_+ - V_-)$ → a very large A_o ensures that $V_+ = V_-$ when the op-amp is in a negative feedback loop.

finite ↑ infinite ↑ ~ 0

6) Comparator

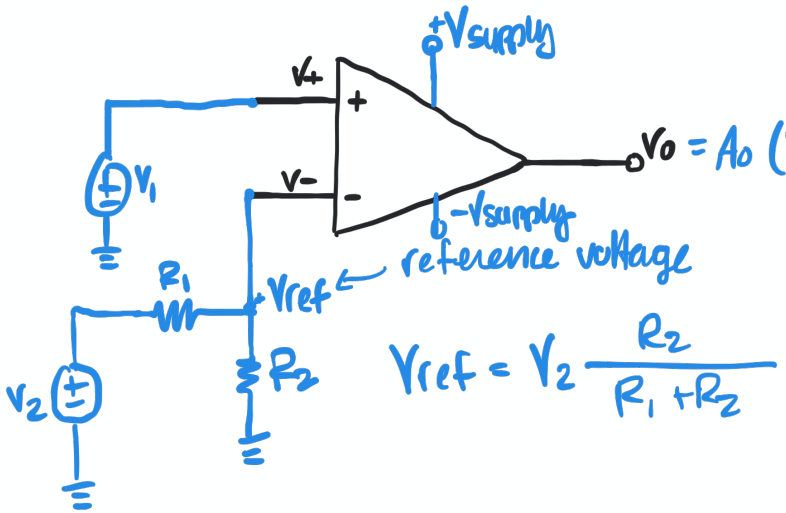
a) Zero-crossing detector



$V_o = A_o(V_+ - V_-) = A_o V_1 \rightarrow V_o = \begin{cases} +V_{supply} & \text{if } V_1 > 0 \\ -V_{supply} & \text{if } V_1 < 0 \end{cases}$

due to $-V_{supply} \leq V_o \leq V_{supply}$

b) comparator w/ non-zero reference voltage

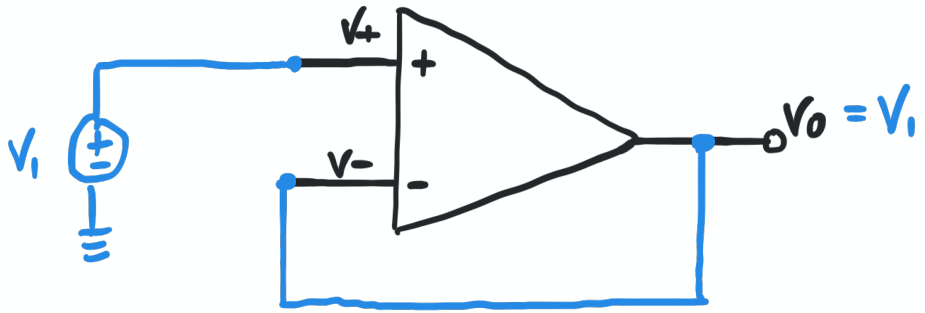


$V_o = A_o(V_+ - V_-) = A_o(V_1 - V_{ref})$

$V_{ref} = V_2 \dfrac{R_2}{R_1 + R_2}$

$V_o = \begin{cases} +V_{supply} & \text{if } V_1 > V_{ref} \\ -V_{supply} & \text{if } V_1 < V_{ref} \end{cases}$

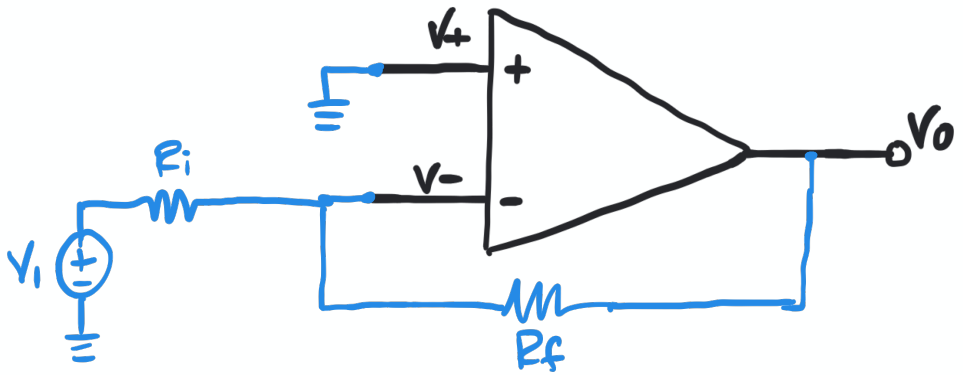
7) Voltage Follower (Buffer)



- outputs input voltage : gain = $\frac{V_o}{V_1} = 1$ unity gain

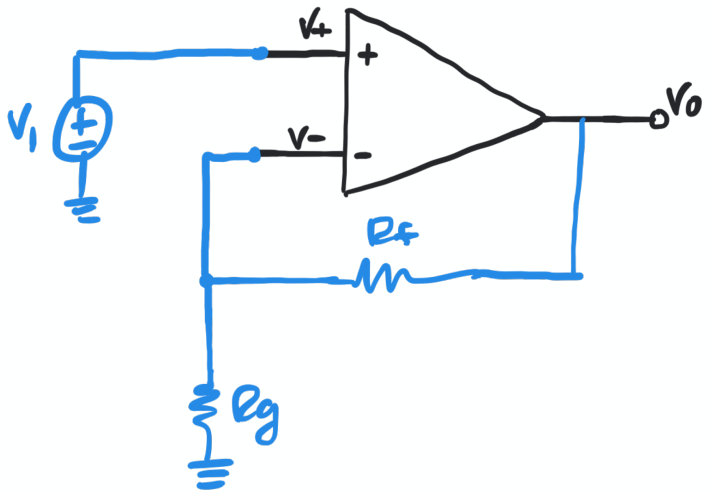
- why? · isolating circuits
  · maximum voltage transfer between mismatched resistances

8) Inverting Amplifier



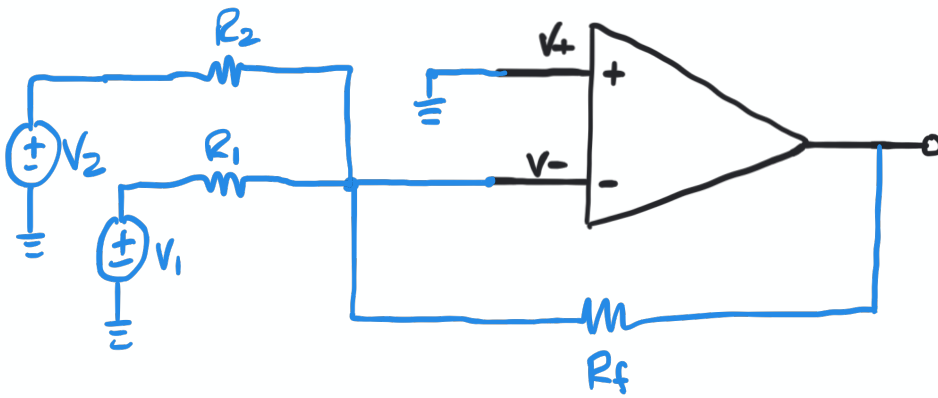
- Amplifies V_i by a factor $\frac{R_f}{R_i}$ and inverts it (multiplies by -1)
- What is gain if $R_f = 10k\Omega$, $R_i = 1k\Omega$? $A = -\frac{10k\Omega}{1k\Omega} = \underline{-10}$
- If $V_i = 0.5V$, what is V_o? $V_o = AV_i = (-10)\cdot(0.5V) = \underline{-5V}$ (A: gain)

9) Non-Inverting Amplifier



- $V_o = \left(1 + \frac{R_f}{R_g}\right) V_i$
- $A = \frac{V_o}{V_i} = \left(1 + \frac{R_f}{R_g}\right)$
- does not invert the signal

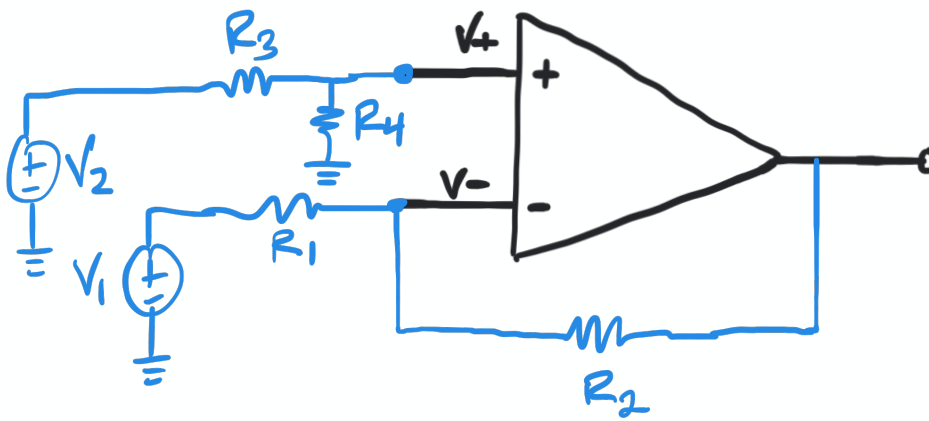
10) Inverting (Weighted) Summer



$$V_o = -\frac{R_f}{R_1}V_1 - \frac{R_f}{R_2}V_2$$

weighted sum of V_1 and V_2

11) Difference Amplifier (Subtractor)



if $R_1 = R_3$ and $R_2 = R_4$

$$V_o = \frac{R_2}{R_1}(V_2 - V_1)$$

- amplifies the difference between V_2 and V_1