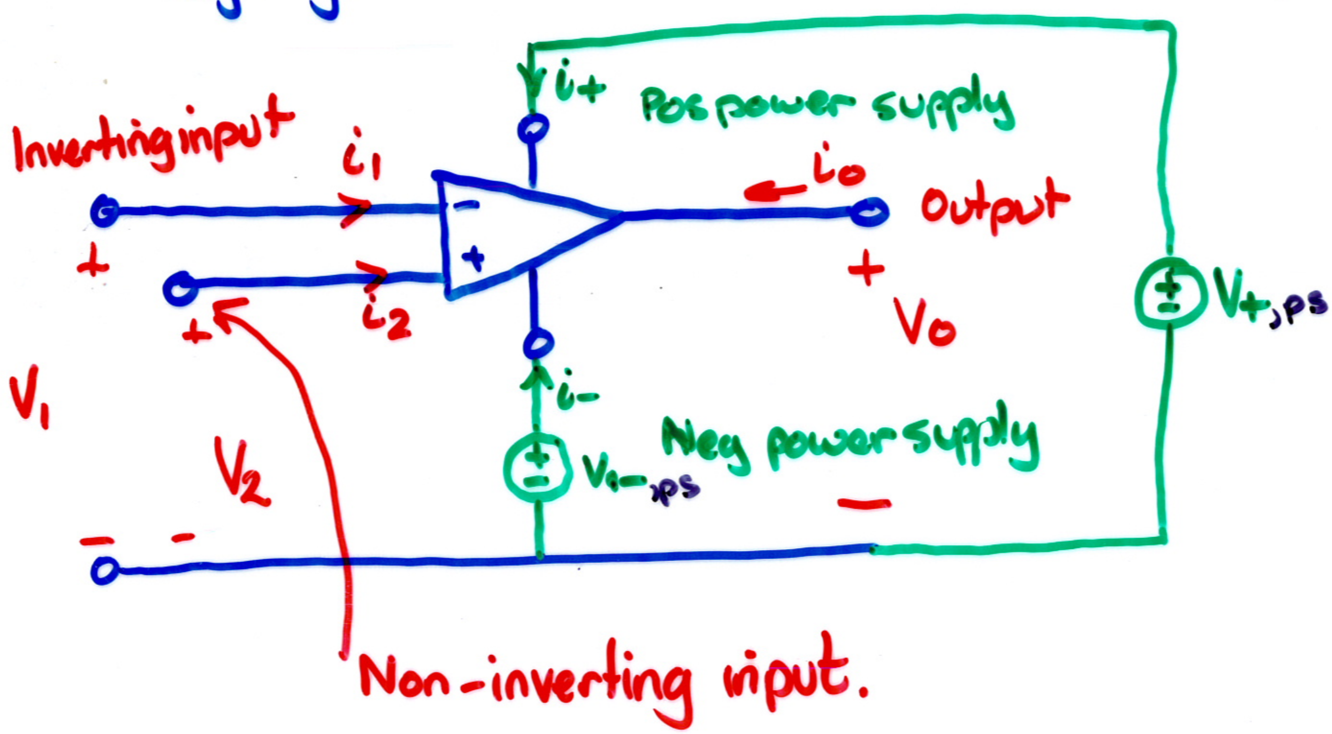
OPERATIONAL AMPLIFIERS

- an important integrated circuit for analog cct design
- originally designed for analog computation
- Simply speaking, a very good voltage amplifier

CHAPTER 6: OPERATIONAL AMPLIFIERS (OP-AMPS)

- high gain active circuit element (Fig. 6.3-2)



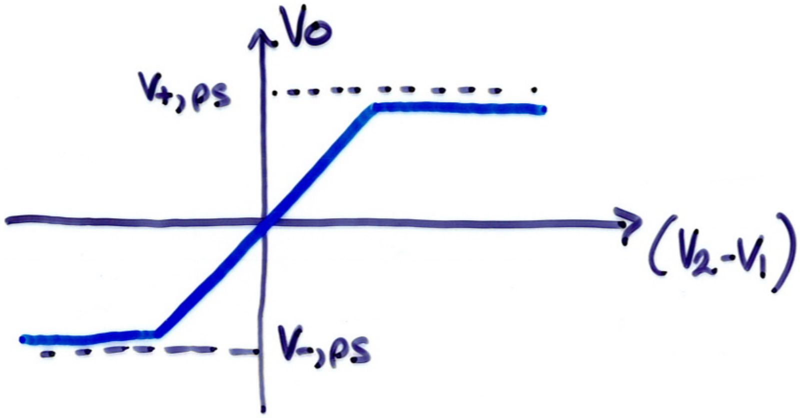
- Power supplies – bias the amplifier, but have few other effects.
  - often omitted from simplified models, but we must be careful to include them where needed
  - Example: KCL implies that

$$i_1 + i_2 + i_o + i_+ + i_- = 0$$

  - Hence try to avoid KCL at op amps.

How do we model op amps?

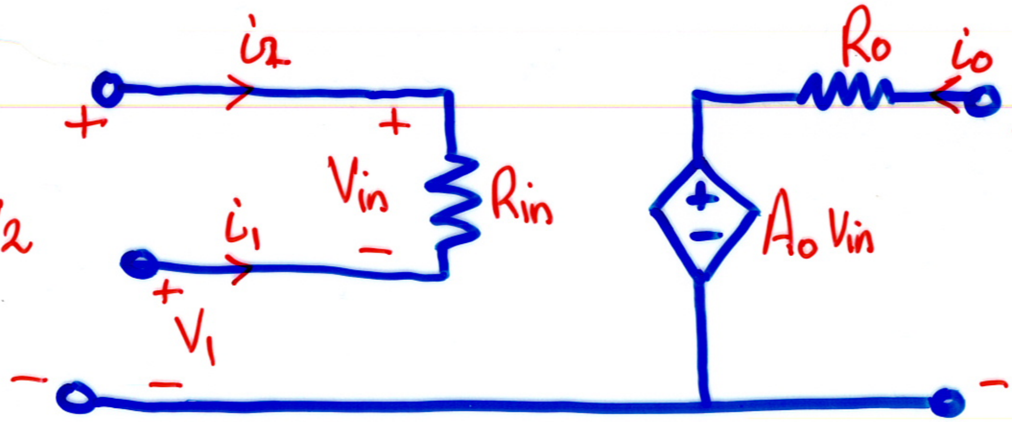
Typical characteristic



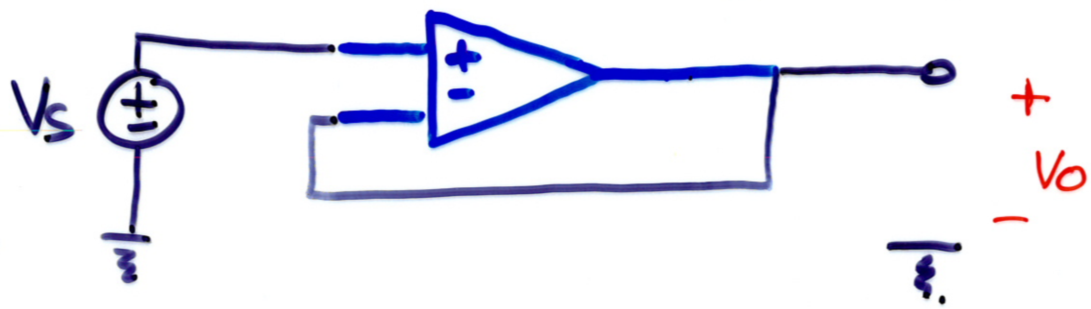
Hence, for input voltages such that $|v_o| < V_{sat}$

for output loads such that $|i_o| < i_{sat}$

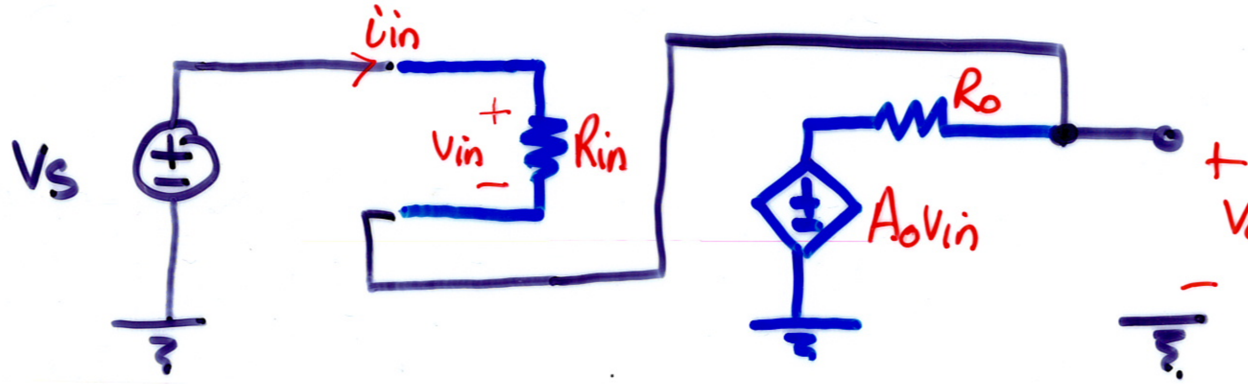
The op amp can be approximated by a simple linear model.



CONSIDER THE OP AMP IN A SIMPLE CIRCUIT



Replace op amp by its model.



KCL at output node: $\dfrac{V_s - V_o}{R_{in}} = \dfrac{V_o - A_o V_{in}}{R_o}$

Controlling voltage: $V_{in} = V_s - V_o$

$$\Rightarrow \quad \frac{V_o}{V_s} = \frac{1}{1 + \dfrac{R_{in}}{R_o + A_o R_{in}}}$$

Typically, $R_{in} \gg R_o$

$$\Rightarrow \frac{V_o}{V_s} \approx \frac{1}{1 + \frac{1}{A_o}}$$

Typically, $A_o \gg 1$

$$\Rightarrow \frac{V_o}{V_s} \approx 1$$

This circuit often called "voltage follower" or "buffer amplifier"

Typically,

R_{in} is of the order of many $M\Omega$

R_o .. .. $10\text{-}100\,\Omega$

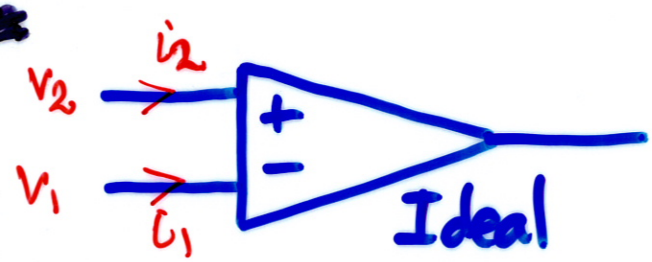
A_o .... 10^5

Large R_{in} ⇒ input current is small

Large A ⇒ $V_{in} = V_s - V_o$ is small

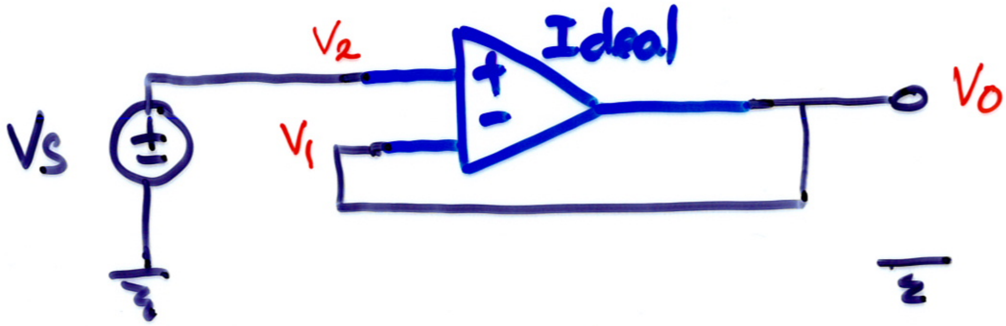
Suggests an idealized op amp model.

[redacted]



$V_2 - V_1 = 0$ $\qquad$ $i_1 = i_2 = 0$

Try this in voltage follower circuit



$V_2 = V_s$

$\Rightarrow V_1 = V_s$, ideal op amp model

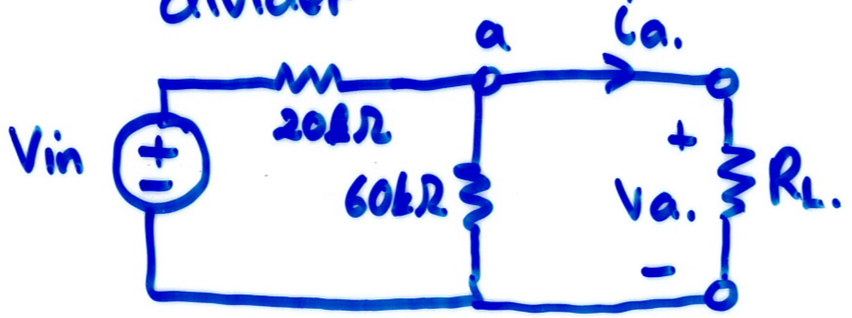
$\Rightarrow V_o = V_1$

$\Rightarrow V_o = V_s$

"BUFFERING"

- when we place a load on a circuit, it can change its performance
- Op-amps (in voltage follower form) are often used to isolate, or buffer circuits from such "loading"

- Consider the following example of a voltage divider



KCL at node A $\quad \frac{V_{in} - V_a}{20k} = \frac{V_a}{60k} + \frac{V_a}{R_L}$

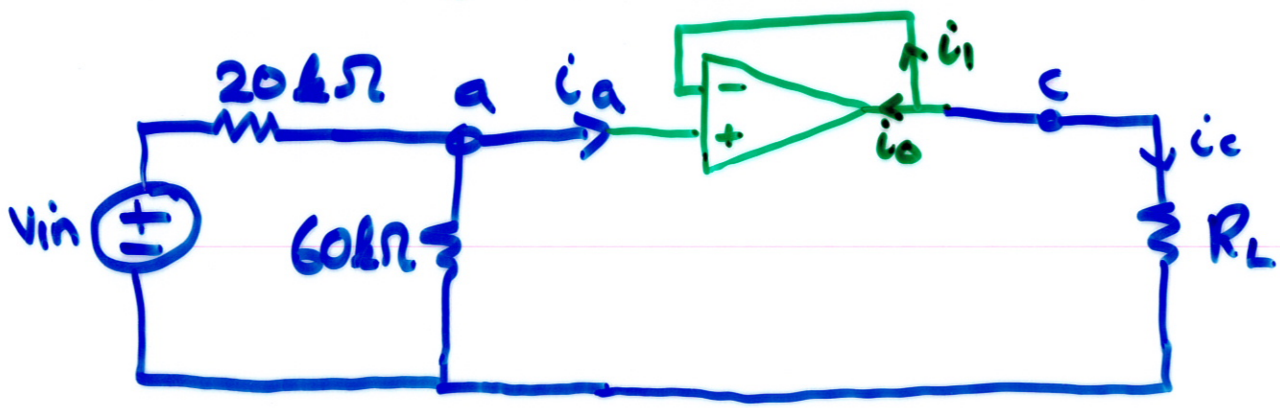
$$\Rightarrow \quad \frac{V_a}{V_{in}} = \frac{3R_L}{4R_L + 60\times10^3}$$

if $R_L \gg 60\times10^3$, $\frac{V_a}{V_{in}} \approx \frac{3}{4}$

However, if $R_L = 30\times10^3$ $\quad \frac{V_a}{V_{in}} = \frac{1}{2}$.

IN SOME CIRCUITS IT IS VERY HARD TO CHANGE R_L + the source resistors (this is why cell phones cost so much to make)

To get around the loading problem, we can use a voltage follower as a "buffer"



KCL at node a.

$$\frac{V_{in} - V_a}{20k} = \frac{V_a}{60k} + i_a$$

KCL at node c

$$i_o + i_1 + \frac{V_c}{R_L} = 0.$$

Ideal op amp $\Rightarrow$ $i_a = 0$, $i_1 = 0$

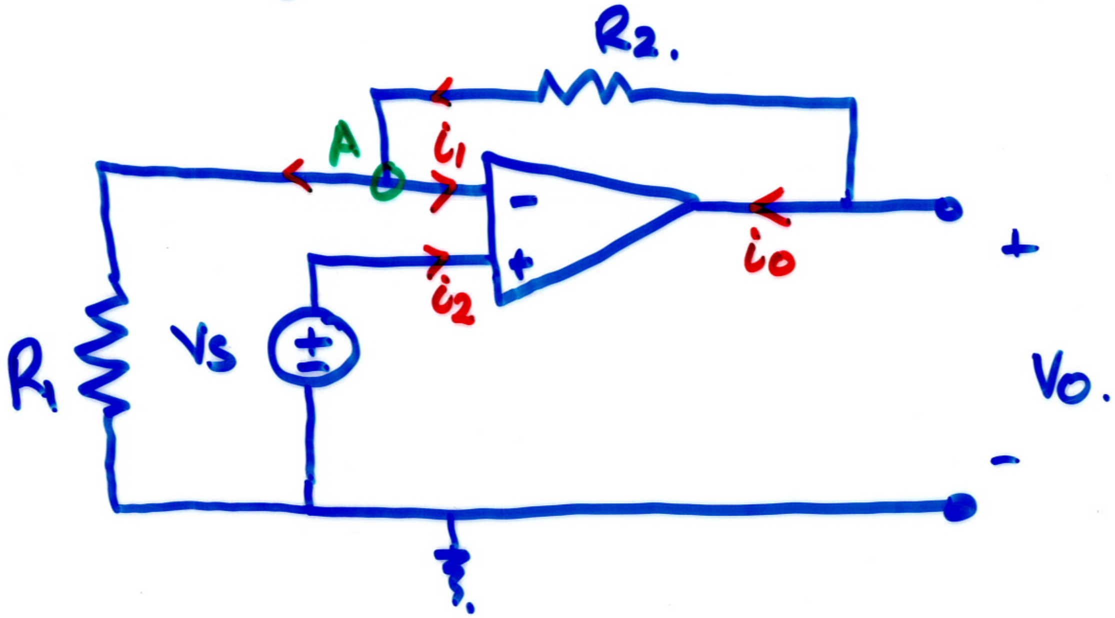
Ideal op. amp and short cct feedback

$$\Rightarrow V_a = V_c$$

$$\Rightarrow V_c = \frac{3}{4} V_{in} \text{, indep of } R_L$$

EXAMPLE

Find the gain V_o/V_s for the following circuit with an ideal op-amp.



KCL at node A — current in = current out

$$\Rightarrow \quad \frac{V_o - V_a}{R_2} = i_1 + \frac{V_a}{R_1}$$

Ideal op-amp $\Rightarrow i_1 = 0$

Ideal op-amp $\Rightarrow V_a = V_s$

$$\Rightarrow \quad V_o/R_2 = V_s\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$\Rightarrow \quad \frac{V_o}{V_s} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$