Fundamentals of Electronics
Week 2

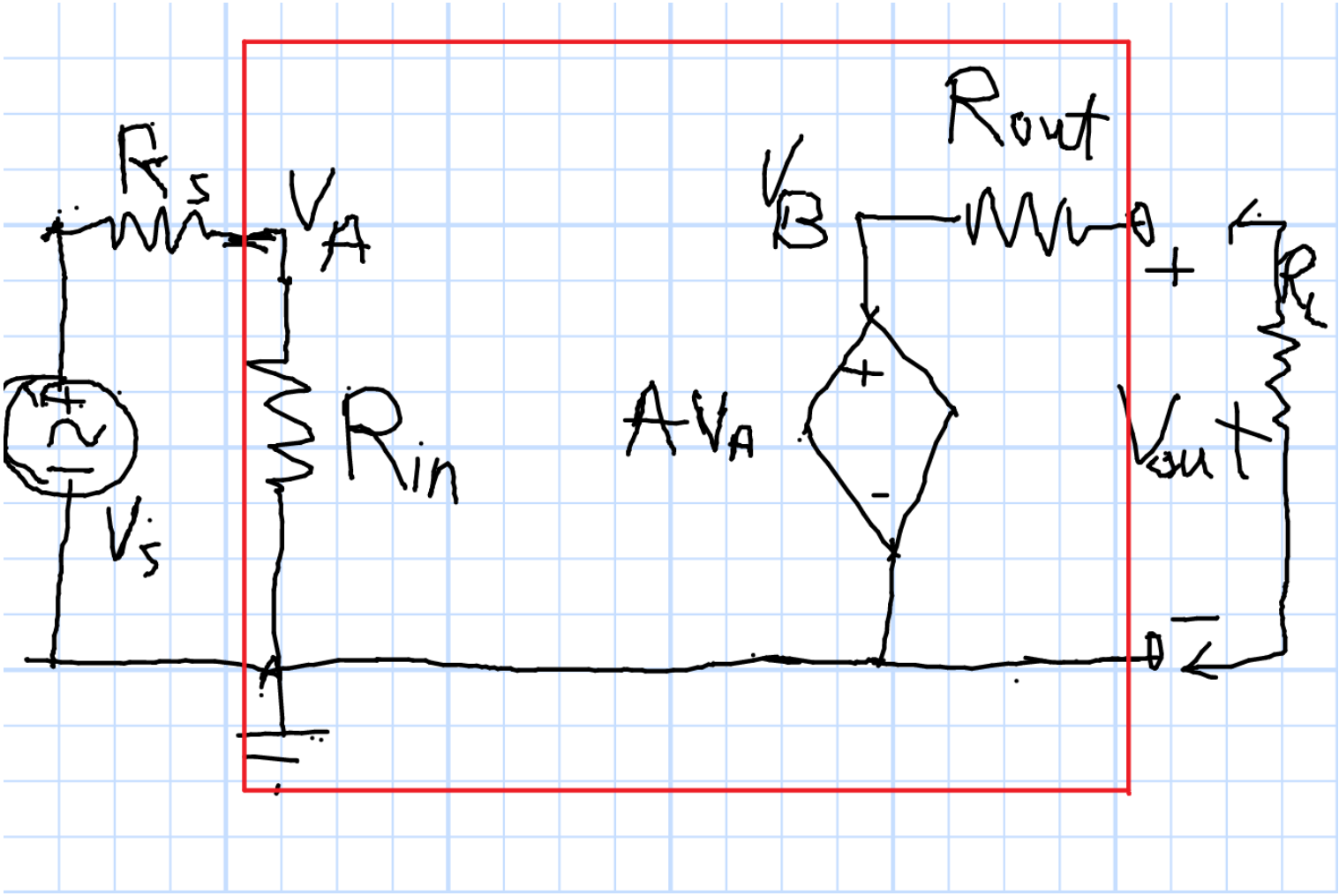
Charles A. DiMarzio
EECE–2412
Northeastern University

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Week 2 Agenda

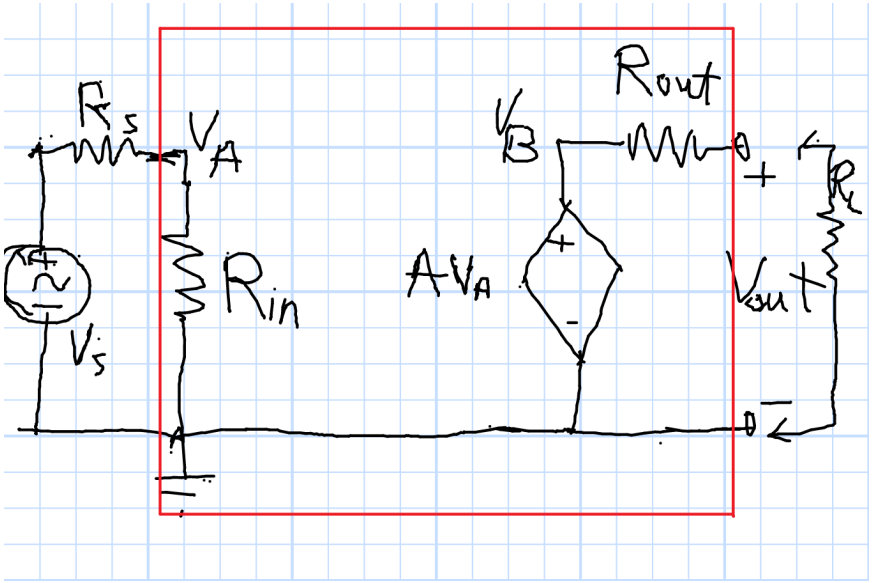
- Amplifier Models
- Ideal Operational Amplifier
- Example Circuits

An Amplifier Model



We want to Choose A, R_{in}, and R_{out}

Input and Output Impedance



- Mix Input and Output Choices as Needed
- Maximum Power to Load for Minimum Reflected Power

Maximum Voltage

$$R_{in} \to \infty$$

$$R_{out} = 0$$

Maximum Power

$$R_{in} = R_S$$

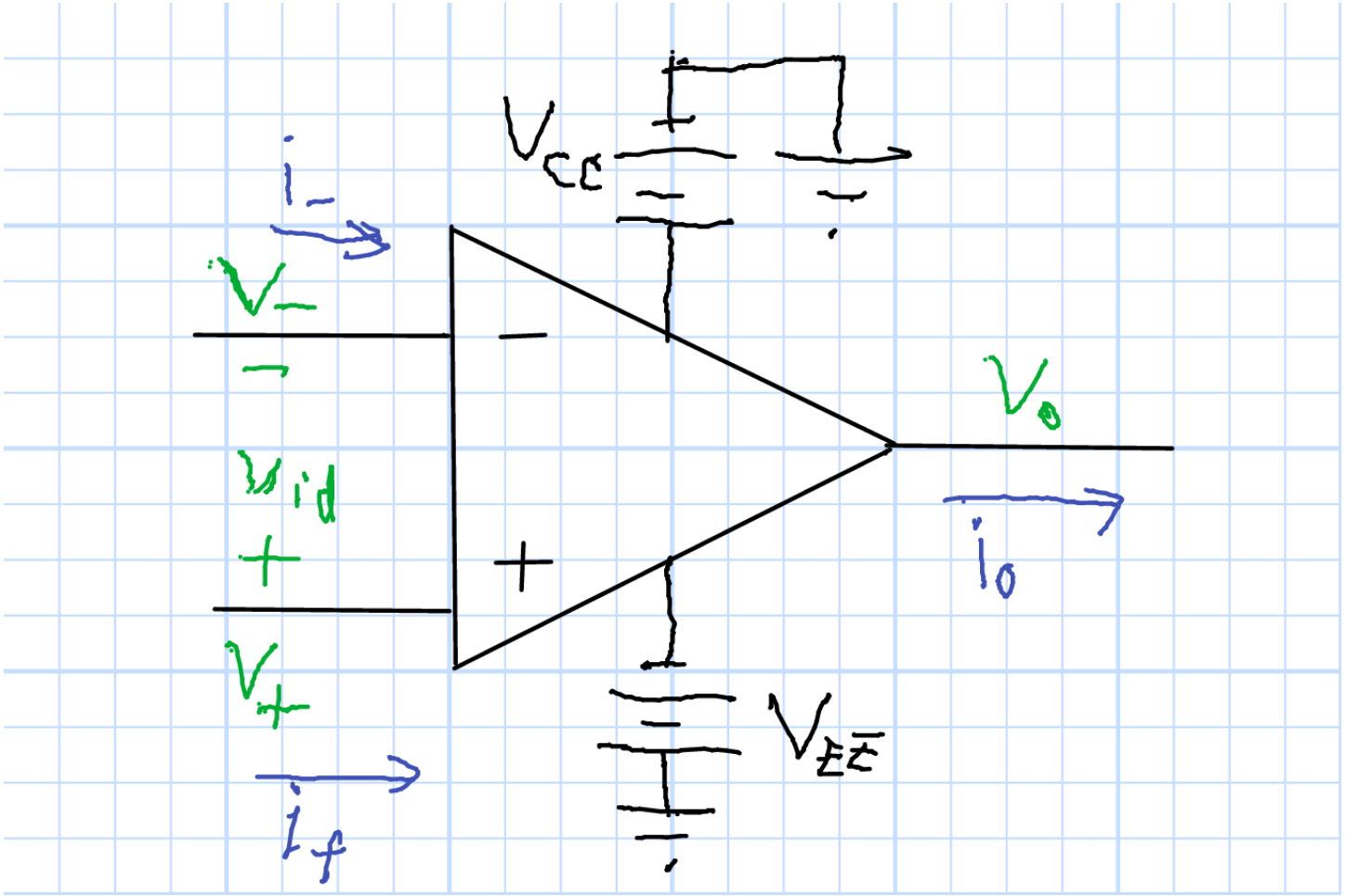
$$R_{out} = R_L$$

Maximum Current

$$R_{in} = 0$$

$$R_{out} \to \infty$$

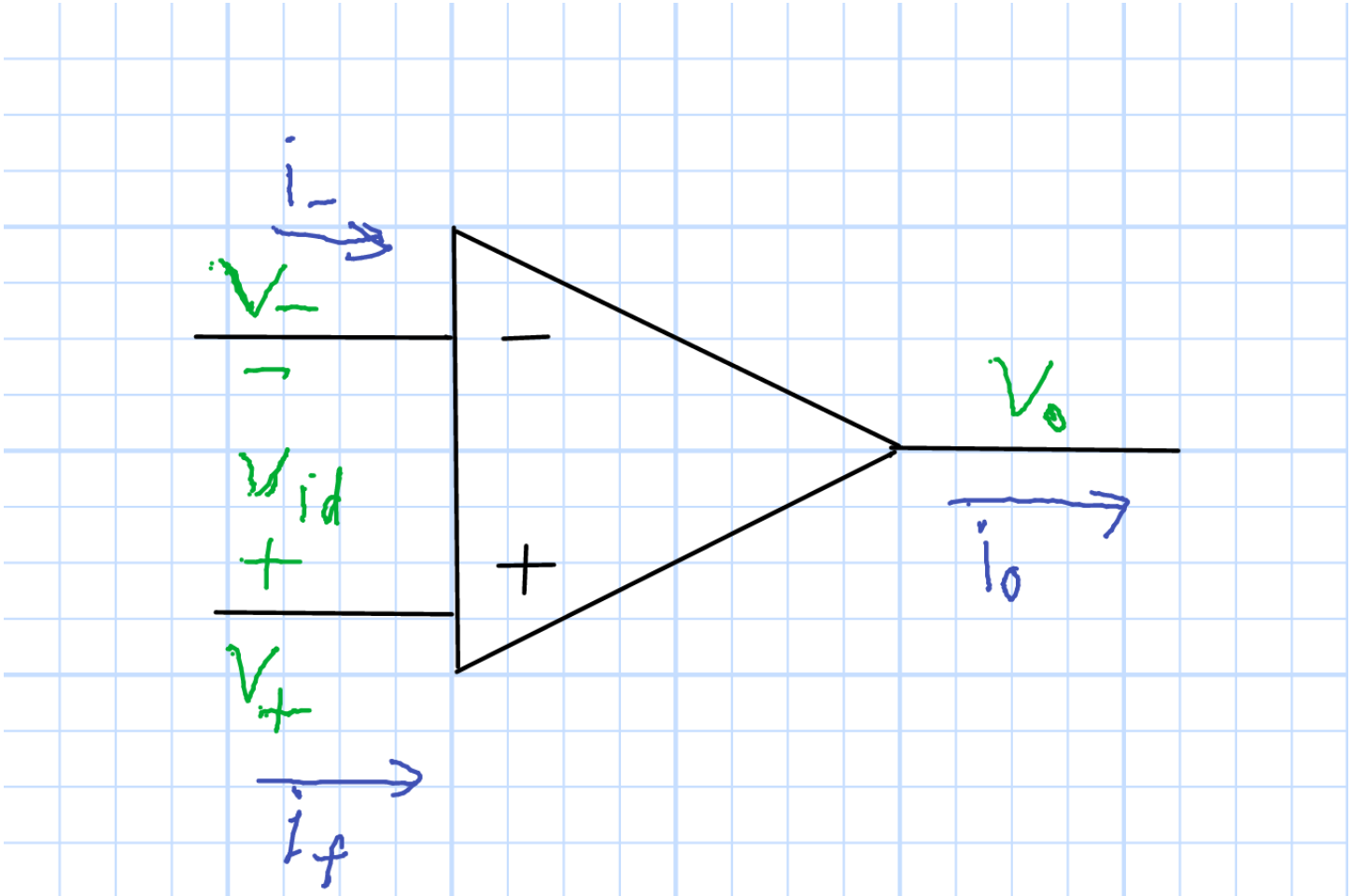
The Operational Amplifier



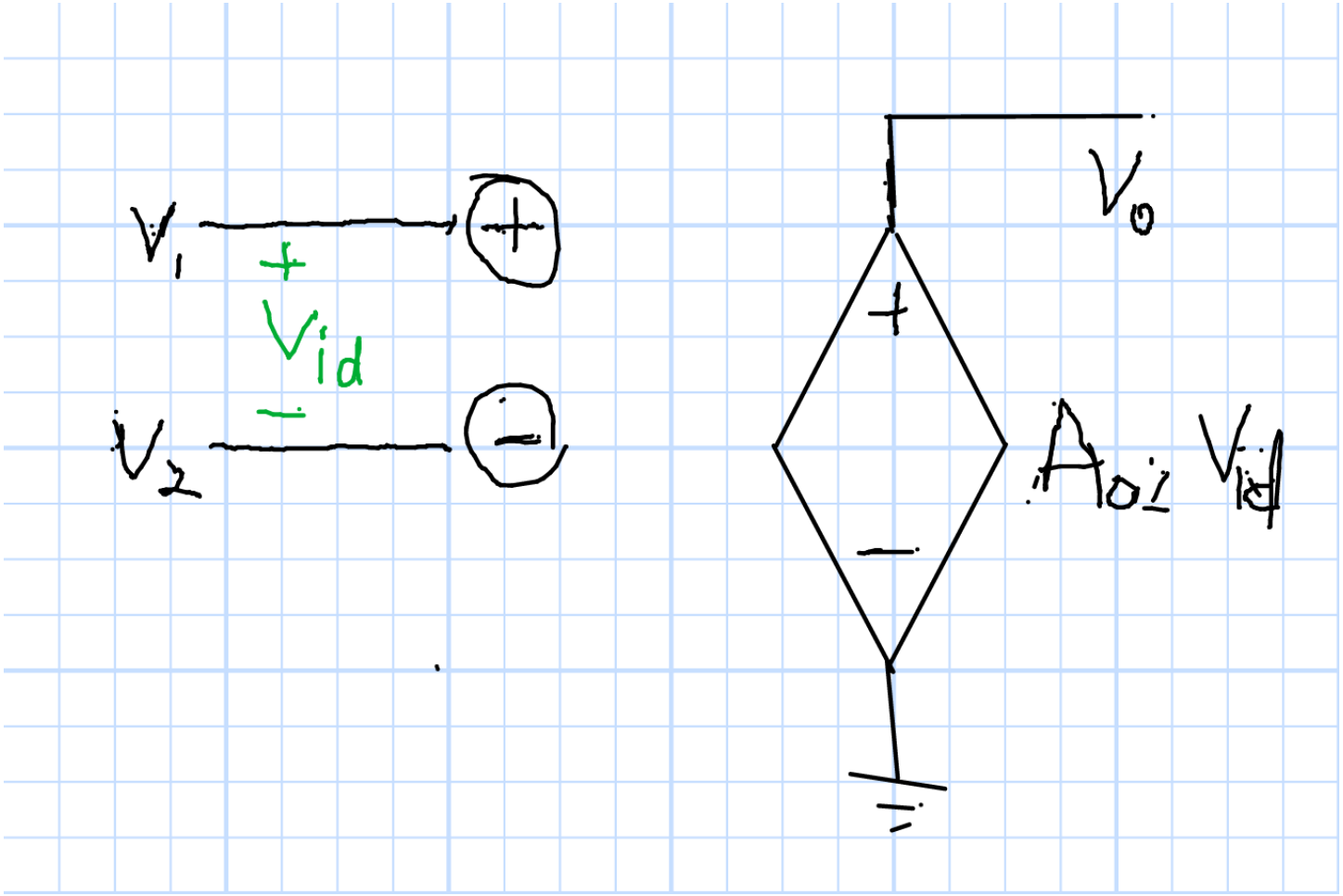
$i_+ = 0 \qquad i_- = 0 \qquad v_o = Av_{id} \qquad A \to \infty$

"Common Mode" $((v_+ + v_-)/2)$ Gain is Zero.

Implied Power Supplies

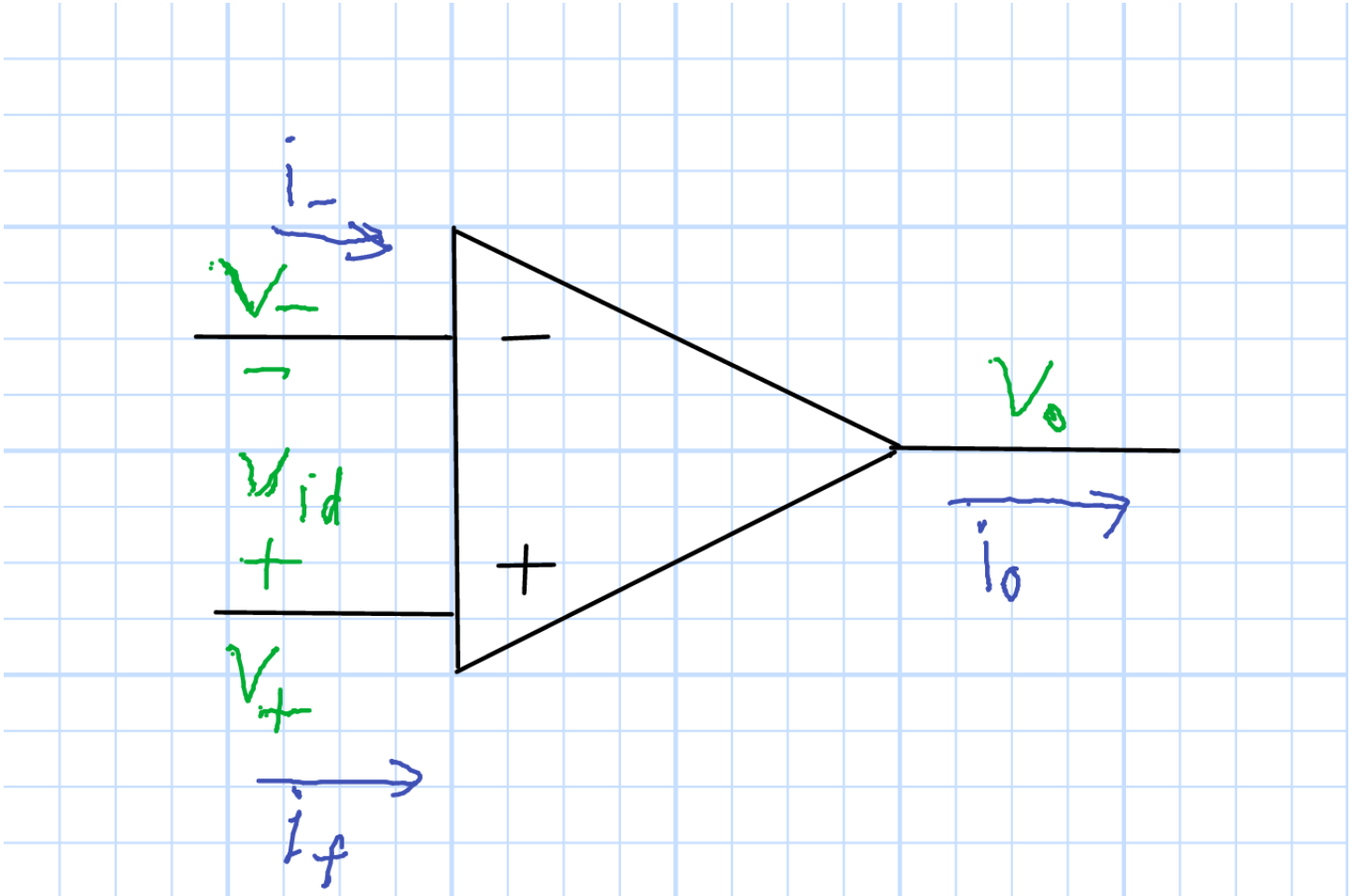


Ideal Op–Amp Model



$vo = A_{OL} v_{id}$ and $A_{OL} \to \infty$ so $v_{id} = 0$. Note open–circuit inputs.

Linear Region Equations

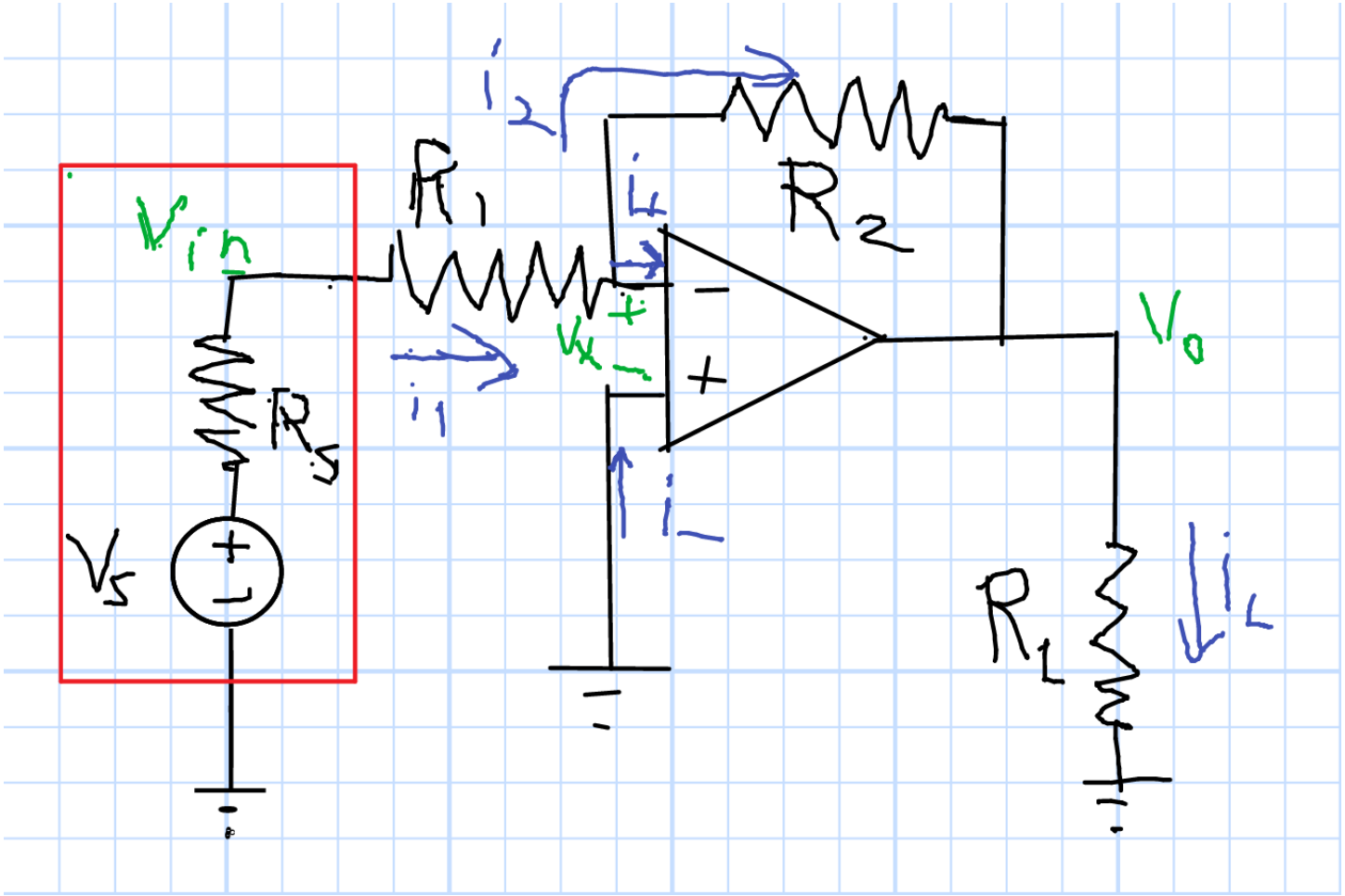


$V_+ = V_-,$ $\qquad\qquad$ $i_+ = i_- = 0$

Assumption: V_o within power rails

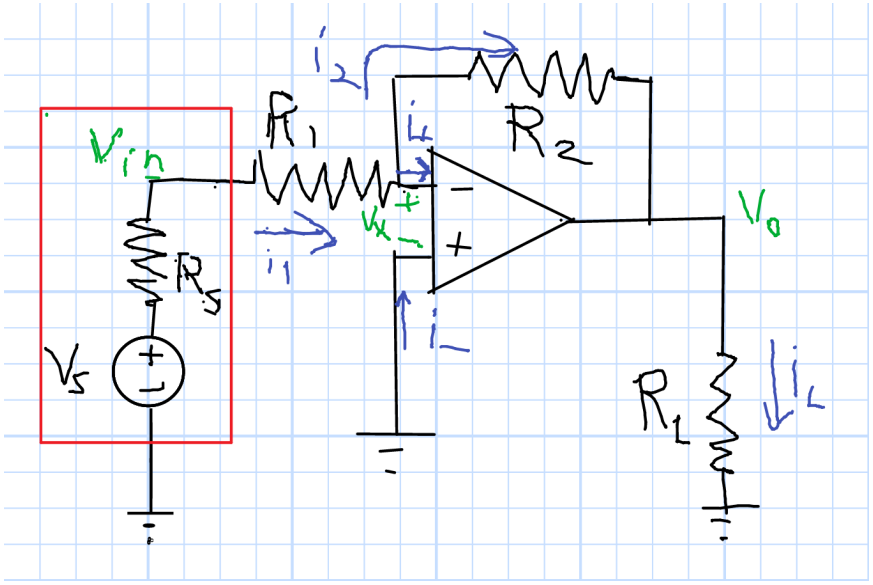
Inverting Amplifier Circuit

$I_+ = 0,\ I_- = 0,\ v_x = 0$: Virtual Ground



$i_1 = i_2$ so $v_0 = -v_{in}\frac{R_2}{R_1}$ or $A_v = -\frac{R_2}{R_1}$

Impedances



- Virtual Ground

$$v_+ = v_-$$

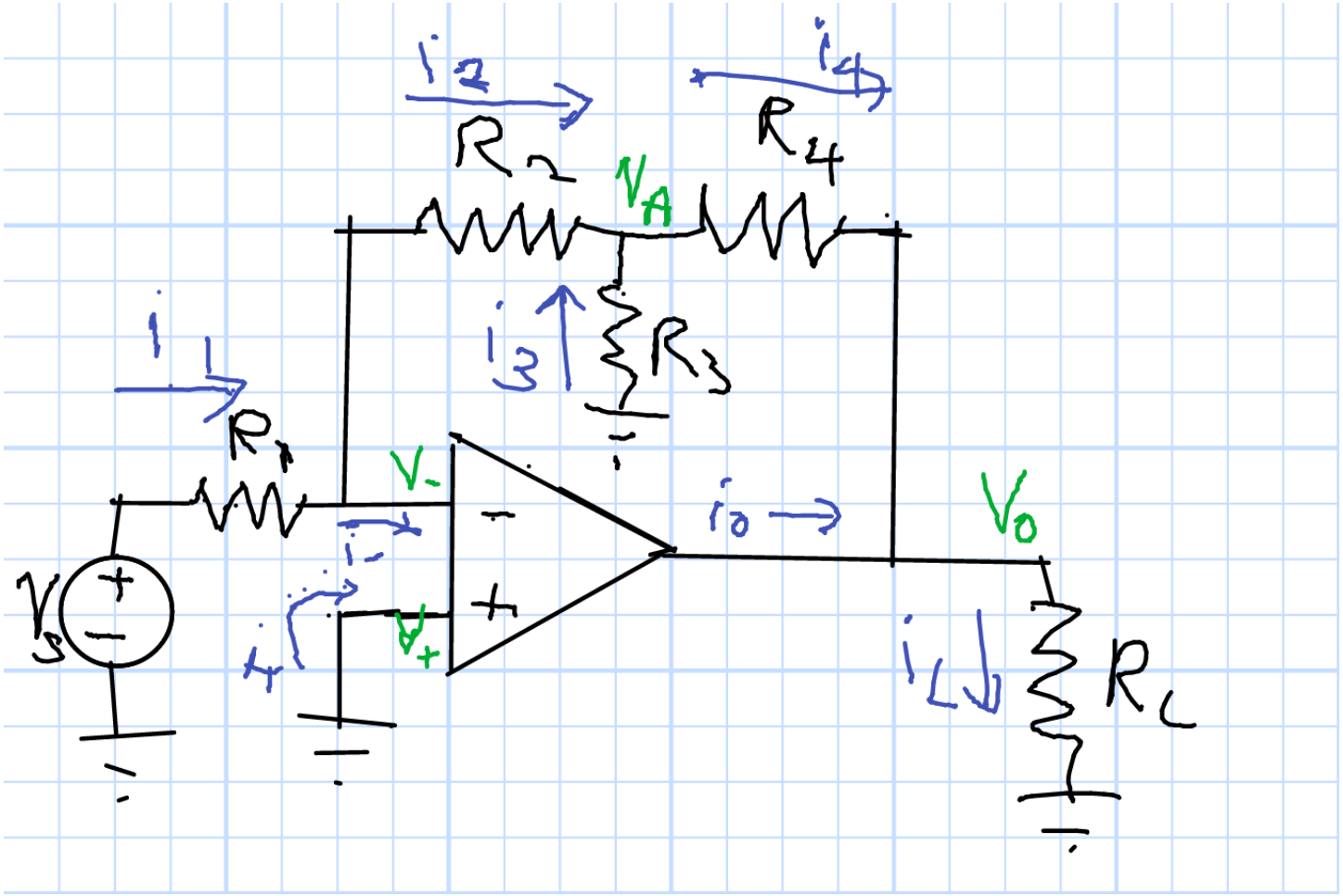
- Input Impedance

$$R_{in} = R_1$$

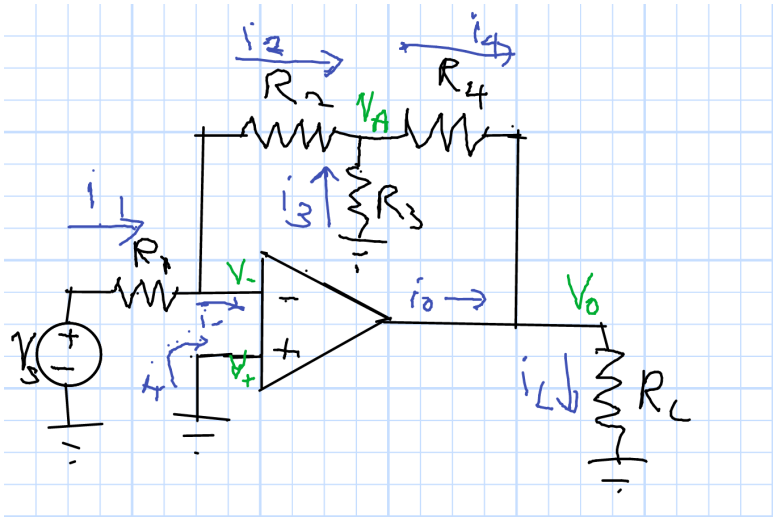
- Output Voltage $= A_v v_{in}$ regardless of load

$$R_{out} = 0$$

High Gain (1)



High Gain (2)



$$i_1 = \frac{v_s}{R_1} \qquad i_2 = i_1$$

Current Divider,
Virtual and Real Grounds

$$i_2 = i_4 \frac{R_3}{R_3 + R_2}$$

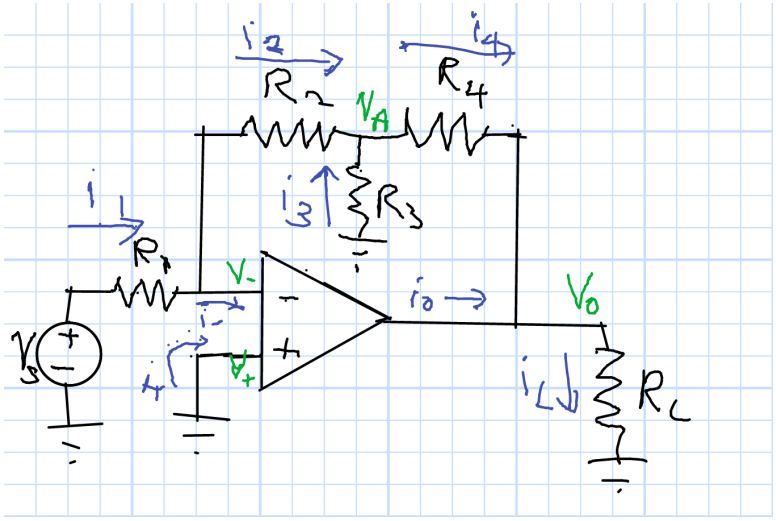
Series and Parallel Combinations

$$v_o = -i_4 \left[R_4 + (R_2 \parallel R_3) \right]$$

$$v_o = i_2 \frac{R_3 + R_2}{R_3} \left[R_4 + \frac{R_2 R_3}{R_2 + R_3} \right] = \frac{v_{in}}{R_1} \frac{R_3 + R_2}{R_3} \left[R_4 + \frac{R_2 R_3}{R_2 + R_3} \right]$$

$$= v_{in} \frac{R_4 R_3 + R_4 R_2 + R_2 R_3}{R_1 R_3} = v_{in} \left[\frac{R_4}{R_1} + \frac{R_2}{R_1} + \frac{R_2 R_4}{R_1 R_3} \right]$$

High Gain (3)



Example Values

$$R_1 = R_3 = 1\text{k}\Omega$$

$$R_2 = R_4 = 20\text{k}\Omega$$

$$R_L = 1\text{k}\Omega$$

$$v_o = v_{in}\left[\frac{R_4}{R_1} + \frac{R_2}{R_1} + \frac{R_2 R_4}{R_1 R_3}\right]$$

$$v_o = v_{in}\,(20 + +20 + 400) = 440 v_s$$

$$i_{in} = i_1 = \frac{v_s}{R_1}$$

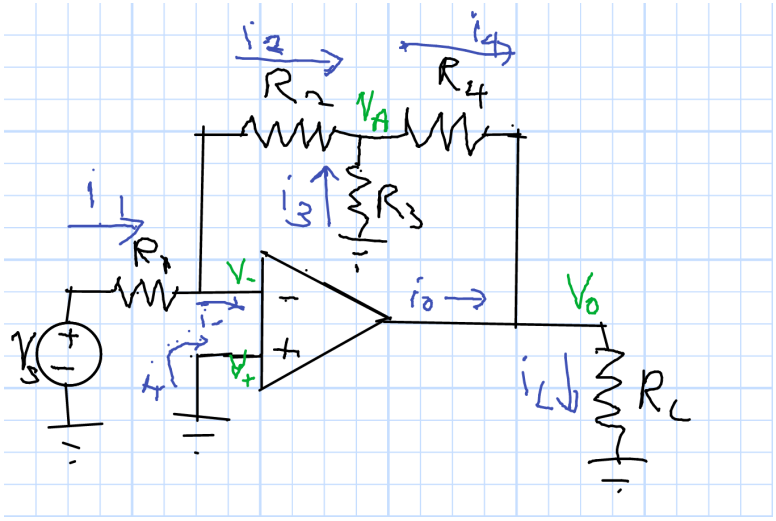
$$i_L = \frac{v_o}{R_L} = 440\frac{v_s}{R_L}$$

$$R_L = R_1 \qquad i_L = 440 i_{in}$$

Power Gain

$$v_o i_L = 440^2 v_s i_{in} = 193,600 v_s i_{in}$$

Impedances



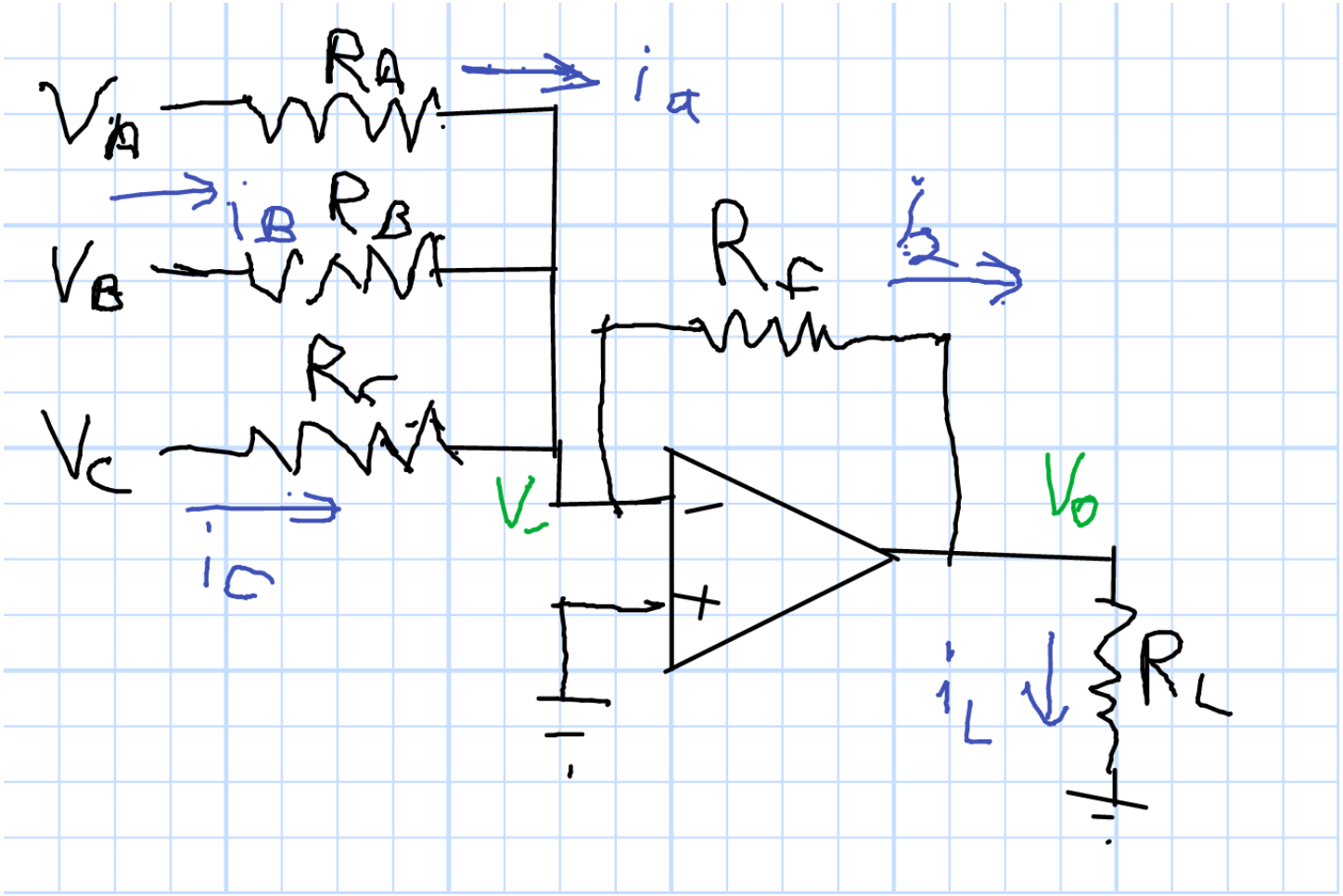
$$R_{in} - R_1$$

Do other Resistors Matter?
Why or Why Not?

$$R_{out} = 0$$

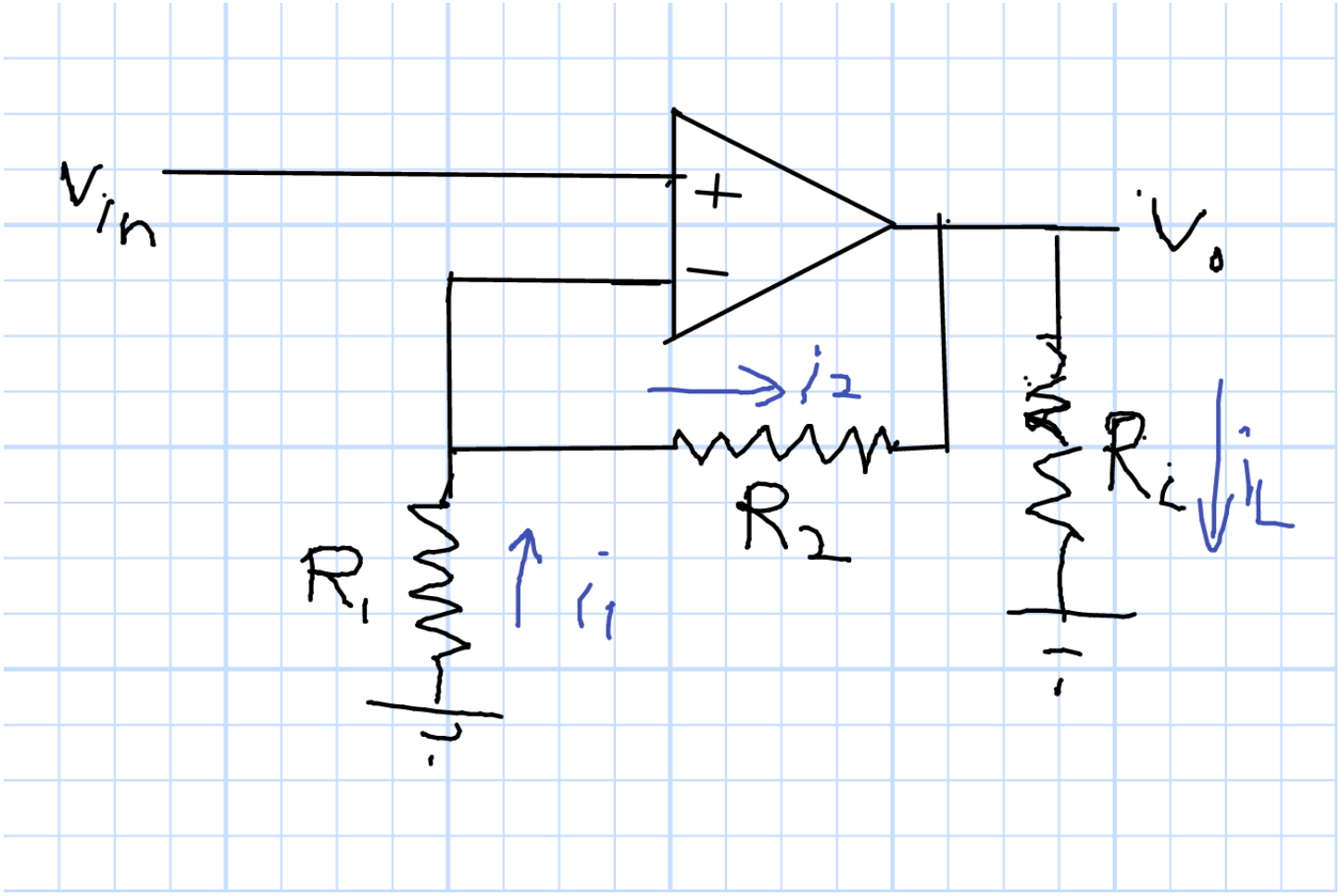
Why?

Summing Junction



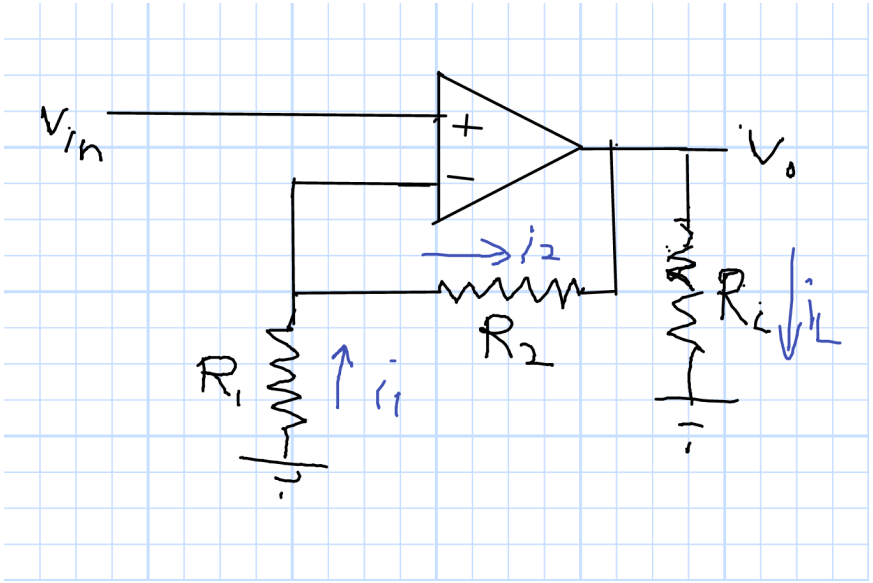
$$v_0 = -\left[\frac{R_f}{R_A}v_A + \frac{R_f}{R_B}v_B + \frac{R_f}{R_C}v_C\right]$$

Non–Inverting Amplifier



$$v_+ = v_- \qquad v_o = v_{in}\left(\frac{R_2}{R_1} + 1\right)$$

Impedances



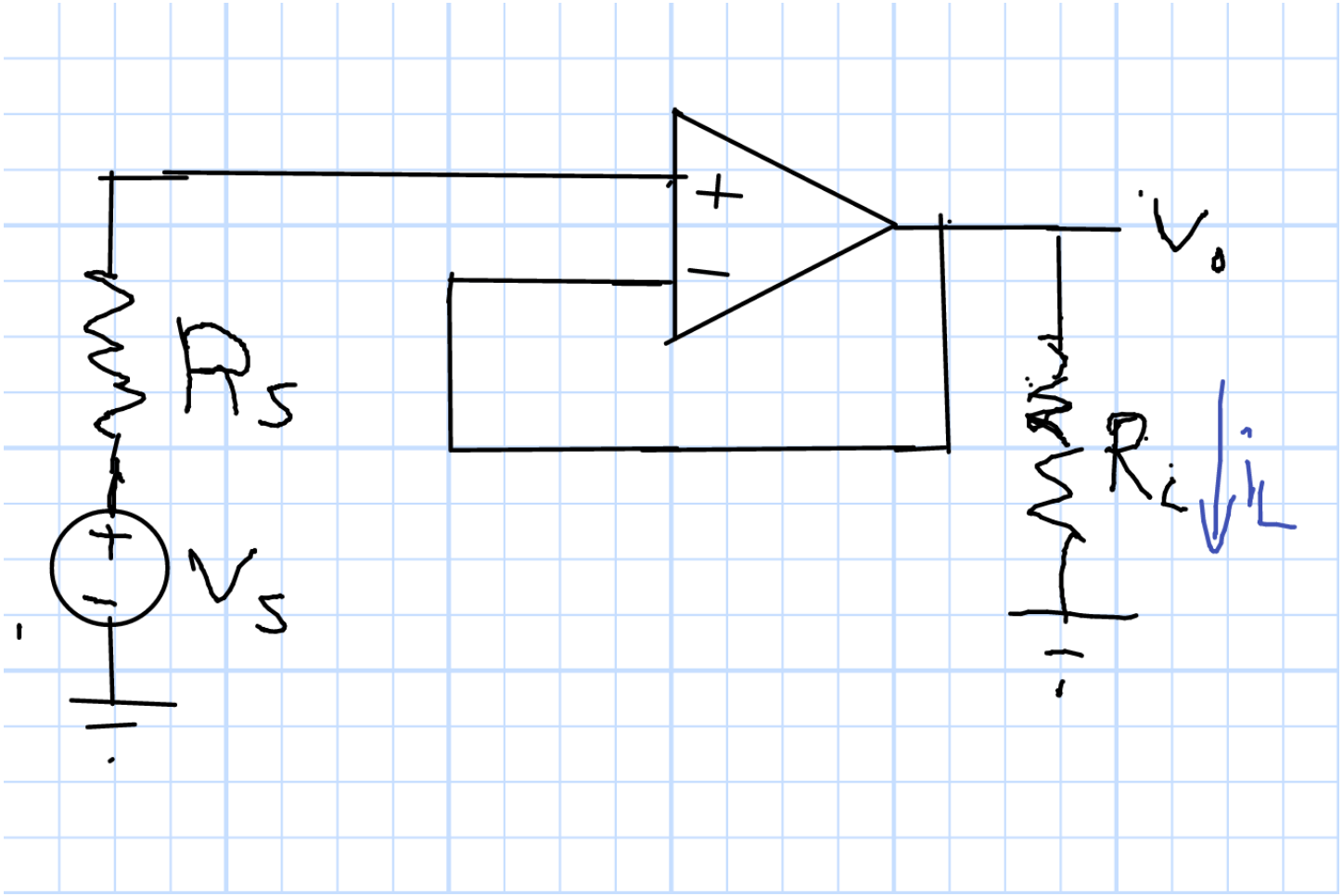
$R_{in} = \infty$

Why?

$R_{out} = 0$

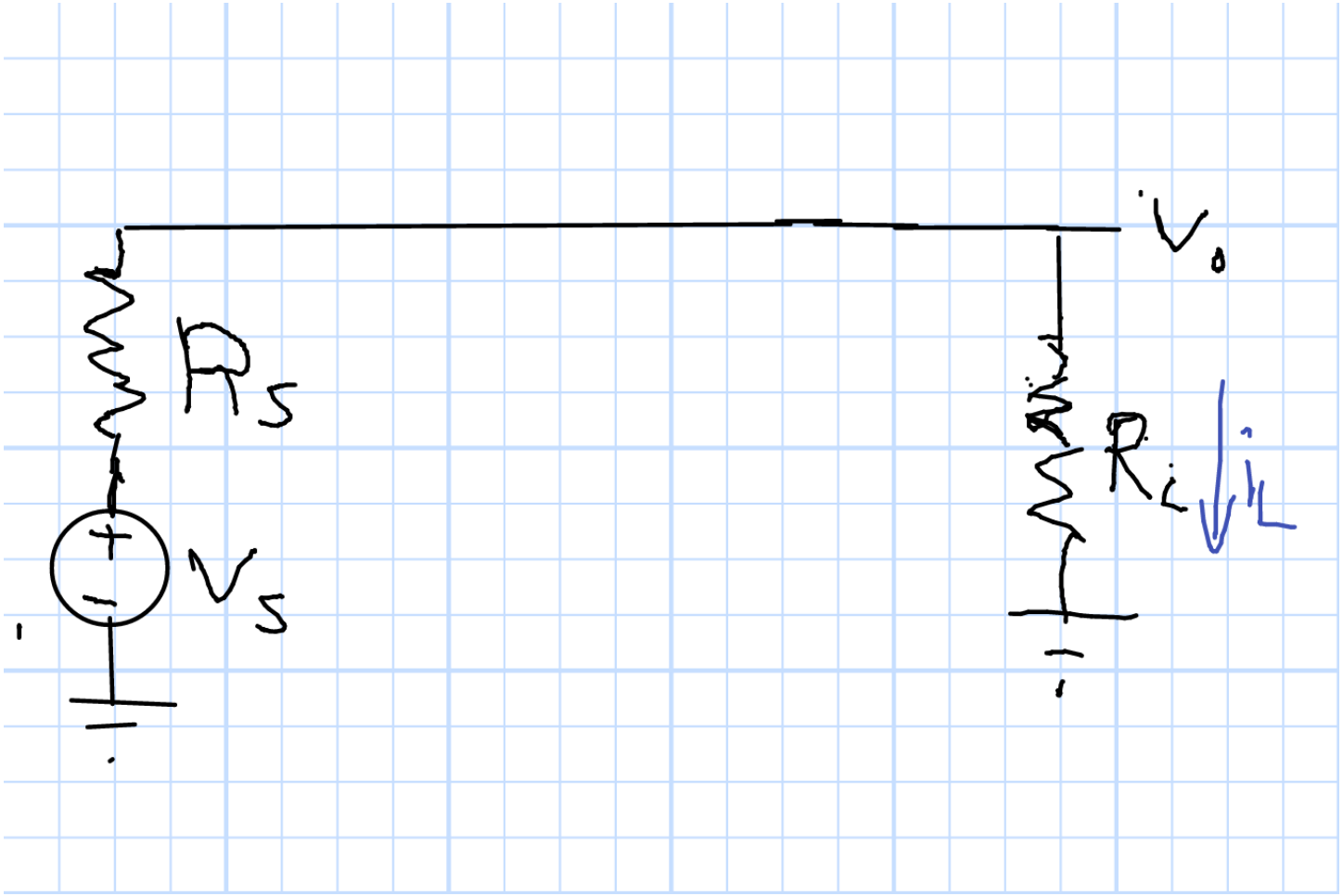
Why?

Voltage Follower



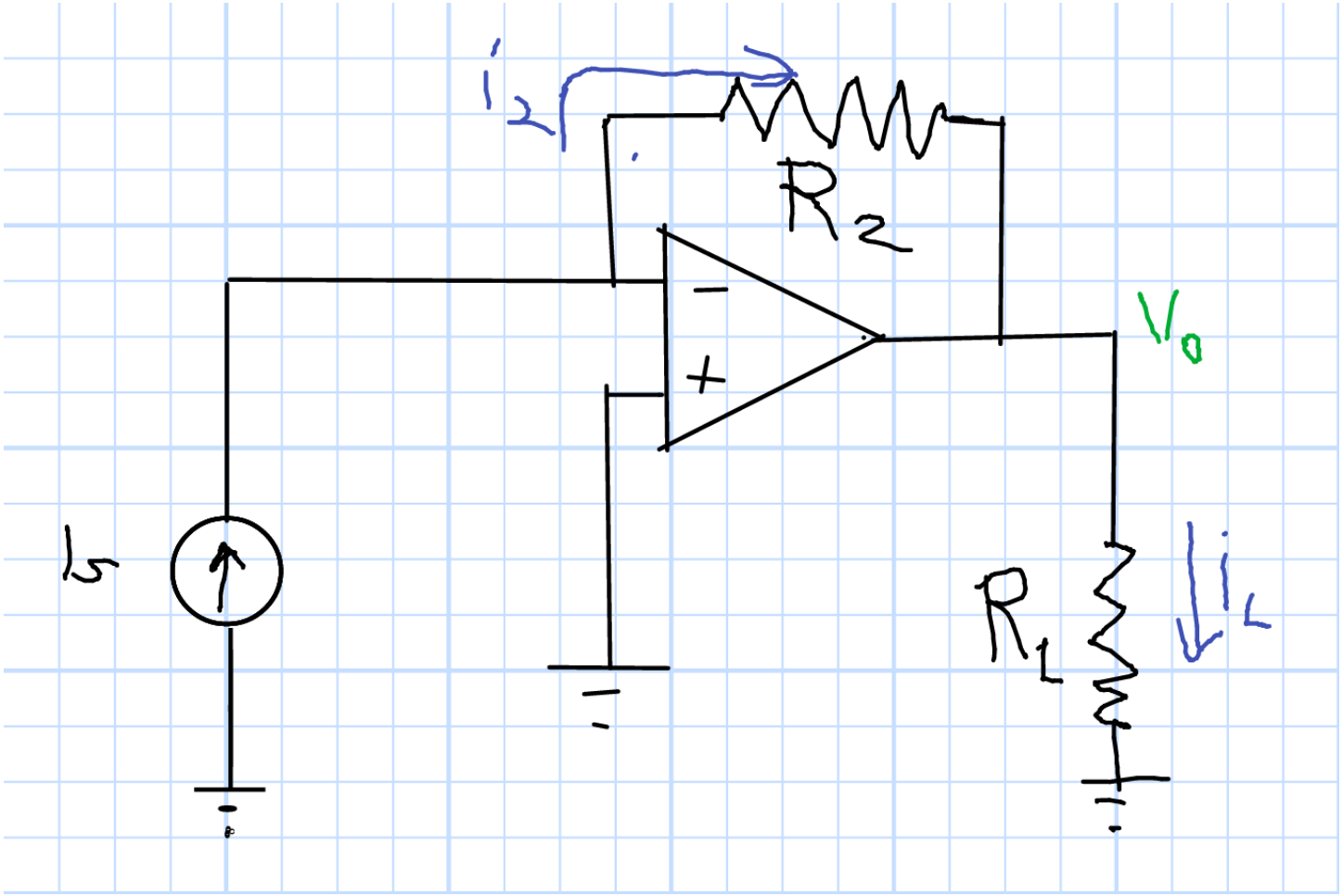
$$v_o = v_{in} = v_s \qquad i_s = 0$$

Why Voltage Follower?



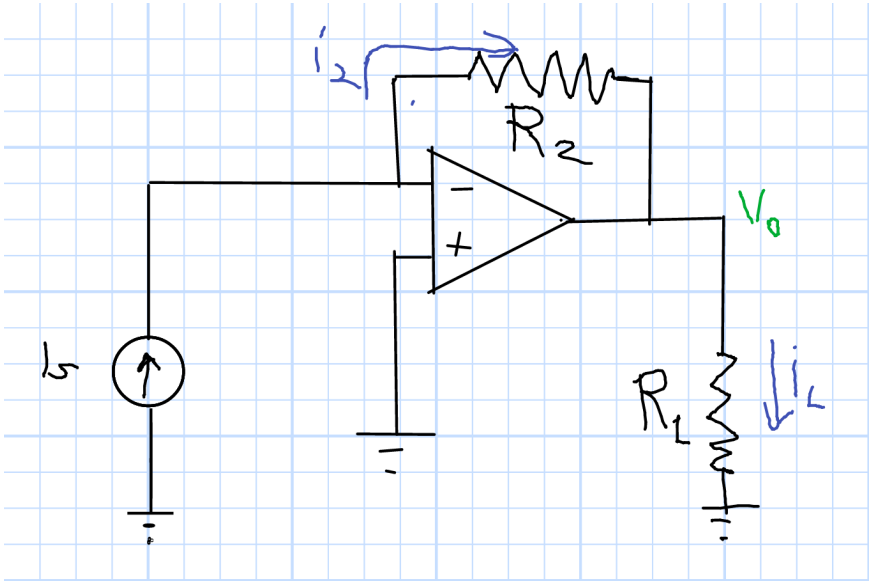
Here, $v_o = v_s \frac{R_L}{R_L + R_s}$. This is important for small R_L, large R_s. The amplifier provides the needed current.

Transimpedance Amplifier



$v_0 = -R_2 i_s$. Useful for photodiodes among other applications

Impedances



$$R_{in} = 0$$

Why is this true?

Why is this good?

$$R_{out} = 0$$

Why?

Example

In–Class Example