Electronics – 96032

POLITECNICO DI MILANO

Linear Applications of OpAmps

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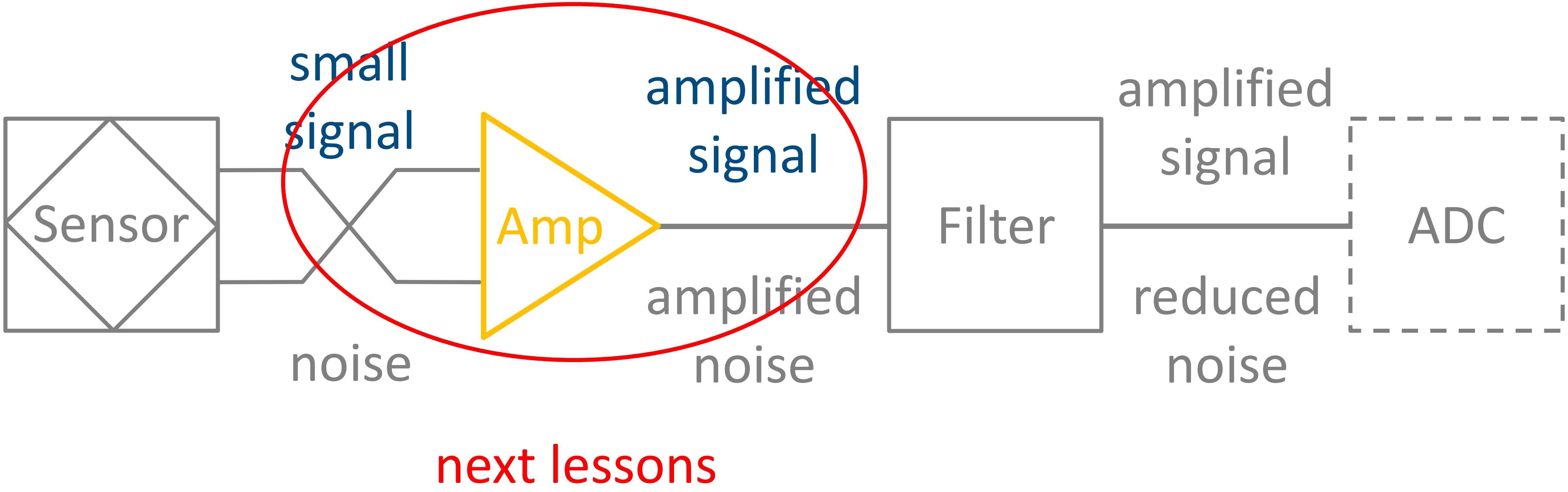
Disclaimer

Slides are supplementary material and are NOT a replacement for textbooks and/or lecture notes

Acquisition chain



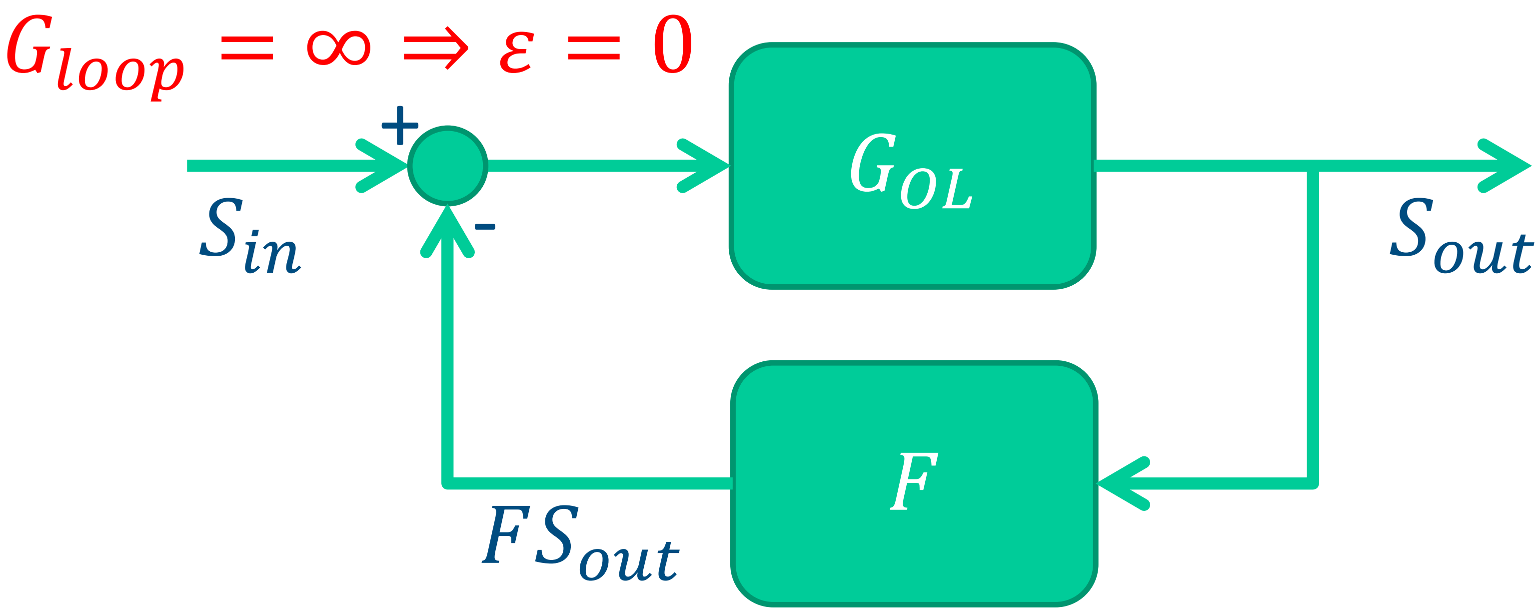
Purpose of the lesson

- We begin our study with the analysis and design of simple amplifiers
- Next lessons will deal with
  - Basic amplifier principles and the feedback amplifier concept
  - Linear applications of OpAmps (this lesson)
  - Feedback amplifier properties
  - Stability of feedback amplifiers
  - Instrumentation amplifiers and OpAmp parameters

Outline

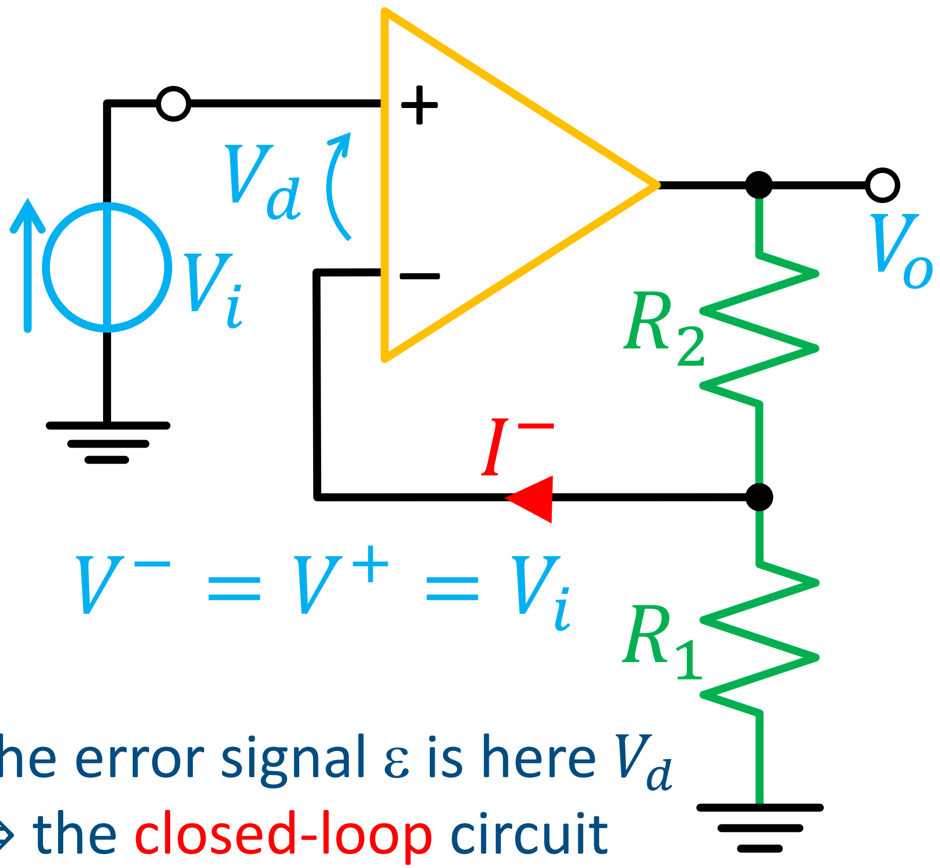
- Non-inverting amplifier
- Inverting amplifier and applications
- Other linear circuits

Calculation of G_{id}



$$G_{loop} = \infty \Rightarrow \varepsilon = \frac{S_{out}}{G_{OL}} = 0 \Rightarrow S_{in} - FS_{out} = 0 \Rightarrow \frac{S_{out}}{S_{in}} = \frac{1}{F} = G_{id}$$

Non-inverting amplifier



$$V^- = V^+ = V_i$$

The error signal ε is here V_d
⇒ the closed-loop circuit keeps the same voltage at the – and + inputs

Since $I^- = 0$, we have

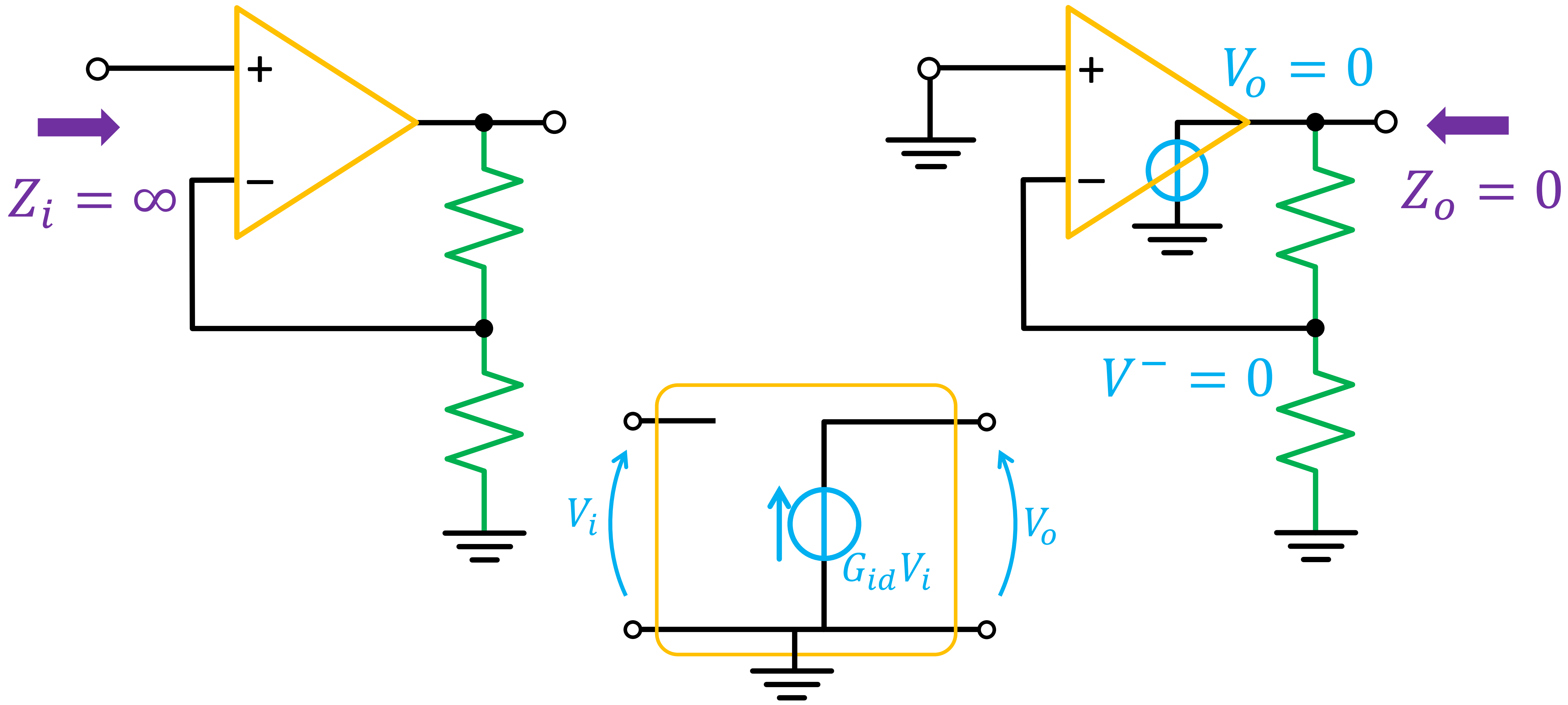
$$V^- = V_o \frac{R_1}{R_1 + R_2}$$

$$V_d = V^+ - V^- = \frac{V_o}{A} = 0$$

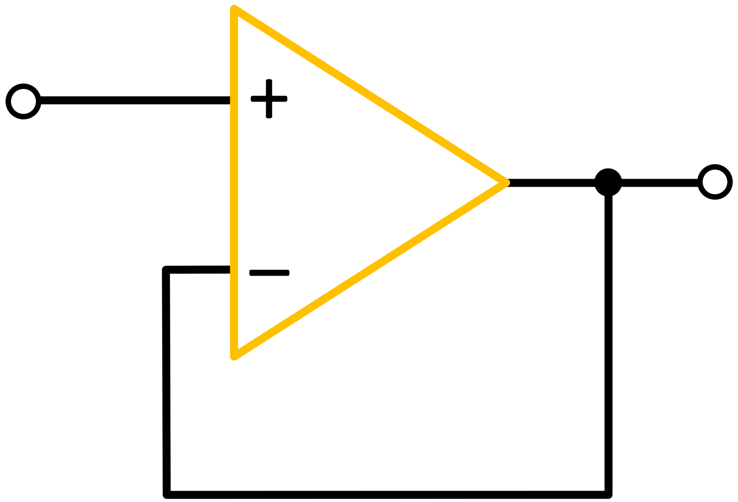
$$\Rightarrow V^- = V^+ = V_i$$

$$G_{id} = \frac{V_o}{V_i} = \frac{R_1 + R_2}{R_1} \geq 1$$

Input and output impedances

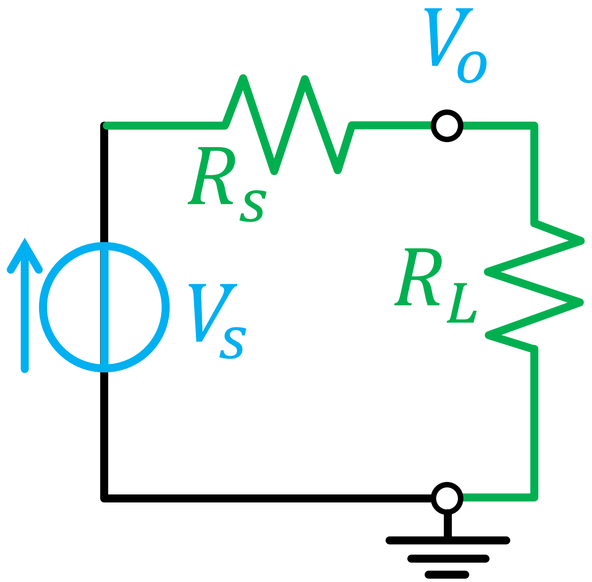


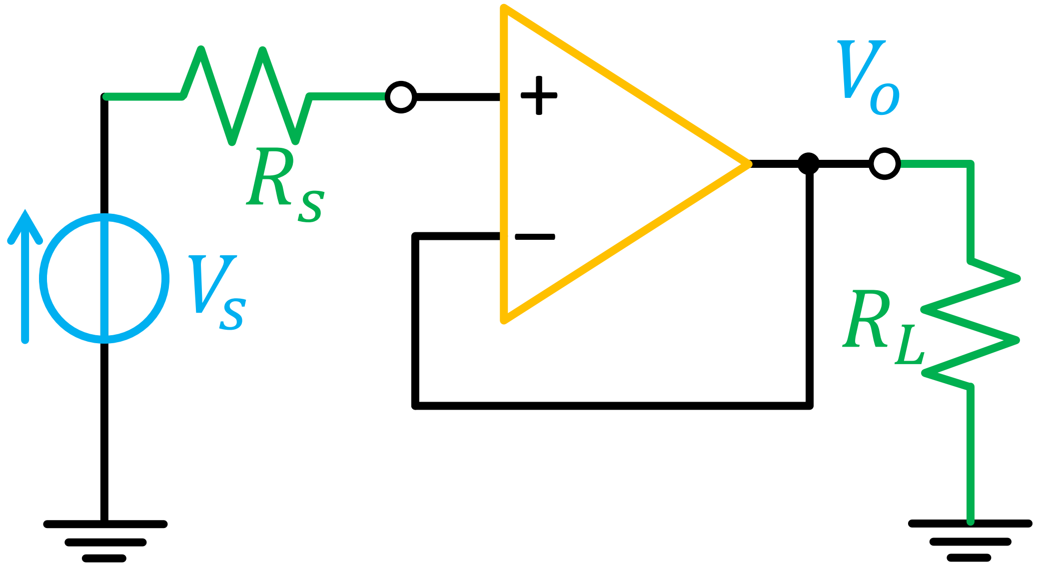
Voltage follower



- A non-inverting amplifier having $R_1 = \infty$ (and $R_2 = 0$) $\Rightarrow G_{id} = 1$
- Used as buffer stage

Buffer stage





$$V_o = V_s \frac{R_L}{R_L + R_s}$$

$$V_o = V_s$$

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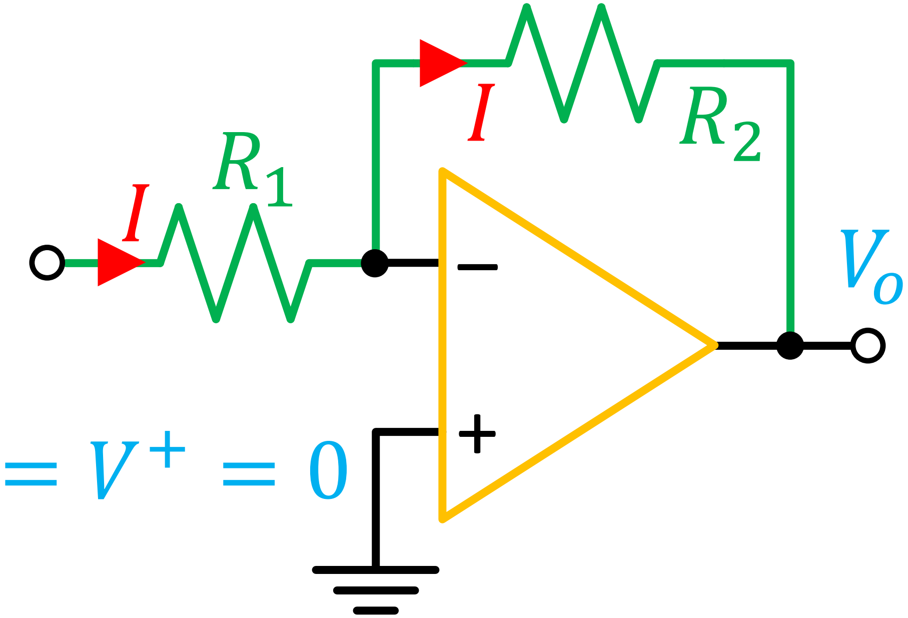
Inverting amplifier



$$V^- = V^+ = 0$$

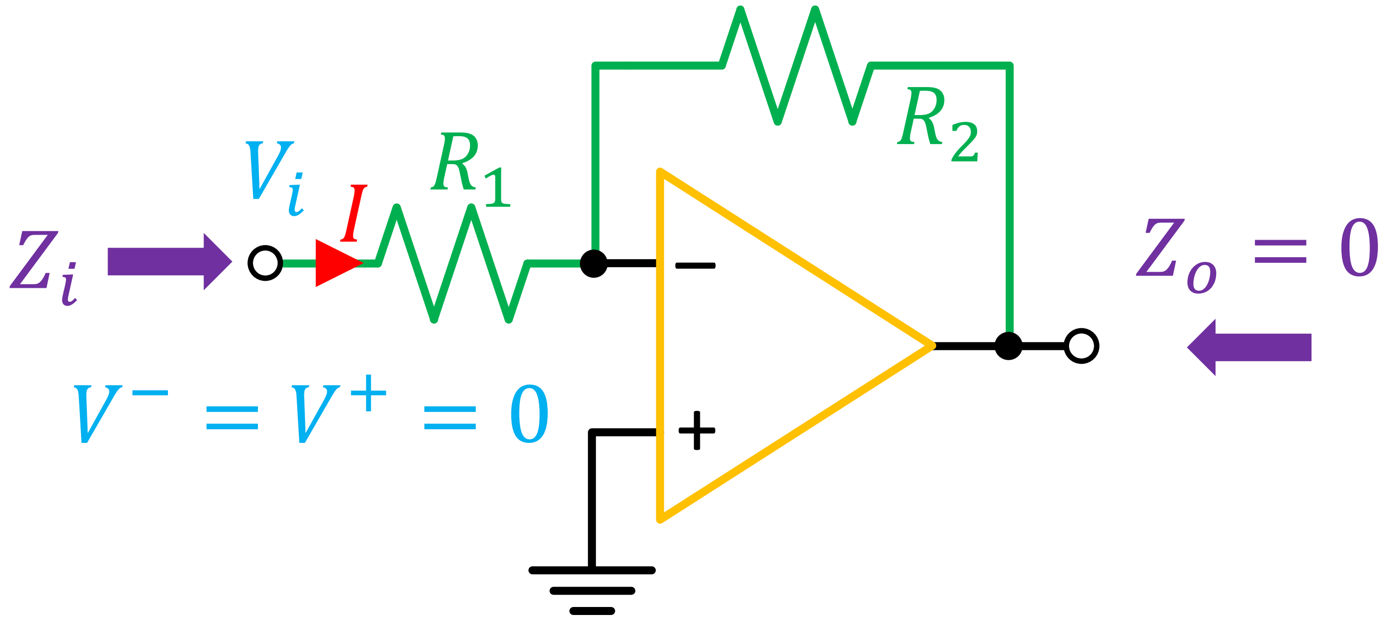
the inverting input is a virtual ground (the feedback keeps it at ground potential even if not physically connected to it)

$$I = \frac{V_i - V^-}{R_1} = \frac{V_i}{R_1}$$

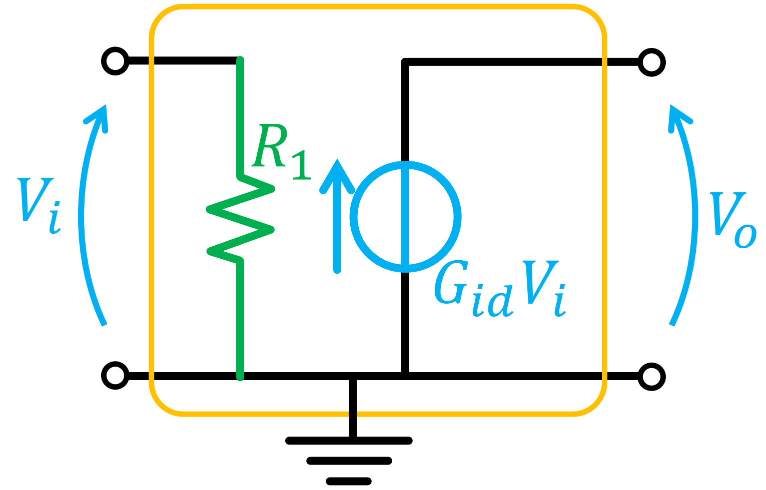
$$V_o = -IR_2 = -V_i\frac{R_2}{R_1}$$

$$G_{id} = \frac{V_o}{V_i} = -\frac{R_2}{R_1}$$

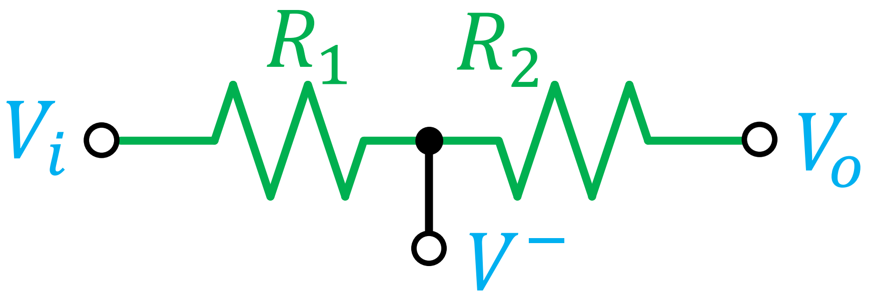
Input and output impedances



$$I = \frac{V_i}{R_1} \Rightarrow Z_i = \frac{V_i}{I} = R_1$$



Another look at the gain

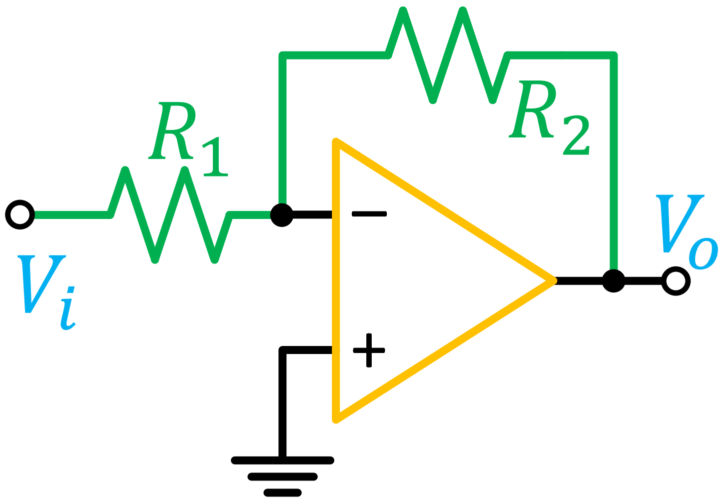


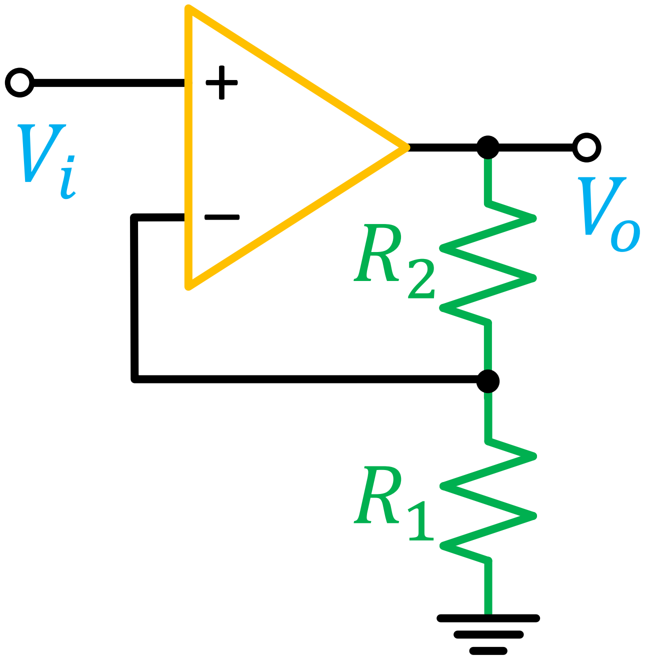
$$V^- = V_i \frac{R_2}{R_1 + R_2} + V_o \frac{R_1}{R_1 + R_2}$$

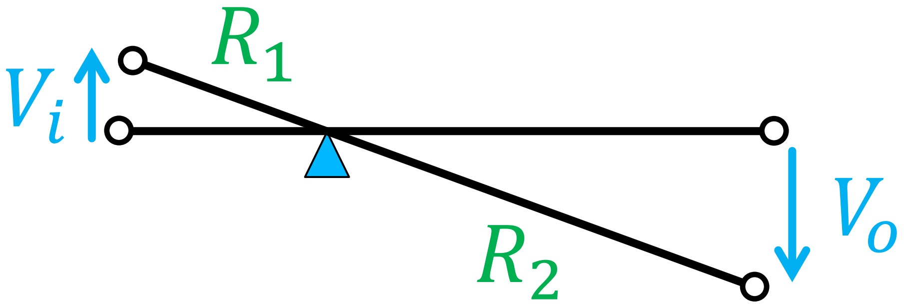
The OA settles to the value of V_o that brings $V^- = V^+ = 0$

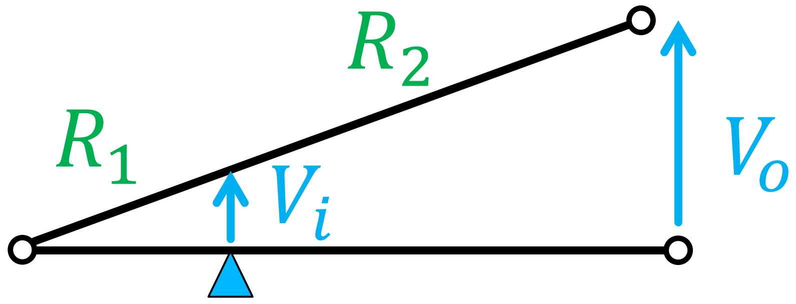
$$V^- = 0 \Rightarrow \frac{V_o}{V_i} = -\frac{R_2}{R_1} = G_{id}$$

The lever analog

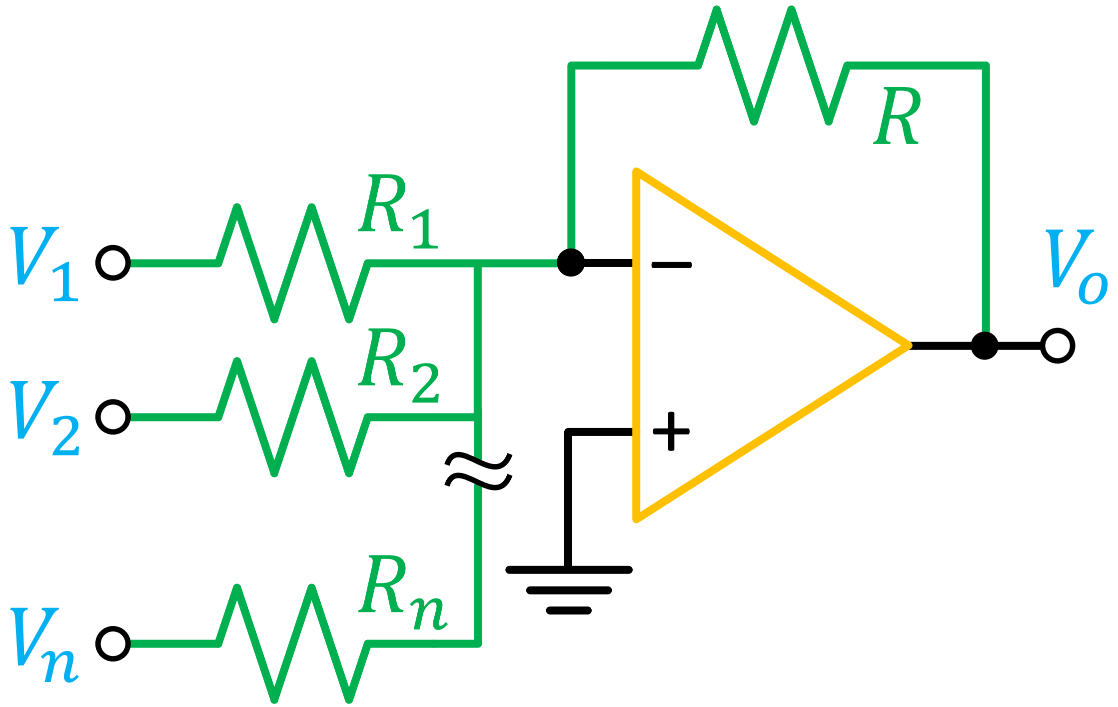




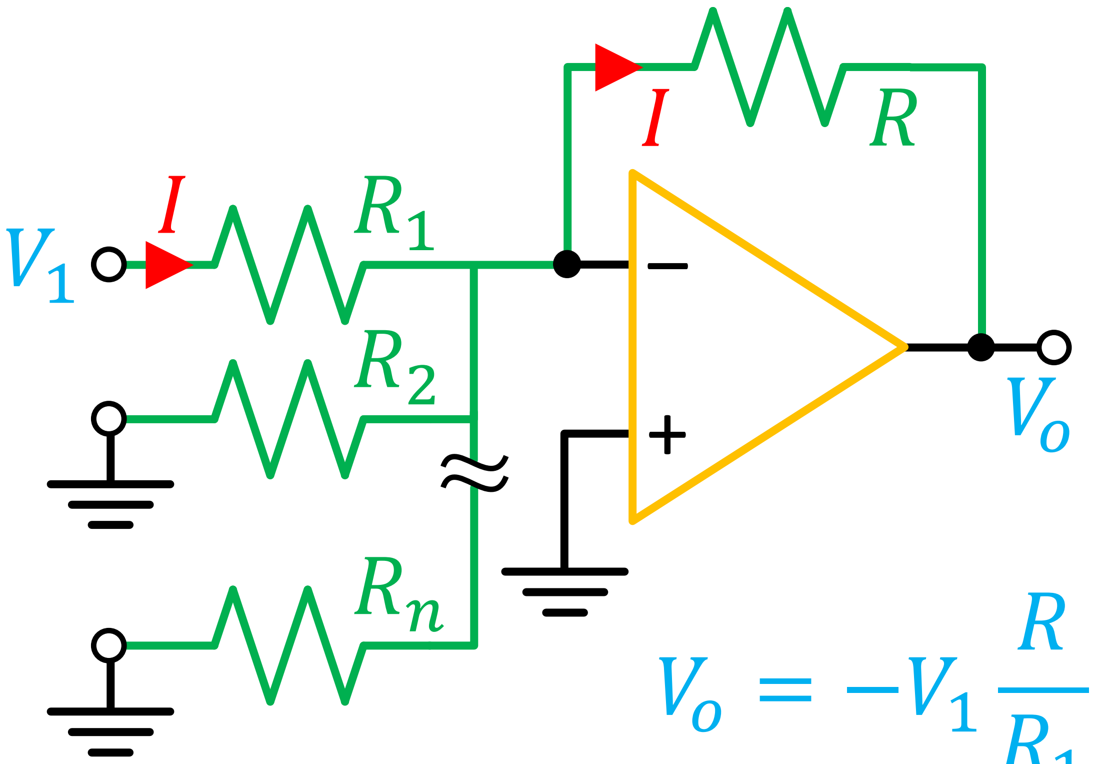




Adder circuit



Superposition principle



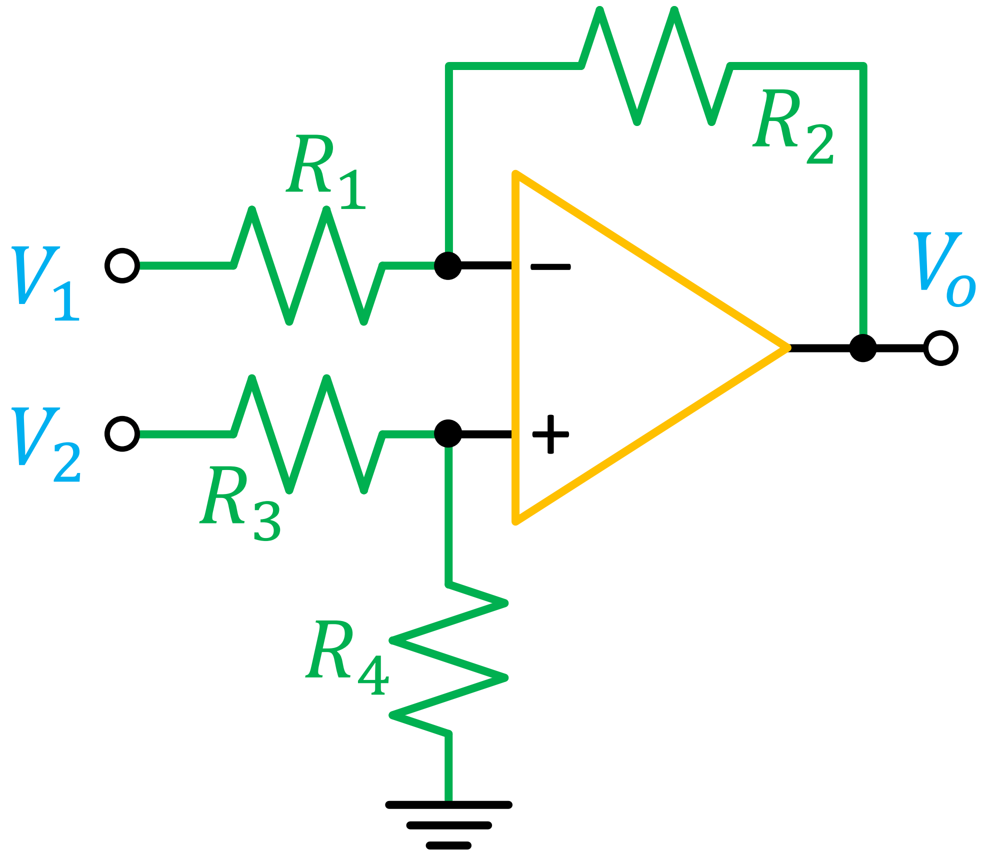
No current flowing in resistors $R_2, \dots, R_n$:

$$V_{o1} = -V_1 \frac{R}{R_1}$$

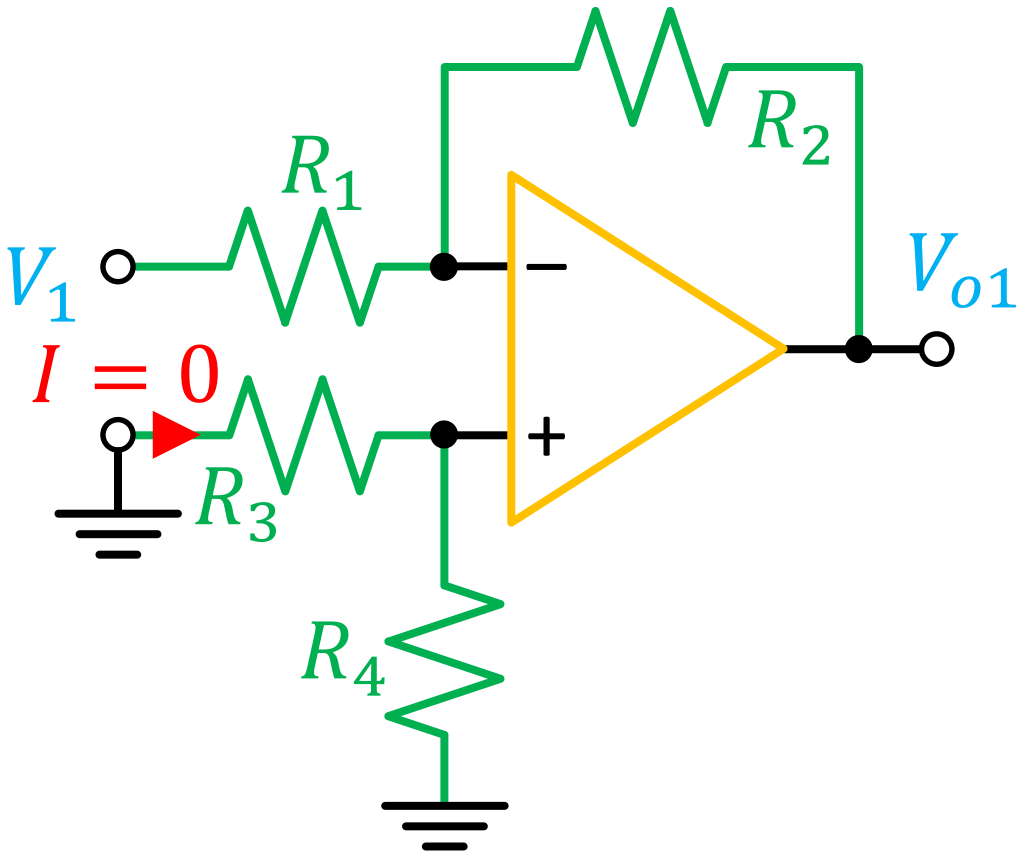
$$V_o = -V_1 \frac{R}{R_1} - V_2 \frac{R}{R_2} - \cdots - V_n \frac{R}{R_n}$$

If $R_1 = R_2 = \cdots = R_n$: $V_o = -\frac{R}{R_1}(V_1 + V_2 + \cdots + V_n)$

Subtractor circuit



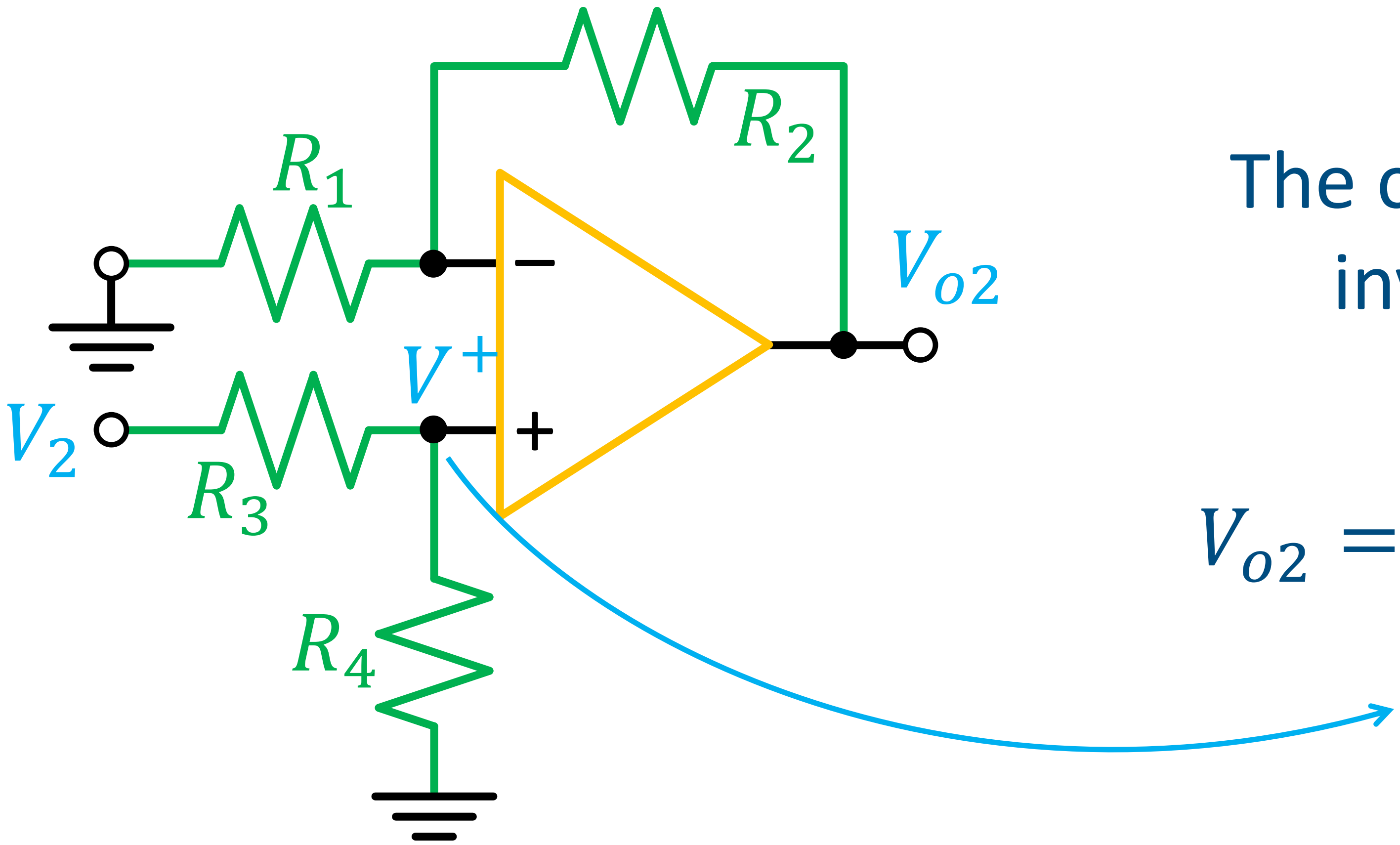
Superposition principle – 1



The circuit becomes an inverting amplifier:

$$V_{o1} = -\frac{R_2}{R_1} V_1$$

Superposition principle – 2



The circuit is now a non-inverting amplifier

$$V_{o2} = V_2 \frac{R_4}{R_3 + R_4} \frac{R_1 + R_2}{R_1}$$

Result

$$V_o = V_{o1} + V_{o2} = -\frac{R_2}{R_1}V_1 + \frac{R_4}{R_3 + R_4}\frac{R_1 + R_2}{R_1}V_2$$

$$= \frac{R_2}{R_1}\left(-V_1 + \frac{1 + R_1/R_2}{1 + R_3/R_4}V_2\right)$$

If we pick $\frac{R_1}{R_2} = \frac{R_3}{R_4}$, we get

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

Resistor values

- Closed-loop gain often depends on resistor ratio, not absolute values
- Low-value resistors draw more current but have better frequency response
- High-value resistors are more noisy and enhance any leakage current
- Typical values are in the range $10 - 100\ \text{k}\Omega$

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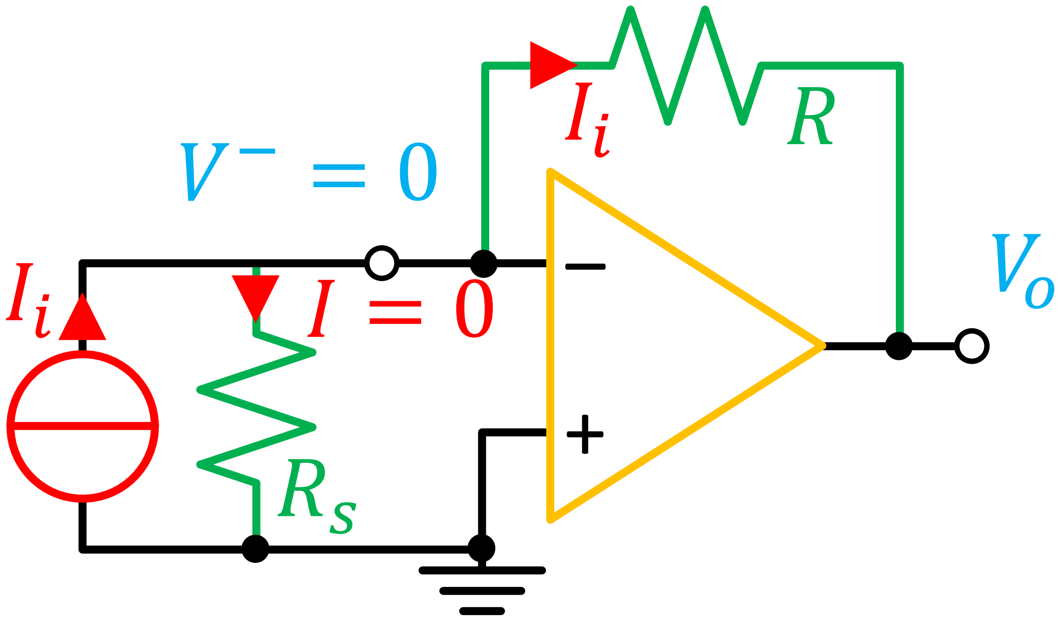
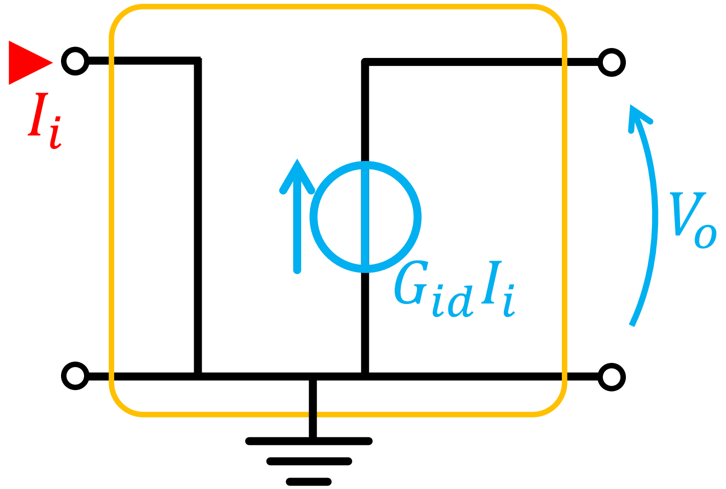
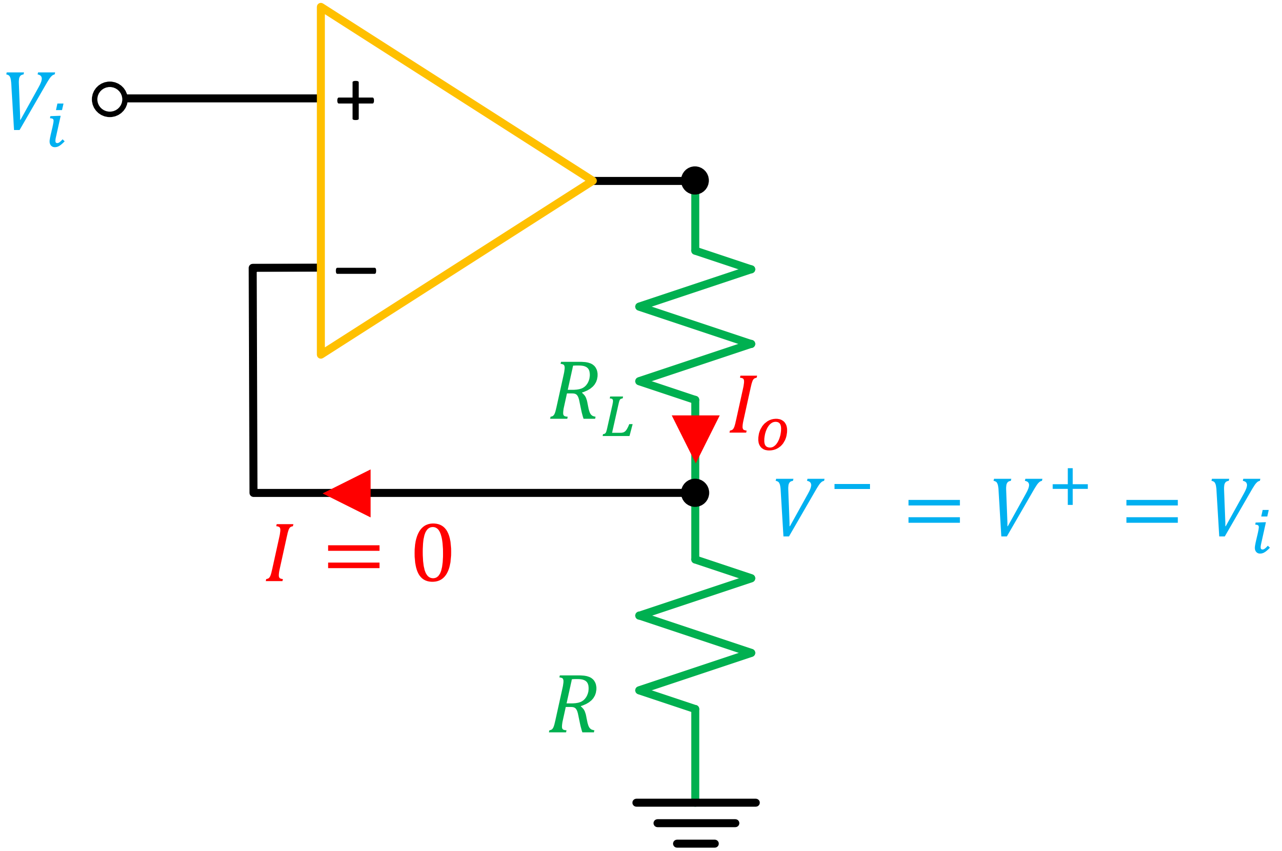
I-V converter (TR amp)



$$V_o = -RI_i$$
$$Z_\mathrm{i} = 0; Z_o = 0$$



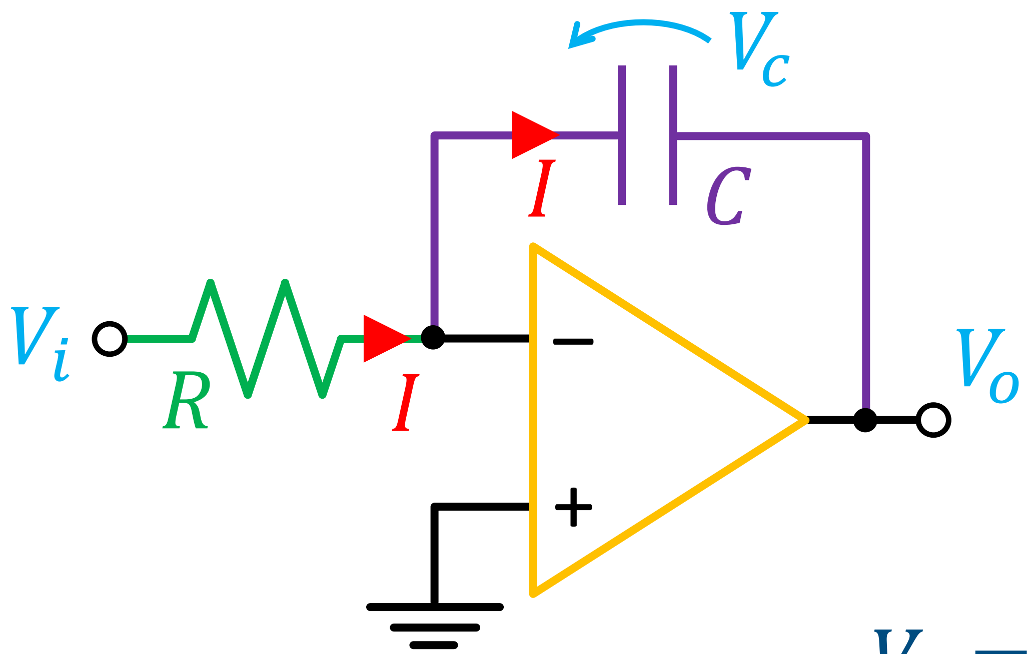
V-I converter (TC amp)



$$I_o = \frac{V_i}{R}$$

$$Z_i = \infty; Z_o = ?$$

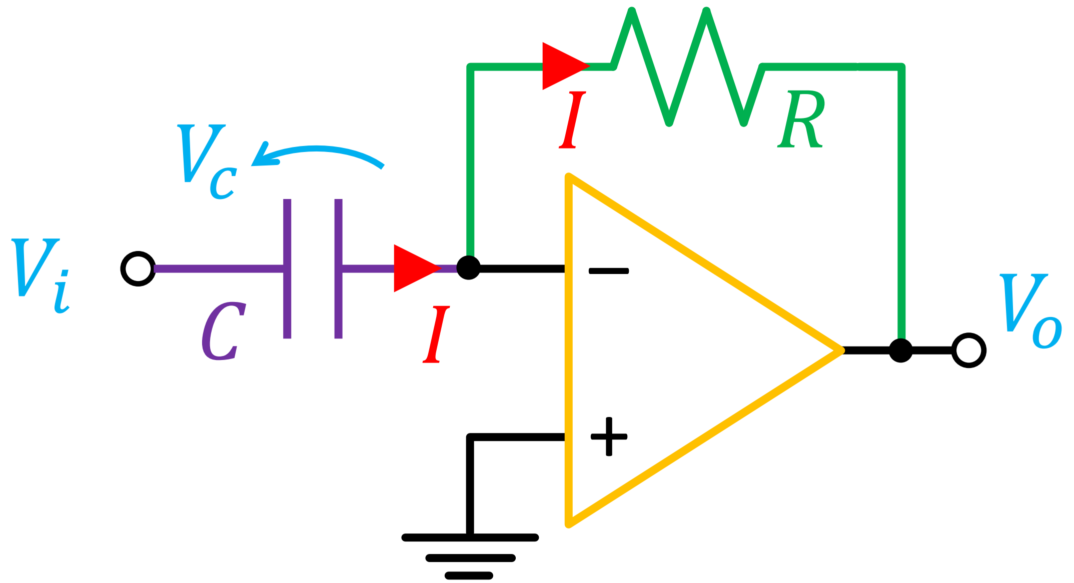
Integrator



$$I = C\frac{dV_c}{dt} \Rightarrow V_c = \frac{1}{C}\int I dt$$

$$V_o = -V_c = -\frac{1}{C}\int I dt = -\frac{1}{RC}\int V_i dt$$

Differentiator



$$I = C\frac{dV_c}{dt}$$

$$V_o = -RI = -RC\frac{dV_c}{dt} = -RC\frac{dV_i}{dt}$$