Differential amplifier = Operational amplifier = = Op amp = OA

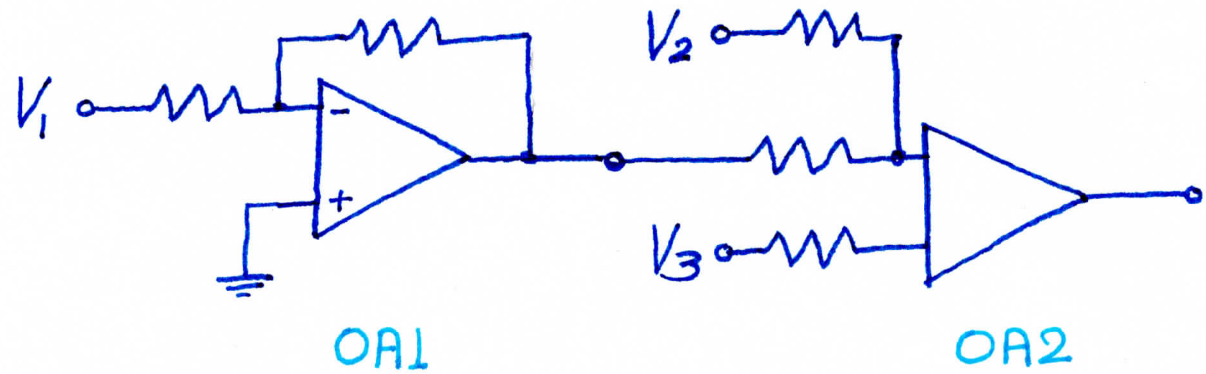
We showed that differential amplifiers are able to perform mathematical operations, e.g.

$$V_{out} = V_1 + V_2 \qquad \text{(Addition)}$$

$$V_{out} = V_2 - V_1 \qquad \text{(Subtraction)}$$

Therefore, we can refer to differential amplifiers as operational amplifiers or op amps.

Multistage op amps



Input voltages V_1, V_2 and V_3

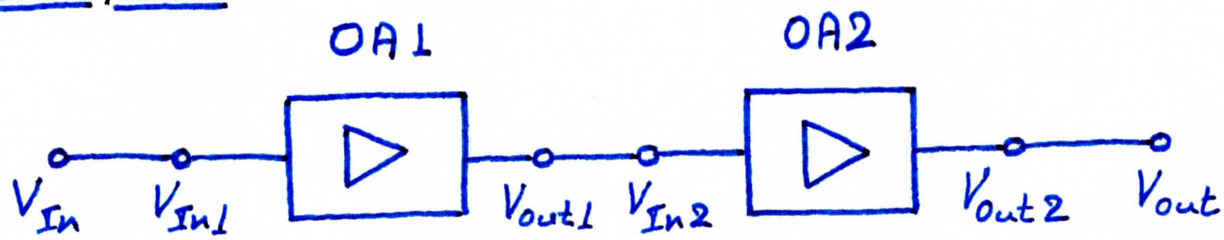
Question: Do V_2 & V_3 affect input voltage of op amp 1 (OA1)? Yes OR No?

To answer question, recall that op amps have zero output resistance ($R_{out} = 0$).

If we apply the superposition theorem, it will show that V_2 & V_3 have no effect on input of op amp 1 (OA1). ⇒ Multi-stage op amp circuits can be evaluated by independently evaluating each stage.

⇒ We can evaluate a multi-stage op amp circuit in a "forward looking" manner.

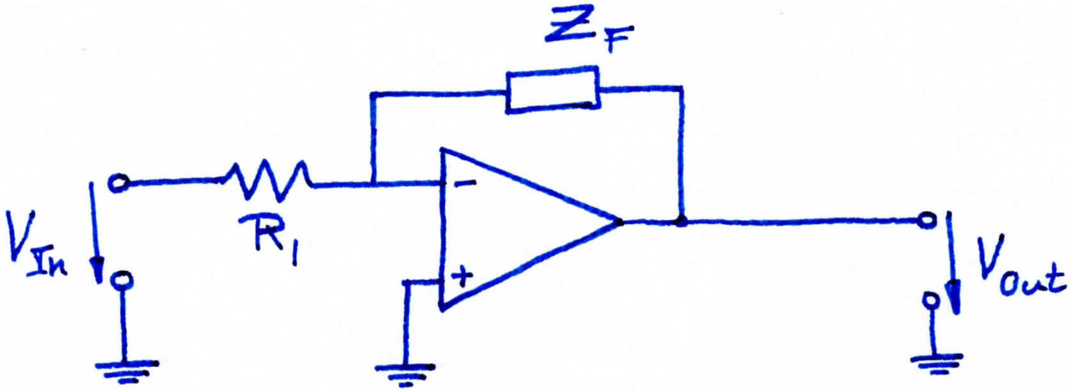
Example:



$$\underbrace{\frac{V_{out}}{V_{In}}}_{H(\omega)} = \underbrace{\frac{V_{out2}}{V_{In2}}}_{H_1(\omega)} \underbrace{\frac{V_{out1}}{V_{In1}}}_{H_2(\omega)} = \frac{V_{out2}}{V_{In1}}$$

$H(\omega)$ → Transfer function

Op amp frequency response due to complex circuit elements



Circuit elements can be complex (e.g. Z_F)

 $Z_F = 1/j\omega C$

 $Z_F = j\omega L$

$\Rightarrow$ V_{out} depends on V_{In} and ω

Example:

Consider: $Z_F = \dfrac{1}{j\omega C}$

Recall $V_{out} = -\dfrac{Z_F}{R_1} V_{In}$

$$\Rightarrow \frac{V_{out}}{V_{In}} = H(\omega) = -\frac{Z_F}{R_1} = -\frac{\frac{1}{j\omega C}}{R_1}$$

$$= -\frac{1}{j\omega R_1 C} = j\frac{1}{\omega R_1 C}$$

$$\Rightarrow \quad |H(\omega)| = \left| j\frac{1}{\omega R_1 C_1} \right| = \frac{1}{\omega R_1 C_1}$$