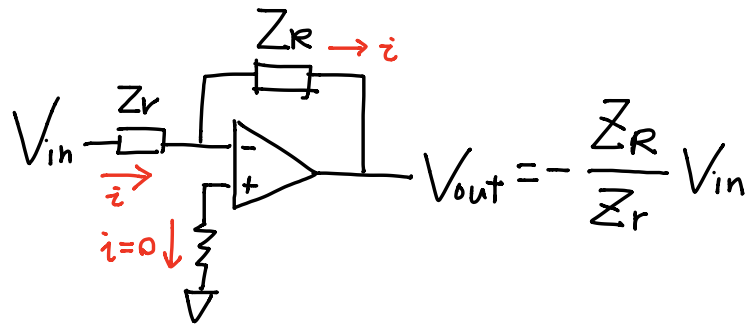
Op-amp Operational Amplifier

Goals of these 2 classes:

1. Golden rules.
2. How do op-amps work? Answer: feedback!!
3. How to do arbitrary signal processing?



Golden rules of an ideal op-amp:

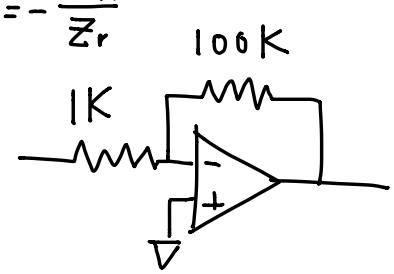
1. $V_+ = V_-$
2. V_+ & V_- terminals do not source/sink current.

Step 1: $V_+ = V_- = 0$ (from both rules)

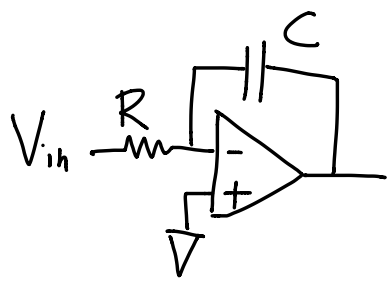
Step 2: $i_{in} = \frac{V_{in}}{Z_{in}} \Rightarrow V_{out} = -i Z_R = -\frac{Z_R}{Z_r} V_{in}$

$\Rightarrow G = -\frac{Z_R}{Z_r}$

Example:



$G = -100$.



(time domain)

$$V_{out}(t) = \frac{1}{C} q = \frac{1}{C}\int i\, dt = \frac{1}{C}\int -\frac{V_{in}}{R}\, dt$$
$$= -\frac{1}{RC}\int V_{in}(t)\, dt$$

(freq domain)

$$V_{out} = -\frac{Z_R}{Z_r} V_{in} = -\frac{1}{iRC\omega} V_{in}$$

Prove 2 pictures are identical:

$$V_{in}(t) = V_{in} e^{i\omega t} \Rightarrow \int V_{in}(t)\, dt = \frac{1}{i\omega} V_{in} e^{i\omega t}$$
$$V_{out}(t) = V_{out} e^{i\omega t}$$

$$\Rightarrow V_{out} \cancel{e^{i\omega t}} = -\frac{1}{RC}\frac{1}{i\omega} V_{in} \cancel{e^{i\omega t}}$$

identical as the freq domain result.

$\Rightarrow$ Gain $G = -\frac{1}{i\omega RC}$ means an integer!!

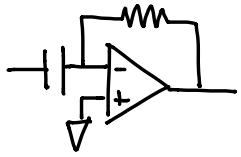
$$y = A\int x(t)\, dt.$$

$$V_{out} = -\frac{1}{RC}\frac{1}{i\omega} V_{in}$$

Where is $i\omega$ coming from? $\partial_t f(t) = i\omega f(t)$, when f oscillates @

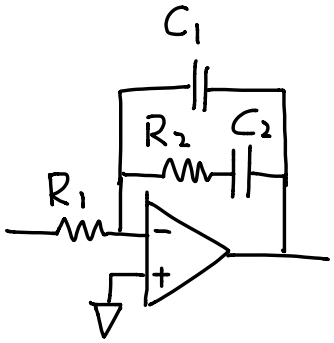
$$\Rightarrow i\omega = \partial_t \Rightarrow V_{out} = -\frac{1}{RC}\frac{1}{\partial_t} V_{in} \;??$$

or $V_{in} = -RC\, i\omega\, V_{out}$
$= -RC\, \partial_t V_{out}$



$$G = -\frac{Z_R}{Z_r} = -\frac{R}{\frac{1}{i\omega C}} = i\omega RC$$

$$V_{out} = i\omega RC V_{in} = RC\partial_t V_{in} \Rightarrow \text{differentiator !!}$$



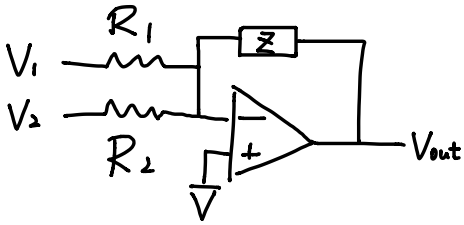
$$G = -\frac{1}{R_1}\left[\left(R_2 + \frac{1}{i\omega C_2}\right) /\!/ \frac{1}{i\omega C_1}\right]$$

$$= -\frac{1}{R_1}\frac{R_2 + \frac{1}{i\omega C_2}}{\left(R_2 + \frac{1}{i\omega C_2} + \frac{1}{i\omega C_1}\right) i\omega C_1}$$

$$= -\frac{1}{R_1}\frac{1 + i\omega R_2 C_2}{i\omega(C_1 + C_2 - \omega^2 R_2 C_1 C_2}$$

$$R_1 /\!/ R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

Summing amplifier

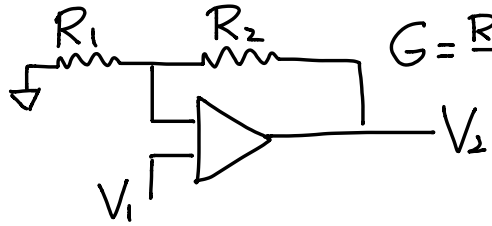


$$i = i_1 + i_2$$

$$\Rightarrow V_{out} = -iZ$$

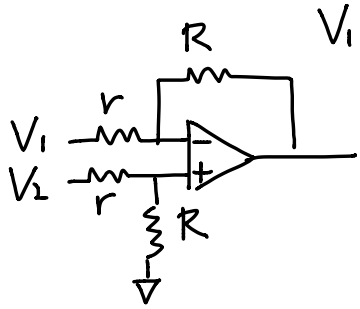
$$= -Z\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right)$$

Non-inverting amplifier



$$G = \frac{R_1 + R_2}{R_1}$$

Difference amplifier



$$V_{out} = \frac{R}{r}(V_2 - V_1)$$