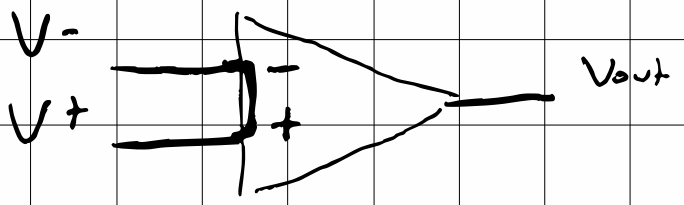
Lecture 15 ME133 2/24/2022

Last time:

- stepper motors
- op amps

Ideal op-amps



$$V_{out} = A_{OL}(V_+ - V_-)$$

$A_{OL} \to \infty$

(1) infinite input impedance

$I_+ = I_- = 0$

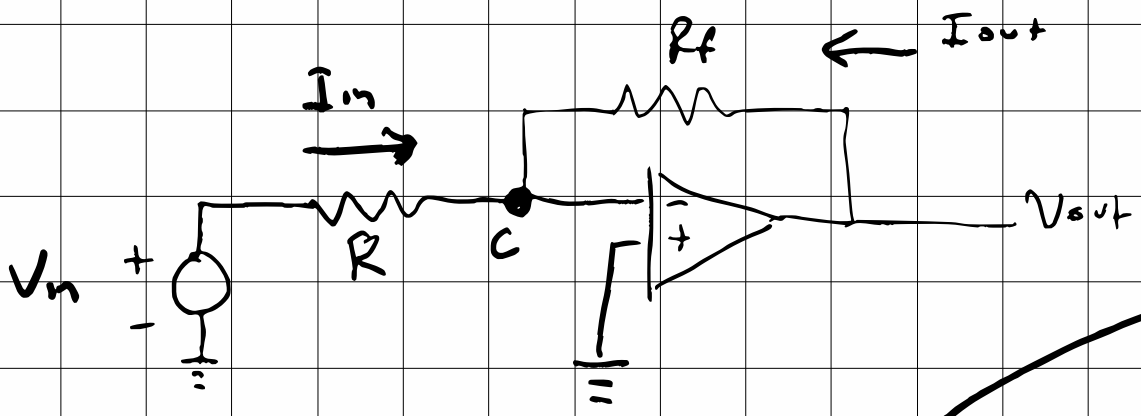
(2.) infinite gain

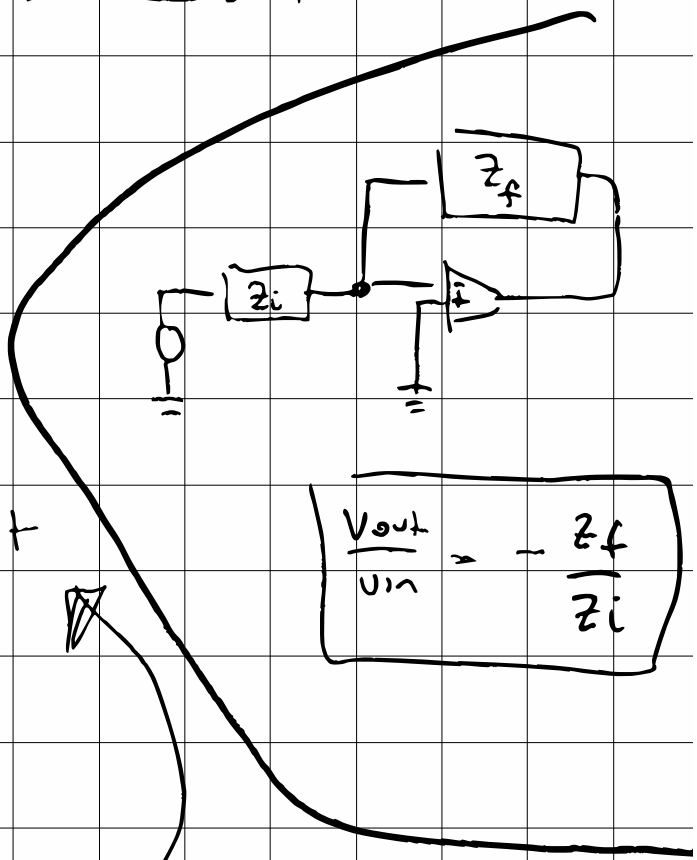
$V_+ = V_-$

(3.) Zero output impedance

V_{out} is independent of I_{out}

Example : Inverting Amplifier





KCL: Node C

$$I_{in} = -I_{out}$$

$$V_C = 0$$

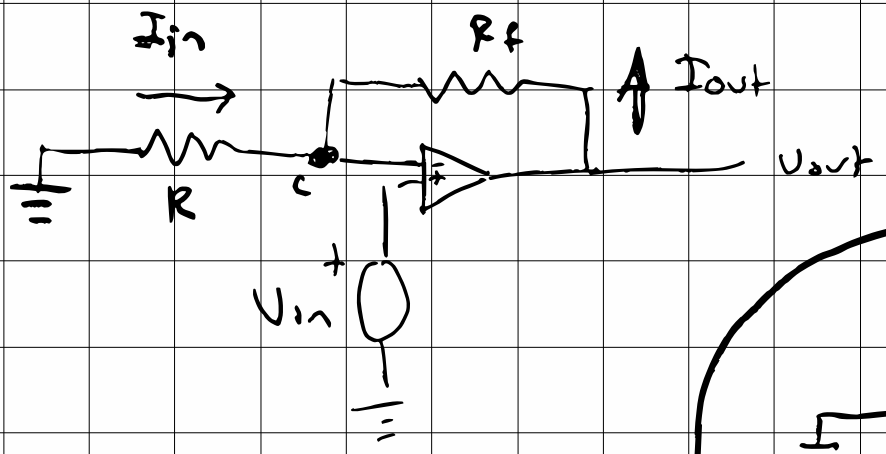
$$\frac{V_{in}}{R} = I_{in}$$

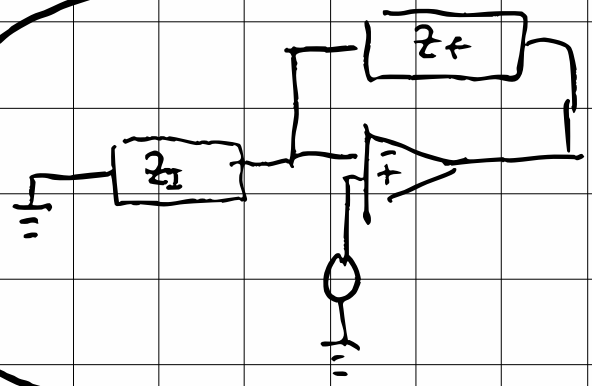
$$\frac{V_{out}}{R_f} = I_{out}$$

$$\frac{V_{in}}{R} = -\frac{V_{out}}{R_f} \Rightarrow \boxed{\frac{V_{out}}{V_{in}} = -\frac{R_f}{R}}$$

$$\boxed{\frac{V_{out}}{V_{in}} = -\frac{Z_f}{Z_i}}$$

Example: non-inverting Amplifier





$V_C = V_{in}$

KCL @ C: $I_{in} = -I_{out}$

$$\frac{V_{out}}{V_{in}} = \left(1 + \frac{Z_f}{Z_I}\right)$$

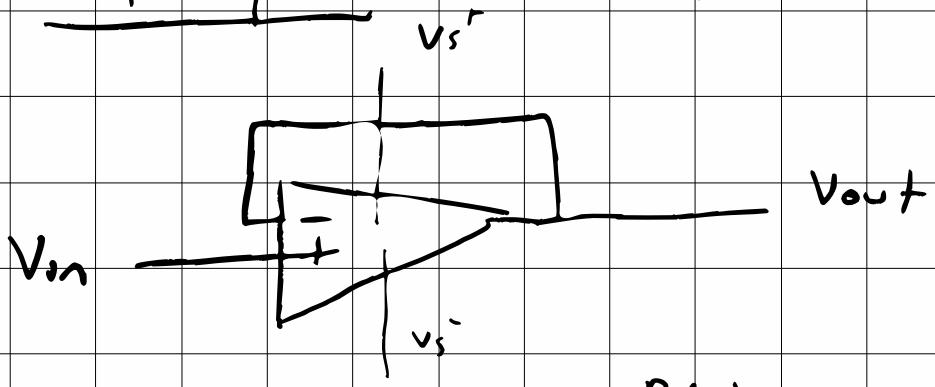
$$I_{in} = -\frac{V_C}{R} = -\frac{V_{in}}{R}$$

$$I_{out} = \frac{V_{out} - V_{in}}{R_f}$$

$$-\frac{V_{in}}{R} = -\frac{(V_{out} - V_{in})}{R_f}$$

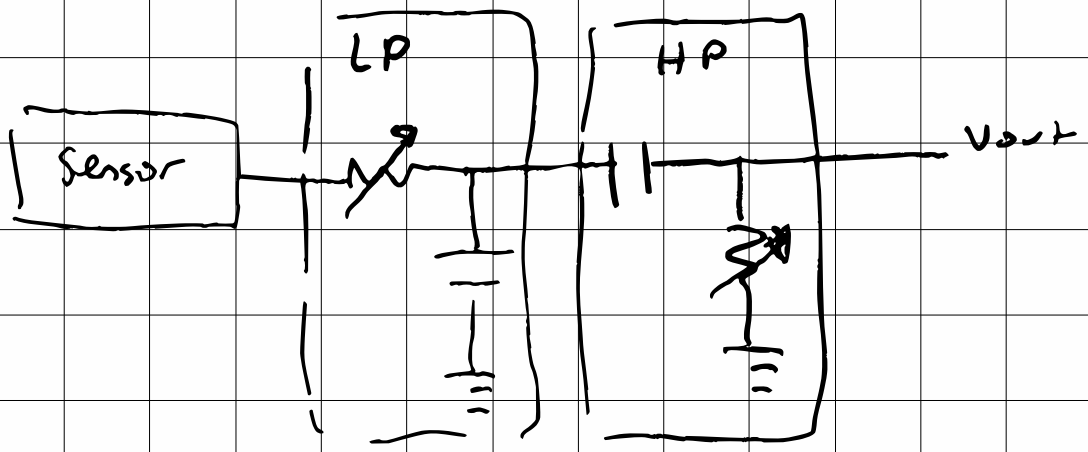
$$\boxed{\frac{V_{out}}{V_{in}} = \left(1 + \frac{R_f}{R}\right)}$$

Example: Buffer.

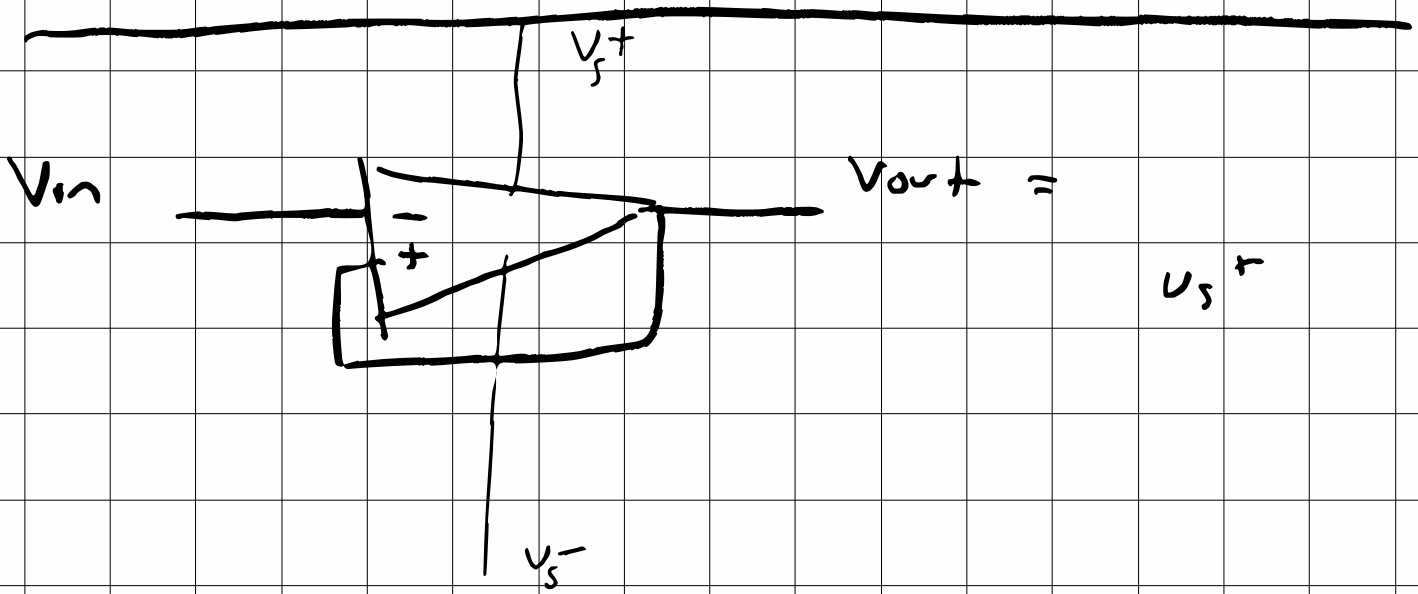


$$\frac{V_{out}}{V_{in}} = \left(1 + \frac{R_f}{R}\right) = 1$$

$$\frac{R_f}{R} \to 0$$

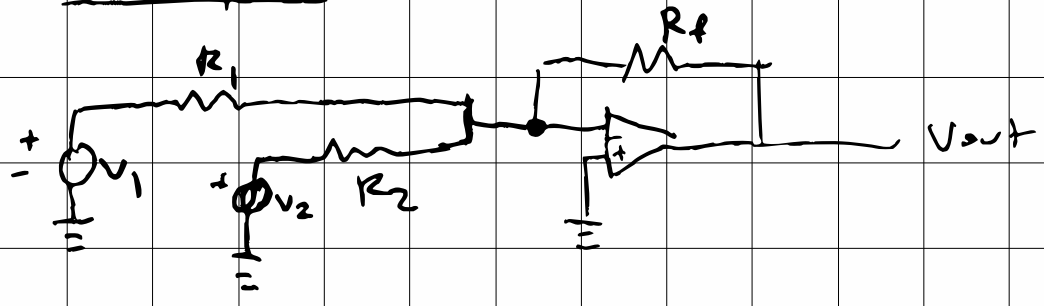


* Buffers isolate output stage from input stage and therefore doesn't load the upstream circuits

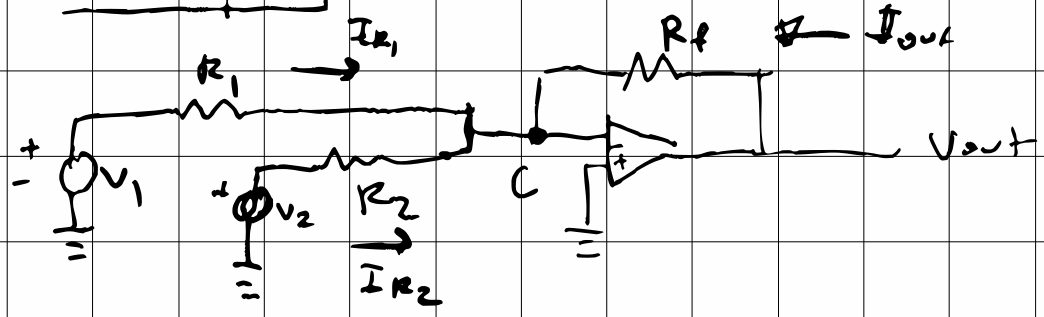


What's an example of positive feedback?

Example: summer



Example: summer



$$V_C = 0$$

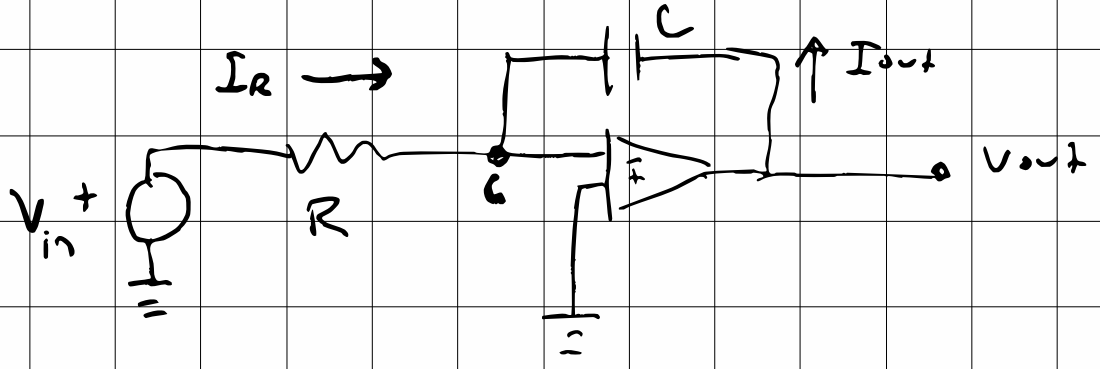
KCL @ NODE C:

$$I_{R_1} + I_{R_2} = -I_{out}$$

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} = -\frac{V_{out}}{R_f}$$

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

Example: Integrator



$$V_G = 0$$

KCL: $I_R = -I_{out}$

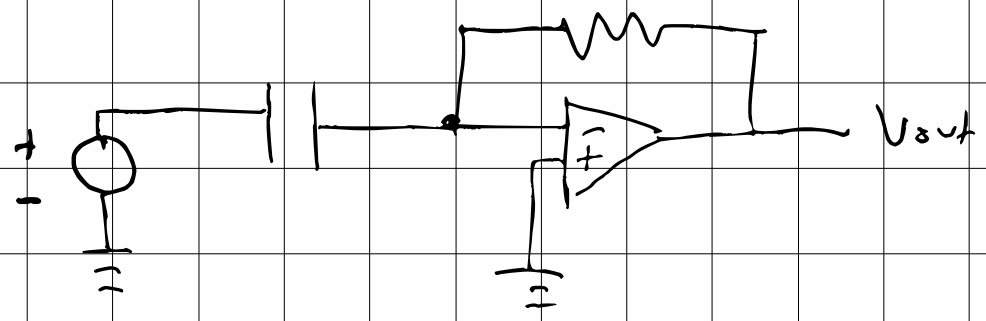
$$\Rightarrow \frac{V_{in}}{R} = -C\frac{dV_{out}}{dt}$$

$$\Rightarrow \frac{dV_{out}}{dt} = -\frac{1}{RC}\cdot V_{in}$$

$$V_{out} = -\frac{1}{RC}\int_0^t V_{in}\,dt$$

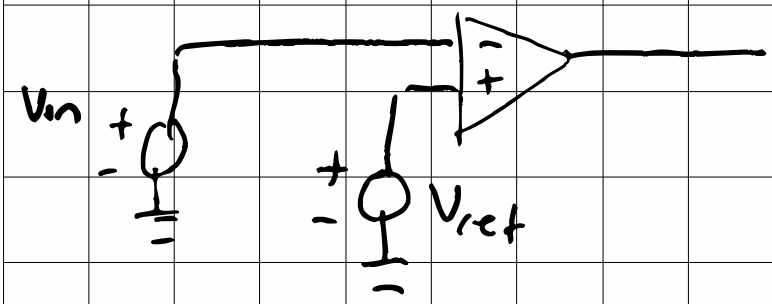
$$\boxed{V_{out}(t) = -\frac{1}{RC}\int_0^t V_{in}(\tau)\,d\tau}$$

Example: Differentiator

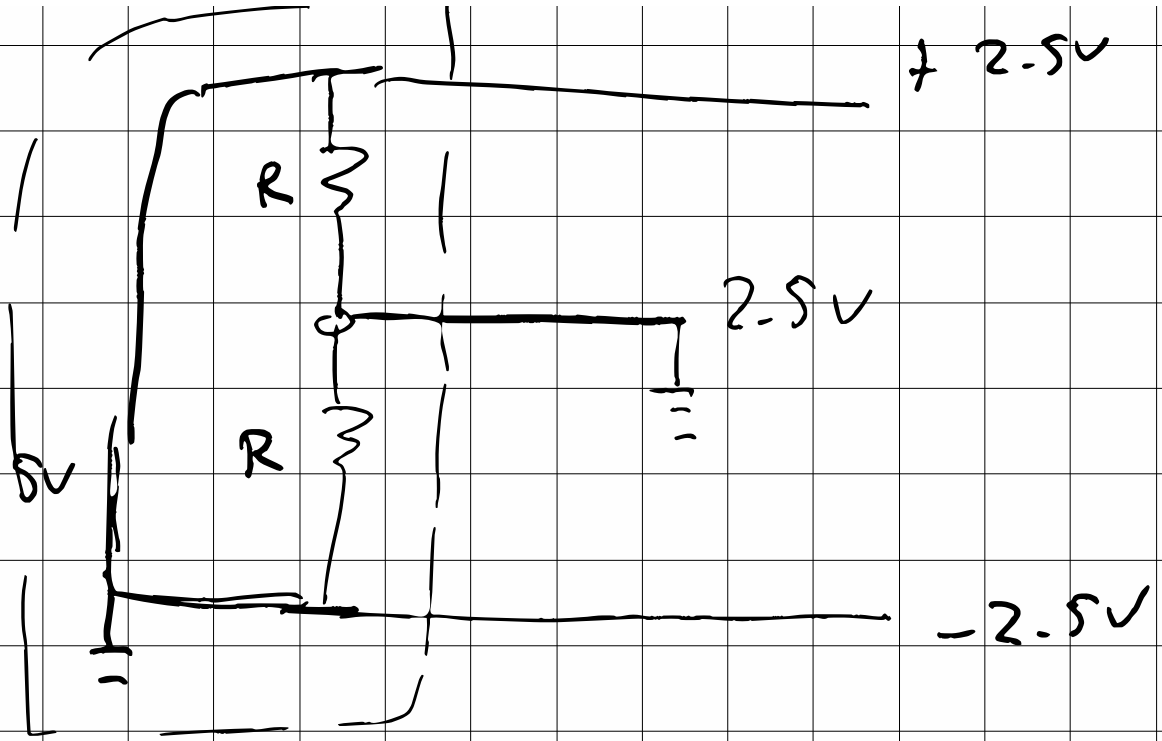


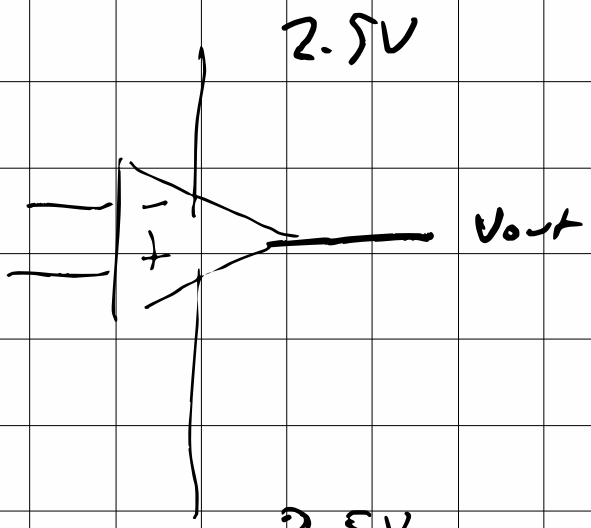
$$V_{out} = -RC\,\dot{V}_{in}$$

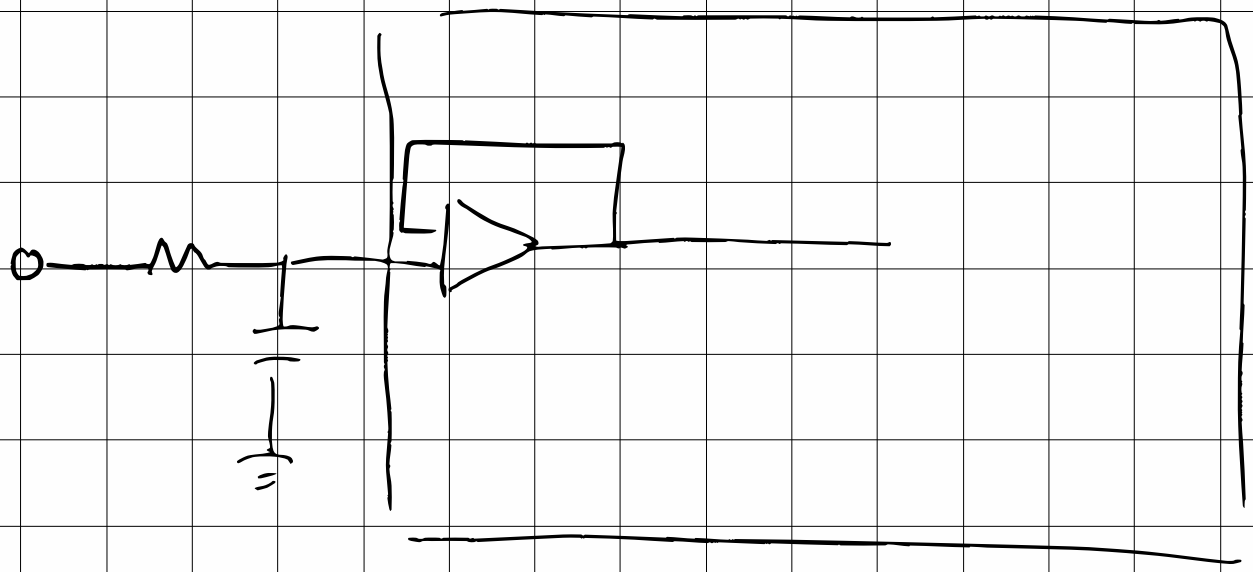
Comparator — No feedback



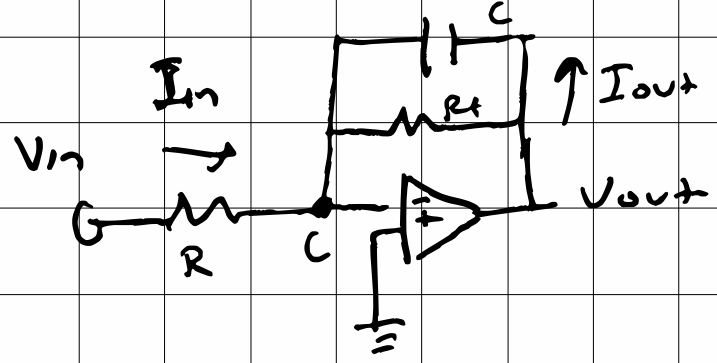
$$V_{out} = \begin{cases} +V_{sat} & V_{in} > V_{ref} \\ -V_{sat} & V_{in} < V_{ref} \end{cases}$$

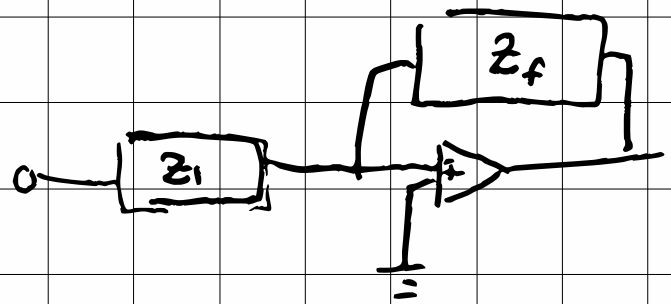

+2.5V
R
2.5V
R
5V
-2.5V


2.5V
Vout
-2.5V



Active filters





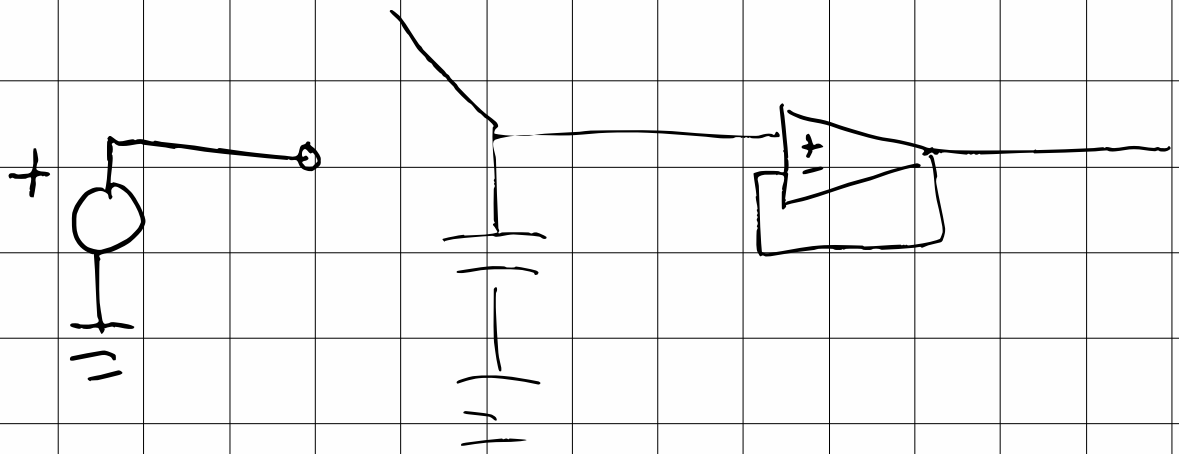
$$I_{in} = -I_{R_f} - I_C$$

$$\frac{V_{in}}{R} = -\frac{V_{out}}{R_f} - C j\omega V_o$$

$$\vdots$$

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R}\left(\frac{1}{1 + CR j\omega}\right)$$

Sample & Hold circuit

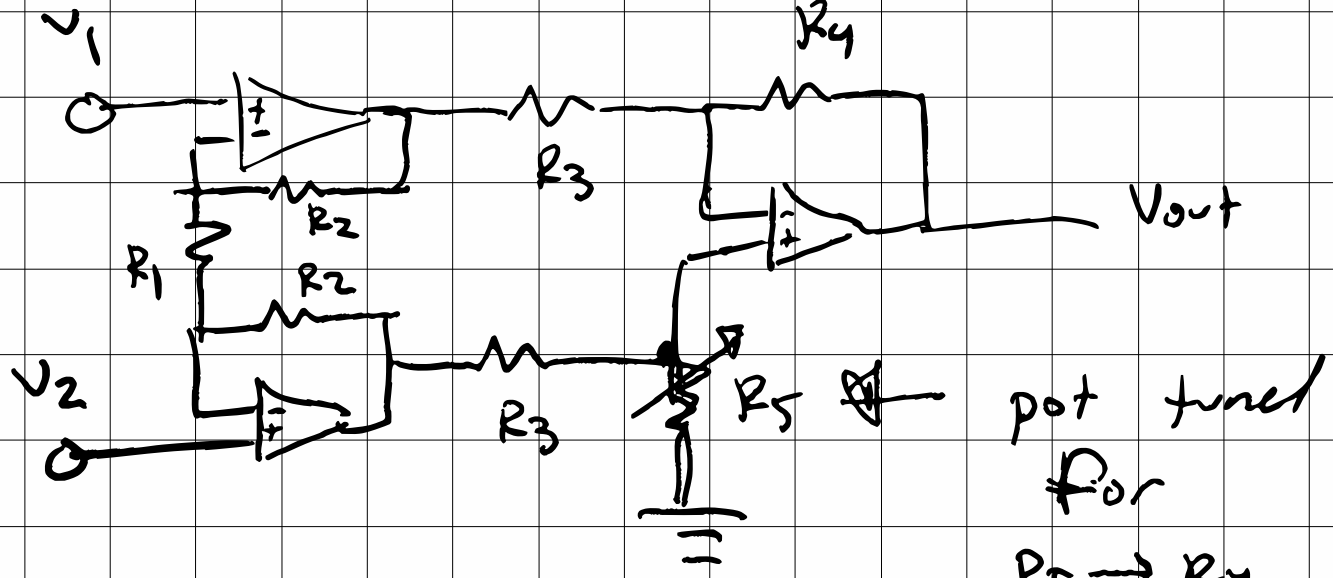


$V_{out}(t) = V_{in}(t)$ switch closed

$V_{out}(t - t_{sample}) = V_{in}(t_{sample})$

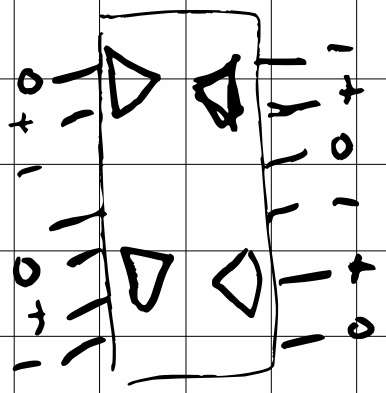
Instrumentation Amplifier

* most important amplifier for differential measurement



pot tuned for $R_5 \rightarrow R_4$

really good @ common mode rejection



Example package.