EECS 16A Module 2

Logistics
- MT2 done.
- Easy HW today.
- MT redo for clobber. (No extensions)
- Thursday lecture – Panos. + OH.

Today
Op-Amps

Negative Feedback

Unreasonable effectiveness of mathematics.

↳ AI, Robotics, feedback, economics, social justice, biology.

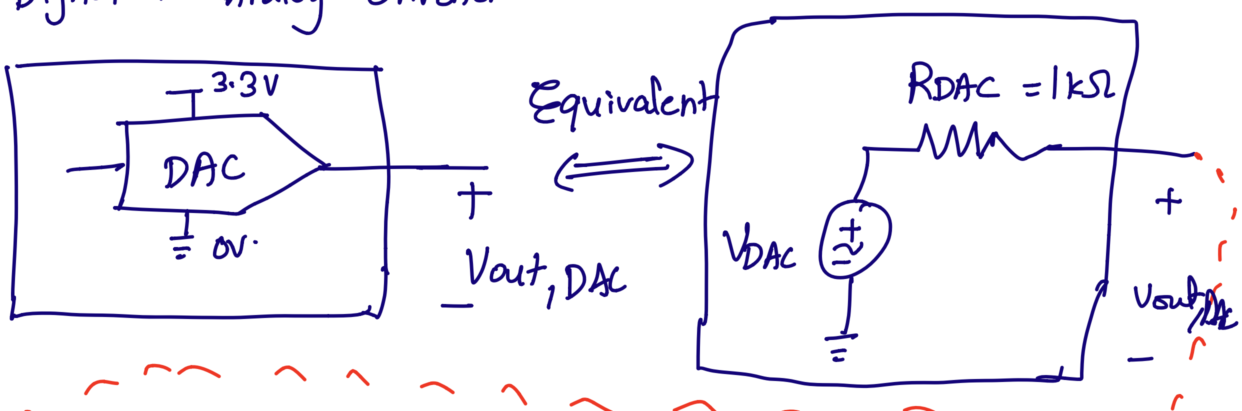
"The loading effect"

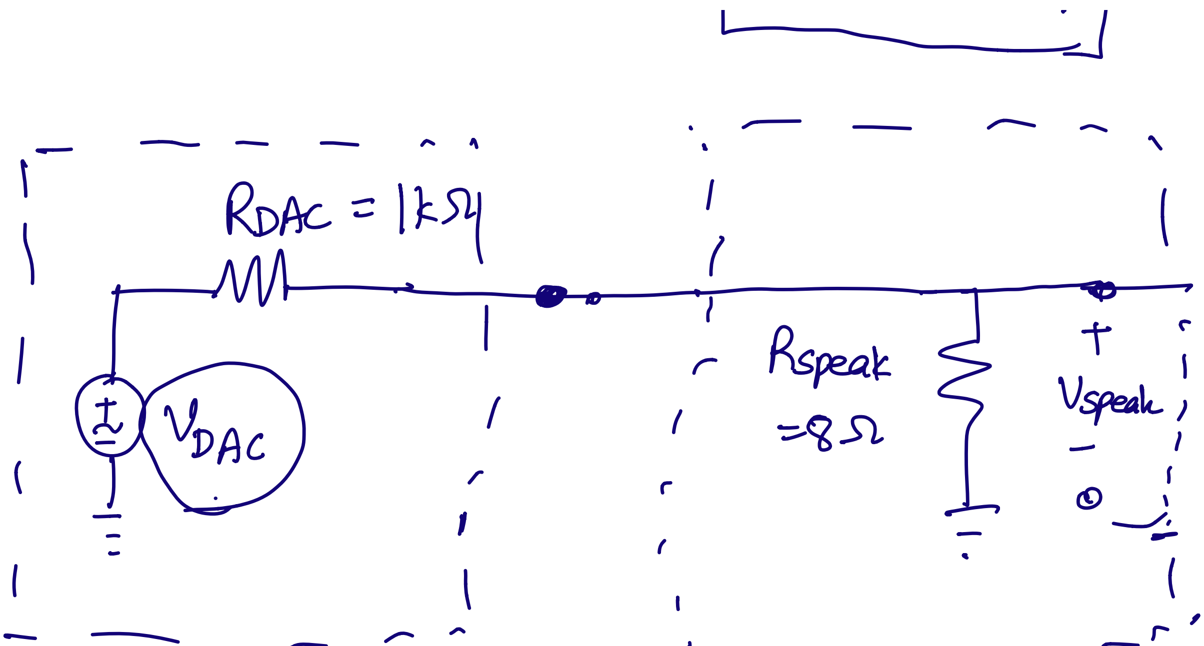
"Digitally" 0, 1, ... "bits"

"Analog"

DAC

Digital to Analog Converter.





Circuit 1: DAC

Circuit 2: Speaker

$$V_{speak} = \frac{R_{speaker}}{R_{spaker} + R_{DAC}} \cdot V_{DAC}$$

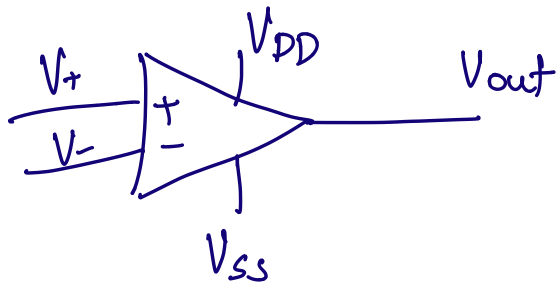
$$= \frac{8\,\Omega}{8 + 1000\,\Omega} \cdot V_{DAC}$$

$$= \frac{8}{1008} \cdot V_{DAC}$$

$$V_{speak} = \frac{1}{126} V_{DAC}$$

"Loading effect"

Op-Amps + Negative feedback



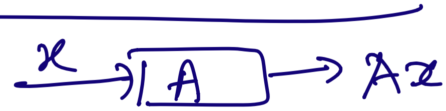
$$V_{out} = \underbrace{V_{SS} + \frac{V_{DD}-V_{SS}}{2}} + A(V_+ - V_-)$$

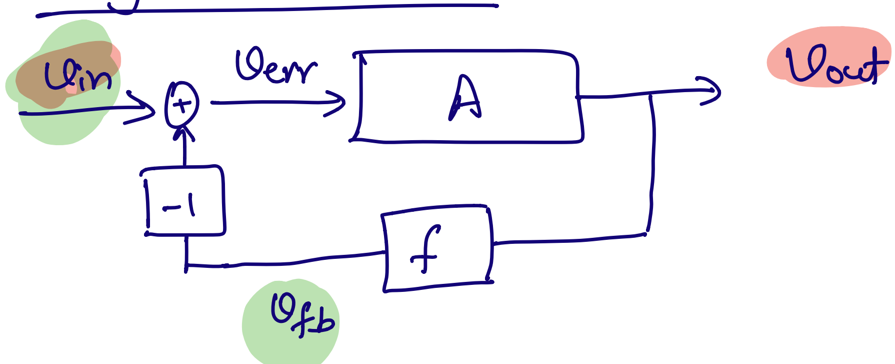
$$= \frac{V_{DD}+V_{SS}}{2} + A(V_+ - V_-)$$

If $V_{DD} = -V_{SS}$ $\boxed{\;\; = 0}$

then, $V_{out} = A(V_+ - V_-)$

Negative feedback:





$$v_{in} - v_{fb} = v_{err} \quad (1)$$

$$v_{out} = A \cdot v_{err} \quad (2)$$

$$v_{fb} = f \cdot v_{out} \quad (3)$$

$$v_{out} = A \; v_{err}$$

$$v_{out} = A(v_{in} - f \cdot v_{out}) \qquad \text{using } (1), (3)$$

$$v_{out} + Af \cdot v_{out} = A \, v_{in}$$

$$(1 + Af) \, v_{out} = A \cdot v_{in}$$

$$\Rightarrow \boxed{v_{out} = \frac{A}{1+Af} \cdot v_{in}}$$

$A \to \infty$ very large gain

$$v_{out} = \frac{1}{\frac{1}{A} + f} \cdot v_{in} \qquad \frac{1}{A} \to 0 \text{ as } A \to \infty$$

$$A \to \infty, \quad \boxed{v_{out} = \frac{1}{f} \cdot v_{in}}$$

v_{in}, v_{fb}.

$v_{in} = f \cdot v_{out}$

$v_{fb} = f \cdot v_{out}$

As $A \to \infty$, in negative feedback

$$v_{fb} = v_{in}$$

"Golden Rules of Op-Amps"

Op-Amp in Negative feedback.

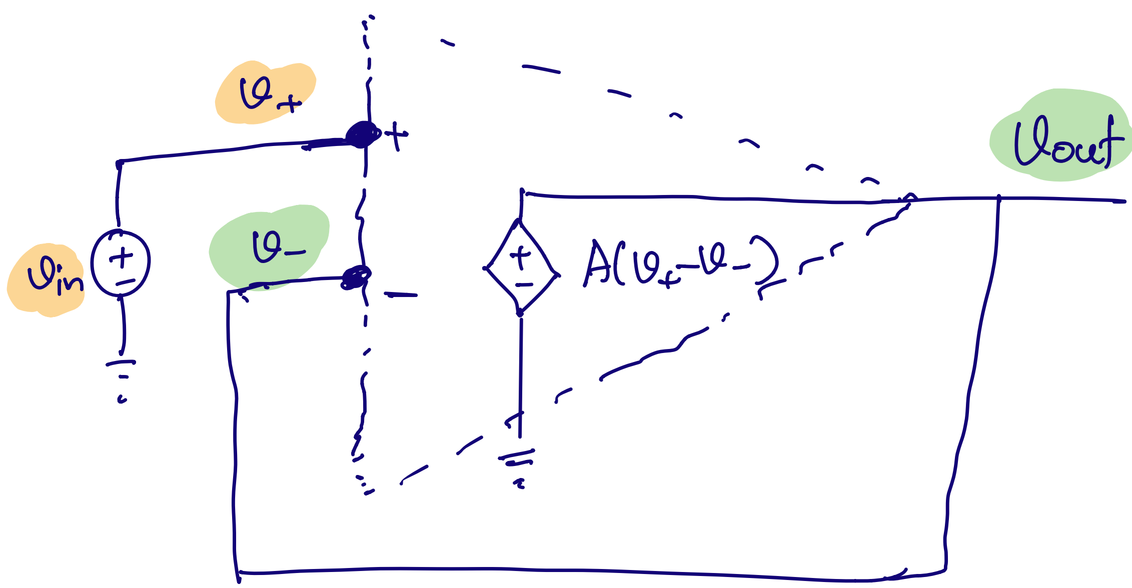
$V_{DD} = -V_{SS}$

"Buffer"

$$V_{out} = A\underbrace{(V_+ - V_-)}_{v_{err}}$$

How to check if op-amp is in negative feedback?

- If Vout goes ↑ and your input goes ↓ then $(v_+ - v_-)$ decreases ↓ ↓ then you are in negative feedback.



$v_- = v_{out}$; $v_{out} = A(v_+ - v_-)$

$v_+ = v_{in}$

$v_{out} = A(v_+ - v_{out})$

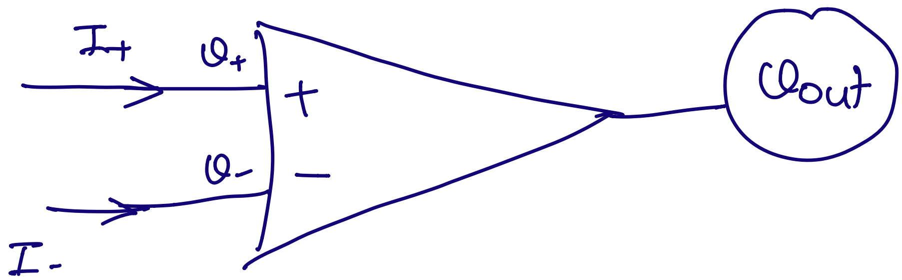
$\Rightarrow v_{out}(1+A) = A \cdot v_+ = A \cdot v_{in}$

$v_{out} = \frac{A}{1+A} v_{in}$

$A \to \infty$ large

$\boxed{v_{out} = v_{in}}$

Golden-Rules of Op-Amps



① $I_+ = 0$, $I_- = 0$

② Only if you are in negative feedback

$$v_+ = v_-$$

"Input to the op-amp": $v_+ - v_-$

$$v_{out} = A(v_+ - v_-)$$

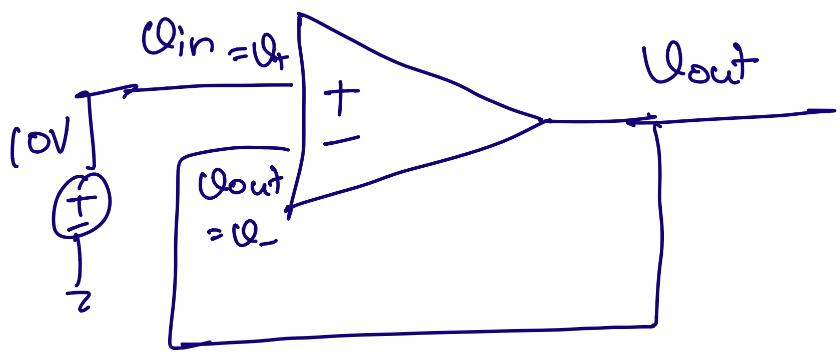
Negative feedback:

If v_{out} goes ↑.

then $(v_+ - v_-)$ goes down.

$$v_{out} = A(v_+ - v_-).$$

$\Rightarrow$ v_{out} goes ↓



$v_{out} \rightarrow 2v_{out}$

$v_{in} = v_+ = 10V$

$v_{out} = v_-$

$$v_{out} = A(v_+ - v_-)$$

v_{out} doubles

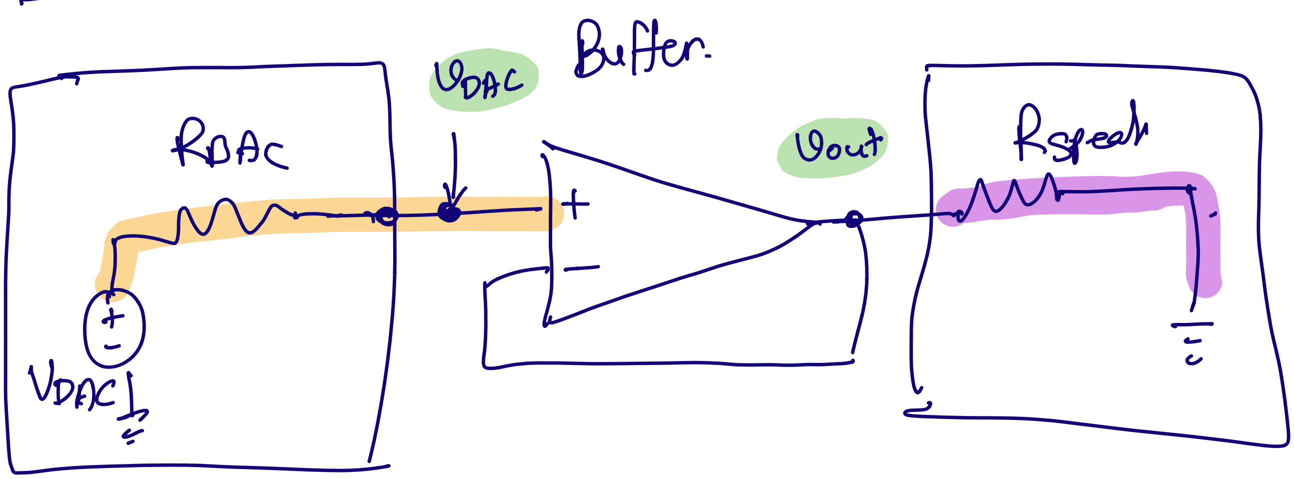
$\nearrow$ used to be $(10V - v_{out})$

does $(v_+ - v_-)$ decrease ?

$$(v_+ - v_-) = (10V - 2v_{out})$$

$$v_{out} = A(v_+ - v_-)$$

decreased



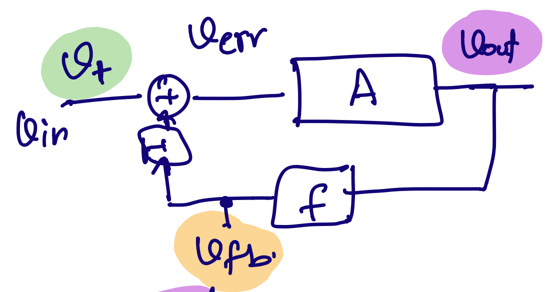
$$v_{out} = v_{DAC} \,!$$

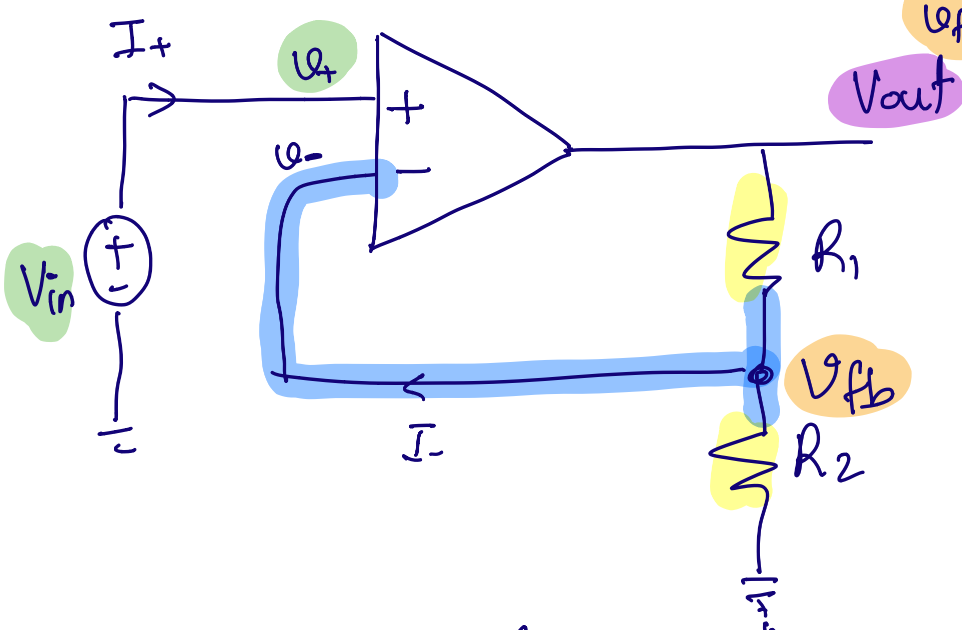
"Design using Op-Amps"

Buffers are a way to have a feedback gain = 1.

What if I want to multiply by 1000?

Non-inverting op-amp





$$v_{fb} = v_{out} \cdot \left(\frac{R_2}{R_1+R_2}\right)$$

$$v_- = v_{fb}$$

$$v_{out} = A(v_+ - v_-)$$

$$v_{out} = A\left(v_{in} - \frac{R_2}{R_1+R_2} \cdot v_{out}\right)$$

$$v_{out} + A \cdot \frac{R_2}{R_1+R_2} \cdot v_{out} = A\, v_{in}$$

$$v_{out} = \frac{A}{1 + A\frac{R_2}{R_1+R_2}} \cdot v_{in}$$

$$\text{"}\frac{R_2}{R_1+R_2} = f\text{"}$$

$$A \to \infty$$

$$v_{out} = \frac{1}{f} \cdot v_{in}$$

$$v_{out} = \frac{1}{\frac{R_2}{R_1 + R_2}} v_{in}$$

$$v_{out} = \frac{R_1 + R_2}{R_2} \cdot v_{in}$$

"Non-inverting amplifier"