(l1)

Lecture 8 - Module 2

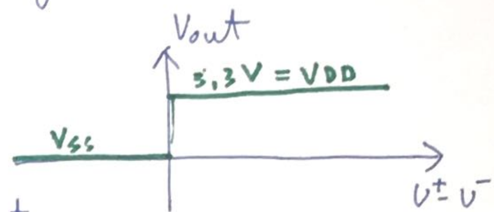
EE16A

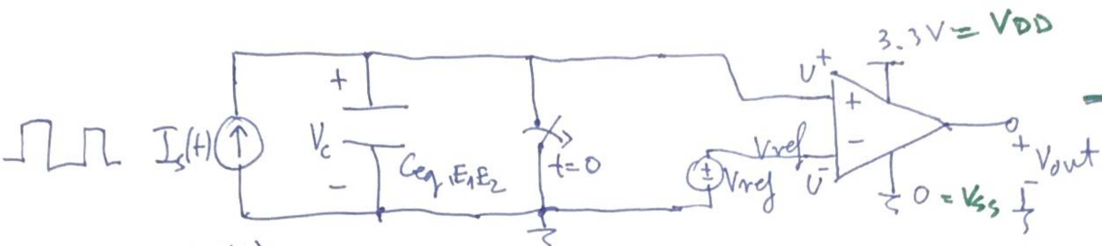
Today:

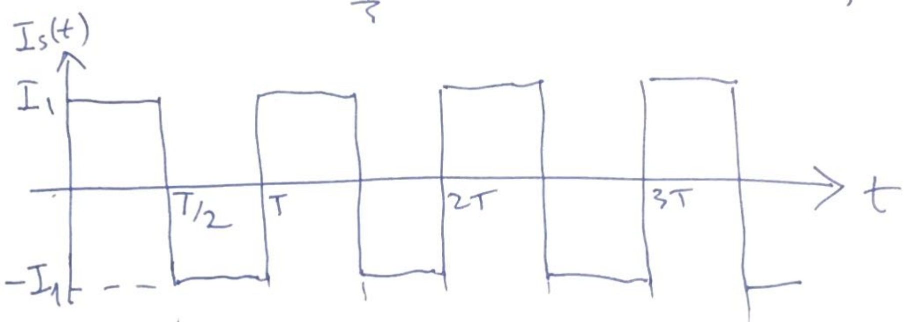
Note 18

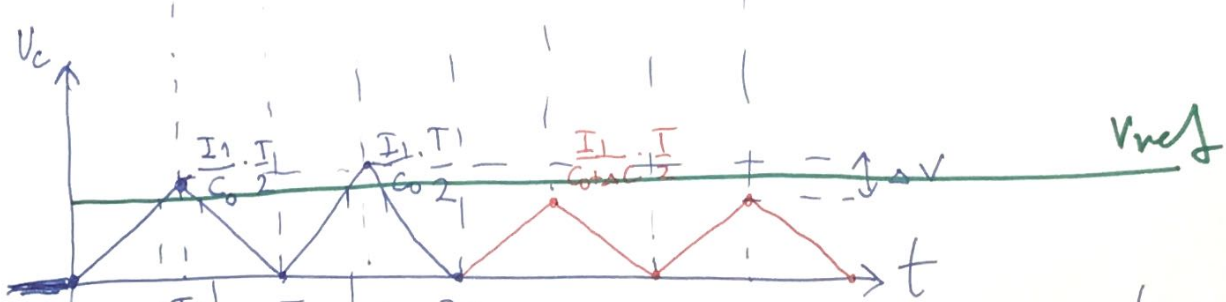
* 2D Touchscreen wrap-up
* Audio system (DAC example)
* Intro to negative feedback
  * Golden rules
  * NFB examples

2D Touchscreen - putting it all together

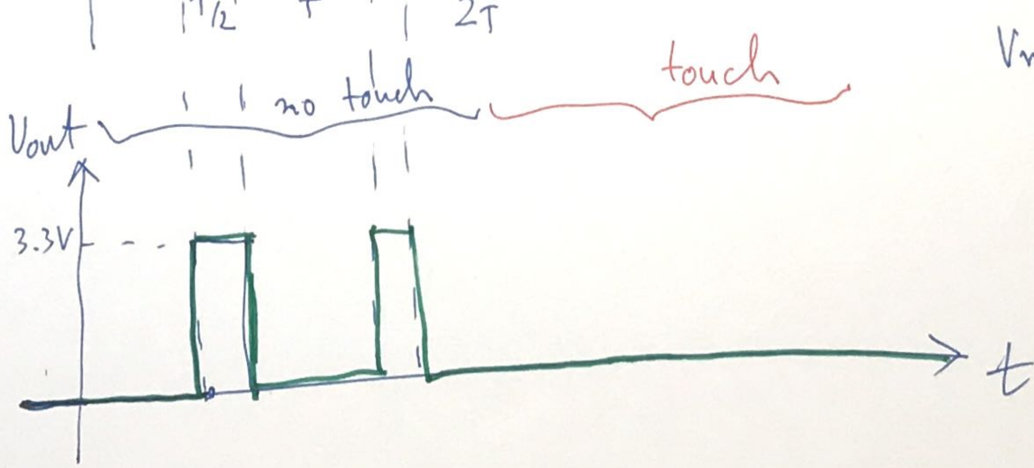








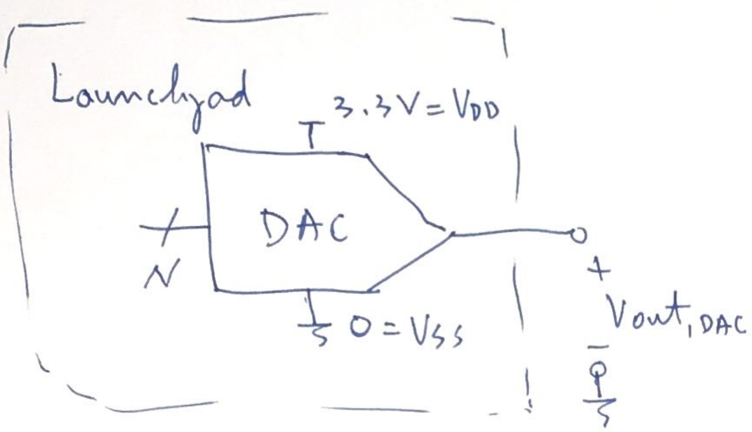
$$V_{ref,opt} = \frac{\left(V_{c,max,touch} + V_{c,max,no,touch}\right)}{2}$$



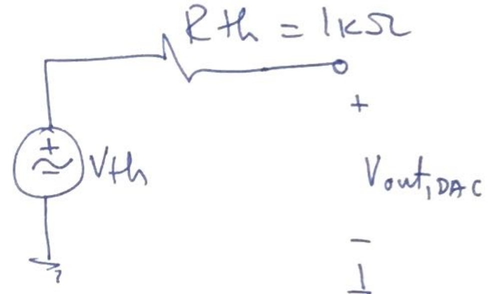
"16A Boombox"

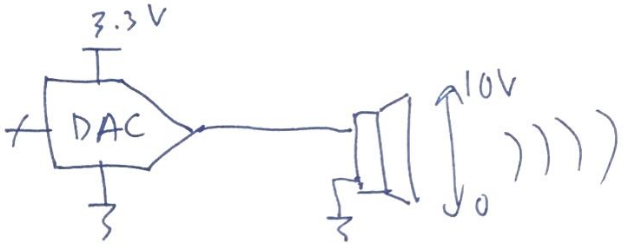
DAC: Digital-to-analog converter

(turns a digital-binary value into analog voltage)



≡ Model

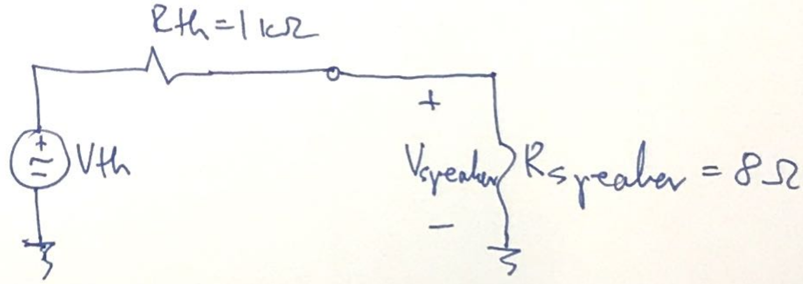




$V_{th} \in [0, 3.3V]$

($0 = V_{SS}$, $3.3V = V_{DD}$)

≡ Model



voltage divider

$$V_{speaker} = \frac{R_{speaker}}{R_{th} + R_{speaker}} \cdot V_{th} = \frac{V_{th}}{126}$$

($R_{speaker} = 8\Omega$, $R_{th} = 1k\Omega$)

Loading effect!

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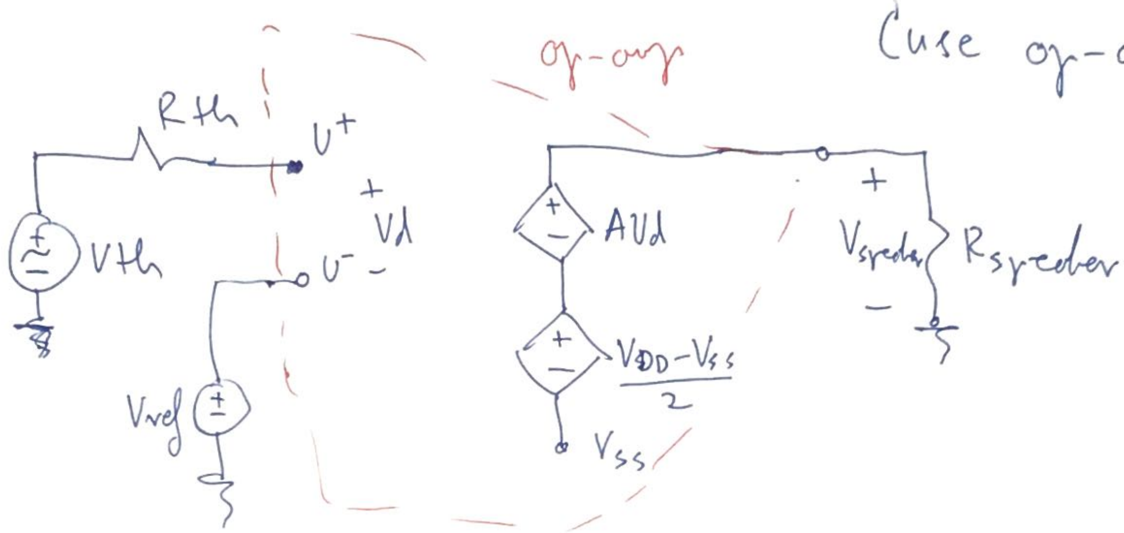
Need to isolate the DAC from speaker (use op-amp)

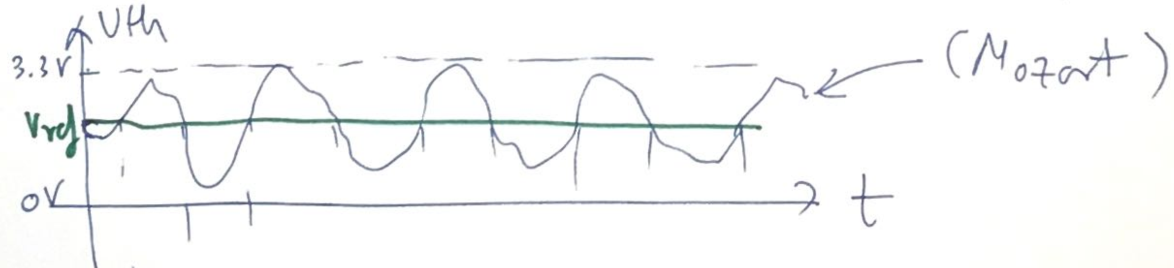


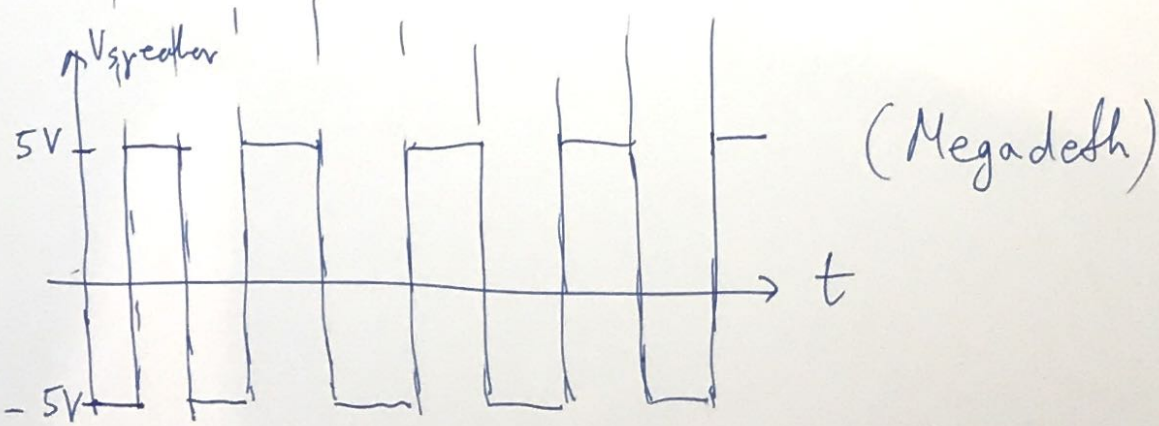
$V_{DD} = -V_{SS} = 5V$

(KVL) $V_{speaker} = \underbrace{V_{SS} + \frac{V_{DD}-V_{SS}}{2}}_{\frac{V_{DD}+V_{SS}}{2} \to 0} + AV_d = AV_d$ when $V_{SS} < A \cdot V_d < V_{DD}$

(input)

$V_d = v^+ - v^- = V_{th} - V_{ref}$

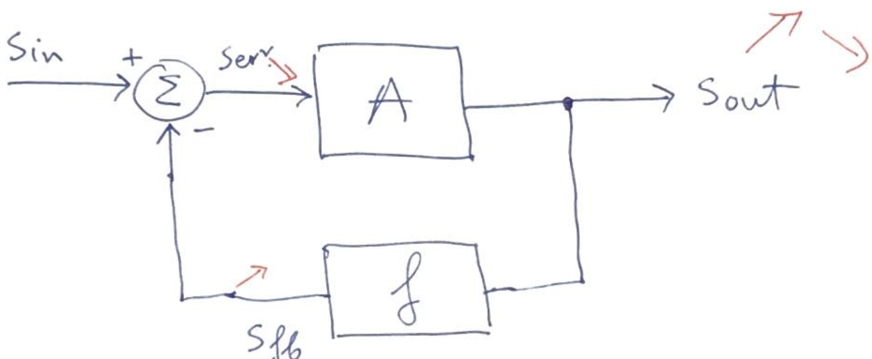




Want isolation with controlable gain (e.g. 3x). Need a way to "tame" the op-amp.

Negative feedback

Concept:



$$\left.\begin{aligned} S_{err} &= S_{in} - S_{fb} \\ S_{out} &= A \cdot S_{err} \\ S_{fb} &= f \cdot S_{out} \end{aligned}\right\} \Rightarrow \frac{S_{out}}{A} = S_{in} - f\, S_{out}$$

$$S_{out}\left(\frac{1}{A} + f\right) = S_{in}$$

$$\frac{S_{out}}{S_{in}} = \frac{1}{\frac{1}{A} + f} = \frac{A}{1 + Af}$$

$$\frac{S_{out}}{S_{in}} \overset{}{\underset{A \to \infty}{=}} \frac{1}{f}$$

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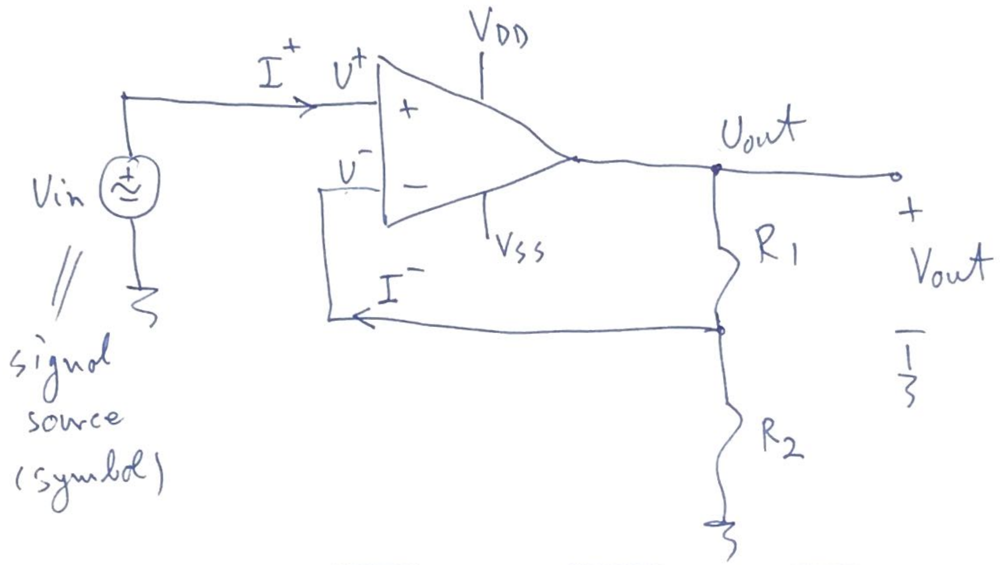
op-amp example NFB

(non-inverting amplifier)



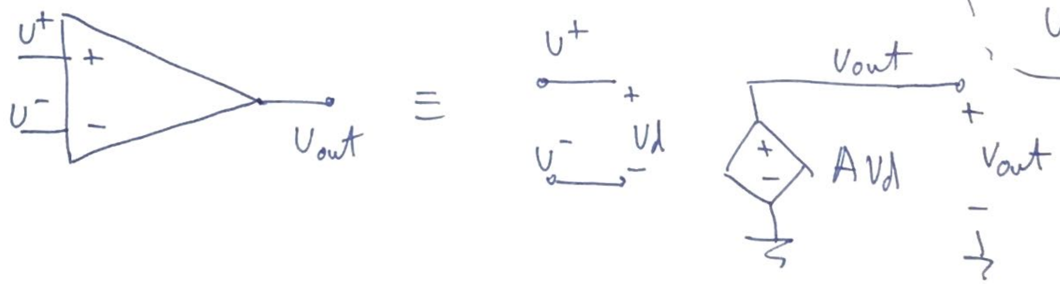
$U^+ \equiv S_{in}$

$V_{out} = S_{out}$

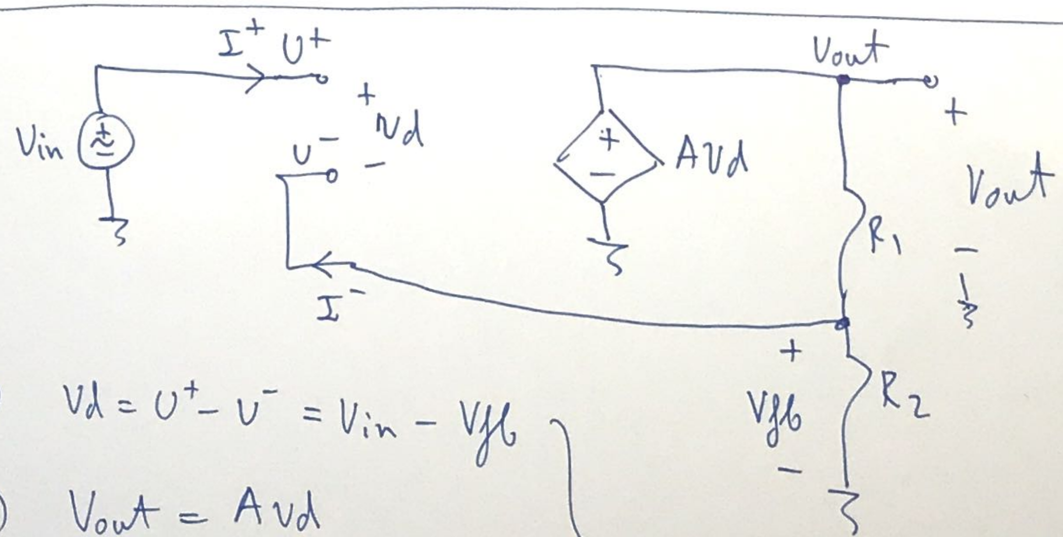
$U^- = S_{fb}$

$U^+ - U^- \equiv S_{err}$

In NFB:



only for $V_{SS} < V_{out} < V_{DD}$



(1) $V_d = U^+ - U^- = V_{in} - V_{fb}$

(2) $V_{out} = AV_d$

(3) $V_{fb} = \frac{R_2}{R_1+R_2} \cdot V_{out}$, $\frac{R_2}{R_1+R_2} = f$

$\Rightarrow V_{out} = A(V_{in} - f \cdot V_{out})$

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$$V_{out} = A(V_{in} - \beta V_{out})$$

$$V_{out}(1 + A\beta) = A V_{in}$$

$$A_v = \text{Gain} = \frac{V_{out}}{V_{in}} = \frac{A}{1 + A\beta}$$

$$A_v \underset{A \to \infty}{=} \frac{1}{\beta} = \frac{R_1 + R_2}{R_2} = \boxed{1 + \frac{R_1}{R_2}}$$

$$A_v = 3 \Rightarrow R_1 = 2R_2$$

$$v_d = \frac{V_{out}}{A} \underset{A \to \infty}{=} \frac{1}{A} \cdot \frac{A}{1 + A\beta} V_{in} = \frac{V_{in}}{1 + A\beta} = 0$$

> In NFB: $U^+ = U^-$ and $A \to \infty$

Golden rules:

(1) $I^+ = I^- = 0$ (always true)

(2) $U^+ = U^-$ (only in NFB & $A \to \infty$)
