(p1)

Module 2, Lecture 8

EECS 16A
Panos Zarkos

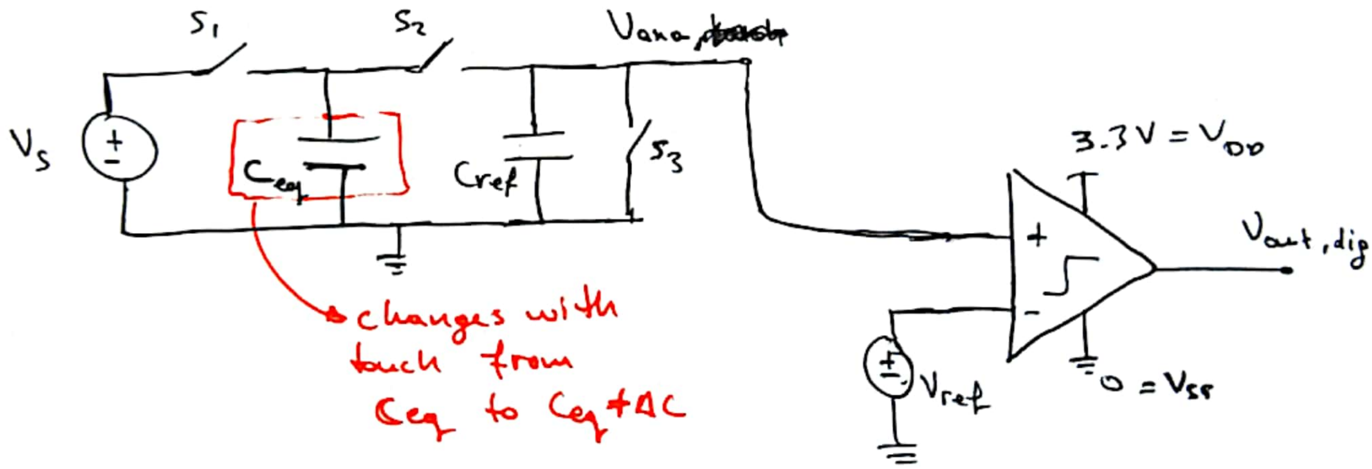
Last Time:
* Built Capacitive Touchscreen
* Charge Sharing

} Note 17, 17B

Today:
* Capacitive Touchscreen Wrap-Up
* Audio System (DAC example)
* Intro to Negative feedback
  * Golden Rules
  * NFB Examples

} Note 18

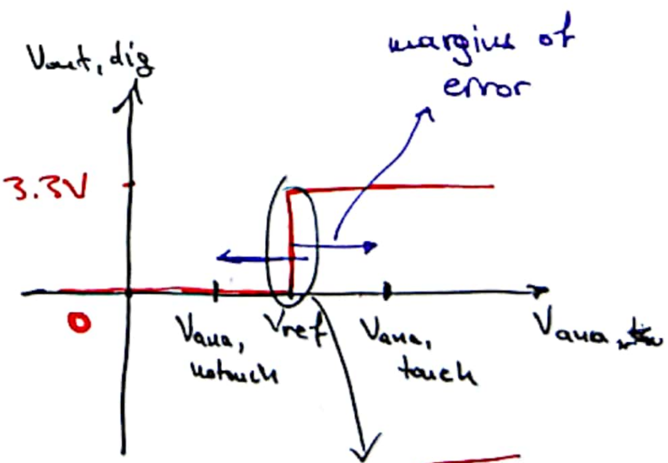
Announcements: HW 4B is out (due Sunday)

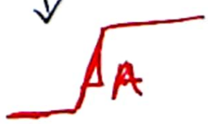


$$V_{ana,\,no\ touch} = \frac{C_{eq}}{C_{eq}+C_{ref}} V_s$$

$$V_{ana,\,touch} = \frac{C_{eq}+\Delta C}{C_{eq}+\Delta C+C_{ref}} \cdot V_s$$

$$V_{ana,\,touch} > V_{ana,\,no\ touch}$$





A, refers to the gain of the op-amp as will be introduced in p3 of the notes

To maximize the margin of error:

$$V_{ref} = \frac{V_{ana,touch} + V_{ana,notouch}}{2}$$

(p2)

* How to choose C_{ref}?

Assume $C_{eq} = 1F$, $\Delta C = 1F$, $V_s = 1V$

If $C_{ref} = 0.01F$:

$$V_{ana,\,notouch} = \frac{C_{eq}}{C_{eq} + C_{ref}} V_s = 0.99\,V$$

$$V_{ana,\,touch} = \frac{C_{eq} + \Delta C}{C_{eq} + \Delta C + C_{ref}} V_s = \frac{2}{2 + 0.01} = 0.998\,V$$

$\Big\}\ 0.08V$

If $C_{ref} = 100F$:

$$V_{ana,\,notouch} = \frac{C_{eq}}{C_{eq} + C_{ref}} V_s = 0.009\,V$$

$$V_{ana,\,touch} = \frac{C_{eq} + \Delta C}{C_{eq} + \Delta C + C_{ref}} \cdot V_s = 0.019\,V$$

$\Big\}\ \Delta V = 0.01V$

If $C_{ref} = 1F$:

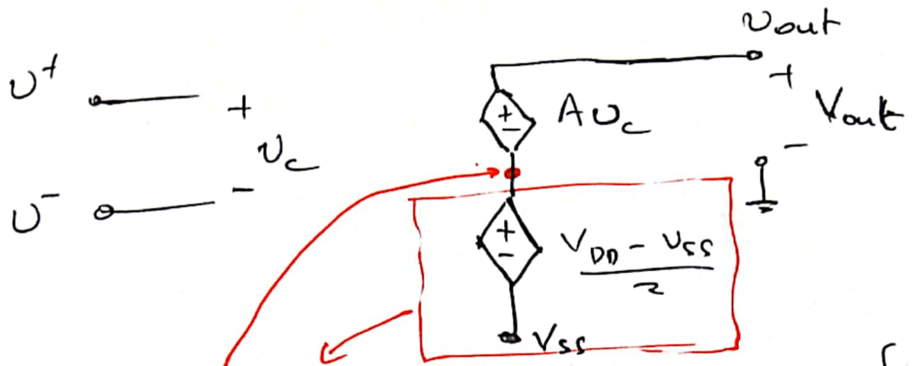
$$V_{ana,\,notouch} = \frac{1}{1+1} \cdot 1 = \frac{1}{2}\,V$$

$$V_{ana,\,touch} = \frac{1+1}{1+1+1} \cdot 1 = \frac{2}{3}\,V$$

$\Big\}\ 0.16V$

→ C_{ref}, C_{eq} and ΔC have to be of approximately the same value to have a big ΔV → big error margin!

Op-Amp Circuit Model

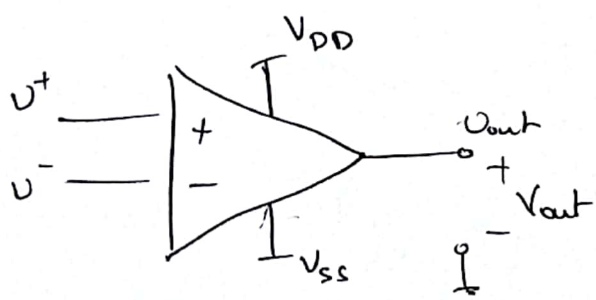


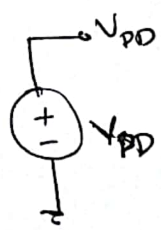
~~this~~ sets that node in-between V_{DD} and V_{SS}

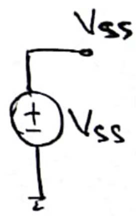
v_{out} cannot be higher than V_{DD} or lower than V_{SS}!

$$v_{out} = \begin{cases} V_{DD}, & \text{if } v^* > V_{DD} \\ \underbrace{\boxed{V_{SS} + \frac{V_{DD}-V_{SS}}{2} + A \cdot v_c}}_{v^*}, & \text{if } V_{SS} < v^* < V_{DD} \\ V_{SS}, & \text{if } v^* < V_{SS} \end{cases}$$

Circuit Symbol



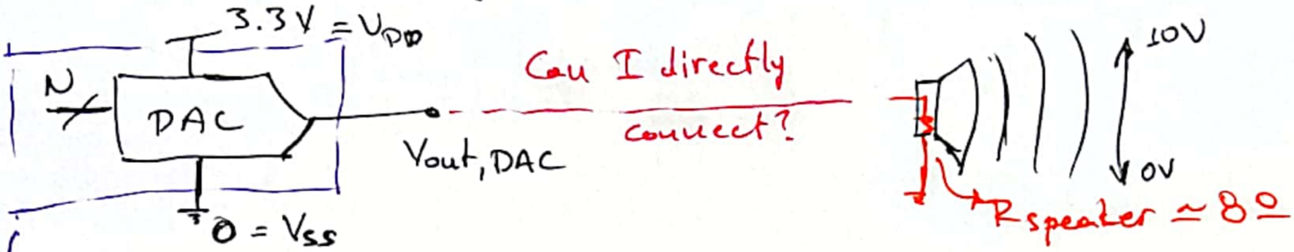




Supply connections are usually not drawn to avoid cramming the circuit diagram but they are in reality coming from independent voltage sources!

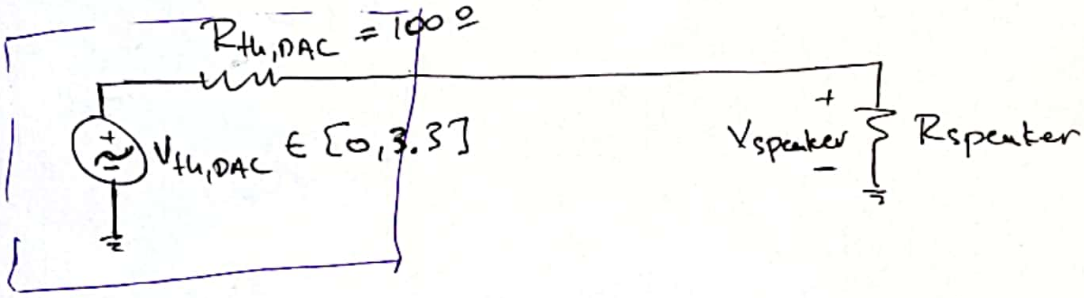
Audio System – "16A Boombox"

Digital to Analog Converter (DA)
Converts a digital-binary value to an analog voltage



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

Thevenin Equivalent



Voltage Divider

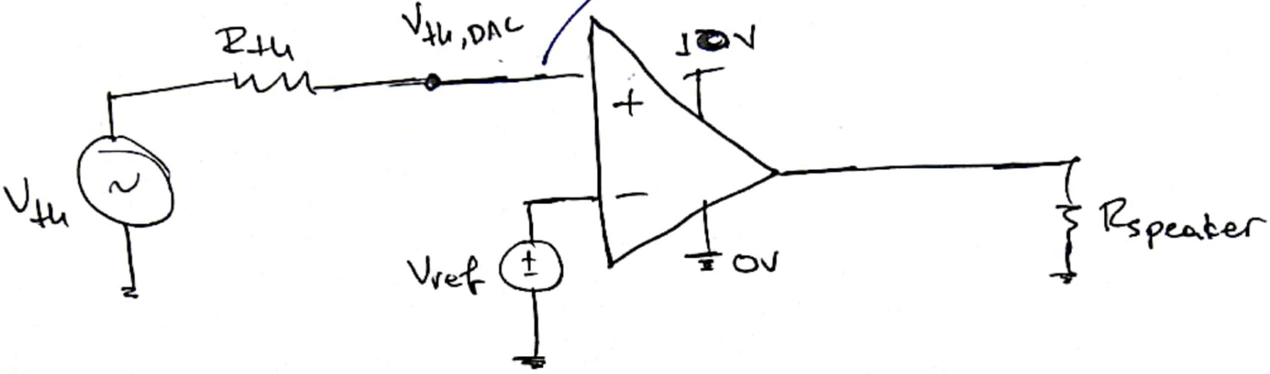
$$V_{speaker} = \frac{R_{speaker}}{R_{speaker} + R_{th,DAC}} \cdot V_{th,DAC}$$

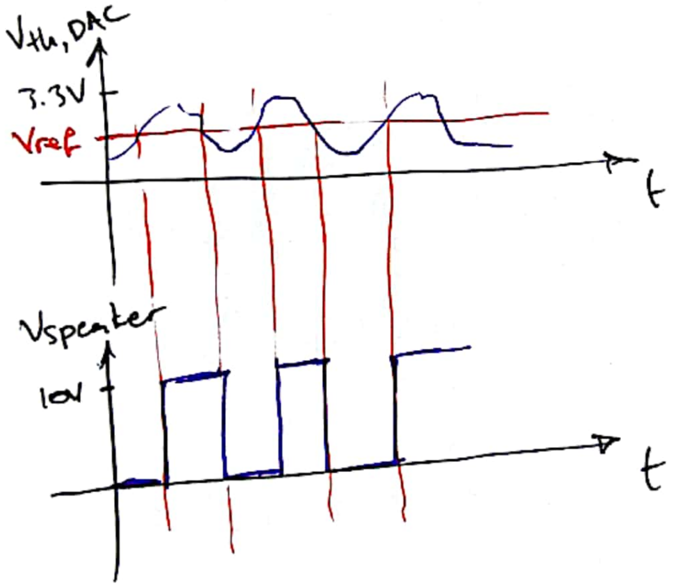
$$= \frac{8\Omega}{8\Omega + 100\Omega} \cdot V_{th,DAC} \simeq 0.1\, V_{th,DAC}$$

$\boxed{\text{Loading Effect!}}$

Goals : 1) Isolate Rspeaker from Thevenin Equivalent of the DAC (get rid of Loading Effect) ✓

2) Amplify by a well-known, stable value of 3 ✗





(Beethoven)

(Iron-Maiden)

We need to "tame" the op-amp.

To do this we will introduce Negative feedback.

(p6)

Negative feedback (NFB)

→ Goal: get a certain gain (e.g. 3)

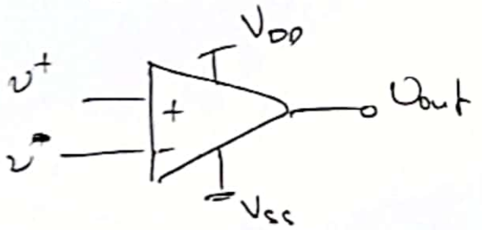
Have: op-amp with large, uncertain gain ($10^3 - 10^7$)

* Key Idea of NFB is best understood using block diagrams.

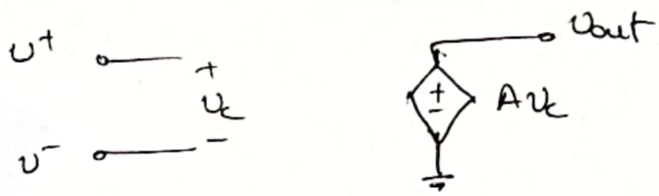
A collection of drawings that indicate how various function operate on quantities of interest.

Op-Amp

Circuit - Symbol

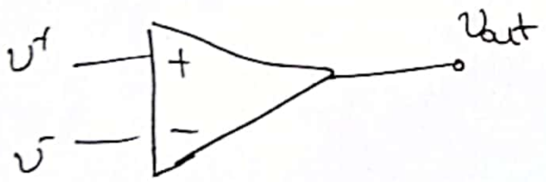


Circuit Model

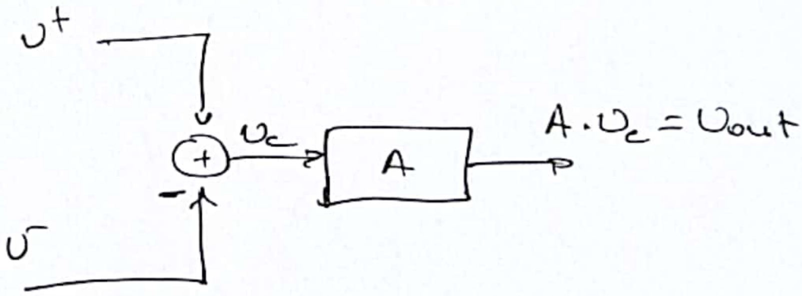


Assume $V_{DD} = -V_{SS}$

Simplified Symbol



⇒ Block Diagram

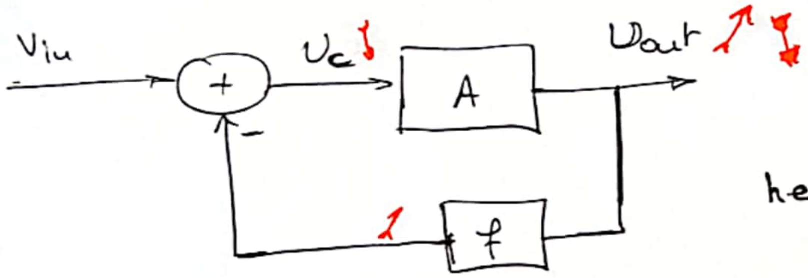


p7

Goal: $V_{out} = 3V_{in}$

NFB: Measure $\frac{V_{out}}{3}$ and compare it against V_{in}.

Block Diagram:



here $f = \frac{1}{3}$

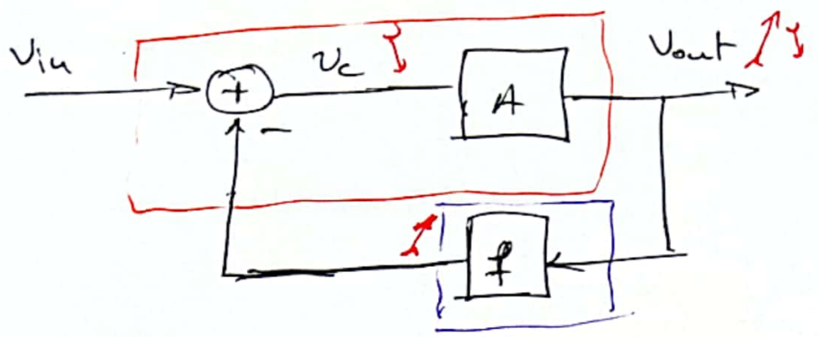
$$\left.\begin{aligned} v_c &= V_{in} - f \cdot V_{out} \\ V_{out} &= A \cdot v_c \end{aligned}\right\} \Rightarrow V_{out} = A\,(V_{in} - f V_{out})$$

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

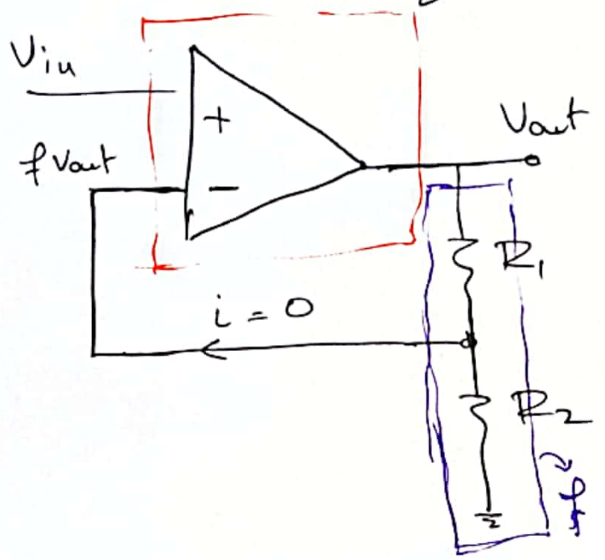
$$\Rightarrow \boxed{V_{out} = \frac{A}{1 + Af} \cdot V_{in}}$$

$$\lim_{A\to\infty} V_{out} = \lim_{A\to\infty} \frac{A}{1+Af} \cdot V_{in} = \frac{\cancel{A}}{\cancel{A}\cdot f} \cdot V_{in} = \frac{V_{in}}{f}$$

$$\Rightarrow \boxed{V_{out} = \frac{V_{in}}{f}} \text{ as } A \to \infty$$



Circuit Implementation of the block diagram



If $R_1 = 2R_2 \Rightarrow$

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

$$= \frac{1}{3} \cdot V_{out}$$

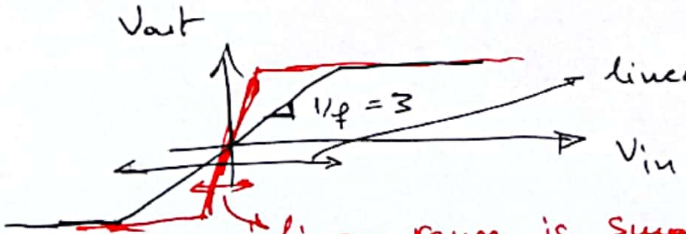
$$\boxed{f = \frac{1}{3} = \frac{R_2}{R_1+R_2}}$$

Goal:

Based on: $V_{out} = \dfrac{V_{in}}{f} \Rightarrow V_{out} = \dfrac{R_1+R_2}{R_2} \cdot V_{in}$

$$\Rightarrow V_{out} = \left(1 + \frac{R_1}{R_2}\right) V_{in}$$

NON-INVERTING AMPLIFIER.

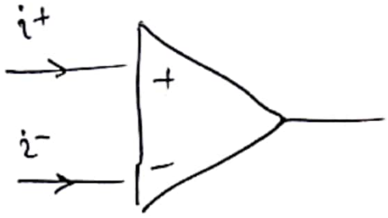


linear range is much bigger.

linear range is small when I use the op-amp as a comparator.

Golden Rules

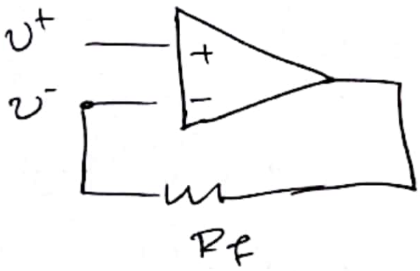
1)



$\boxed{i^+ = i^- = 0}$

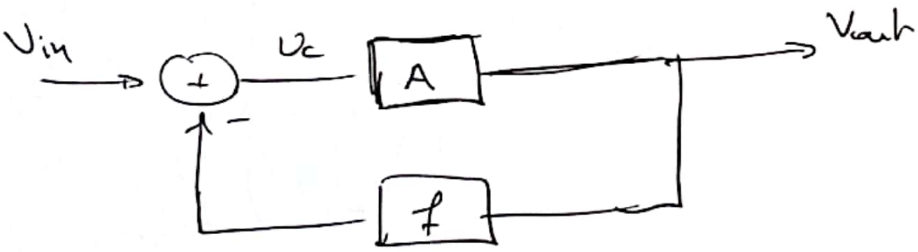
Always

2) Op-Amp in NFB with $A \to \infty$:



$\boxed{v^+ = v^-}$

Proof: $v^+ - v^- = v_c$



$$v_c = V_{in} - f \cdot V_{out}$$

$$= V_{in} - A \cdot f\, v_c$$

$$\Rightarrow v_c (1 + Af) = V_{in}$$

$$\Rightarrow v_c = \frac{1}{1+Af} \cdot V_{in} \xrightarrow{A \to \infty} v_c = 0 .$$

$$\Rightarrow v_+ - v_- = 0$$

$$\Rightarrow \boxed{v_+ = v_-}$$ G.R. #2 ✓