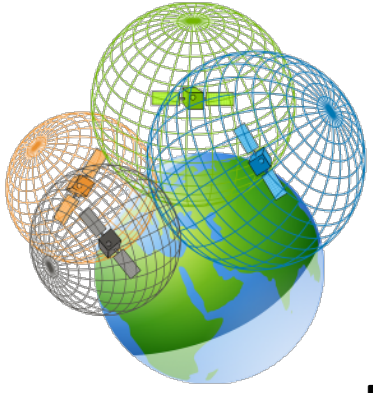


Welcome to EECS 16A!

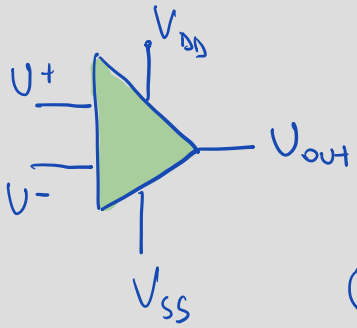
Designing Information Devices and Systems I

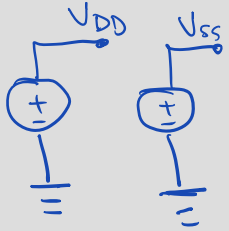
Ana Claudia Arias and Miki Lustig

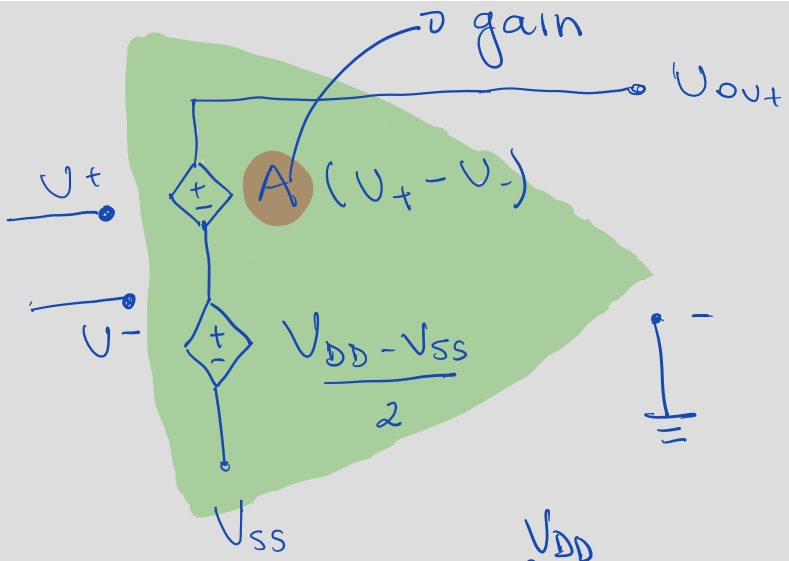
Fall 2021

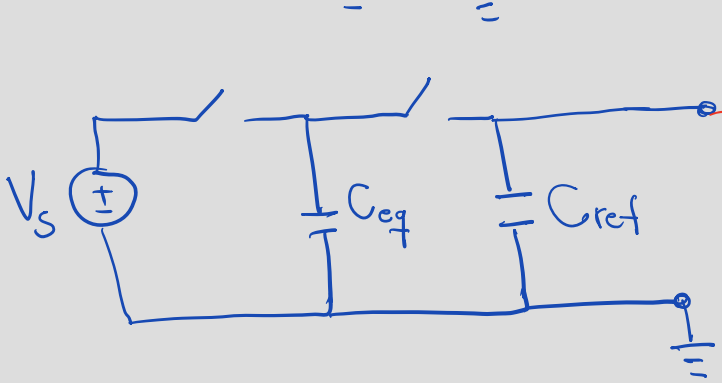
Module 2
Lecture 10
Negative Feedback (Note 18)

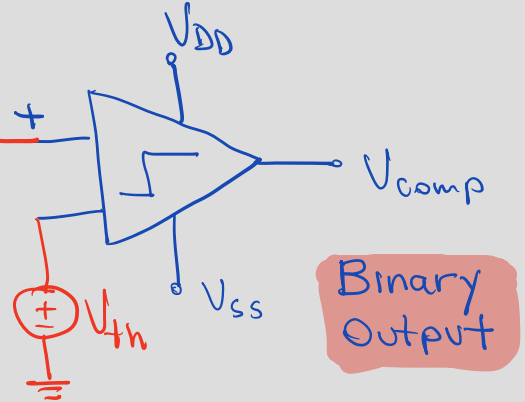
Last Lecture…











Binary Output

New Design – Let's play music

Problem

- We want to play music loud!
- Music is stored as digital signal
- Speakers are analog

Tools

- Resistors
- Capacitors
- Open-circuits
- Voltage Dividers
- Op-Amps
- Thevenin Equivalence
- Norton Equivalene
- KCL / KVL
- Element Def.

Specs

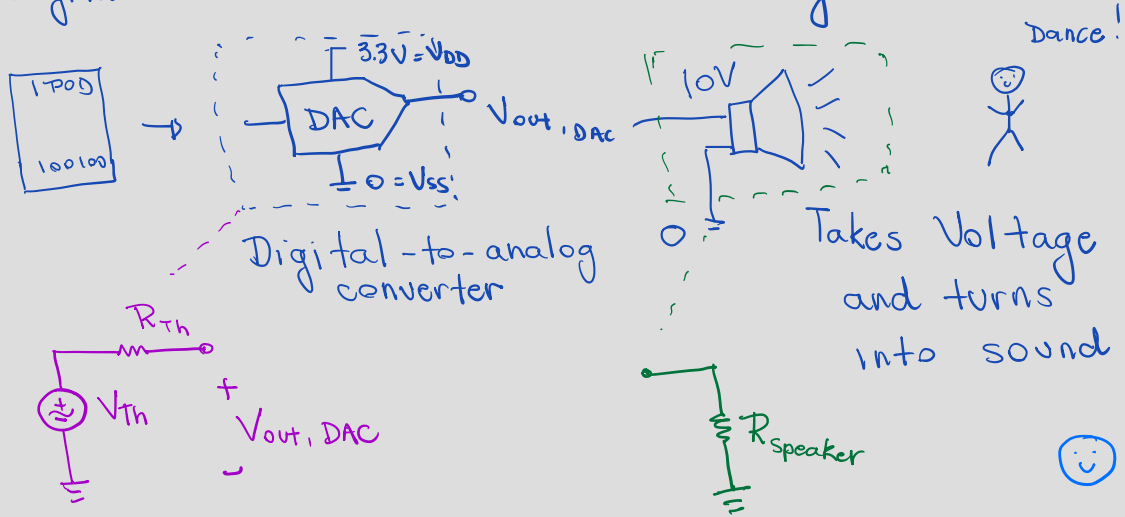
- Speaker takes 0-10V ✓
- Need to go from digital to analog. ?

New Design – Let's play music

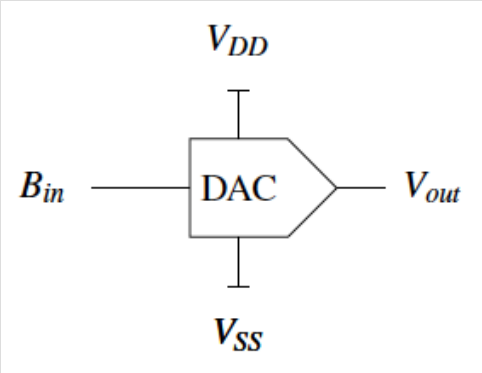
* Want to play music LOUD

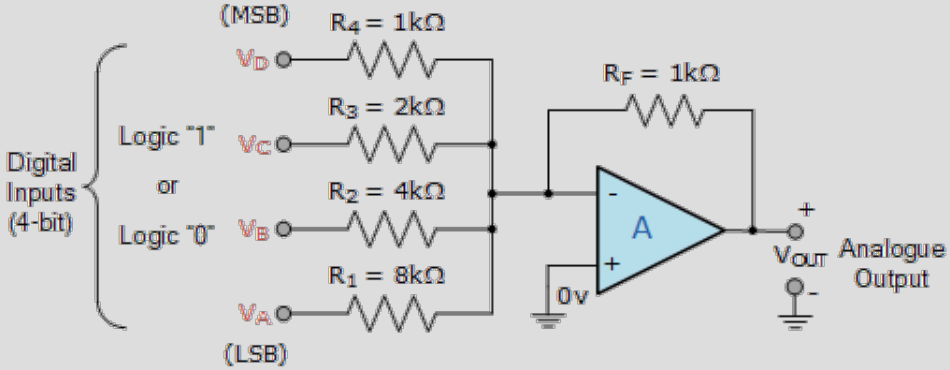
↳ Music is stored as digital signal

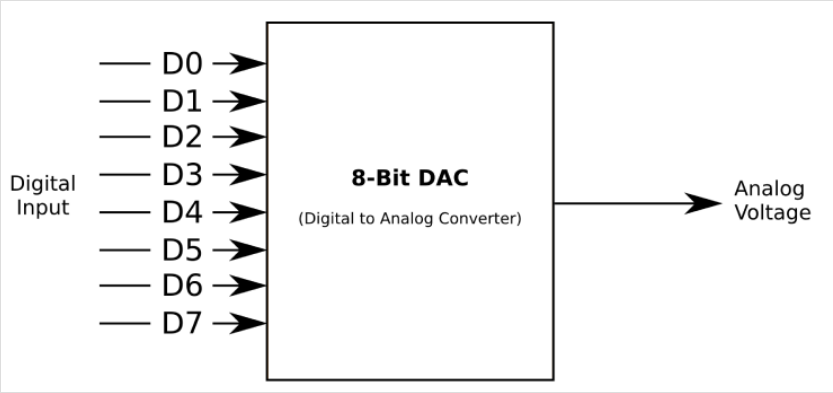
Digital ⟶ Analog



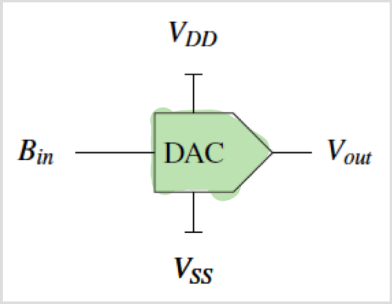
Digital to Analog Converter - DAC







Equivalence comes in handy again

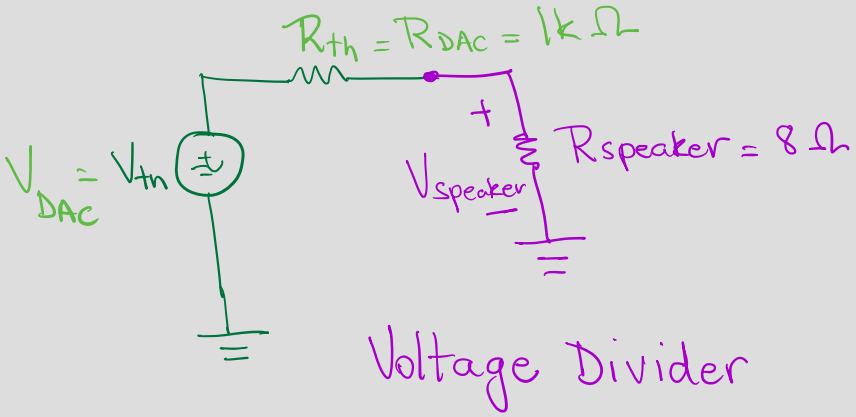


$$V_{speaker} = \frac{R_{speaker}}{R_{th} + R_{speaker}} \cdot V_{th}$$

$R_{speaker} = 8\,\Omega$, $R_{th} = 1000\,\Omega$, $R_{speaker} = 8\,\Omega$

$$V_{speaker} = \frac{V_{th}}{126}$$

Not loud!

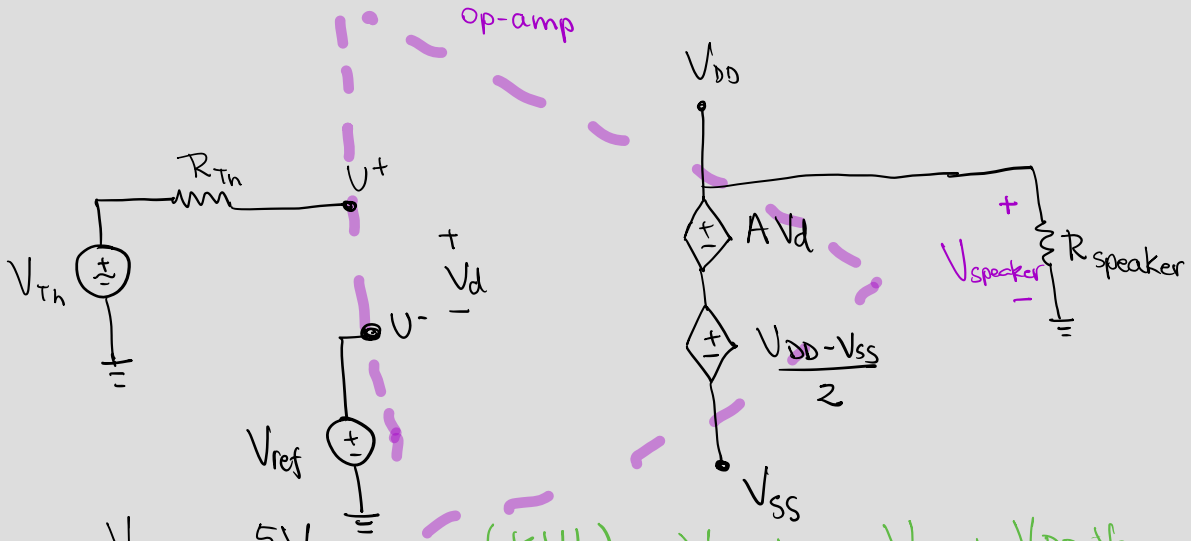


Voltage Divider

loading Effect

- Need to increase V_{out}
- Speaker needs 0-10V
- DAC 0-3.3V
- Tool ?

Digital to Analog Converter - DAC



* 

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

10V output

(Input)

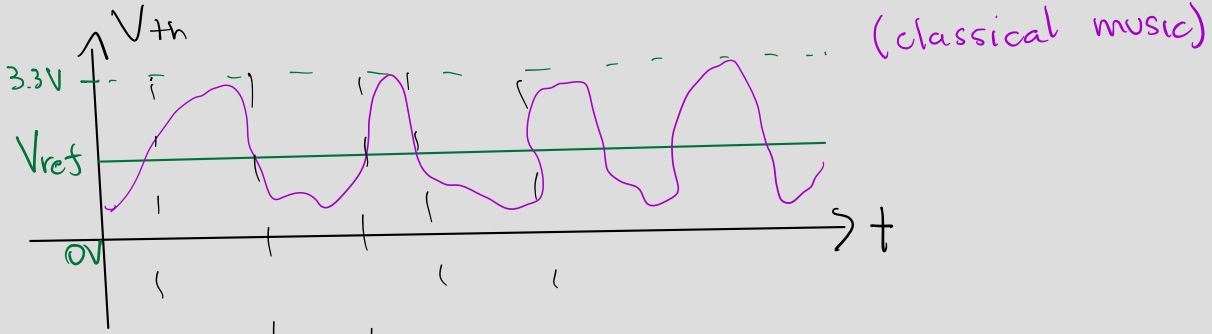
(KVL) $V_{speaker} = V_{SS} + \frac{V_{DD}-V_{SS}}{2} + AV_d = AV_d$

$\frac{V_{DD}+V_{SS}}{2} \to 0$

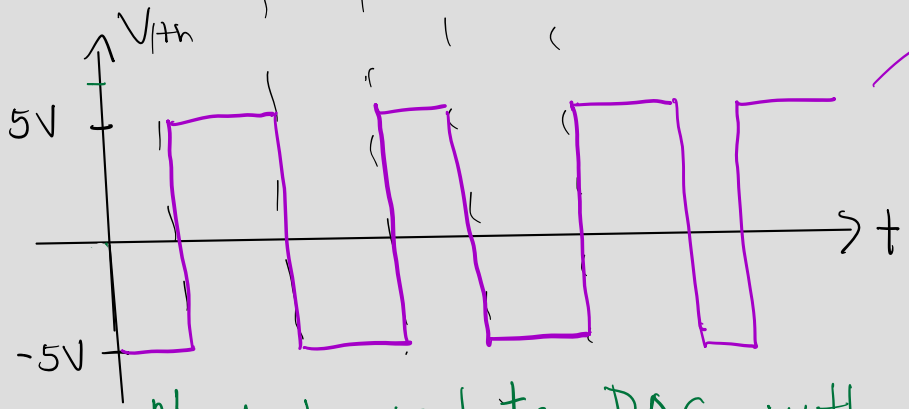
when: $V_{SS} < AV_d < V_{DD}$

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

Digital to Analog Converter - DAC



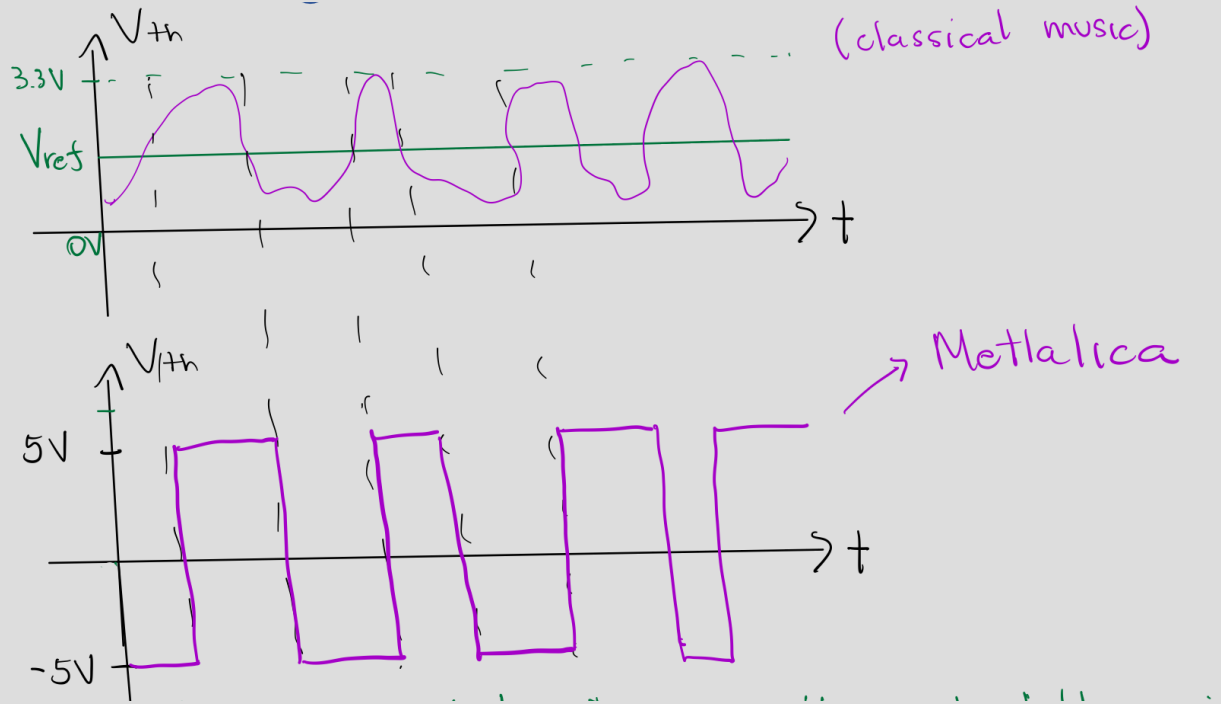
(classical music)



→ Metlalica

Need to isolate DAC with controlable gain!
e.g. 3x

Music output with design #1



Need adjustments to our music output and gain of 3 – need more "tools" in the system

$$S_{err} = S_{in} - S_{fb}$$

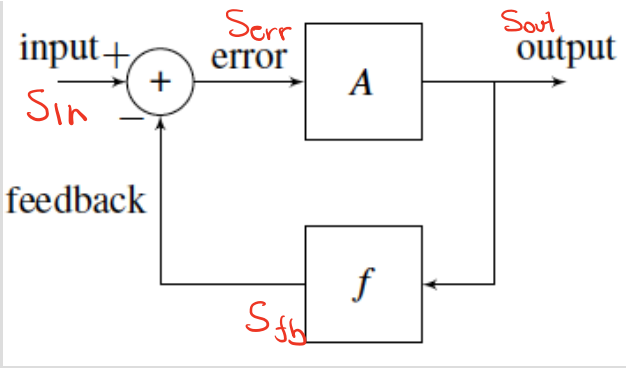
$$S_{out} = A \cdot S_{err}$$

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

$$\frac{S_{out}}{A} = S_{in} - S_{fb}$$

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

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



- Making small adjustments to correct output on the fly
- Basis of control theory
- Many examples in daily life:

- Biology
- Self-driving car
- Human driving car
- Hand-eye coordination
- ....

Negative Feedback

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

- Describes the behaviour of the system - transfer function.
- How S_{out} depends on S_{in}

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

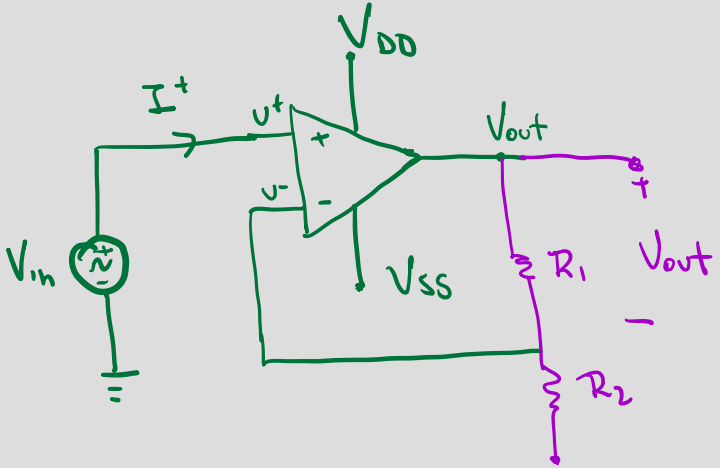
↳ We control the output via block f!

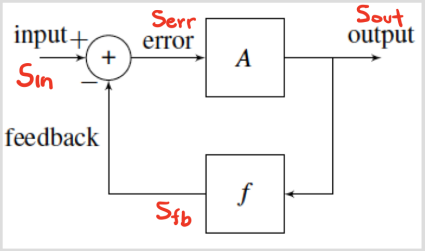
So $V_{out} = \frac{1}{f} V_{in}$ for very large gain.

↳ we can set f to get any output.

(Beautiful result) ☺

Need to isolate the DAC from speaker – OP-Amp with NFB





$V^+ = S_{in}$

$V_{out} = S_{out}$

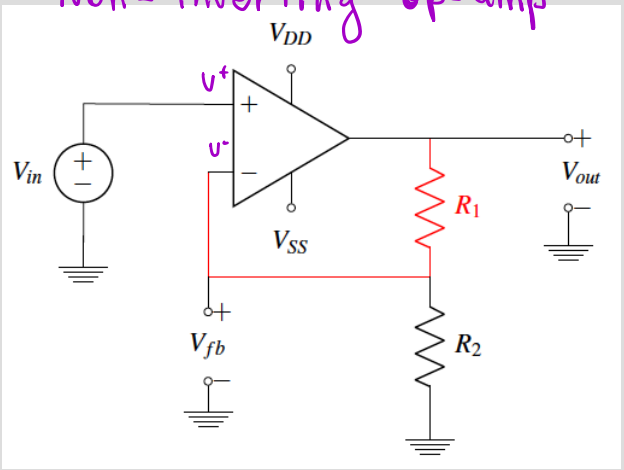
$V^- = S_{fb}$

$V^+ - V^- = S_{err}$

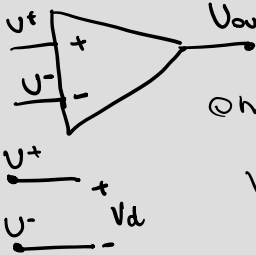
- We want to measure V_{out}, take a portion of the signal and feedback as V^-

Op-Amp in negative feedback

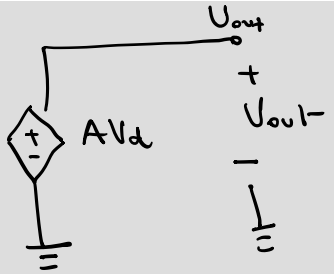
Non-inverting op-amp



Model:



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



Simpler model as the second source is not "needed".

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

(2) $V_{out} = AV_d$

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

"BUFFER CIRCUIT" $\hookrightarrow f$

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

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

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

$A_v = \frac{1}{f}$ $\quad A \to \infty$ $\quad \hookrightarrow \frac{R_1+R_2}{R_2} = 1 + \frac{R_1}{R_2}$

Golden Rules of Op-Amps

For our design we want $A = 3$

$$V_d = \frac{V_{out}}{A} \quad \text{if} \quad A \to \infty$$

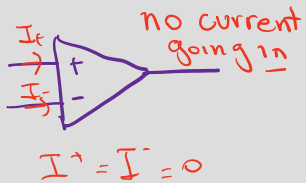
$$V_d = \frac{1}{A} \cdot \frac{A}{1+Af} V_{in} = \frac{V_{in}}{1+Af} = 0$$

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

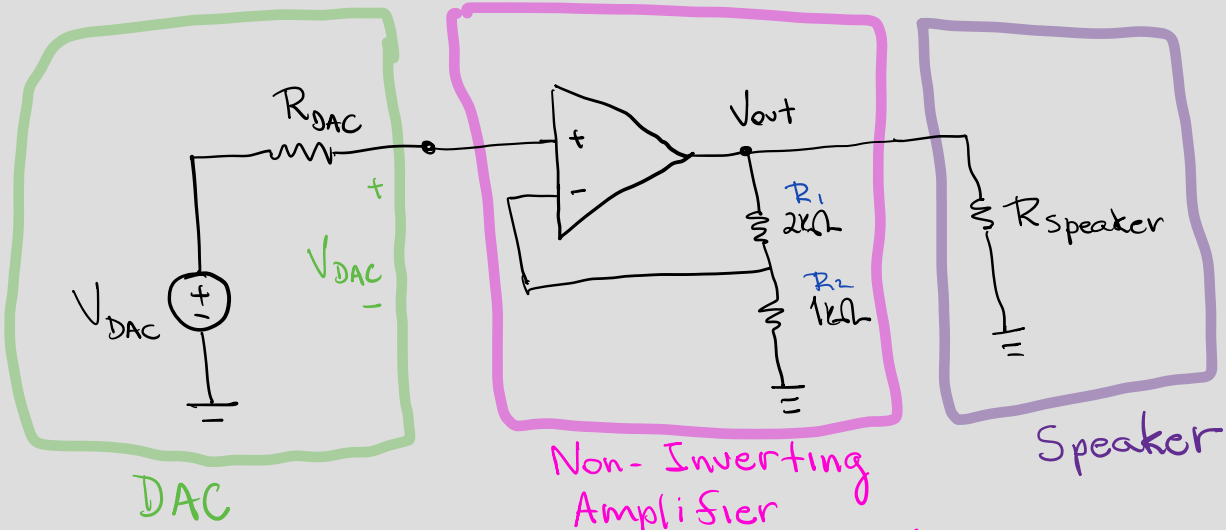
Rules: (Golden Rules)

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

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



Let's go back to playing music



$$\text{Gain} = 1 + \frac{R_1}{R_2}$$

Party time!

Yay!

New Design – Let's play music

Problem

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- Element Def.

Specs

- Speaker takes 0-10V ✓
- Need to go from digital to analog. ?
  - DAC ✓
  - Op-amp in Negative Feedback (NFB) ✓
  - Gain of 3. ✓