(e1)

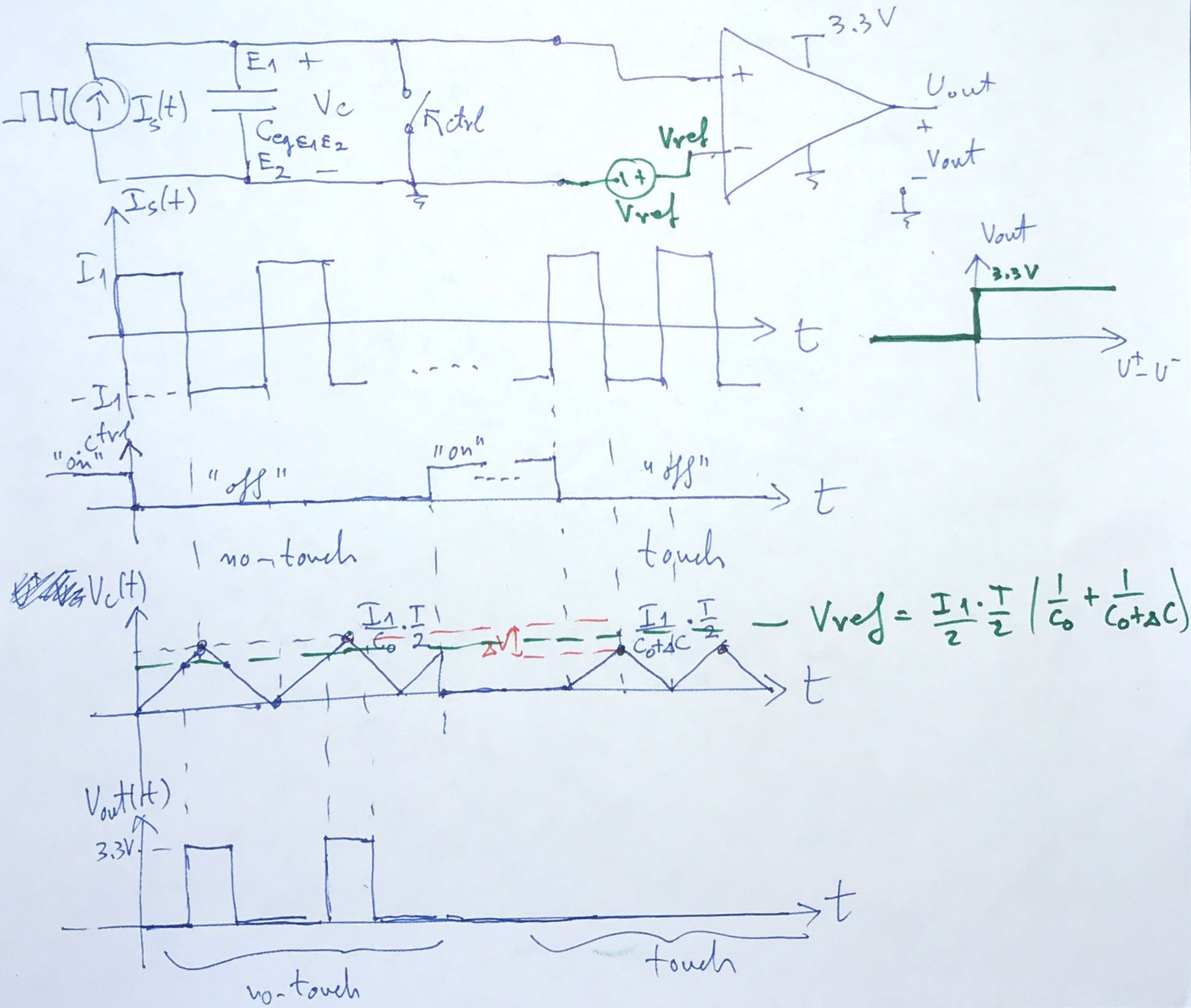
Lecture 8 - Module 2

EE16A

Today:
Note 18

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

2D Touchscreen - putting it all together

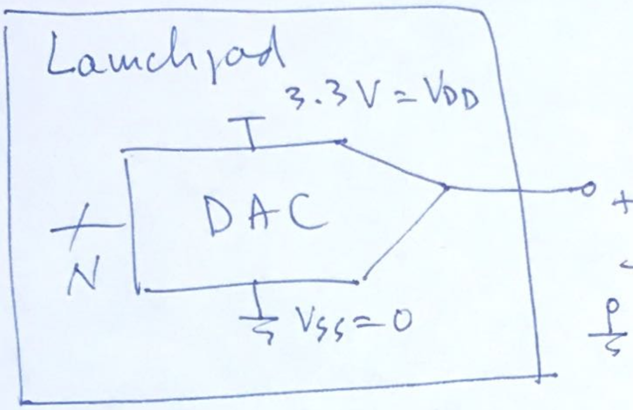


$$V_{ref} = \frac{I_1}{2} \cdot \frac{T}{2} \left(\frac{1}{C_0} + \frac{1}{C_0 + \Delta C} \right)$$

(l2) "16A Boombox"

DAC : Digital-to-analog converter

(turns a digital-binary value into analog voltage)



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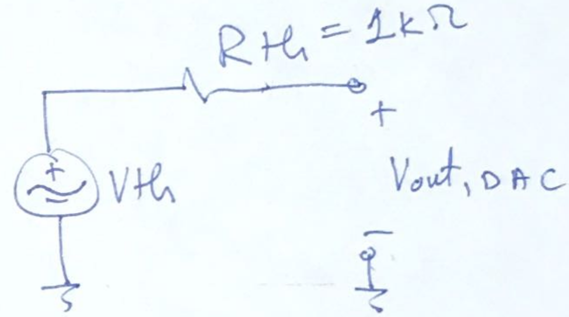
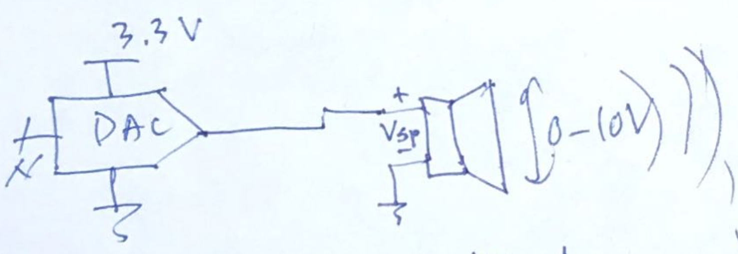
Model





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

$\quad \parallel \quad\quad \parallel$

$\quad V_{SS} \quad V_{DD}$

Want

$V_{speaker} \in [0, 10V]$

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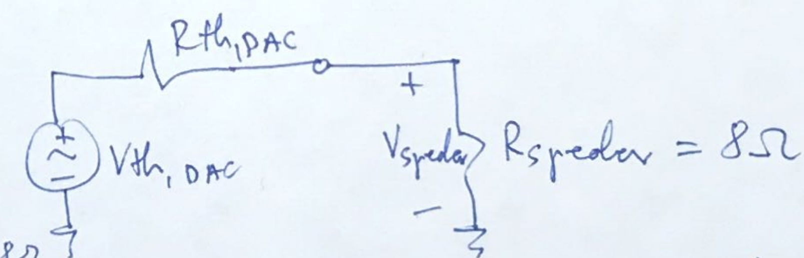
Model

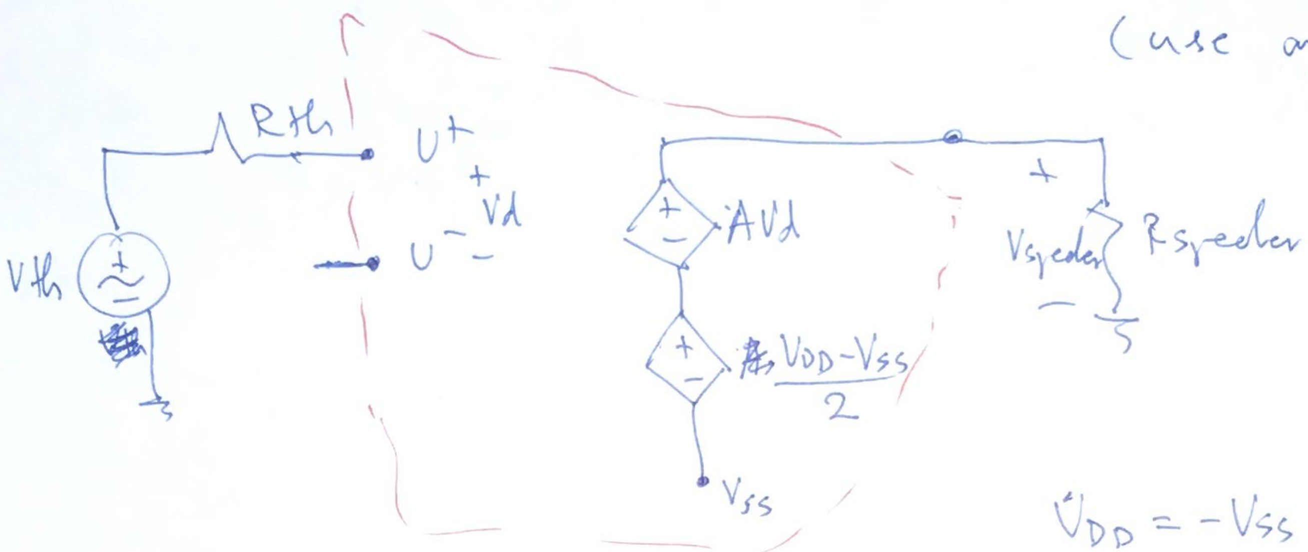


$$V_{speaker} = \frac{\overset{\sim 8\Omega}{R_{speaker}}}{\underset{1k\Omega}{R_{th,DAC}} + \underset{8\Omega}{R_{speaker}}} \cdot V_{th,DAC} = \frac{V_{th,DAC}}{126}$$

voltage divider

Loading effect!

(L3) Need to isolate the DAC from the speaker (use op-amp)

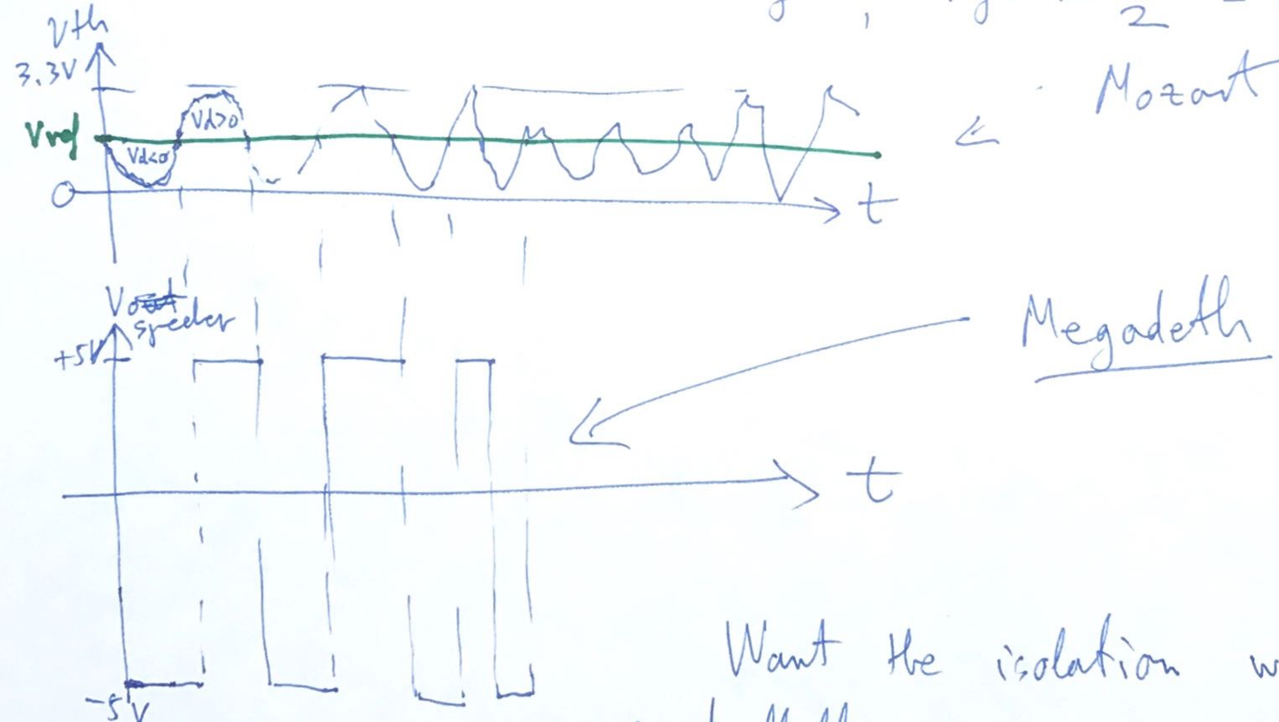


$V_{DD} = -V_{SS} = 5V$

$A \to \infty$

$$V_{speaker} = \underbrace{V_{SS} + \frac{V_{DD}-V_{SS}}{2}}_{0} + A \cdot V_d = A \cdot V_d \text{ only when } V_{SS} < A \cdot V_d < V_{DD}$$

(input) $V_d = U^+ - U^- = V_{th} - V_{ref}$, $V_{ref} = \frac{3.3V - 0}{2} = 1.65\,V$



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

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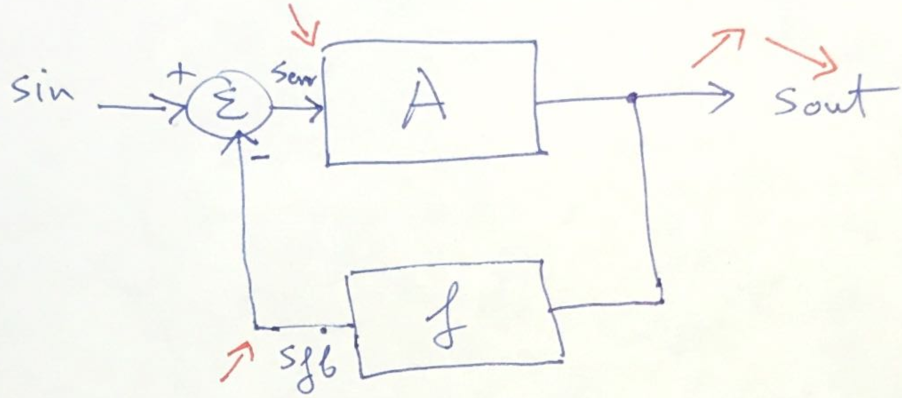
Negative feedback

Concept:



$$S_{err} = S_{in} - S_{fb}$$
$$S_{out} = A \cdot S_{err}$$
$$S_{fb} = f \cdot S_{out}$$

$$\Rightarrow \quad \frac{S_{out}}{A} = S_{in} - f \cdot S_{out}$$

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

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

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

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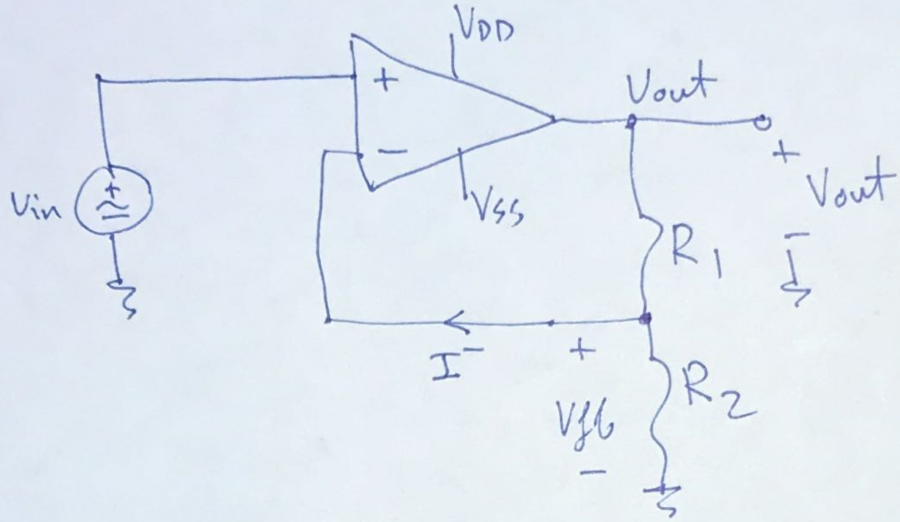
op-amp example NFB

(non-inverting amplifier)



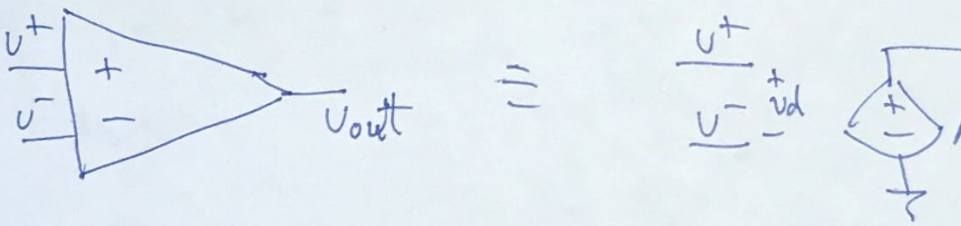
$U^+ \equiv S_{in}$

$V_{out} \equiv S_{out}$

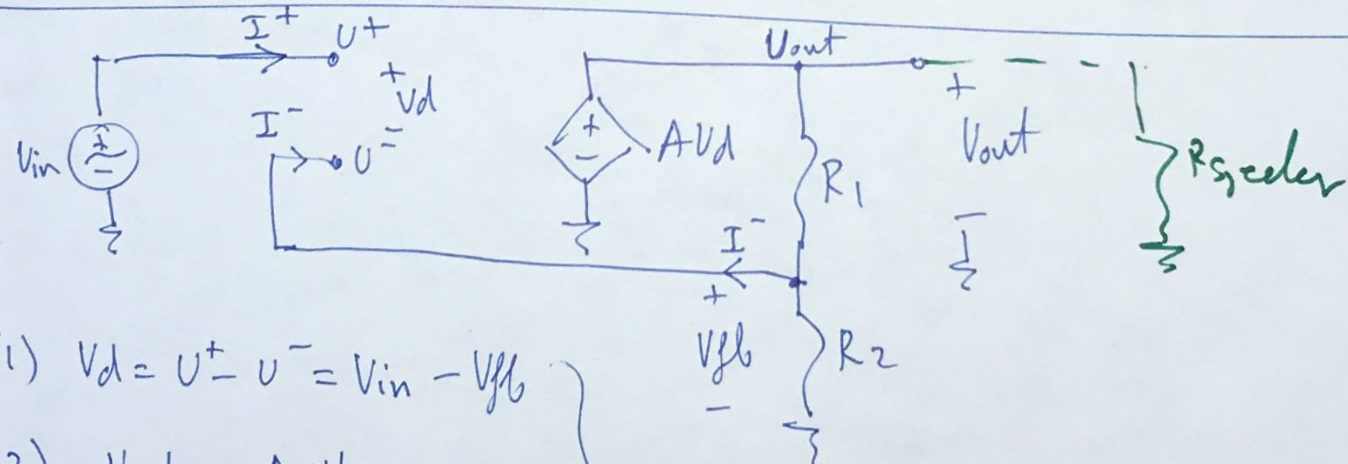
$U^- \equiv S_{fb}$

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

In NFB:



only for $V_{ss} \leq V_{out} \leq V_{dd}$



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

(2) $V_{out} = A \cdot V_d$

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

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

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

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

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$$A_v = \frac{V_{out}}{V_{in}} = \frac{A}{1+Af} = \frac{1}{\frac{1}{A}+f} \underset{A\to\infty}{=} \boxed{\frac{1}{f}}$$

↑ voltage gain

$$A_v = 3 \Rightarrow f = \frac{1}{3} \qquad f = \frac{R_2}{R_1+R_2}$$

$$A_v\Big|_{A\to\infty} = \frac{1}{f} = \frac{R_1+R_2}{R_2} = \boxed{1+\frac{R_1}{R_2}}$$

$A_v = 3 \Rightarrow \boxed{R_1 = 2R_2}$

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

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

Golden rules:

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

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