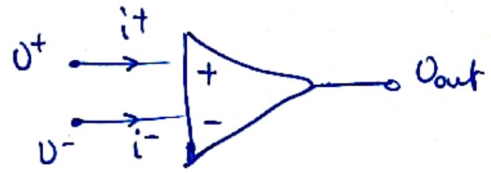
Module 2, Lecture 9

EECS 16A
Panos Zarkos

Last Time: * Audio System (DAC Example)
* Intro to NFB
} Note 18

Today: * NFB Inspection
* Troll problem w/ Op-Amps
* Cascading Ckt Blocks (building large functions)
} Note 19

Review: Op-Amp Golden Rules

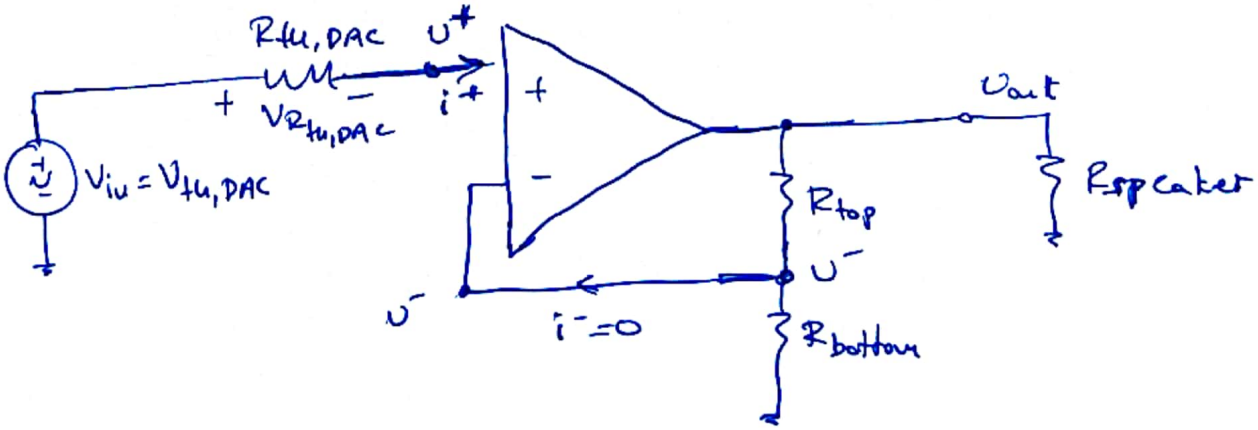


GR #1: $\boxed{i^+ = i^- = 0}$ Always.

GR #2: For an Op-Amp in Negative Feedback with $A \to \infty$

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

The NON-INVERTING AMPLIFIER (Revisited)



(P2)

GR #1: $i^+ = 0 \Rightarrow I_{R_{th,DAC}} = i^+ = 0$

$V_{R_{th,DAC}} = R_{th,DAC} \cdot \cancel{I_{R_{th,DAC}}}^{\,0} = 0$ (ohm's law)

$V_{R_{th,DAC}} = V_{in} - v^+ = 0$

$\Rightarrow \underline{V_{in} = v^+}$ (1)

Voltage Divider: $v^- = \dfrac{R_{bottom}}{R_{top} + R_{bottom}} \cdot V_{out}$ (2)

GR #2: $v^- = v^+ = V_{in}$ (3)

(2) $\overset{(3)}{\Rightarrow}$ $V_{in} = \dfrac{R_{bottom}}{R_{top} + R_{bottom}} \cdot V_{out}$

$\Rightarrow \dfrac{V_{out}}{V_{in}} = \dfrac{R_{top} + R_{bottom}}{R_{bottom}} = 1 + \dfrac{R_{top}}{R_{bottom}}$

$$A_V = \frac{V_{out}}{V_{in}} = 1 + \frac{R_{top}}{R_{bottom}}$$

A_V = voltage gain of the circuit.

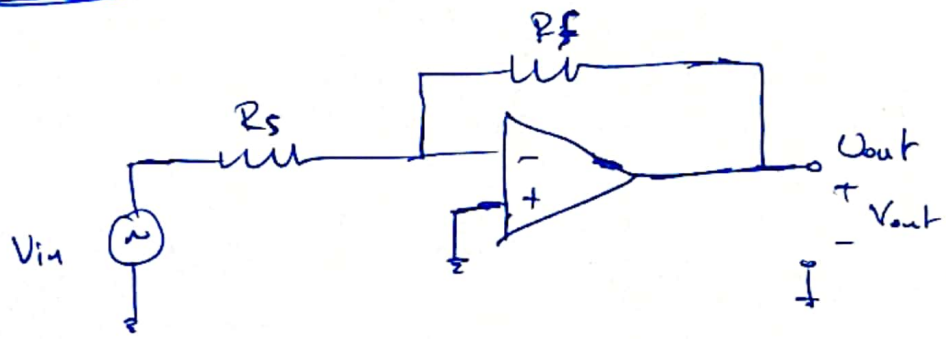
Do not confuse with the gain of the op-amp! (A)

Determining the polarity of the feedback:

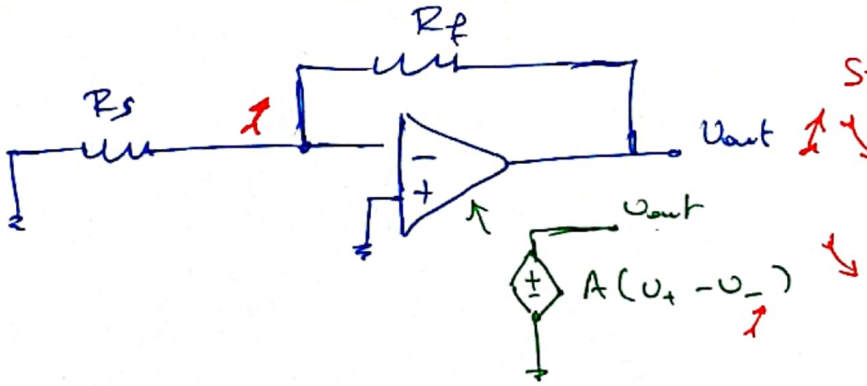
Step 1: Turn-off all independent sources

Step 2: Apply a disturbance at the output and follow it through the feedback to see if it got suppressed at the output.

Example #1: The INVERTING AMPLIFIER



Step 1:



Solve! How? → UVA for OpAmps

→ Steps 1-4: Same

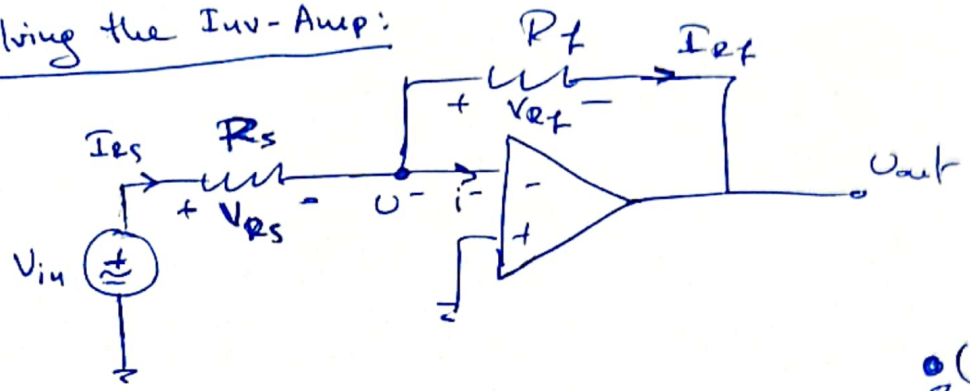
Step 5: Same+
a) Do NOT write a KCL eq. for the output of the op-amp.
b) Write a KCL eq. for v^+ and v^- regardless whether you know their voltages.

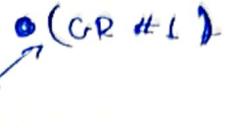
Steps 6-7: Same

Step 8: Same + add the eq: $v^+ = v^-$ to your system.

(p4)

Solving the Inv-Amp:





KCL on U_- : $I_{Rs} = I_{Rf} + i^-$

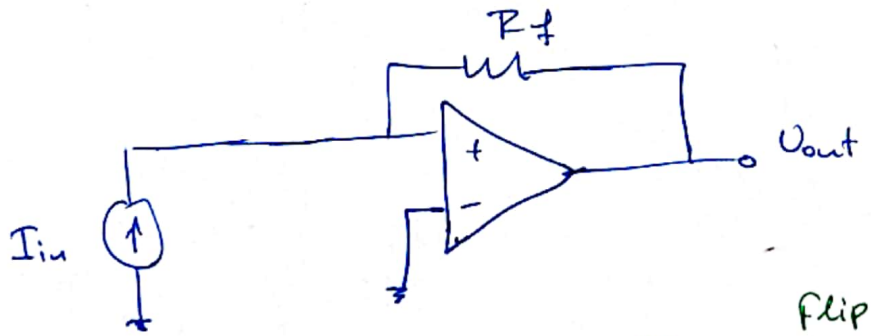
$$\Rightarrow \frac{V_{in} - U^-}{R_s} = \frac{U^- - V_{out}}{R_f} \quad (1)$$

GR #2 : $U_- = U_+ = 0$ (2)

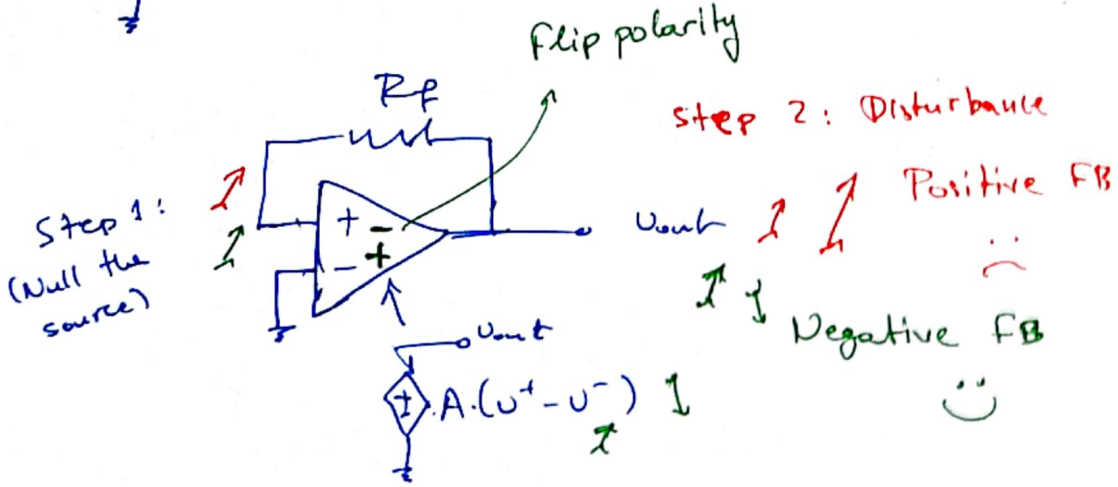
$$\Rightarrow (1) \xrightarrow{(2)} \frac{V_{in}}{R_s} = -\frac{V_{out}}{R_f} \Rightarrow$$

$$\boxed{A_V = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_s}}$$

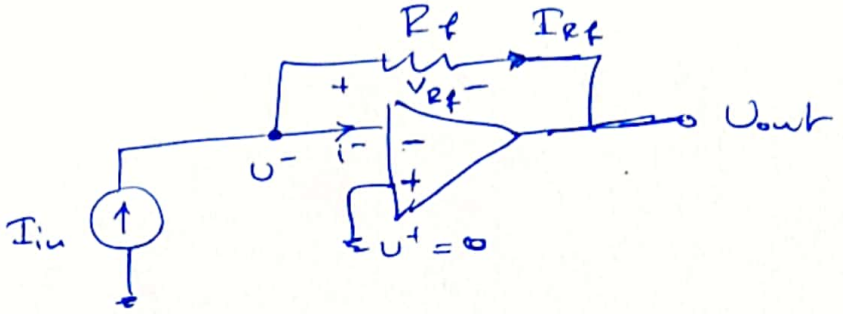
Example #2: Trans-Resistance Amplifier



Check NFB:



(p5)



KCL on U^- : $I_{in} = I_{Rf} + \overset{\nearrow 0 \text{ (GR \#1)}}{i^-}$

$$I_{in} = \frac{V_{Rf}}{R_f} = \frac{U^- - V_{out}}{R_f}$$

GR #2 $\Rightarrow U^- = U^+ = 0$

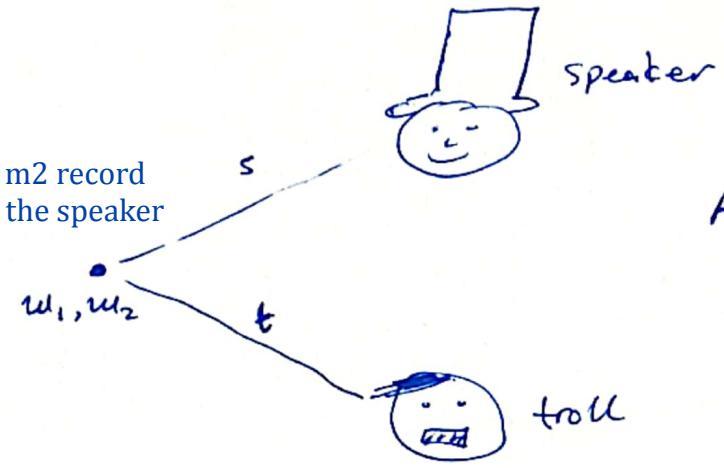
$$I_{in} = -\frac{V_{out}}{R_f} \Rightarrow \boxed{\frac{V_{out}}{I_{in}} = -R_f}$$

Simulation link: http://tinyurl.com/y238s36u

Experiment with Comparator and Inverting-Amplifier

Also useful the corresponding recording from lecture of 07/23.

Troll Problem w/ ckts!

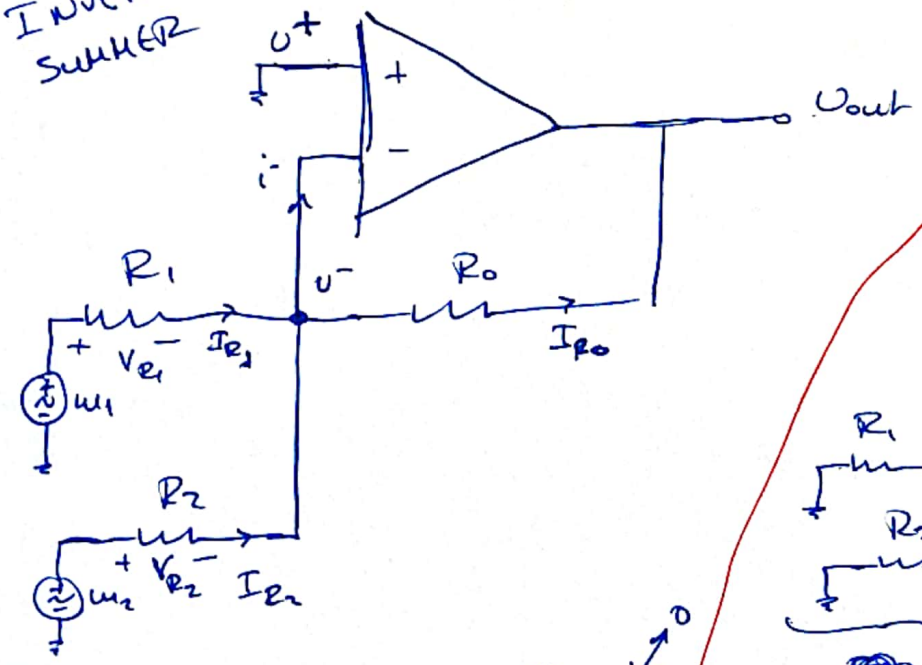


Microphones m1, m2 record both the troll and the speaker

$$A \cdot \begin{bmatrix} s \\ t \end{bmatrix} = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

$$\Rightarrow s = \underbrace{b_{11}}_{\text{weights}} \cdot u_1 + b_{12} \cdot u_2$$

INVERTING SUMMER



KCL on v^-: $I_{R_1} + I_{R_2} = I_{R_0} + \overset{0}{i^-}$

$$\Rightarrow \frac{V_{R_1}}{R_1} + \frac{V_{R_2}}{R_2} = \frac{V_{R_0}}{R_0}$$

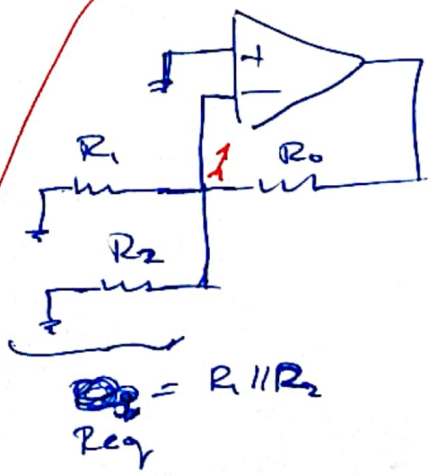
GR #2

GR #2

$$\Rightarrow \frac{u_1 - 0}{R_1} + \frac{u_2 - \overset{0}{v^-}}{R_2} = \frac{\overset{0}{v^-} - v_{out}}{R_0} \Rightarrow \boxed{v_{out} = -\frac{R_0}{R_1} u_1 - \frac{R_0}{R_2} \cdot u_2}$$

Can independently set the weights by picking R_1 and R_2! ☺

Check NFB:

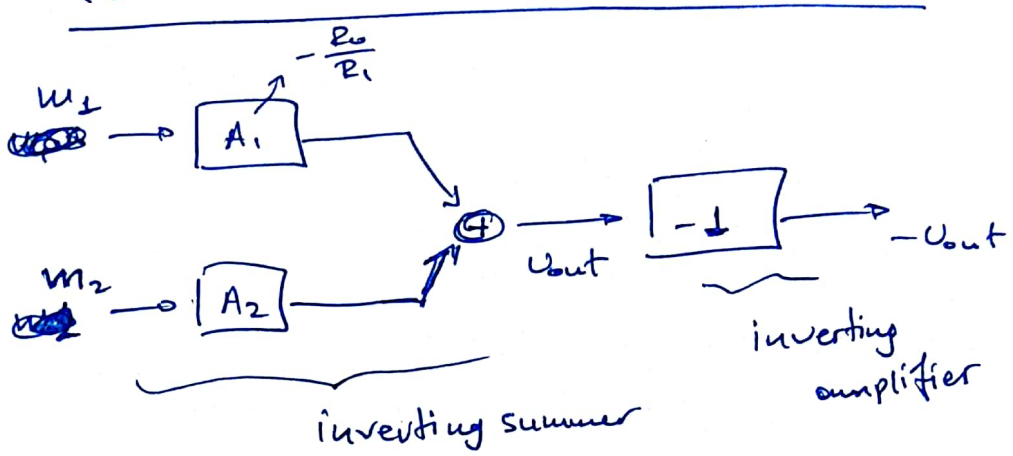


☺ NFB ✓

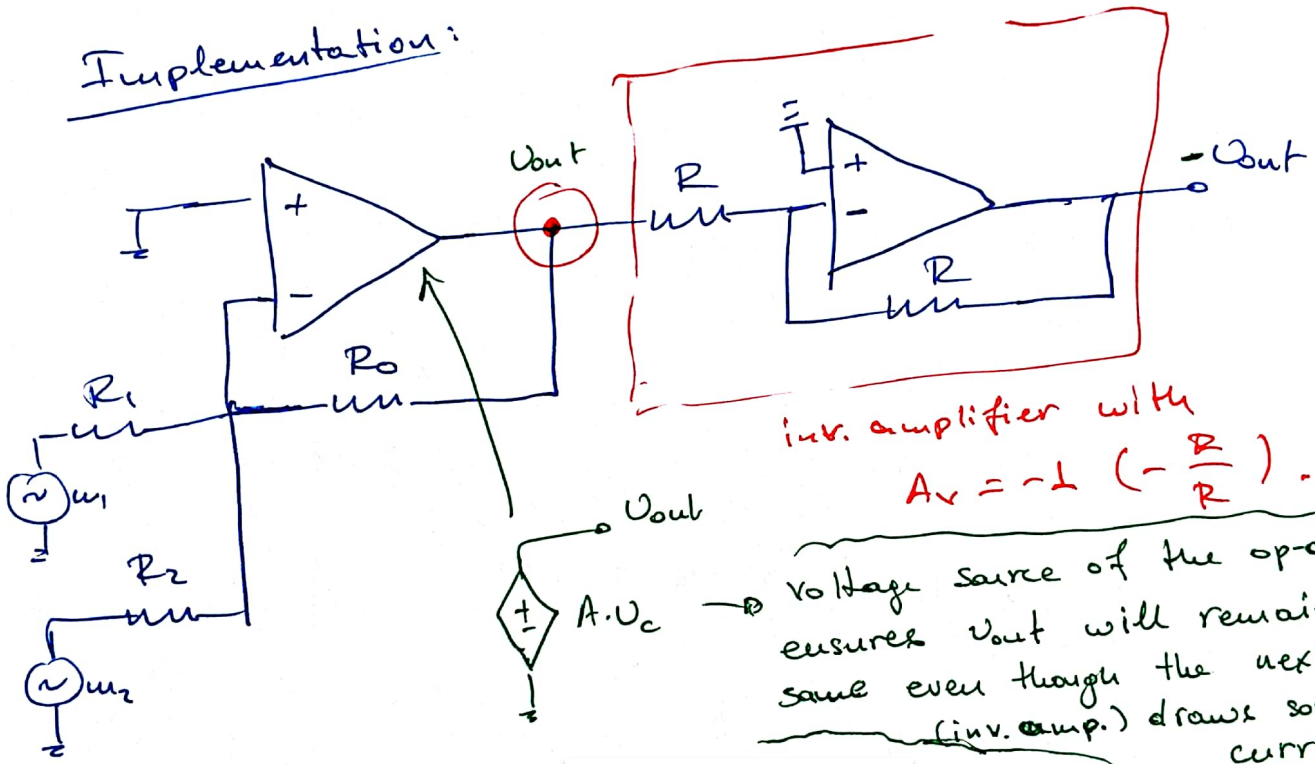
$R_{eq} = R_1 \| R_2$

(p7)

Think in Block Diagram fashion!



Implementation:



inv. amplifier with

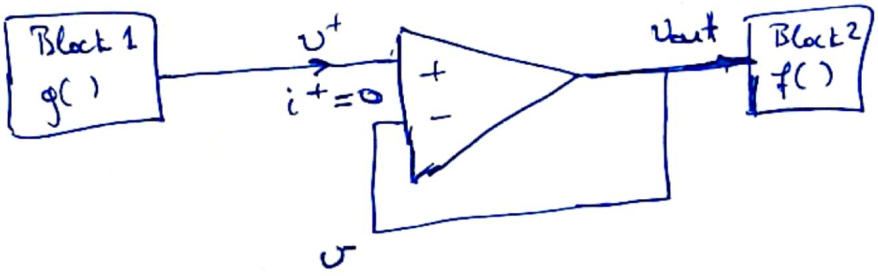
$A_v = -1 \left(-\frac{R}{R}\right)$.

voltage source of the op-amp ensures V_{out} will remain the same even though the next stage (inv. amp.) draws some current

Cascading Blocks (safe way)

Want: $Out_{block_1} = In_{block_2}$
Problem: loading !

To ensure Block 2 won't affect Block 1 (through loading) I need to isolate them:



$V_{out} = v^-$ (same node) $\Rightarrow v^+ = V_{out}$
$v^+ = v^-$ (GR #2)
$i^+ = 0$ (GR #1) $\Rightarrow$ no loading !

Notice: $Out_{block_1} = v^+$
$In_{block_2} = V_{out}$
$\Rightarrow Out_{block_1} = In_{block_2}$

and no loading which is what I wanted :)