Op-Amp in negative feedback

Model:

- \( \text{only for } V_{ss} < V_{out} < V_{DD} \)
- Simpler model as the second source is not needed.

\[
\begin{align*}
V_{out} &= A \left( V_{in} - f \cdot V_{out} \right) \\
V_{out} (1 + A\xi) &= A \cdot V_{in} \\
A_v &= \text{Gain} = \frac{V_{out}}{V_{in}} = \frac{A}{1 + A\xi} \\
A_v &= \frac{1}{A \to \infty} \\
&= \frac{R_1 + R_2}{R_2} = \frac{1 + R_1}{R_2}
\end{align*}
\]

(1) \( V_{dd} = V^+ - V^- = V_{in} - V_{ss} \)
(2) \( V_{out} = A \cdot V_{dd} \)
(3) \( V_{ss} = \frac{R_2}{R_1 + R_2} \cdot V_{out} \)

"BUFFER CIRCUIT"
Golden Rules of Op-Amps

For our design we want $A = 3$

\[ V_d = \frac{V_{out}}{A} \text{ if } A \to \infty \]

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

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

Rules: (Golden Rules)

1. $I^+ = I^- = 0$ (always true)
2. $U^+ = U^-$ (only in NFB & $A \to \infty$)

no current going in

$I^+ = I^- = 0$
Let’s go back to playing music

DAC

\[ V_{DAC} \]

\[ R_{DAC} \]

Non-Inverting Amplifier
(Feedback gain = 3)

\[ V_{out} \]

\[ 2 \times Q \]

\[ 1 \times Q \]

Speaker

\[ R_{speaker} \]

Party time!
Yay!
Today
Checking for Negative Feedback

Step 1 – Zero out all independent sources: replacing voltage sources with wires and current sources with open circuits as in superposition.

Step 2 – Wiggle the output and check the loop – to check how the feedback loop responds to a change.
- If the error signal decreases, the output must also decrease. The circuit is in negative feedback.
- If the error signal increases, the output must also increase. The circuit is in positive feedback.

Now let's solve it...
NFB =) GR #2 applies
\[ U^+ = U^- \]

\[ V_{in} = U_1 = I_1R_1 \]
\[ V_{out} = U_3 = I_2R_2 \]

\[ I_1 + I_2 = 0 \]
\[ \frac{V_{in}}{R_1} + \frac{V_{out}}{R_2} = 0 \]

\[ V_{out} = R_2 \left( -\frac{V_{in}}{R_1} \right) \]

\[ Av = \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1} \]
A faster way...

\[ \text{GR2: } U^+ = U^- \]
\[ U_2 = U^- \]
\[ U^+ = 0 \Rightarrow U_2 = 0 \]

\[ \text{GR1 + KCL } (I_1 = I_2 + I^-) \]
\[ \frac{U_2 - U_1}{R_1} = \frac{U_3 - U_2}{R_2} + I^- \]

\[ -\frac{U_1}{R_1} = \frac{U_3}{R_2} \]

\[ \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1} \]

Diagram of an operational amplifier circuit with input voltage source, resistors, and output voltage.
Example circuit 2 (trans-resistance amplifier)

\[ I_T = 0 \Rightarrow U_1 = U_2 \]

**Invert polarity**

**Step 1**

**Step 2**: Check for NFB

Increase output → + moves up
output increases by a lot

X Not in NFB
The input is current; output is voltage: we use this model in the lab for photo sensors!
Example circuit 3 - Check NFB:

\[ (- V_f) \]
Voltage Divider

\[ V_s = \frac{R_2}{R_1 + R_2} \cdot V_{out} \]

NFB (GR=2)

\[ U^- = U^+ \]

\[ V_{in} = -V_s \]

\[ U^- = \frac{V_s}{U^+} \]

\[ V_{in} = -\frac{R_2}{R_1 + R_2} \cdot V_{out} \Rightarrow \]

\[ \frac{V_{in}}{V_{out}} = -\frac{R_2}{R_1 + R_2} \]

\[ A_v = \frac{V_{out}}{V_{in}} = -\frac{R_1 + R_2}{R_2} = -(1 + \frac{R_1}{R_2}) \]
Artificial Neuron

- Neurons in our brain are interconnected.
- The output of a single-neuron is dependent on inputs from several other neurons.
- This idea is represented with vector-vector multiplication – the output is a linear combination of several inputs.
- An artificial neuron circuit must perform addition and multiplication.

\[
\begin{bmatrix}
a_1 \\
a_2 \\
\end{bmatrix} \cdot \begin{bmatrix}
v_1 \\
v_2 \\
\end{bmatrix} = a_1 v_1 + a_2 v_2
\]
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- This idea is represented with vector-vector multiplication – the output is a linear combination of several inputs.
- An artificial neuron circuit must perform addition and multiplication.
\[- \frac{V_1}{R_1} - \frac{V_2}{R_2} = \frac{V_{out}}{R_3}\]

\[V_{out} = -\frac{R_3}{R_1} V_1 + \left(\frac{R_3}{R_2} V_2\right) + \ldots + \left(\frac{R_3}{R_n} V_n\right)\]

Only negative weights. How can we make \(a_1\) and \(a_2\) positive?

All weights are negative. Add another inverting amplifier circuit.
\[
\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}
\]

It results from

Inverting amplifier

\[
V_{out} = -\frac{R_2}{R_1} \cdot V_{in}
\]

\[
V_{out} = -V_{in} \quad \text{(when } R_1 \text{ and } R_2 \text{ are the same)}
\]
Unity Gain Buffer

- Allows us to isolate circuits

\[ U^+ = V_{in} \]
\[ U^- = V_{out} \]
\[ GB = 1 \]
\[ U^+ = U^- \]
\[ V_{in} = V_{out} \]