EECS 16A - Module 2

Today:
* Quick Review
* Inverting Amplifier
* Cascading CE & BC Blocks
* Design Example

Logistics
- OH right after lecture (Pavone)
  - Same link as Prof. Pavone
- No extension for HW 2 Rete

Review: Op-Amp Golden Rules

\[ \begin{align*}
  &v^+ \quad i^+ \\
  &v^- \quad i^-
\end{align*} \]

GR #1: \( i^+ = i^- = 0 \) Always

GR #2: \( v^+ = v^- \) For an Op-Amp in Negative Feedback and with infinite gain \( A \)
**Non-Inverting Amplifier**

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

Non-inverting because the voltage gain is always \( > 0 \)

**Inverting Amplifier**

\[ V_{out} = A \cdot (V^+ - V^-) \]

if \( V_{out} > 0 \) \( \Rightarrow \) \( V_{out} \) is positive

Established Negative Feedback!
Let's analyze this circuit:

\[ V_{\text{in}} \rightarrow I_{R_1} R_1 + V_{R_1} - V_{R_2} \rightarrow I_{R_2} R_2 + V_{R_2} \rightarrow V_{\text{out}} \]

KCL on the inverting node: \( I_{R_1} = I_{R_2} \)

Ohm's law:
\[
\frac{V_{R_1}}{R_1} = \frac{V_{R_2}}{R_2}
\]

\[ \Rightarrow \frac{V_{\text{in}} - V^-}{R_1} = \frac{V^- - V_{\text{out}}}{R_2} \] (1)

GR #2: \( V^- = V^+ = 0 \) (2)

(1) \( \Rightarrow \) \[ \frac{V_{\text{in}}}{R_1} = -\frac{V_{\text{out}}}{R_2} \]

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

\( \Delta \) Voltage gain
Why negative coefficients?

\[ V_{out} = aV_{in1} + bV_{in2} + cV_{in3} + \ldots \]
\[ \text{want } b < 0 \]

Inversion is a very useful operation in general (for signal processing, sensing, matrix-matrix mult)

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**Cascading Circuit Blocks**

\[ V_{in} \rightarrow \text{Sensor} \rightarrow V_{out,s} \rightarrow -3 \rightarrow V_{out} \]

\[ \text{equivalent} \]

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Before connection: \( V_c = V_{out,s} \)

After connection: \( V_c = V_r = \frac{R}{R+R_s} V_{out,s} \)

\[ = V_{out,s} \checkmark \]
Solution: Add a buffer!

\[ U_r = V_- = V_+ = V_c = V_{out,s} \checkmark \]

Takeaway: Safe way to connect these blocks is by adding buffers in between.
**Design Example**

Countdown Timer Circuit

Button \(\rightarrow\) 2 sec \(\rightarrow\) LED (2V)

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**Step 1: Specification**

Build a circuit that after a button is pushed measures 2s and then applies 2V on an LED.

Assumption: You can only press the button once.

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**Step 2: Strategy**

Push the button \(\rightarrow\) Turn-on timer \(\rightarrow\) Timer \(\rightarrow\) LED

2s
Step 3: (Implementation)

Turn-on ctrl: \[ - \] (switch)

\[ I_c = C \frac{dV_c}{dt} = \frac{I_s}{C} t + V_c(0) \]

Putting it all together:
Set \( V_{\text{ref}} = V_c(2) \)

Step 4: (Verify)

\[ V_c(t) = \frac{I_s}{C} t + V_c(0) \]

\( I_s \) is unknown!

Before button pushed:

\[ i_2 \]

\[ I_s \]

Solution:

Connect the switch to ground.
Revisit Step 3:

NOTE: Now the switch is CLOSED
BEFORE the button is pushed
and OPEN after it is pushed

Before the button is pushed:

\[ V_c = 0 = \text{constant} \]
\[ I_c = C \cdot \frac{dV_c}{dt} \]

\[ I_s = I_w + I_c, \text{ but } I_c = 0 \]
\[ \Rightarrow I_w = I_s \text{ (path of least resistance)} \]
After the button is pushed

\[ V_c(t) = \frac{I_s}{C} t + V_c(0) \]

\[ V_{\text{ref}} = V_c(2) = \frac{I_s}{C} \cdot 2 \]