Lecture 40 (07/21/22)

Announcements

- Midterm Monday
- Review Session Saturday 3-5pm in HP Auditorium
- Up until capacitive touchscreen (not charge sharing) in scope
Agenda

- Comparators w/ Capacitive Touchscreens
- Op-Amps vs Comparators
- Op-Amps in Negative Feedback
Capacitive Touchscreen Model
Comparators w/ Capacitive Touchscreens

output w/o touch

output w/ touch
Op-Amps vs Comparators

- Comparators are actually different from op-amps in practice.
  - Specifically designed to output only the rails and are faster than op-amps.

- As shown in the previous lecture, Op-Amps can be used as comparator but are generally slower.
OpAmps

• Now, we're more interested in the OpAmp behavior between the rails

**unless otherwise stated, we'll assume opamps are ideal (A→∞), \( V_{SS} = -V_{DD} \), and \( V_{SS} \) and \( V_{DD} \) are large enough for our output**

• We're gonna take a look at the following circuit:
Golden Rules for Op-Amps

1. $I_+ = I_- = 0$: no current goes into the opamp (current for the output is coming from the rails)

2. When in negative feedback, $u_+ = u_-$
Negative Feedback

Feedback will push the system in the opposite direction in which it’s moving.
Is this in NFB?

\( U_+ = U_- \) \( \Rightarrow \) NFB

(negative feedback)

\begin{align*}
V_{out} &= A(U_+ - U_-) \\
U_+ &= \frac{R_2}{R_1 + R_2} V_{out} \\
V_{out} &= A(U_+ - \frac{R_2}{R_1 + R_2} V_{out}) \\
V_{out} + A^2 \frac{R_2}{R_1 + R_2} V_{out} &= AU_+ \\
\lim_{A \to \infty} \frac{A(\frac{R_2}{R_1 + R_2})}{1 + A \frac{R_2}{R_1 + R_2}} &= 1 \\
U_- &= \frac{A(\frac{R_2}{R_1 + R_2})}{1 + A \frac{R_2}{R_1 + R_2}} U_+ \\
U_- &= \frac{R_1 + R_2}{R_2} U_- = \frac{AU_+}{1 + A \frac{R_2}{R_1 + R_2}}
\end{align*}
When is a Circuit in NFB?

- Dink method:
  - Increase Vout and see if it decreases \((U_+ - U_-)\). If so, we have NFB
Op-Amp Example (non-inverting amplifier)

Goal: find expression for $\text{V}_{\text{out}}$

This is in NFB

$U_+ = U_-$

$V_{\text{in}} = U_-$

$U_- = \frac{R_2}{R_1 + R_2} V_{\text{out}}$

$V_{\text{in}} = \frac{R_2}{R_1 + R_2} V_{\text{out}}$

$V_{\text{out}} = \left(1 + \frac{R_1}{R_2}\right)V_{\text{in}}$
Application

mp3 IC

DAC

3.3V

10V

8Ω

Speaker

DAC

1kΩ

vn
Application

\[ V_s = \frac{\frac{8}{8+1000}}{V_m} \]

\[ R_2 = 1k\Omega, \quad R_1 = 2k\Omega \]

\[ V_s = \frac{R_1}{R_1 + R_2} V_m \]
Solving OpAmp Problems

1. Identify whether the system is in NFB

2. Use Golden Rule(s) and NBA to solve for V_{out} (mainly KCL)
OpAmp Example 2 (inverting amplifier)

\[
V_{out} = -\frac{R_f}{R_{in}} V_{in}
\]

\[
(V_{in} - U_) - i_{in} R_{in} = i_f R_f
\]

\[
V_{in} - U_ = \frac{U_ - V_{out}}{R_{in}}
\]

\[
\frac{V_{in} - V_{out}}{R_{in}} = \frac{U_ - V_{out}}{R_f}
\]

\[
I_{in} = i_f
\]

\[
\frac{1}{R_{in}} + \frac{1}{R_f} = \frac{1}{NFB}
\]
OpAmp Example 3

\[ (V_1 - V_-) = i_1 R_1 \]
\[ (V_2 - V_-) = i_2 R_2 \]
\[ (V_+ - V_{out}) = i_3 R_3 \]
\[ i_1 + i_2 = i_3 \]

\[ V_1 - V_- + V_2 - V_- = \frac{V_2 - V_{out}}{R_2} \]
\[ \frac{V_1 - V_-}{R_1} + \frac{V_2 - V_-}{R_2} = \frac{V_2 - V_{out}}{R_3} \]

\[ V_{out} = \frac{-R_2}{R_1} V_1 - \frac{R_3}{R_2} V_2 \]

\[ \frac{V_1}{R_1} - \frac{V_2}{R_2} + \frac{V_{out}}{R_2} = \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) V_2 \]

\[ \text{is in NFB} \]
OpAmp Example 4 (Unity gain buffer)

Vout = Vin

Vout = U_-

Vin = U_- = Vout

No current from Vin to Vout
Test

Positive Feedback

\[ V_{out} = A \left( V_{out} - V_{in} \right) \]
\[ (1-A)V_{out} = -AV_{in} \]
\[ A \to \infty \left( V_{out} = \frac{-A}{1-A} V_{in} \right) \]
\[ V_{out} = V_{in} \]
Op Amp Example 5 (transresistance Amplifier)

\[ U_+ = V_{\text{Ref}} \]

\[ I_{\text{in}}(R) = U_- - V_{\text{out}} = V_{\text{Ref}} - V_{\text{out}} \]

\[ V_{\text{out}} = V_{\text{Ref}} - R I_{\text{in}} \]