Touchscreens: OpAmps

Why OpAmps?

- **Comparator**: based on the threshold, the output voltage is either high or low
- **Input resistance**: very high; no input current; capacitors will not discharge while measuring
- **High Gain**: ideally infinity; property makes this useful as a comparator because the output shoots to one of the two rails

Downside

It is nice to have a non-infinite gain to do something with. With a high gain and limiting supply rails, the opamp can only really be used as a comparator.

Examples:

- **Audio Speakers**:
  - Gain is lower than for a comparator (single or double digits)
  - Limited signal → amplifies (boost voltage) → louder sound is played on the speakers
  - Don’t want the signal to clip because this would distort the sound we are trying to produce

- **Sensors**:
  - Want gradation such that the output value indicates something (i.e. pressure applied to the screen)
  - Sensor output is too small → need to amplify
  - Again, don’t want infinite gain so that we can actually get a continuous reading out of the sensor
OpAmps

![OpAmp Diagram]

Figure 1: Basic OpAmp

**Example 1**

- $V_H = 5V$ and $V_L = -5V$ are referenced to ground
- $V_p = 1\mu V$ and $V_n = 0V$ (ground)
- Assume ideal opamp with a gain $A = \infty$

**Example 2**

- $V_H = 5V$ and $V_L = -5V$ are referenced to ground
- $V_n = V_p = 2V$
- $A(V_p - V_n)$ therefore $V_{out} = 0V$

**Example 3**

- $V_H = 5V$ and $V_L = -1V$ are referenced to ground
- $V_n = V_p = 2V$
- $V_{out} = 2V$
- $A(V_p - V_n) = 0$ but it is 0 referenced halfway between the positive and negative rails
- The opamp’s internal reference is halfway between the 2 supplies
Negative Feedback

• Like a restoring force using inverting input
• Control the gain
• Without changing $V_p$, the internals of the opamp, or the supply voltages, how can you pull $V_{out}$ away from the positive rail?
  – Increase $V_n$ to pull $V_{out}$ down
  – In effect, reduce the gain the overall circuit (including the opamp) provides
• Ideal opamp: $V_p = V_n$
• Finite gain: $V_p$ is almost equal to $V_n$ (off by some factor)
• "Golden rules": $v_p = v_n$, current in to $v_p$, $v_n = 0$

Buffer

• Assume the opamp is ideal (infinite gain)
• Feed the whole output back into $V_n$
• System stabilizes to $V_p = V_n$
  – When the output voltage tries to go slightly above or below $V_p$, the opamp "kicks in" and pushes $V_{out}$ down or up
  – Does not infinitely oscillate (for a well-designed opamp) → asymptotically approaches $V_p = V_n$
• The point of the buffer is to make it so that loading (resistance) on the output side does not affect what happens on the input side (like independent circuits)

![Figure 2: Buffer](image-url)

In effect, the input voltage does not get amplified. However, the circuit is "split" into independent parts.
Non-Inverting Amplifier

- No voltage drop across $R_s$ because current into $V_p$ is 0 A
- Control the effective gain by choosing resistors
- Op-amp gain $A$ does not directly affect the system but must be really high
  
  $$V_0 = \frac{R_1 + R_2}{R_2} \cdot V_s$$

- Notice that the $V_s$ coefficient is always positive and greater than 1
- "Golden Rules" applicable because negative feedback comes through the voltage divider
- If $R_2$ is not there or is not grounded, this effectively becomes a buffer

Inverting Amplifier

- "Golden Rules" applicable because there is negative feedback
- Here, we are applying $V_s$ to $V_n$ (inverting signal)
  
  - Inverting effect $V_0 = \frac{-R_f}{R_l} \cdot V_s$
– Can be made into an attenuator is $R_f < R_s$

• $V_p$ is grounded

• Real-life example: noise cancelling headphones invert the noise and add the inverted signal to the original to the desired original tp cancel

Design Exercises

Touch Screen Sensor

• Use a non-inverting amplifier because we specified that the voltage must be positive (between 0 and 10 volts)

• What should the resistors be such that the gain is 2?

1. $R_1 = R_2 = 1\Omega$
   – Wastes power
   – OpAmps cannot provide the current necessary for this resistance.

2. $R_1 = R_2 = 1K\Omega$
   – Resistance cannot be too high because non-idealities start to appear
   – If $R_{input}$ is not "infinite" and $R_1$ and $R_2$ are too high, $I_{input}$ can no longer be ignored.

Current Source

• KCL: $i_1 + i_2 + i_n = 0 \rightarrow i_1 = \frac{V_s}{R_s}$

• Current through $R_L$ does not change → constant current source
**Summing Amplifier**

- Sums 2 signals → amplifies with inversions
- "Golden Rules" apply
  - \( i_n = i_p = 0 \text{A} \)
  - \( V_n = V_p = 0 \text{V} \)
- KCL at \( V_n \):
  \[
  i_1 + i_2 + i_f + i_n = 0 \\
  \frac{0-V_1}{R_1} + \frac{0-V_2}{R_2} + \frac{0-V_{out}}{R_f} = 0 \\
  \frac{V_1}{R_1} - \frac{V_2}{R_2} = \frac{V_{out}}{R_f} \\
  V_{out} = -R_f \left( \frac{V_1}{R_1} + \frac{V_2}{R_2} \right)
  \]
- What can this be used in?
  - Analog calculator
  - Noise cancelling headphones
  - Music mixers (adding two audio streams together)