Lecture notes by Rachel Zhang (03/10/2015)

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 $\rightarrow$ amplifies (boost voltage) $\rightarrow$ 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 $\rightarrow$ need to amplify
  - Again, don't want infinite gain so that we can actually get a continuous reading out of the sensor

OpAmps

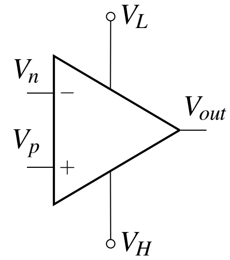


Figure 1: Basic OpAmp

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) $\rightarrow$ 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)

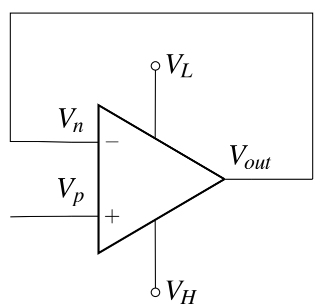


Figure 2: Buffer

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

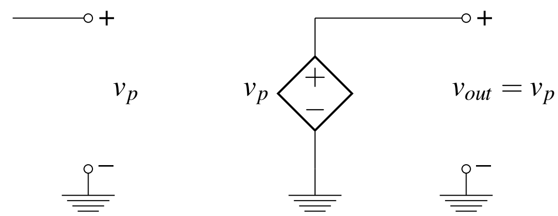


Figure 3: Buffer Conceptual Equivalent

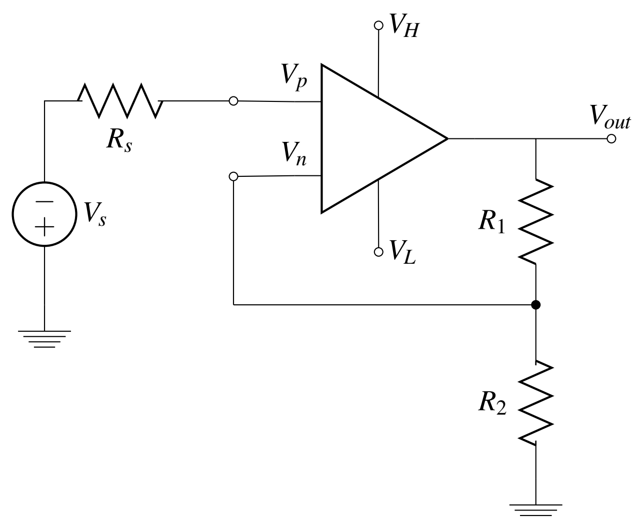


Figure 4: Non-Inverting Amplifier

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 $V_0 = \frac{-R_f}{R_s} \cdot V_s$

- Can be made into an attenuator is $R_f < R_s$

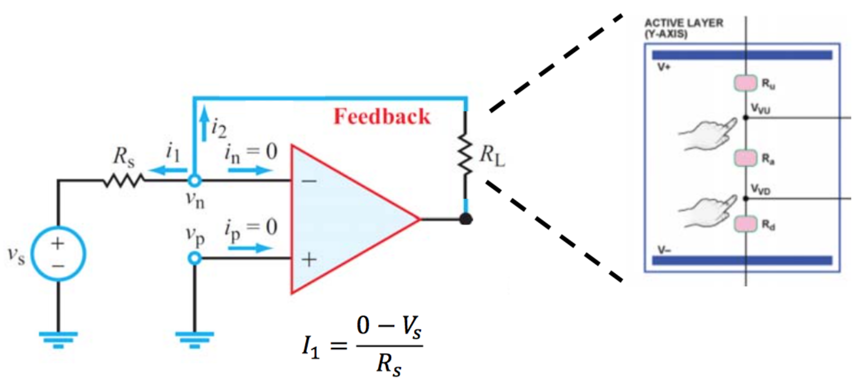
- V_p is grounded
- Real-life example: noise cancelling headphones invert the noise and add the inverted signal to the original to the desired original tp cancel

Design Exercises

Touch Screen Sensor

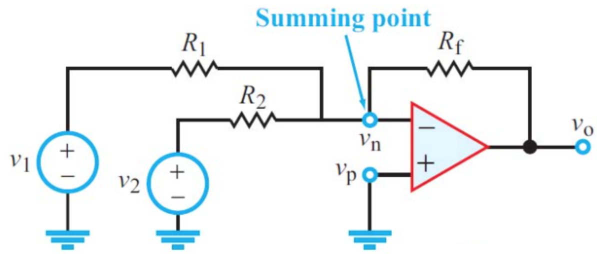
- Use a non-inverting amplifier because we specified that the voltage must be positive (between 0 and 10 volts)
- What should the resistors be such that the gain is 2?
  1. $R_1 = R_2 = 1\Omega$
     - Wastes power
     - OpAmps cannot provide the current necessary for this resistance.
  2. $R_1 = R_2 = 1K\Omega$
     - 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 $\rightarrow$ **constant current source**

Summing Amplifier



- Sums 2 signals $\rightarrow$ amplifies with inversions
- "Golden Rules" apply
  - $i_n = i_p = 0A$
  - $V_n = V_p = 0V$
- 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)