Hands-on Lab 5: Sensing Part 2

EECS 16B Fall 2022

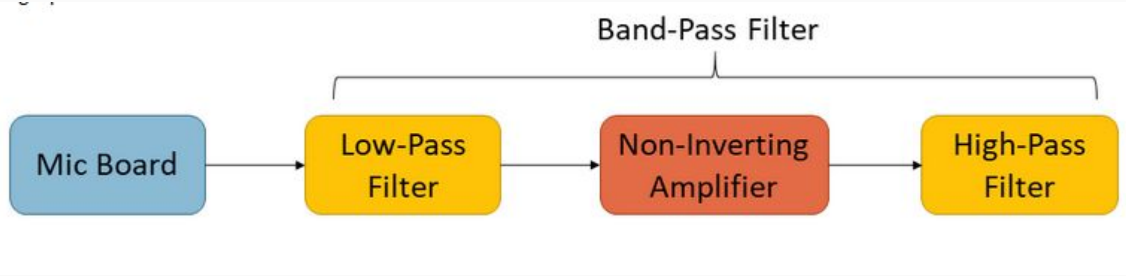
Slides: http://links.eecs16b.org/lab5-slides

Administrivia (Lab Reports)

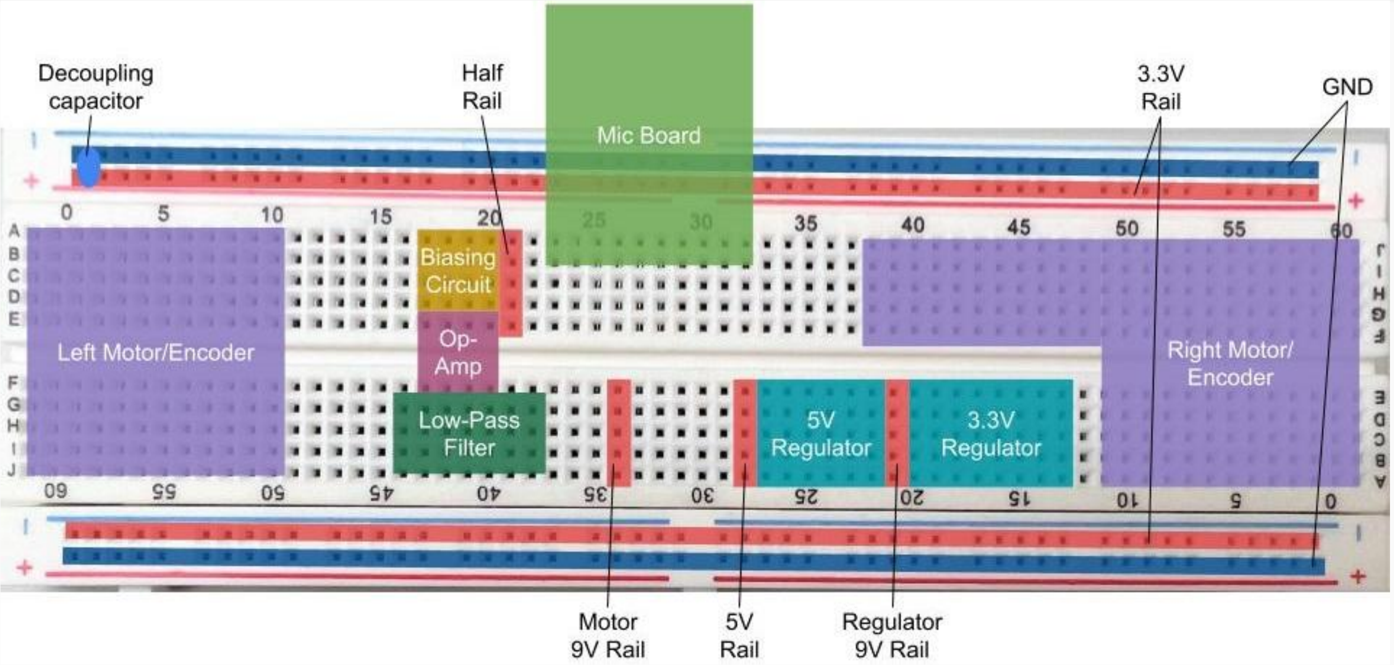
- **Midterm Lab Report will be released by October 2nd**
- Everyone should have their sid.txt submitted on the Gradescope assignment. Instructions copied below
  - **Lab computers:** open “Git Bash” and run “cd $USERPROFILE/Desktop && echo SID > sid.txt”
  - **macOS/Linux:** open “Terminal” and run “cd $HOME/Desktop && echo SID > sid.txt”
  - **General Windows:** open “Command Prompt” and run “cd %userprofile%\Desktop; echo SID > sid.txt”
  - Replace SID with your unique Berkeley Student ID
- The following week is a buffer week (lab makeups + lab report help)

Lab 5 Overview

- Re-tune your mic board
- Implement the following:
  - Low Pass Filter (LPF)
  - High Pass Filter (HPF)
  - Chain LPF and HPF together -> Band Pass Filter
- Build the **HPF** on some randomly empty space - will be discarded after lab
- Reminder: do NOT use the prestripped jumper wires within your breadboard



BREADBOARD LAYOUT



Filters

Filters

- **Cutoff frequency** (f_c) is where signal has attenuated by 1/2 power (3dB)
- Recall:

$$P = IV = \frac{V^2}{R}$$

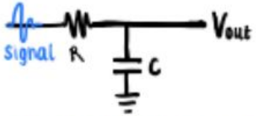
$$\frac{P}{2} = \frac{1}{2} \cdot \frac{V^2}{R} = \frac{1}{R}\left(\frac{V}{\sqrt{2}}\right)^2$$

- We can find the cutoff frequency by finding the frequency that causes the voltage to drop to $\mathbf{(1/\sqrt{2})V_0 \approx 0.707V_0}$
- For RC circuits, the cutoff frequency is given by: $f_c = \frac{1}{2\pi RC}$ [Hz]

Low-pass Filter Cutoff Derivation

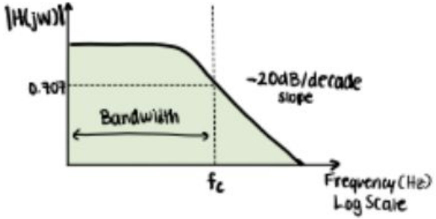
Lowpass Filter

Circuit Schematic



Think: the "gate" C is lower.

Low Pass Frequency Response



$$\hat{V}_{out} = \hat{V}_{in} \cdot \frac{Z_C}{Z_R + Z_C} = \hat{V}_{in} \frac{\frac{1}{j\omega C}}{R + \frac{1}{j\omega C}} = \hat{V}_{in} \frac{1}{j\omega RC + 1}$$

$\frac{V_{out}}{V_{in}} = H(j\omega)$ and cutoff frequency is at half power, where $\frac{|\hat{V}_{out}|}{|\hat{V}_{in}|} = \frac{1}{\sqrt{2}} = 0.707$.

$$|H(j\omega)| = \frac{1}{\sqrt{2}} = \frac{\sqrt{1}}{\sqrt{(\omega RC)^2 + (1)^2}} = \frac{1}{\sqrt{1 + (\omega RC)^2}}$$

$$2 = 1 + (\omega RC)^2$$

$$1 = \omega RC$$

$\omega = \frac{1}{RC}$ angular cutoff frequency

$f_c = \frac{1}{2\pi RC}$ cutoff frequency

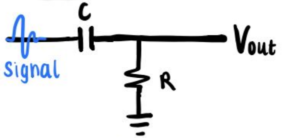
Conceptually: as $\omega \to \infty$, $|H(j\omega)| \to 0$
as $\omega \to 0$, $|H(j\omega)| \to 1$

Everything that is less than f_c gets through. Note that our cutoff isn't clean & perfect because the attenuation is gradual.

High-pass Filter Cutoff Derivation

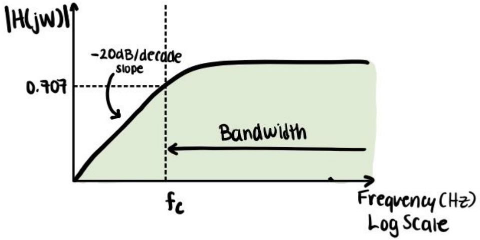
High Pass Filter

Circuit Schematic



Think: the "gate" is higher.

High Pass Frequency Response



$$\tilde{V}_{out} = \tilde{V}_{in} \cdot \frac{Z_R}{Z_R + Z_C} = \tilde{V}_{in} \frac{R}{\frac{1}{jwC} + R}$$

$$|H(jw)| = \frac{|\tilde{V}_{out}|}{|\tilde{V}_{in}|} = \frac{1}{\sqrt{2}} = \frac{\sqrt{R^2}}{\sqrt{\left(\frac{1}{wC}\right)^2 + R^2}}$$

$$\frac{1}{2} = \frac{R^2}{\left(\frac{1}{wC}\right)^2 + R^2}$$

$$\left(\frac{1}{wC}\right)^2 + R^2 = 2R^2$$

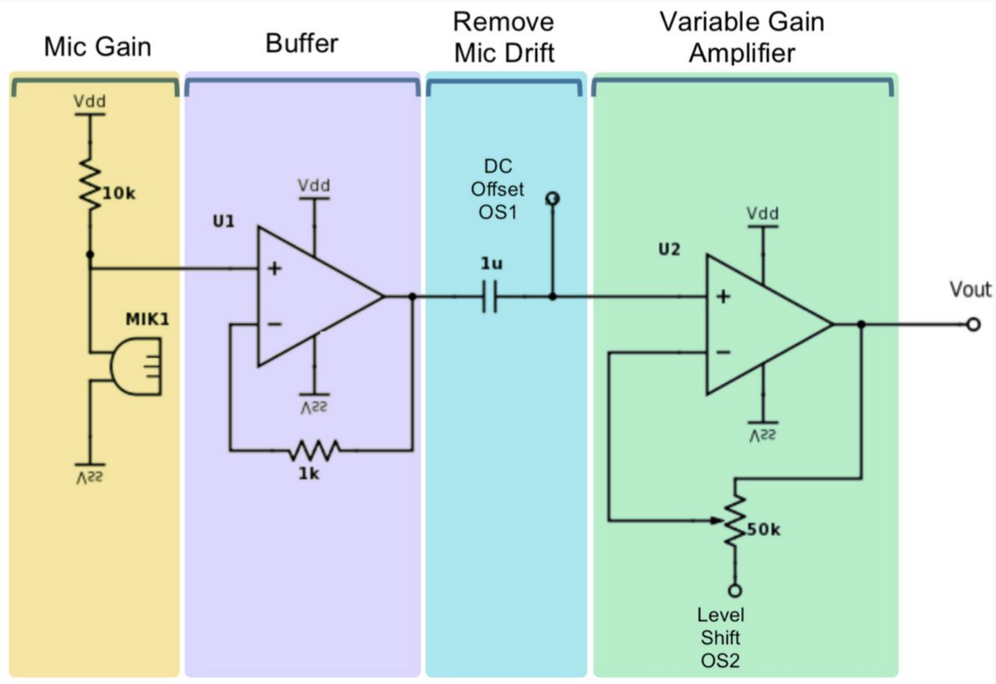
$$\left(\frac{1}{wC}\right)^2 = R^2$$

$w = \frac{1}{RC}$ angular cutoff frequency

$f_c = \frac{1}{2\pi RC}$ cutoff frequency

Conceptually: as $w \to \infty$, $|H(jw)| \to 1$
as $w \to 0$, $|H(jw)| \to 0$

Review: Mic Board Schematic



1. Mic Gain

- Mic is a variable current source,
- Convert it to a voltage signal

2. Buffer

- Prevent Loading

3. Removing Mic Drift

- The 1μF capacitor is a *coupling capacitor*, meaning it serves as a short to AC voltage but blocks DC voltage
- **OS1** - centers signal at 1.65V. Connected through a 100kΩ resistor, since OS1's voltage isn't equal to our signal.
- **NEW: This creates a high pass filter, but its cutoff frequency is 1.59Hz, so nearly all the signal passes**

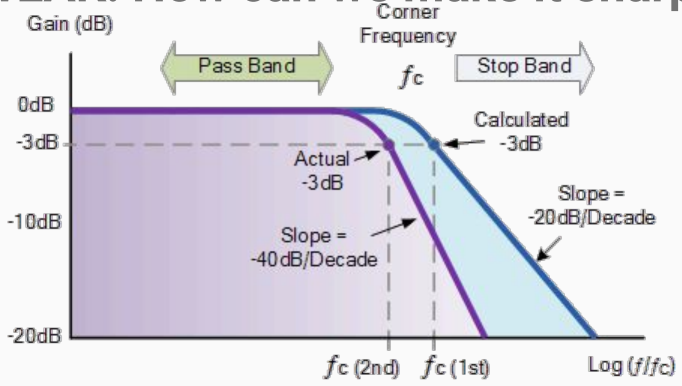
4. Non-inverting amplifier

- Uses a potentiometer for variable gain
- **OS2** - serves as a virtual ground so we don't amplify the 1.65V offset

Concept Check!

- **What happens if we put a DC voltage through a high pass filter?**

- **Our cutoff is kinda WEAK. How can we make it sharper?**



Concept Check!

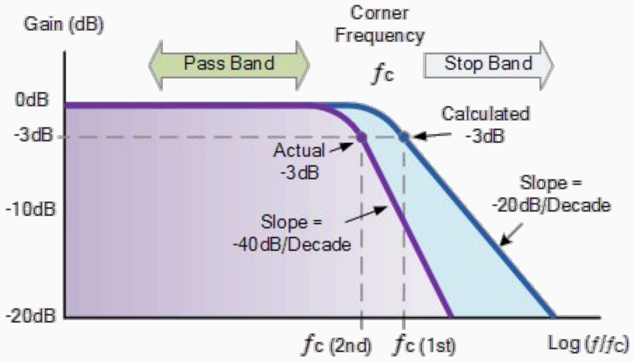
- What happens if we put a DC voltage through a high pass filter?

  It gets destroyed. w = 0Hz. Centers signal at 0V.

- Our cutoff is kinda WEAK. How can we make it sharper?

  Cascade filters!

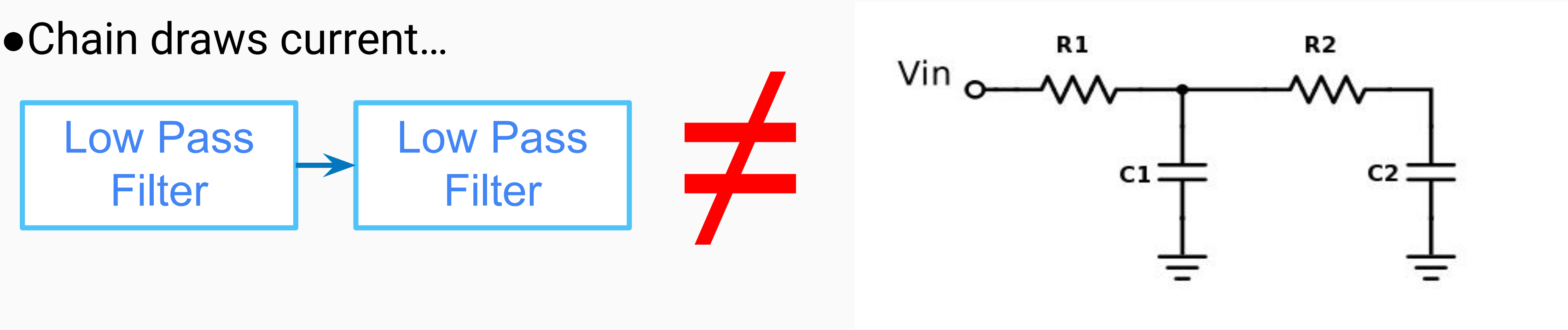
  But careful about loading.



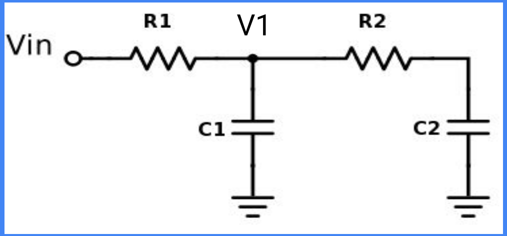
Why Can’t I Chain Passive Filters?!

- Sometimes we need to filter more than once (ie: band-pass, 2nd order filter, etc.)

- Chain draws current…



Why Can't I Chain (continued)



- For low pass filter, expect output of first filter V1 = Vin $\frac{1}{j\omega RC + 1}$
  - But now, we have a second filter loading the output
- Note that R2 and C2 are in series:

$$Z_2 = Z_{R2} + Z_{C2} = R_2 + \frac{1}{j\omega C_2} \longrightarrow Z_2 = \frac{j\omega R_2 C_2 + 1}{j\omega C_2}$$

- Note that C1 and Z2 are in Parallel: $Z_{tot} = Z_{c1} || Z_2 = \left[\frac{1}{Z_{C1}} + \frac{1}{Z_2}\right]^{-1}$

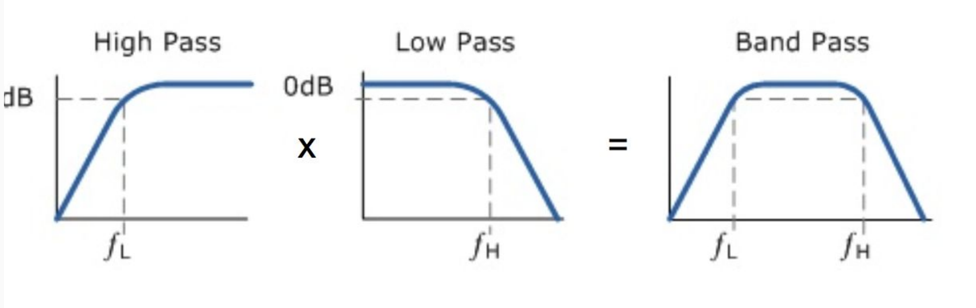
- Using Voltage Divider Formula: $V_1 = V_{in} \frac{Z_{tot}}{Z_{tot} + Z_{R1}}$

Why Can't I Chain (continued)

- The voltages at V1 after the first filter isn't the same as with just one low pass filter! Why?
  - We changed the cutoff frequency!
- Normal filter calculations ***falsely*** assume:
  - High output impedance (output draws no current)
  - Low input impedance (input provides as much current as needed)
- Instead, we need to add a buffer in between the filters

Band-pass Filters

- Band-pass Filter
  - Allows a range of frequencies to pass
  - Requires two cutoff frequencies
- We can make a band-pass from a high and low-pass filter: ($f_L < f_H$)
  - f_L: lower cutoff frequency
  - f_H: higher cutoff frequency



Important Forms/Links

- Help request form: https://eecs16b.org/lab-help
- Checkoff request form: https://eecs16b.org/lab-checkoff
- Extension Requests: https://eecs16b.org/extensions
- Makeup Lab: https://makeup.eecs16b.org
- Slides: links.eecs16b.org/lab5-slides
- Anon Feedback: https://eecs16b.org/lab-anon-feedback