

# Hands-on Lab 5: Sensing Part 2

EECS 16B Spring 2023

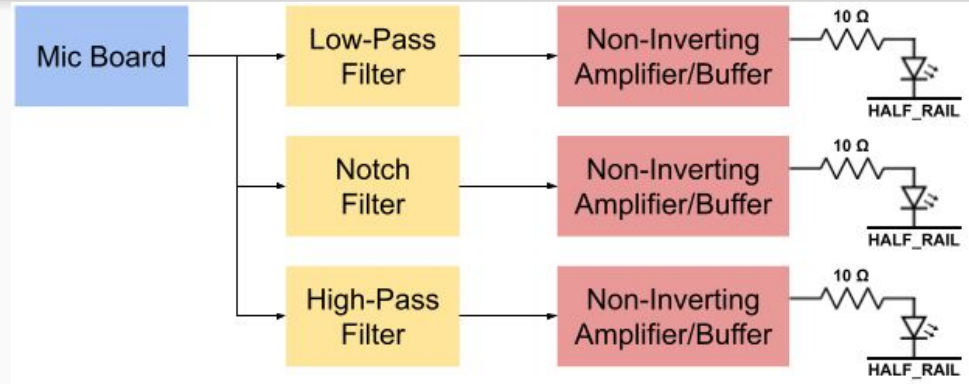
Slides: [links.eecs16b.org/lab5-slides-sp23](https://links.eecs16b.org/lab5-slides-sp23)

# Administrivia

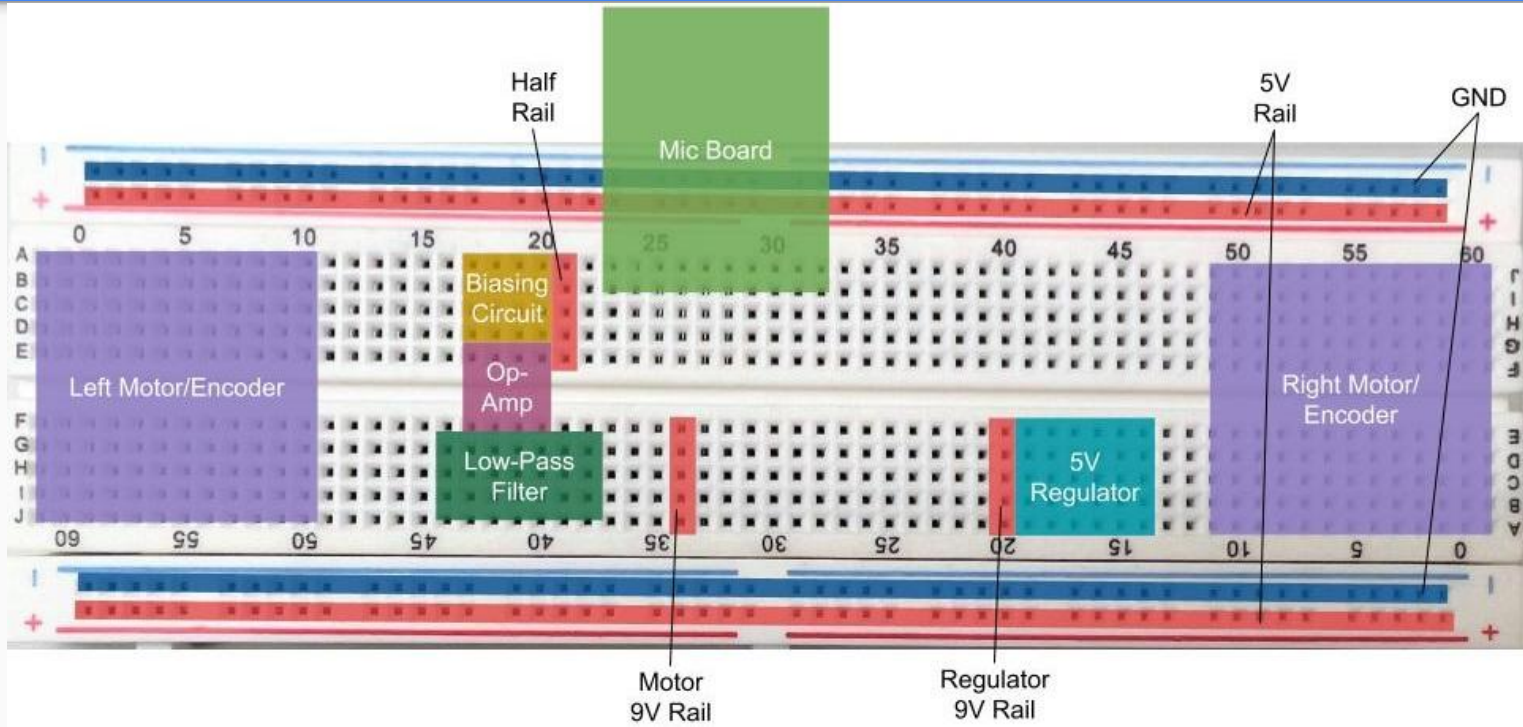
- **Continue working on the Midterm Lab report! It is due 3/10**
- The following week is a buffer week (lab makeups + lab report help) + study for midterm

# Lab 5 Overview

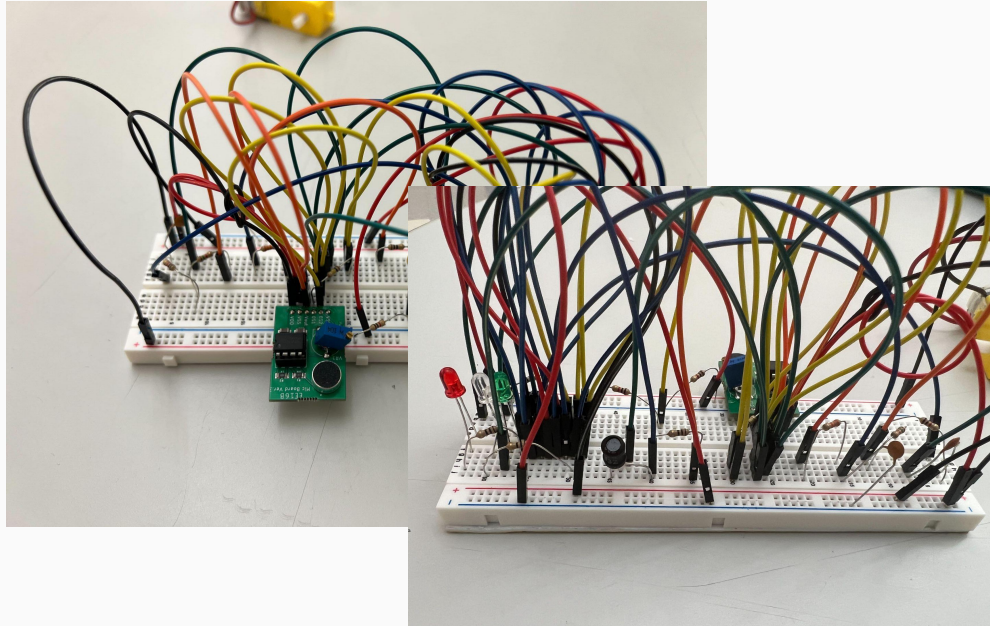
- Re-tune your mic board
- Implement the following:
  - High Pass Filter (HPF)
  - Notch Filter
  - Together we make a color organ!
- Build the **HPF** and **Notch** on some randomly empty space - will be discarded after lab, we recommend building on a **second breadboard**, there are large ones connected to the lab stations.



# BREADBOARD LAYOUT



# Breadboard No-No's



- **Messy Wiring**, and the use of excessive **Jumper Wires** make circuits exponentially more difficult to debug.
- As our breadboard circuits get more and more complex and large, we **HIGHLY** recommend students to clean up their breadboards (it makes both our lives easier), as there also may be no space for future circuits.

# Filters

# First Order Filters

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

- Recall:

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

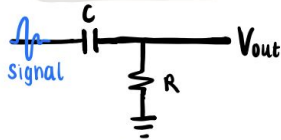
$$\frac{P}{2} = \frac{1}{2} \cdot \frac{V^2}{R} = \frac{1}{R} \left( \frac{V}{\sqrt{2}} \right)^2$$

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

# High-pass Filter Cutoff Derivation

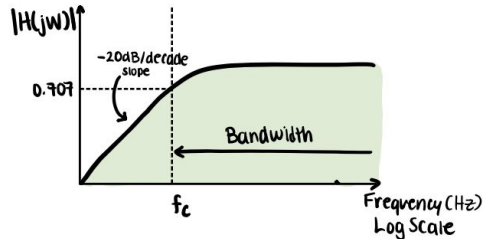
## High Pass Filter

### Circuit Schematic



Think: the "gate" is higher.

### High Pass Frequency Response



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

$$|H(j\omega)| = \frac{|\hat{V}_{out}|}{|\hat{V}_{in}|} = \frac{1}{\sqrt{2}} = \frac{\sqrt{R^2}}{\sqrt{(\frac{1}{\omega C})^2 + R^2}}$$

$$\frac{1}{2} = \frac{R^2}{(\frac{1}{\omega C})^2 + R^2}$$

$$(\frac{1}{\omega C})^2 + R^2 = 2R^2$$

$$(\frac{1}{\omega C})^2 = R^2$$

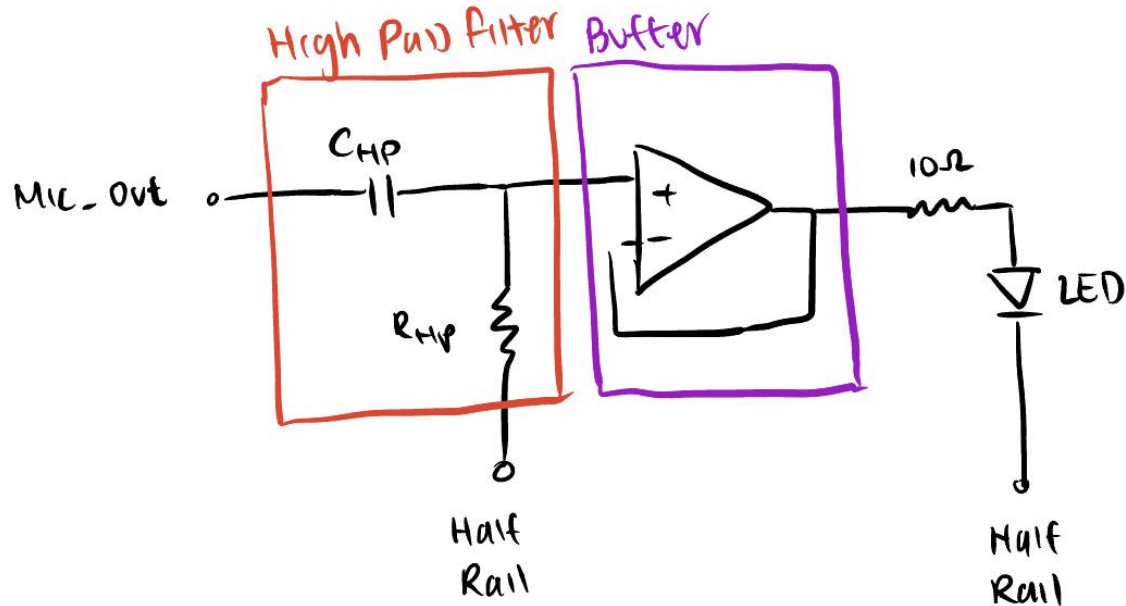
Conceptually: as  $\omega \rightarrow \infty$ ,  $|H(j\omega)| \rightarrow 1$   
as  $\omega \rightarrow 0$ ,  $|H(j\omega)| \rightarrow 0$

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

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



# Color Organ High Pass Filter



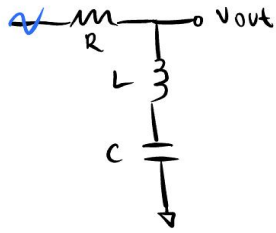
# Notch Filters (make sure to return inductor)

- **Notch Frequency:** The only frequency where the signal gets attenuated **OR** the only frequency where the signal passes through (depends on your filter implementation!)
- **Q factor:** The quality of the filter (is there a steep attenuation slope?), a higher Q factor -> higher quality filter

Notch Frequency:  $\omega = \sqrt{1/(LC)}$  ,  $f = \omega/(2\pi)$ , we will be using  $f$ , rather than  $\omega$  !!

Q Factor (only for RLC in series) =  $\omega L/R$  ( $\omega$  = Notch frequency)

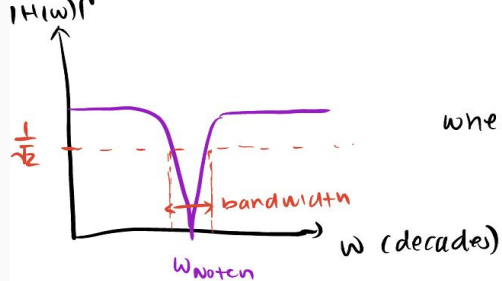
# Notch Frequency Derivation



Notch Frequency:

$$\begin{aligned}
 H(j\omega) &= \frac{j\omega L + \frac{1}{j\omega C}}{R + j\omega L + \frac{1}{j\omega C}} \\
 &= \frac{j^2\omega^2 LC + 1}{j\omega RC + j^2\omega^2 LC + 1} \\
 &= \frac{1 - \omega^2 LC}{j\omega RC - \omega^2 LC + 1}
 \end{aligned}$$

Freq-Response



when is  $|H(j\omega)| = 0$ ?

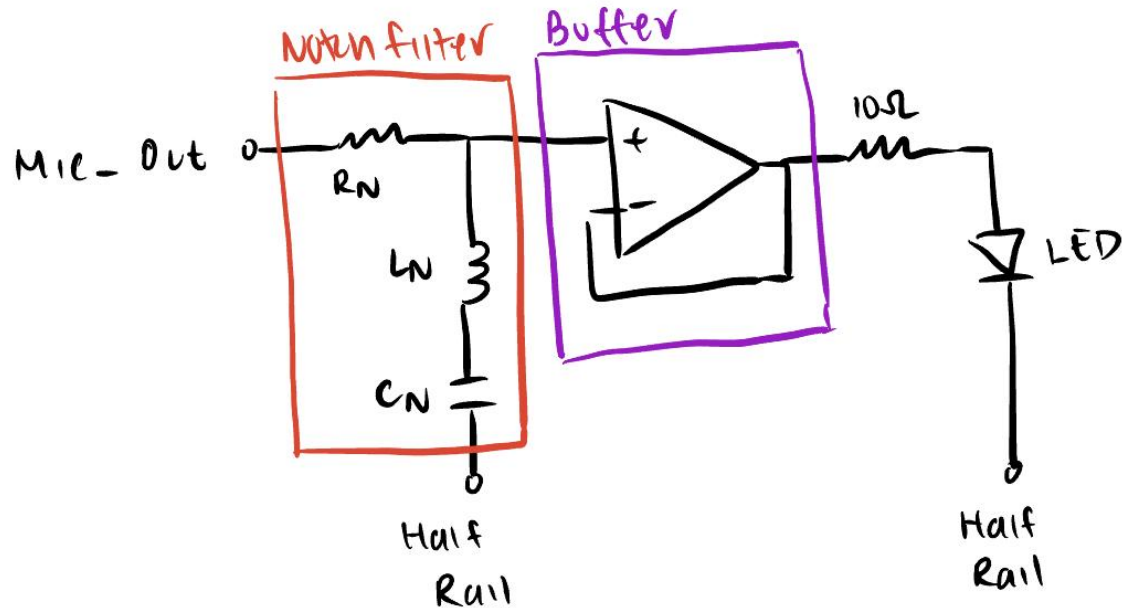
$$1 - \omega^2 LC = 0$$

$$1 = \omega^2 LC$$

$$\rightarrow \sqrt{\frac{1}{LC}} = \omega_{notch}$$

$$\rightarrow \boxed{\frac{1}{2\pi\sqrt{LC}} = f_{notch}}$$

# Color Organ Notch Filter

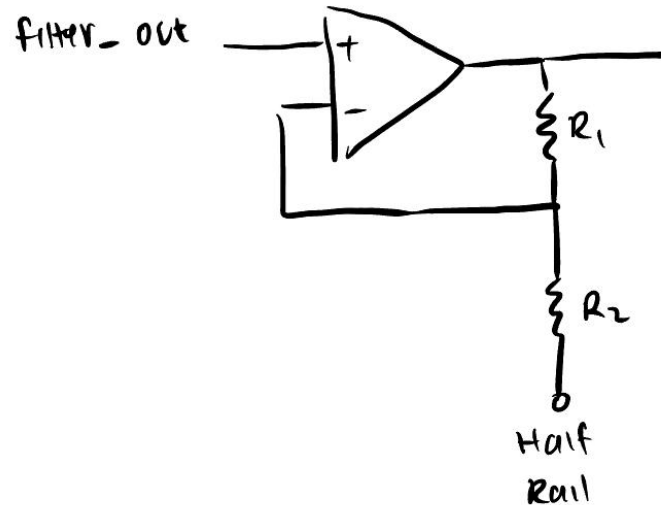


# Debugging: Why aren't my LEDs lighting up?

- Make sure your filter(s) indeed does work using the function generator (sweep a range of frequencies, ones that should be attenuated, and ones that should pass through).
- Increase the gain of your system!
- You can start by increasing the gain of your micboard by tuning the potentiometer (CCW for increasing gain).
- If your LED lights up after adjustment, tune your micboard back to normal, and use this gain to build a non-inverting amplifier at the output of your filter!

# Review: Non-Inverting Amplifier Schematic

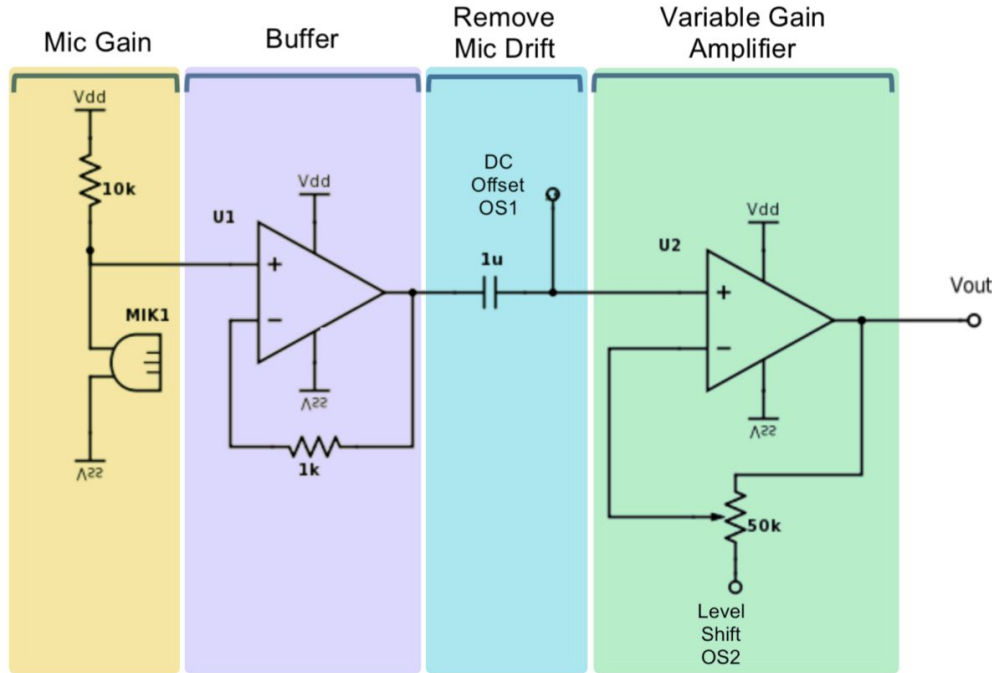
\* Buffer can be swapped for non-inverting amplifier!



$$\text{Gain} = 1 + \frac{R_1}{R_2}$$

\* Choose reasonable ( $1\text{k}\Omega >$ ) values for  $R_1, R_2$ .

# 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

# 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-sp23](https://links.eecs16b.org/lab5-slides-sp23)
- Anon Feedback: <https://eecs16b.org/lab-anon-feedback>
- Lab Grades error: <https://links.eecs16b.org/lab-checkoff-error>