Lab 5: Sensing Part 2

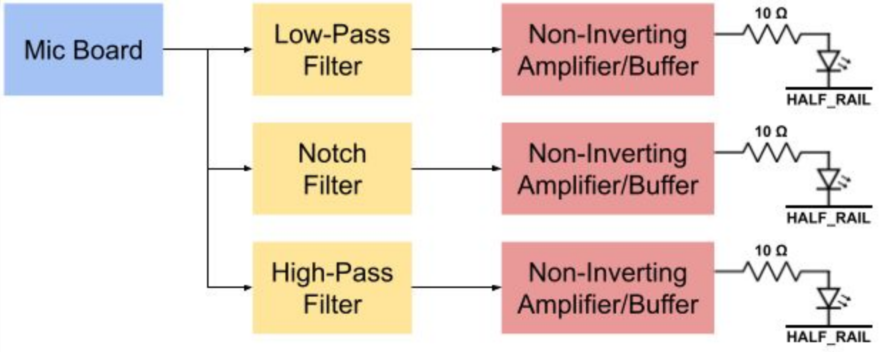
EECS 16B Fall 2023

Slides: links.eecs16b.org/lab5-slides

Administrivia

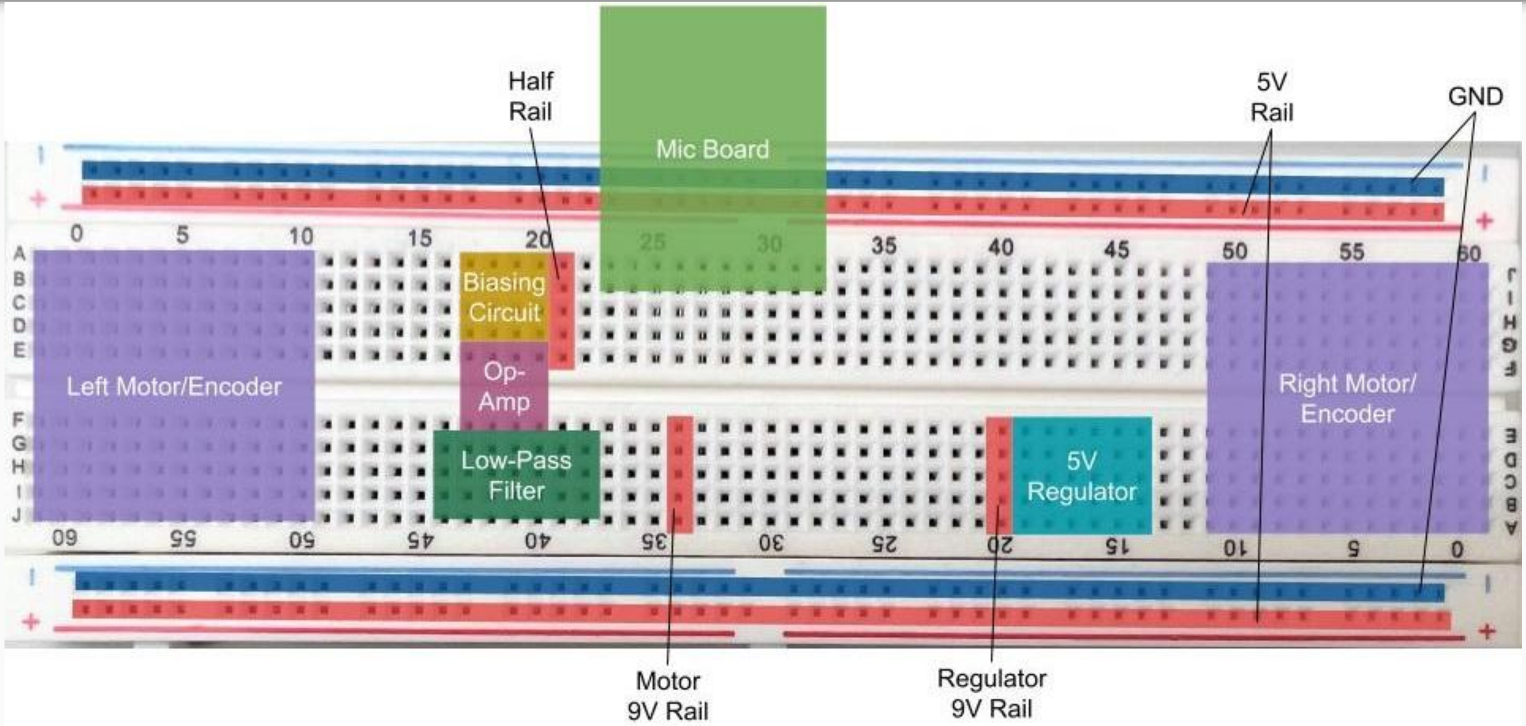
- **Continue working on the Midterm Lab report! It is due 10/6**
- The following two week are a buffer weeks (lab makeups) + time to study for midterm
- This lab also has loud noises - if needed, don't hesitate to step out for a minute!

Lab 5 Overview

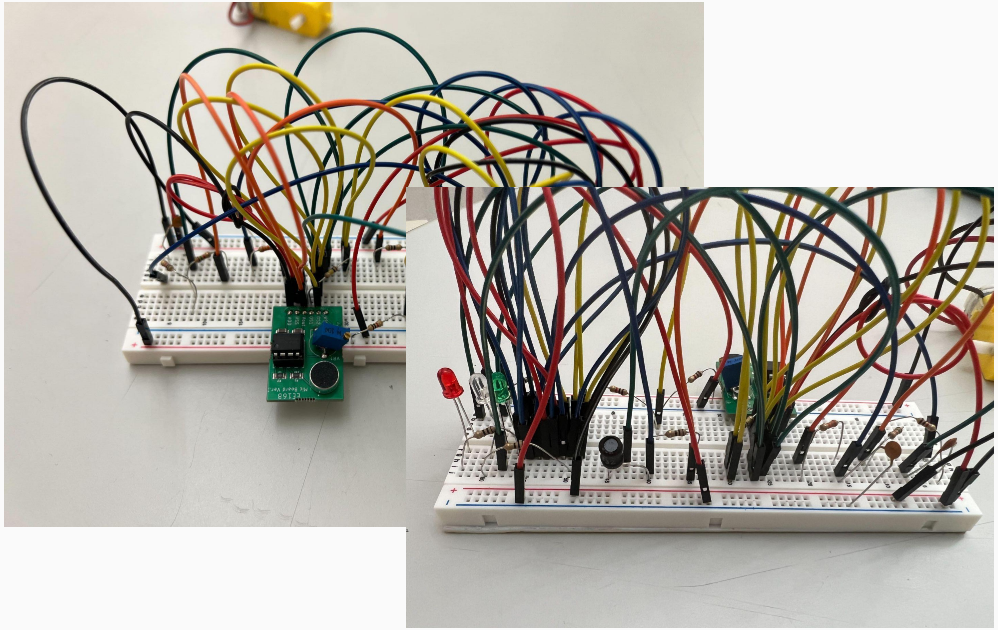


- Re-tune your mic board
- Implement the following:
    - High Pass Filter (HPF)
    - Notch Filter
    - Together we make a color organ!
- Build the **HPF** and **Notch** on some random empty space – they will be discarded after lab, we recommend building on a **second breadboard,** there are large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

BREADBOARD LAYOUT



Breadboard Reminder



- **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 REQUIRE students to clean up their breadboards and it 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:

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

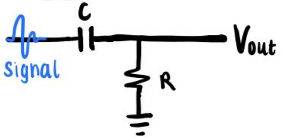
$$\frac{P}{2} = \frac{1}{2} \cdot \frac{V^2}{R} = \frac{1}{R}\left(\frac{V}{\sqrt{2}}\right)^2$$

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

High-pass Filter Cutoff Derivation

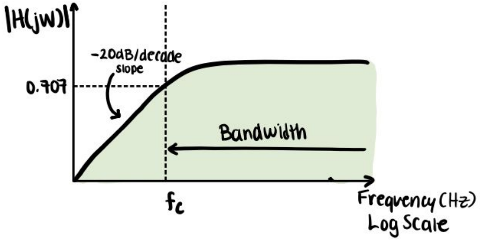
High Pass Filter

Circuit Schematic



Think: the "gate" is higher.

High Pass Frequency Response



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

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

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

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

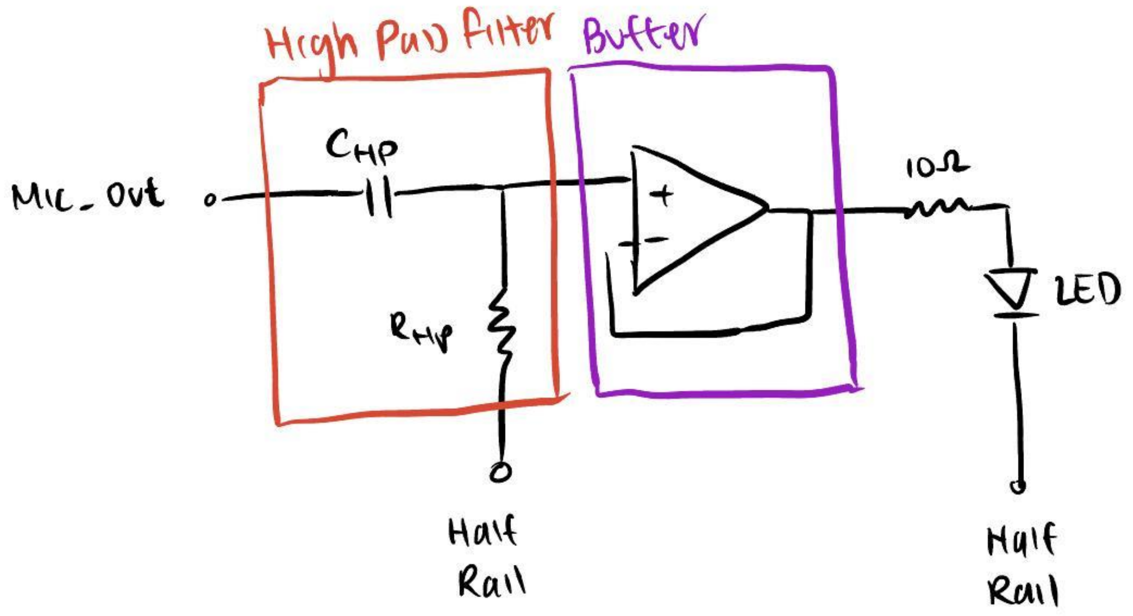
$$\left(\frac{1}{\omega C}\right)^2 = R^2$$

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

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

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

Color Organ High Pass Filter



Notch Filters (make sure to return inductor)

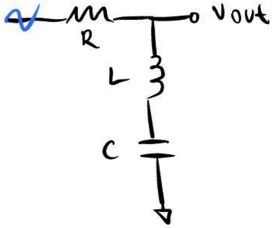
- **Notch Frequency**: The only frequency where the signal gets attenuated **OR** the only frequency where the signal passes through (depends on your filter implementation!)
- **Q factor**: The quality of the filter (is there a steep attenuation slope?), a higher Q factor -> higher quality filter

- **Notch Frequency:** $\omega = \text{sqrt}(1/ (LC))$, $f = \omega/(2\pi)$,
- **Q Factor (only for RLC in series)** = $\omega L/R$ (ω = Notch frequency)

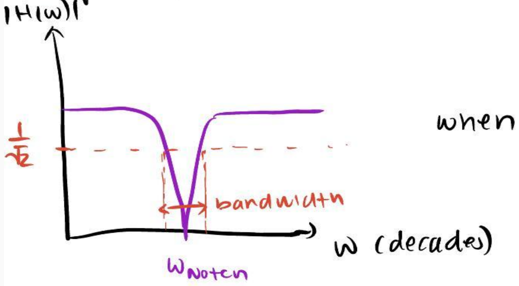
New Component: Inductor

- Inductors MAY be polarized (to be consistent, assume the long leg is (+) and short leg is (-), and breadboard accordingly).
- These inductors are to be LOANED, make sure to return them once you are done with the lab / leave for the day!
- Do not cut their legs or bend them too much!

Notch Frequency Derivation



Freq - Response



Notch Frequency:

$$H(j\omega) = \frac{j\omega L + \frac{1}{j\omega C}}{R + j\omega L + \frac{1}{j\omega C}}$$

$$= \frac{j^2\omega^2 LC + 1}{j\omega RC + j^2\omega^2 LC + 1}$$

$$= \frac{1 - \omega^2 LC}{j\omega RC - \omega^2 LC + 1}$$

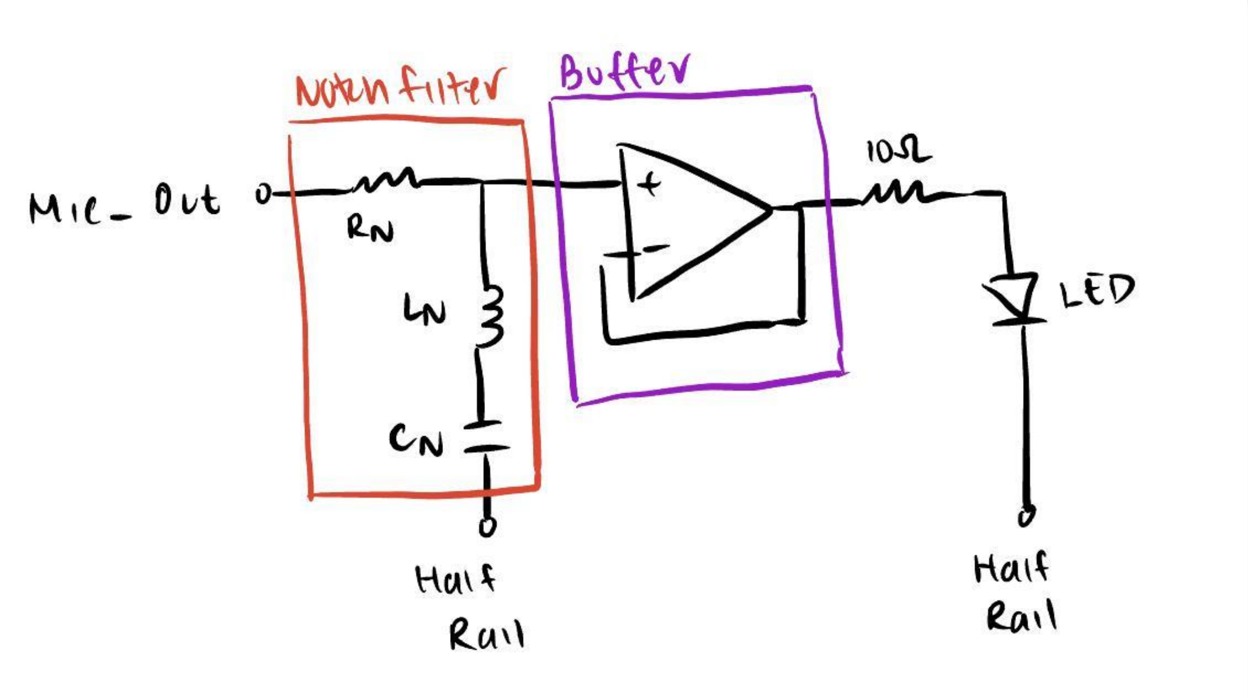
when is $|H(j\omega)| = 0$?

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

$$1 = \omega^2 LC \rightarrow \sqrt{1/LC} = \omega_{notch}$$

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

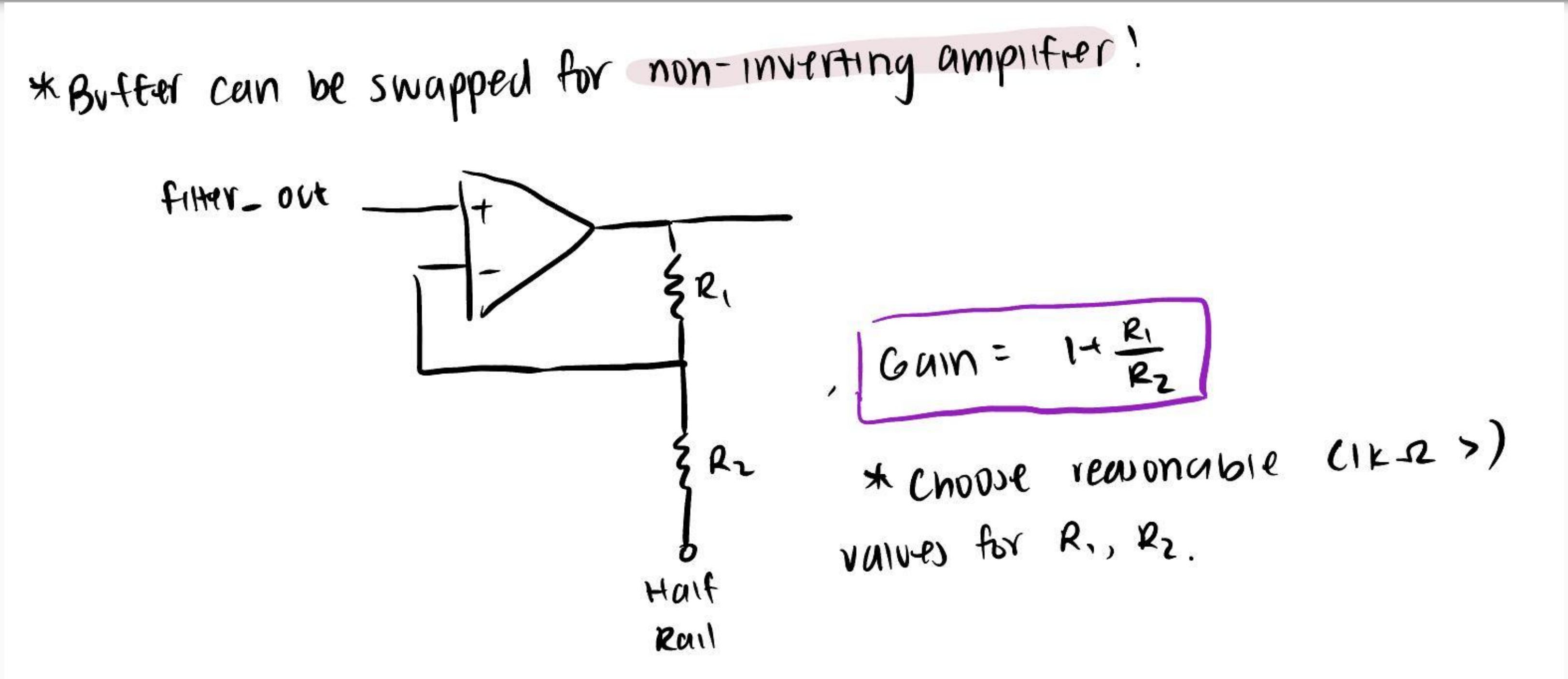
Color Organ Notch Filter



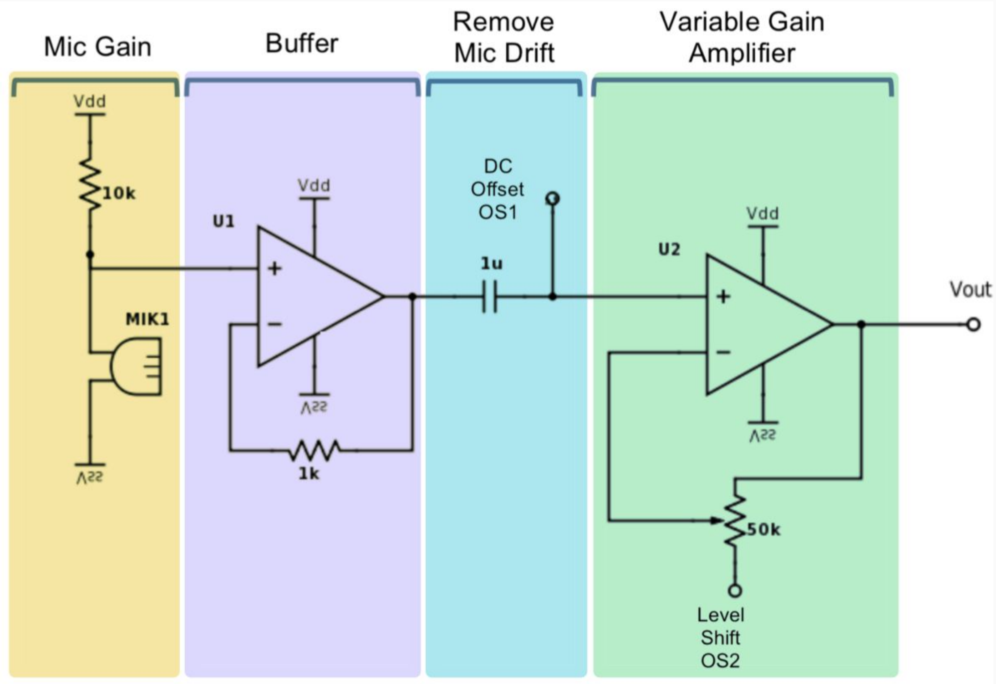
Debugging: Why aren’t my LEDs lighting up?

- 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



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 2.5V offset

Important Forms/Links

- Help request form: https://eecs16b.org/lab-help
- Checkoff request form: https://eecs16b.org/lab-checkoff
- Slides: links.eecs16b.org/lab5-slides
- Anon Feedback: https://eecs16b.org/lab-anon-feedback
- Lab Grades error: https://links.eecs16b.org/lab-checkoff-error