Lab 5: Sensing Part 2

EECS 16B Spring 2024

Slides: links.eecs16b.org/lab5-slides

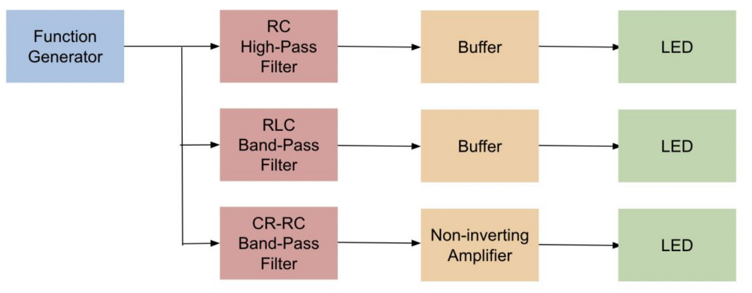
Administrivia

- **Continue working on the Midterm Lab report! It is due 3/6**
- The following two week are a buffer weeks (lab makeups) + time to study for midterm

For all forms, the lab section is meant to be your regular lab section!

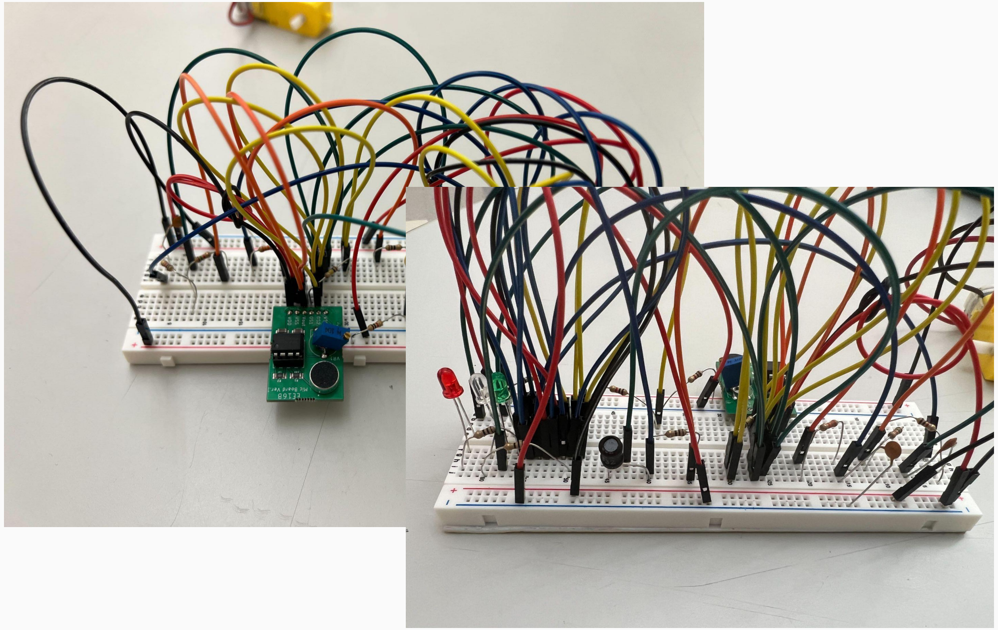
Lab 5 Overview

- Re-tune your mic board
- Implement the following:
  - High Pass Filter (HPF)
  - RLC Band-Pass Filter
  - Cascading Bandpass Filter



- **Today's circuitry is entirely separate from the car!**
  - Use the spare breadboard at each station
  - RETURN THE OP-AMPs, LEDs, and INDUCTORs used for today's lab

Breadboard Reminder



- **Messy Wiring,** and the use of excessive **Jumper Wires** make circuits exponentially more difficult to debug.
- This lab contains a lot of components, and require a lot of space. Plan how you will lay out your circuit wisely!

Filters

First Order Filters

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

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

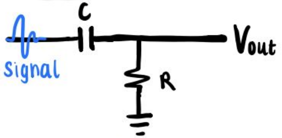
$$\frac{P}{2} = \frac{1}{2} \cdot \frac{V^2}{R} = \frac{1}{R}\left(\frac{V}{\sqrt{2}}\right)^2$$

- 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

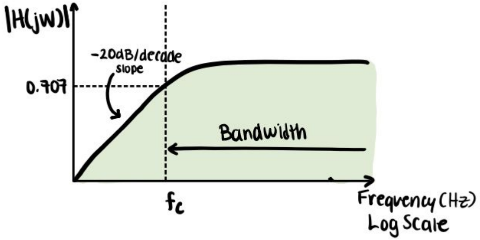
High Pass Filter

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 $\omega \to 0$, $|H(j\omega)| \to 0$

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!

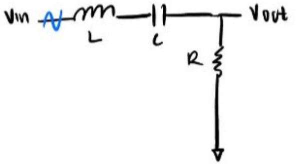
RLC Filters (make sure to return inductor)

- **Resonance 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.

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

Resonance Frequency Derivation

RLC Bandpass



$$H(j\omega) = \frac{V_{out}}{V_{in}} = \frac{Z_R}{Z_R + Z_L + Z_C}$$

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

$$= \frac{1}{1 + j\left(\omega L - \frac{1}{\omega C}\right)}$$

Resonant Frequency ⇒ when $|H(j\omega)| = 1$

⇒ when $\omega L - \frac{1}{\omega C} = 0$

⇒ $\omega^2 L - \frac{1}{C} = 0$

$\omega^2 = \frac{1}{LC}$

$\omega = \sqrt{\frac{1}{LC}}$

⇒ resonant frequency: $\omega_0 = \sqrt{\frac{1}{LC}}$

Series Damping: $\alpha = \frac{R}{2L}$ (see lecture 3B)

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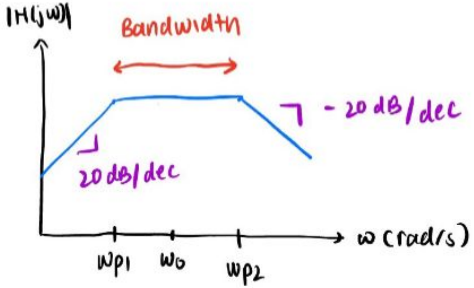
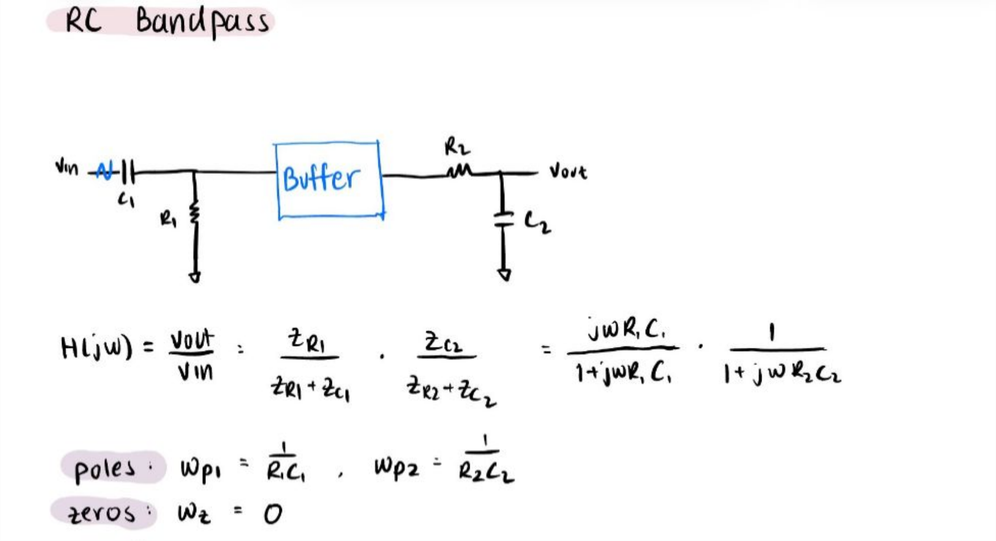
poles: $-\alpha \pm \sqrt{\alpha^2 - \omega_0^2} = -\frac{R}{2L} \pm \sqrt{\left(\frac{R}{2L}\right)^2 - \frac{1}{LC}}$

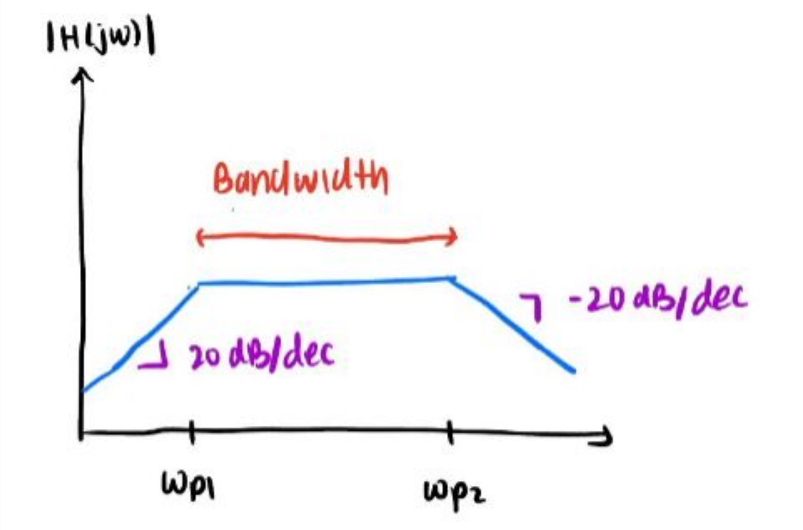
Q factor: $\frac{\omega_0 L}{R}$

Magnitude Response:



RC Band Pass


RC Bandpass
Vin
C1
R1
Buffer
R2
Vout
C2
H(jw) = Vout/Vin = ZR1/(ZR1 + ZC1) · ZC2/(ZR2 + ZC2) = jwR1C1/(1 + jwR1C1) · 1/(1 + jwR2C2)
poles : wp1 = 1/(R1C1) , wp2 = 1/(R2C2)
zeros : wz = 0

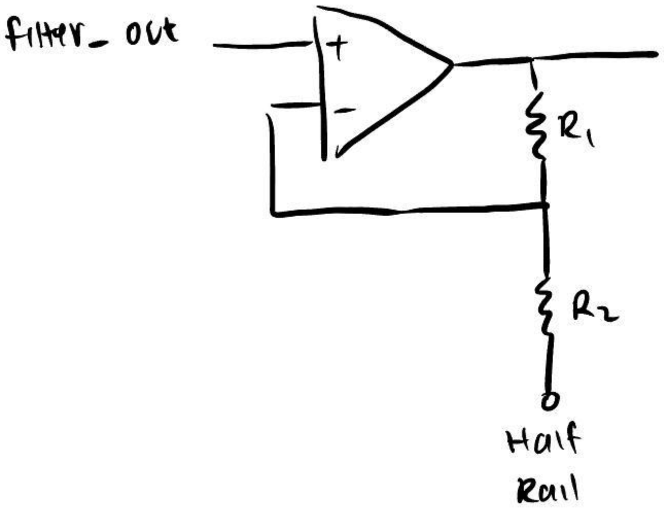

|H(jw)|
Bandwidth
20 dB/dec
-20 dB/dec
wp1
wp2

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).
- Build a non-inverting amplifier
- DON'T USE WHITE LEDs

Review: Non-Inverting Amplifier Schematic

* Buffer can be swapped for non-inverting amplifier!



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

* Choose reasonable (1kΩ >) values for R_1, R_2.

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