EE 230 Lab 7 (Design Lab 2) - Active Crossover Network

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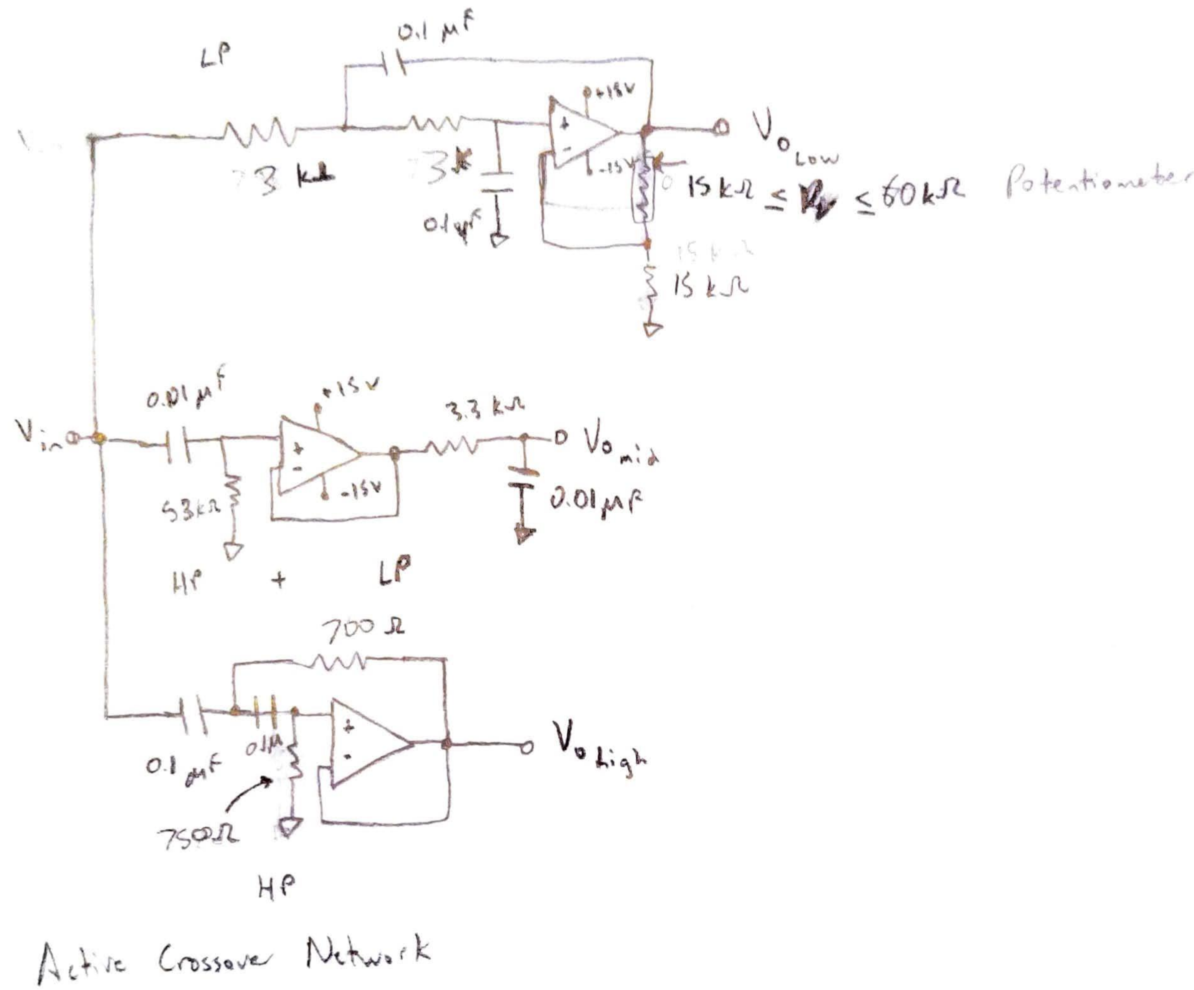
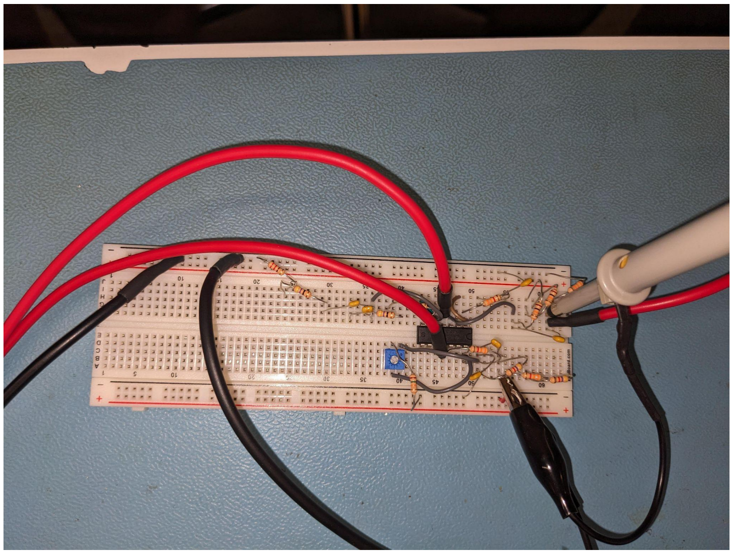
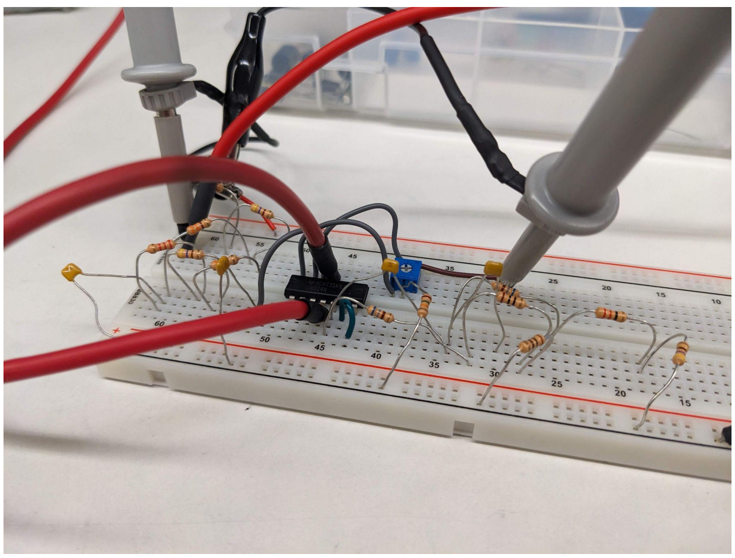
Lab Date: 10/17/2023

Our Circuit Design



Photos

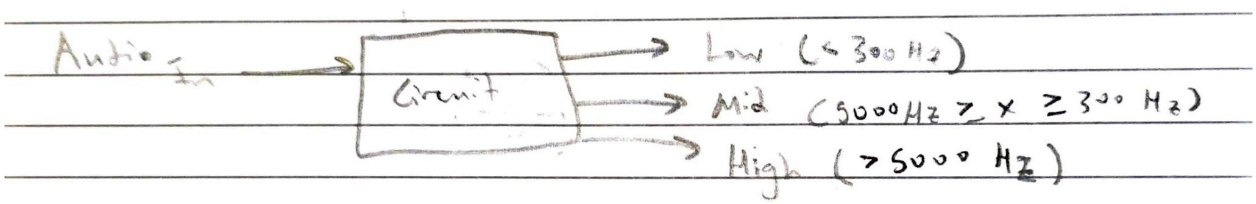




Top picture: Our original circuit with all three components of the network
Bottom picture: Our low pass and high pass filter components with adjusted resistors and corrected circuit paths (see *Description* for performance explanations).

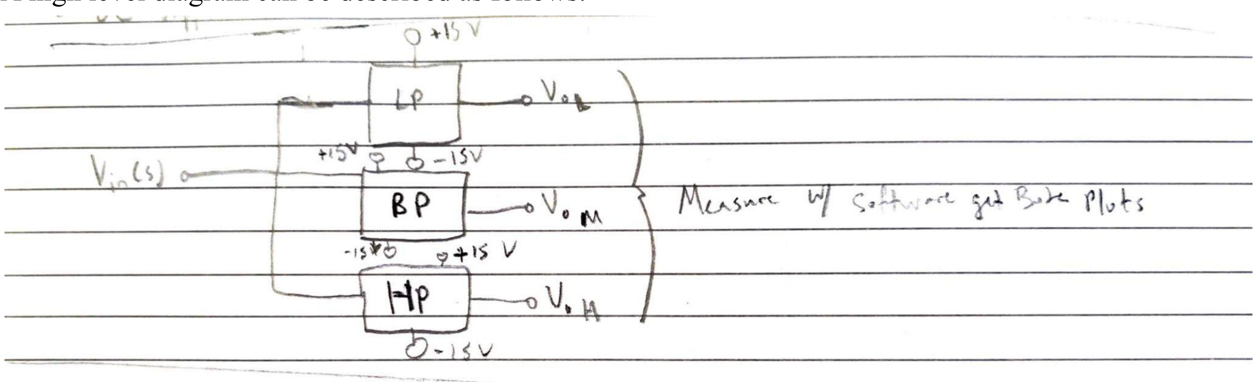
Description

Our active crossover network consists of three outputs described at a high level like a simple three-way speaker system would function. The specifications for each component of the network is referenced from the lab document:



- Low outputs signals with frequencies below 300 Hz, f_c = 200 Hz, roll-off 40 dB/decade and adjustable passband gain 1-5 V/V
- Mid outputs signals with frequencies between f_{cH} = 300 Hz and f_{cL} = 5000 Hz, 20 dB/decade, passband gain 1 V/V
- High outputs signals with frequencies above 5000 HZ, f_c = 6000 Hz, roll-off 40 dB/decade, passband gain 1 V/V
- Input resistance must be > 10 kΩ
- DC supply at +-15 V

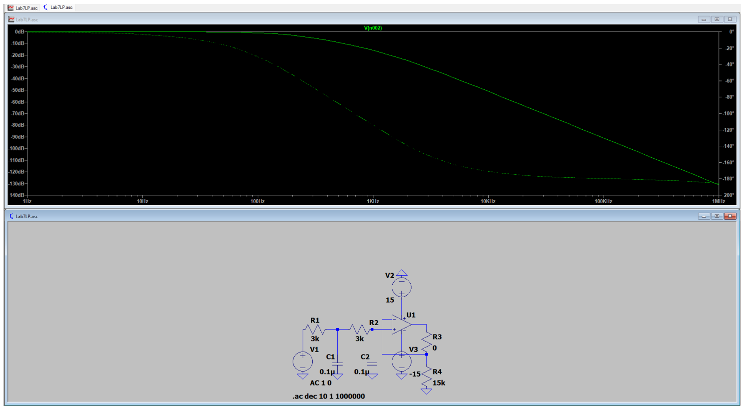
A high level diagram can be described as follows:



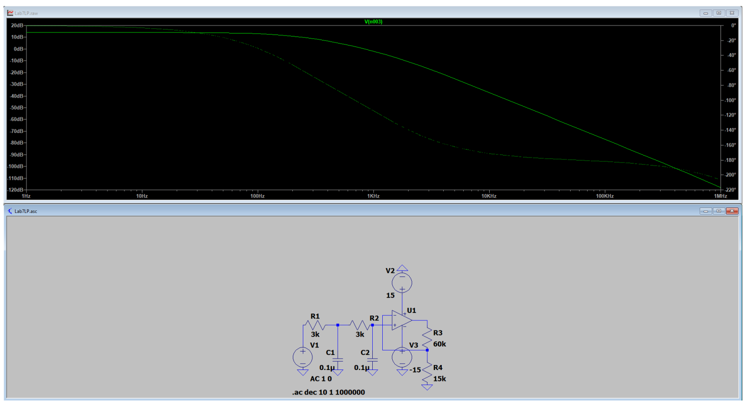
In an AC circuit, filters are used to limit a range of signal frequencies that can be outputted or "passed" through the circuit. In this design problem, a speaker system needs the ability to control which signal frequencies are sent to which device (subwoofer, midrange, tweeter) so they can output the signal's sound correctly.

To meet the lab requirements, our circuit utilizes the concept of active filters to achieve the restrictive output based on frequency and the passband gain requirements. Our design is divided into three critical components, a low pass filter, band pass filter (passive low and high pass cascaded + buffer amp), and high pass filter. Each filter was first designed and simulated in LTspice to ensure the above specifications were achieved with each component and our calculations for each R and C were accurate. We were successful in achieving the desired lab specifications with our above design. Below, each component filter is described with the LTspice simulation, calculations, and resulting frequency response bode plot.

1. **Low-Pass Active Filter (2nd Order)**



At G = 1 V/V



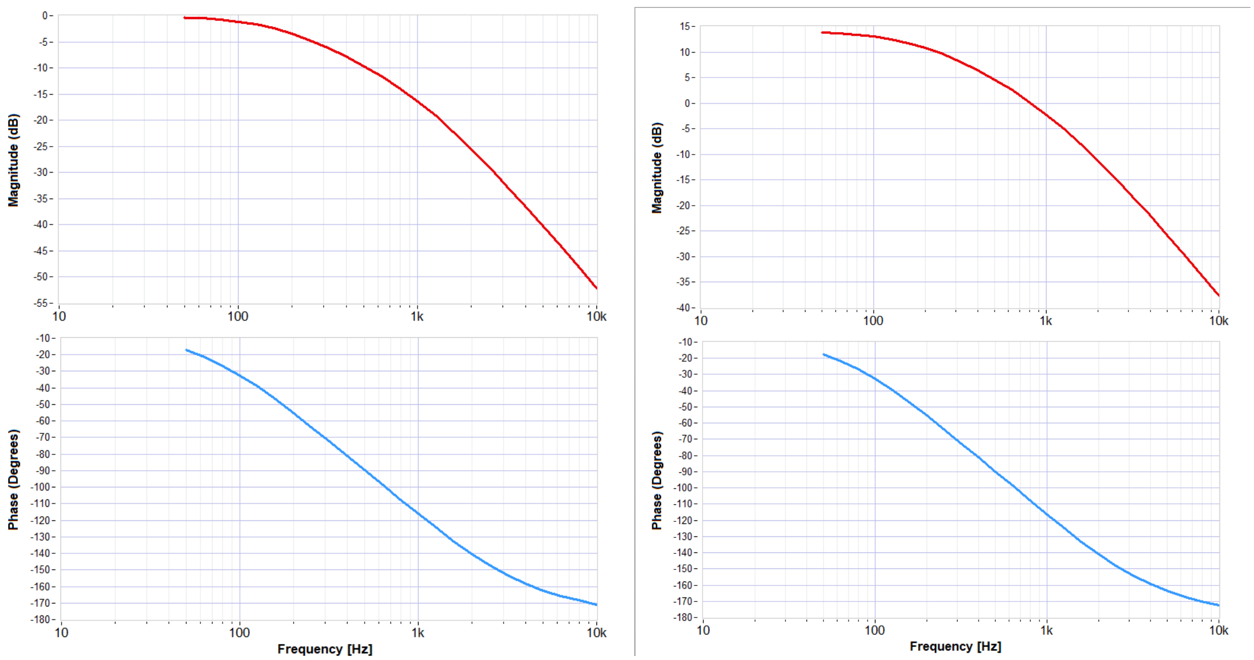
At G = 5 V/V

To achieve a 40 dB/decade response with the above corner frequency of 200 Hz, we utilized a 2nd-order low pass active filter, where an op-amp with a potentiometer is used to adjust the gain resistor ratio in real time, between 1 and 5 V/V.

- R3 is adjusted between 15 kΩ and 60 kΩ with R4 = 15 kΩ to achieve the 1-5 V/V passband gain (potentiometer in circuit photos)
- Two capacitors of 0.1 µF and two resistors of 3 kΩ (or 2.2k + 470 + 330 Ω resistors in series with given lab kit hardware) are used in the 2nd-order filter to achieve the observed frequency response

Low-Pass Frequency Response Plot

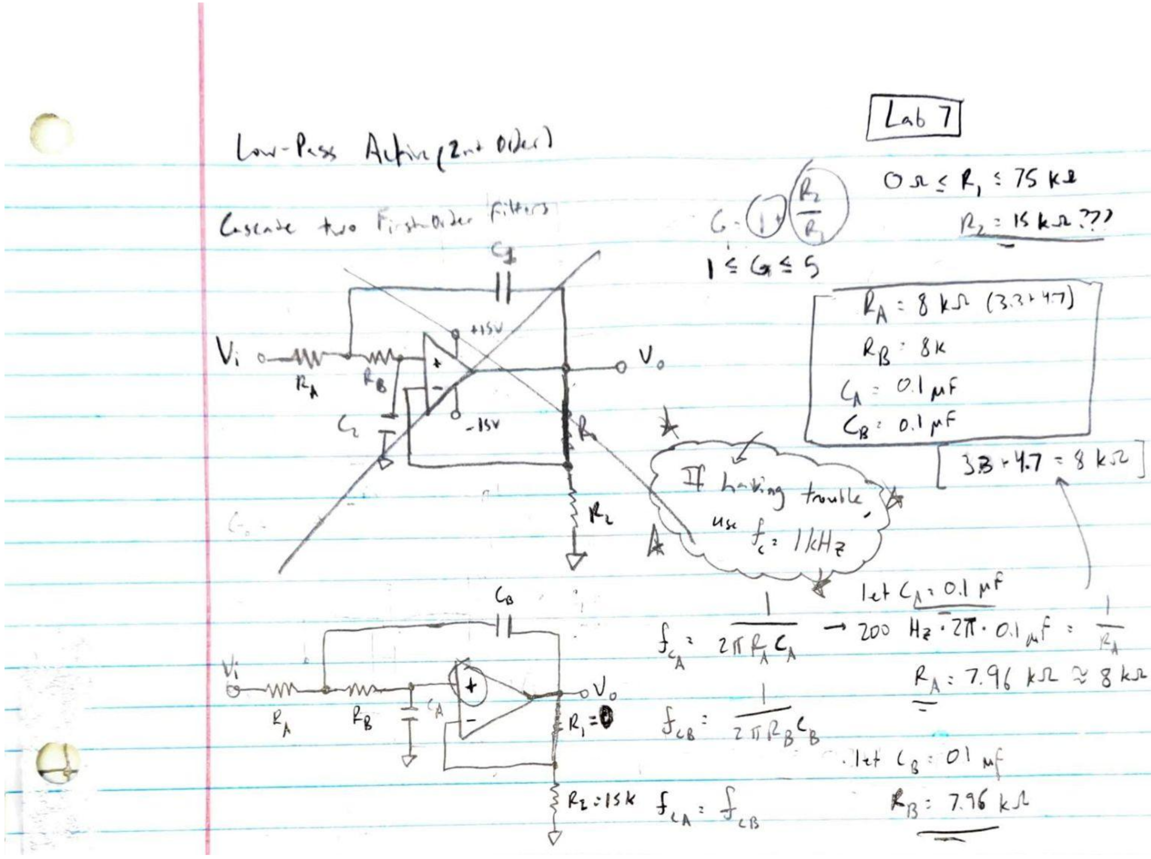
On our circuit, -3dB frequency is seen at the expected 200 Hz, with a 40 dB/decade rolloff. We performed a test at 0 dB or 1 V/V passband gain (left) and 15 dB or ~5 V/V (right) showing this 1-5 V/V range performs correctly on the low-frequency component of the network.



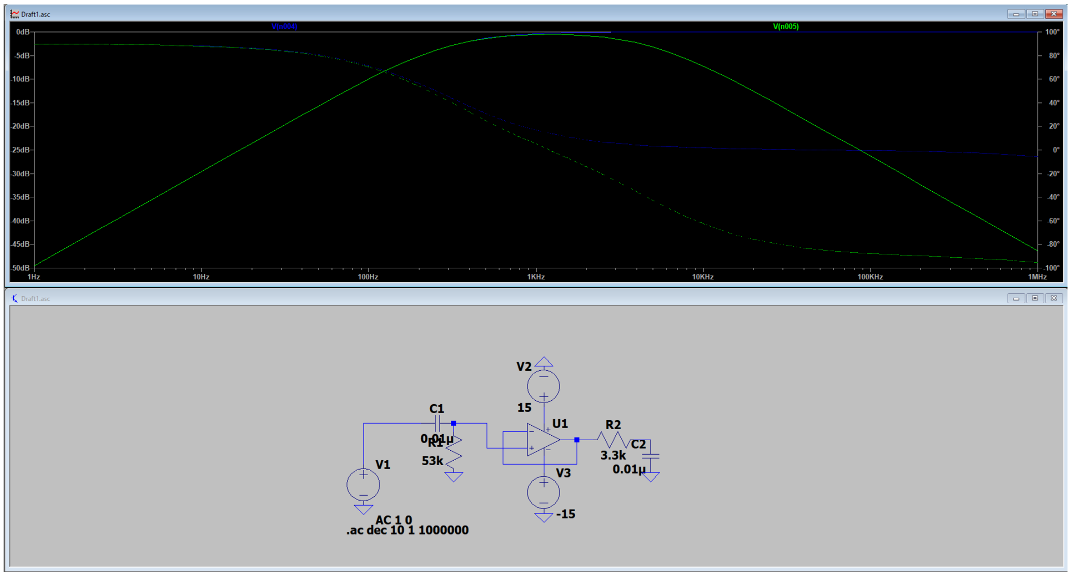
Performance: While our calculations proved to be correct and our circuit design was confirmed with an online reference, the simulator originally indicated a corner frequency of 90 Hz, nearly ⅓ our expected frequency. After simulating trials with different resistors, we concluded R1 = R2 = 3 kΩ resulted in the correct corner frequency = 200 Hz rather than our calculated R1 = R2 = 7.96 kΩ. We are unsure why the measurements do not reflect the calculations. Possible reasons include the use of non-ideal components or the relationships between the components in this particular configuration. The capacitor impedance should not significantly affect the performance of this filter as both capacitors have relatively small capacitance.

Calculations:

Due to our limited availability of capacitors, C_1 and C_2 were both picked to be 0.1 μF.



2. Band-Pass Active Filter (1st Order)

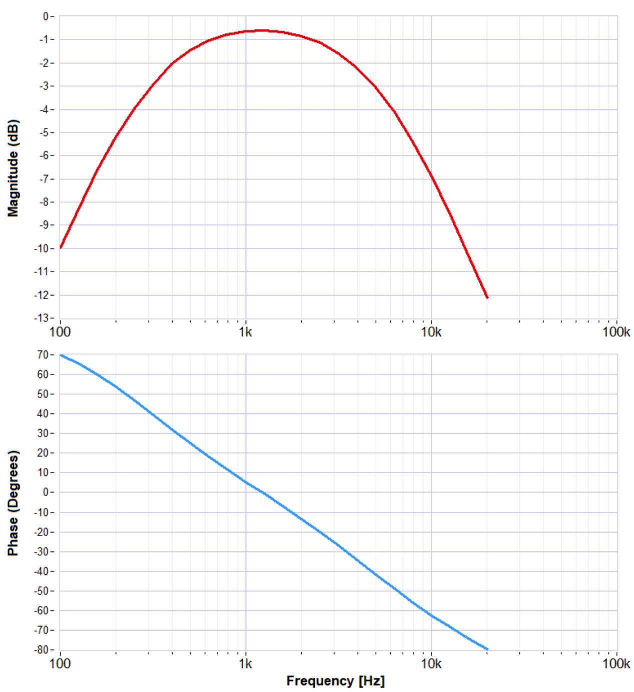


To achieve a 20 dB/decade response with the above corner frequencies of 300 Hz and 5000 Hz, we utilized a 1st-order band pass active filter, where an op-amp is used as a buffer between a low pass and high pass filter in cascade to maintain a passband gain of 1 V/V.

- C1 = C2 = 0.01 µF
- R1 = 53 kΩ (33k + 10k + 10kΩ resistors in series due to available lab kit hardware)
- R2 = 3.3 kΩ

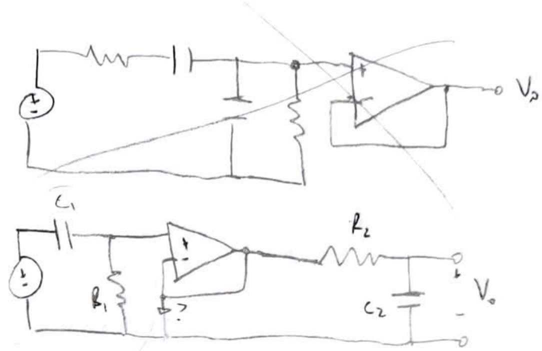
Band-Pass Frequency Response Plot

On our circuit, -3dB frequencies are seen at the expected 300 Hz and 5000 Hz, with a 20dB/decade rise and drop.



Performance: This filter behaved as expected with our calculated R and C. No additional simulation or analysis was needed to determine the expected output.

Calculations
Due to our limited availability of capacitors, C_1 and C_2 were both picked to be 0.01 μF.



$R_1 = 53\ k\Omega\ (33 + 10 + 10)$
$R_2 = 3.3\ k\Omega\ (3.18\ k\Omega)$
$C_1 = C_2 = 0.01\ \mu F$

$f_{c_H} = \frac{1}{2\pi R C_1}$ $f_{c_L} = \frac{1}{2\pi R_2 C_2}$

$C_1 = 0.01\ \mu F$, $C_2 = 0.01\ \mu$

$f_{c_H} = 300\ Hz$

$300\ Hz = \frac{1}{2\pi \cdot 0.01 \cdot R}$

$\frac{1}{R} = 1.8849E\text{-}5$

$R_1 = 53{,}051\ \Omega$

$53\ k\Omega \rightarrow [\underline{33 + 10 + 10}]$

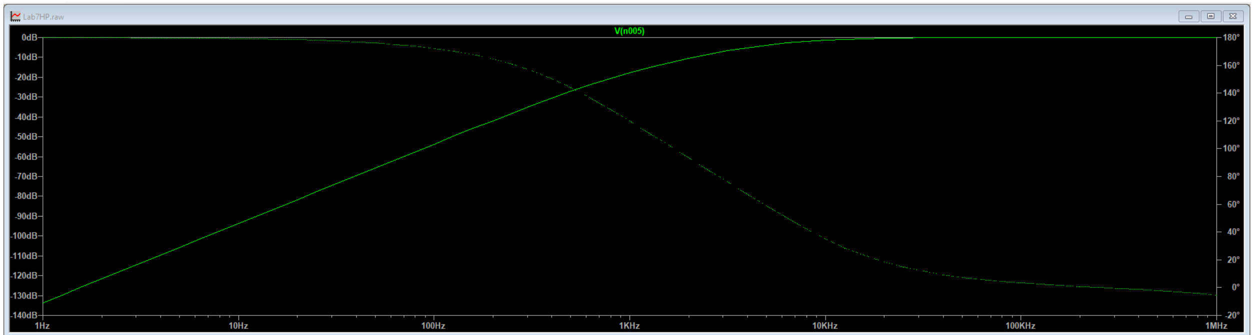
$5000 = \frac{1}{2\pi \cdot 0.01\mu \cdot R_2}$

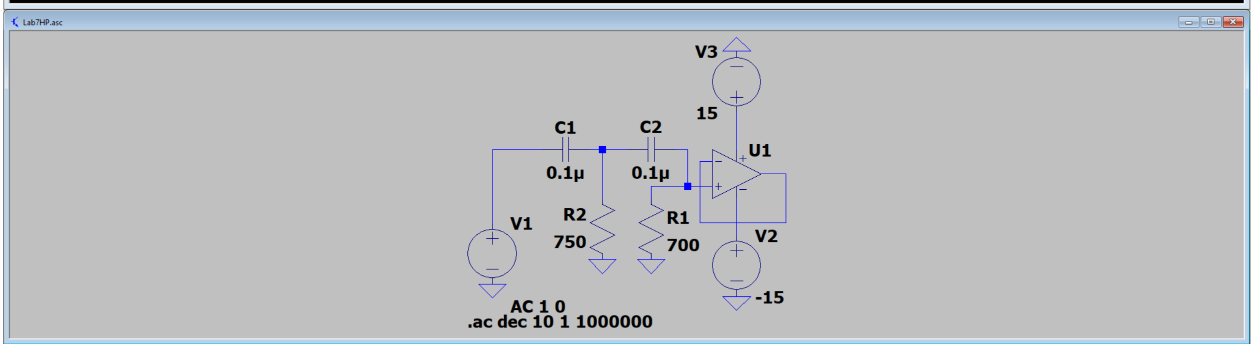
$R_2 = 3183.1\ \Omega$

$3.18\ k\Omega$

$\approx 3.3\ k\Omega$

3. High-Pass Active Filter (2nd Order)



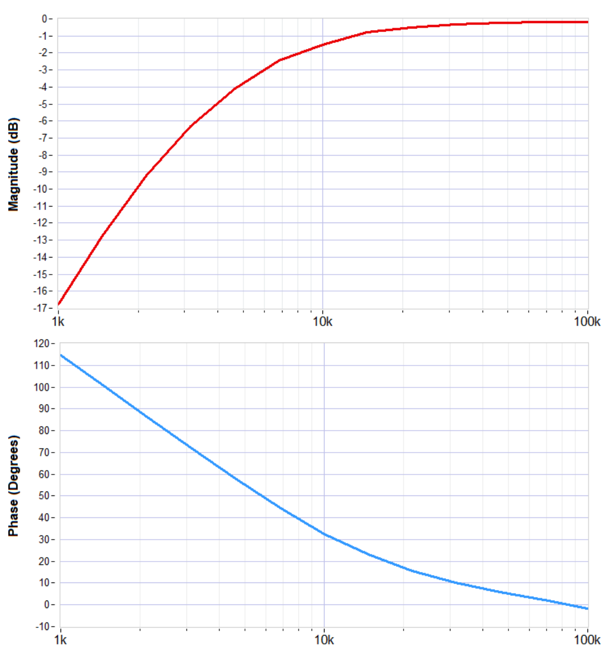


To achieve a 40 dB/decade response with the above corner frequency of 6000 Hz, we utilized a 2nd-order high pass active filter, where an op-amp is used to keep the passband gain at 1 V/V.

- C1 = C2 = 0.1 μF
- R1 = 700 Ω (680 + 10 + 10 Ω in series)
- R2 = 750 Ω (680 + 22 + 47 Ω in series)

High-Pass Frequency Response Plot

On our circuit, -3dB frequency is seen at the expected 6000 Hz, with a 40 dB/decade rolloff.



Performance: While our calculations proved to be correct and our circuit design was confirmed with an online reference, the simulator originally indicated a corner frequency of 10 kHz, nearly double our expected frequency. After simulating trials with different resistors, we concluded R1 = 700 Ω and R2 = 750 Ω resulted in the correct corner frequency = 6 kHz rather than our calculated R1 = R2 = 267 Ω. We are unsure why the measurements do not reflect the calculations. Possible reasons include the use of non-ideal components or the relationships between the components in this particular configuration. The capacitor impedance should not significantly affect the performance of this filter as both capacitors have relatively small capacitance.

Calculations:
Due to our limited availability of capacitors, C_1 and C_2 were both picked to be 0.1 μF.

$$f_c \; 6000 \text{ Hz} = \frac{1}{2\pi\sqrt{C_1C_2R_1R_2}}$$

$$C_1C_2 \downarrow 0.1 \cdot 0.1$$

$$37699.1^2 = \frac{1^2}{\left(\sqrt{0.1^2 \cdot R_1R_2}\right)^2}$$

$$1.421 \times 10^{-5} = \frac{1}{R_1R_2}$$

$$\sqrt{70361.9} = \sqrt{R_1R_2}$$

$$R_1 = R_2 = 265.3\ \Omega \quad (220 + 47)\ \Omega$$

$$37699.11^2 = \frac{1^2}{\left(\sqrt{C_1C_2R_1R_2}\right)^2}$$

$$x = \frac{1}{C_1C_2R_1R_2}$$

$$\cancel{0.1} \cdot 0.1$$

$$1e{-14}$$

$$1.421 \times 10^{-5} = \frac{1}{R_1R_2}$$

$$R_1R_2 = 70361.93$$

Let $R_1 = R_2$

$$\sqrt{R_1^2} = \sqrt{70361.93}$$