ENGR 202 Lab 6: Cross Over Design

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1 Introduction

The purpose of this lab is to use basic filters to design and implement three-way crossover to drive a speaker system. A low-pass, high-pass, and band-pass filter will each be designed with ordinary resistors, capacitors, and inductors, the values of which will be determined using transfer functions and frequency response analysis.

The output signals of the crossover design will be amplified using operational amplifiers in a negative feedback loop configuration to produce a substantial gain which will not source a harmful amount of current from a device such as a laptop or smartphone. The amplified signals will be connected to their respective speakers. The initial design will be put together on a breadboard, and the final design will be soldered to a prototyping board.

Crossovers are used to pass frequencies to each respective speaker is best suited for. In any speaker system, it is important to filter out the frequencies which a given speaker is not designed to produce. Otherwise, the speakers will reduce the quality of the sound. There is also the risk of damaging a given speaker by outputting frequencies beyond its limits.

2 Design

Three circuit design templates were created for each filter type using resistors, capacitors, and inductors. By selecting the desired corner frequency and finding the transfer function for each filter, the relationship between the impedance elements can be found. Due to the limited vareity of capacitor and inductors, the values will be chosen based on the available components and a resistance high enough to avoid overloading the audio jack. These resistance values will be approximated by linking multiple select resistors in series.

2.1 Low Pass Filter

$$H(\omega) = \frac{\bar{V_o}(\omega)}{\bar{V_i}(\omega)} = \frac{\frac{1}{j\omega C}}{\frac{1}{j\omega C} + R} = \frac{1}{1 + j\omega RC}$$

$$H(\omega) = \frac{1}{1 + j\frac{\omega}{\omega_c}} \qquad \omega_c = \frac{1}{RC}$$

The sub box can produce frequencies lower than $200\,\mathrm{Hz}$, which will be the corner frequency of the low pass filter. Using a $0.1\,\mu\mathrm{F}$ capacitor requires a resistance of $7960\,\Omega$.

$$(2\pi * 200) = \frac{1}{R(0.1\mu)} \qquad R = 7960$$

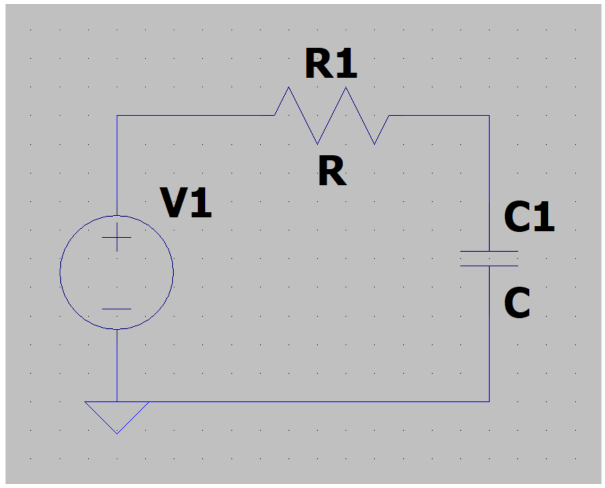

Figure 1: Low Pass Filter Template

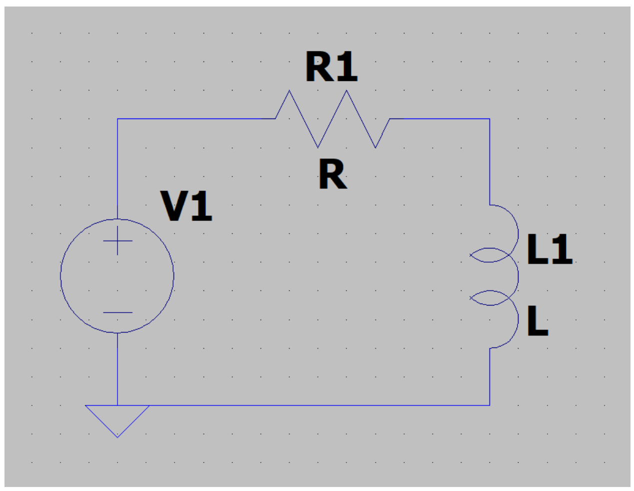

Figure 2: High Pass Filter Template

2.2 High Pass Filter

$$H(\omega) = \frac{\bar{V_o}(\omega)}{\bar{V_i}(\omega)} = \frac{j\omega L}{R + j\omega L} = \frac{j\omega \frac{L}{R}}{1 + j\omega \frac{L}{R}}$$

$$H(\omega) = \frac{j\frac{\omega}{\omega_c}}{1 + j\frac{\omega}{\omega_c}}, \qquad \omega_c = \frac{R}{L}$$

The tweeter can produce frequencies greater than $6\,\mathrm{kHz}$, which will be the corner frequency of the high pass filter. Using a $100\,\mathrm{mH}$ inductor requires a resistance of $3770\,\Omega$.

$$(2\pi * 6K) = \frac{R}{100m} \qquad R = 3770$$

2.3 Band Pass Filter

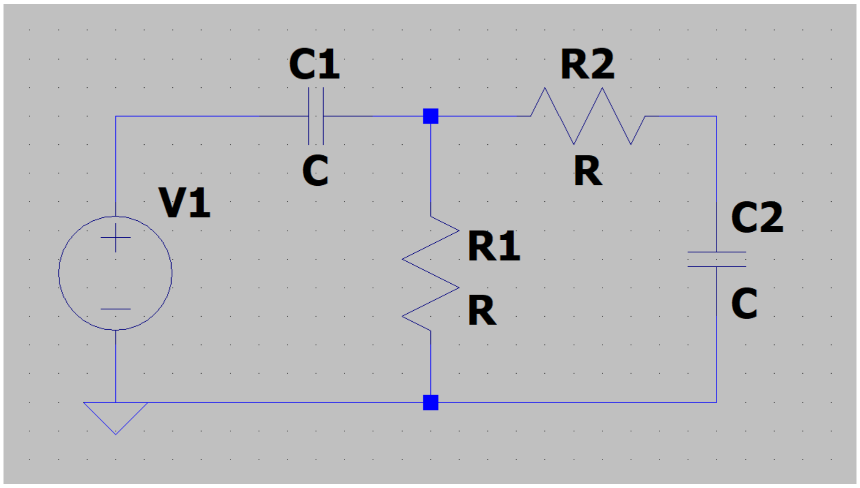

Figure 3: Band Pass Filter Template

$$H(\omega) = \frac{\bar{V}_o(\omega)}{\bar{V}_i(\omega)} = \frac{R_1//(\bar{Z}_{C2} + R_2)}{\bar{Z}_{C1} + (R_1//(\bar{Z}_{C2} + R_2))} \left(\frac{\bar{Z}_{C2}}{\bar{Z}_{C1} + R2} \right)$$

$$\omega_1 = \frac{1}{R_1 C_1}, \qquad \omega_2 = \frac{1}{R_2 C_2}$$

The mid-range speaker must produce the frequencies that the tweeter and sub box are unable to produce. The corner frequencies of the band pass filter will be $200\,\mathrm{Hz}$ and $6\,\mathrm{kHz}$. Using a $0.1\,\mu\mathrm{F}$ capacitor for the high pass section requires a resistance of $7960\,\Omega$. Using a $0.01\,\mu\mathrm{F}$ capacitor for the low pass section requires a resistance of $2650\,\Omega$.

$$(2\pi * 200) = \frac{1}{R_1(0.1\mu)} \qquad R_1 = 7960$$

$$(2\pi * 6K) = \frac{1}{R_2(0.01\mu)} \qquad R_2 = 2650$$

2.4 Amplifiers

The LM386 op-amps will be used to amplify the output signals of each filter in the crossover. The op-amps each be supplied with $12\,\mathrm{V_{pp}}$. Assuming that the crossover output signals will not exceed $0.8\,\mathrm{V_{pp}}$, the amplifiers may provide a gain of 15. The op-amps will configured in a negative feedback loop with an input resistance of $100\,\Omega$ and a feedback resistance of $1.5\,\mathrm{k}\Omega$.

$$G = \frac{-R_f}{R_i} = \frac{-1.5k}{100} = -15$$

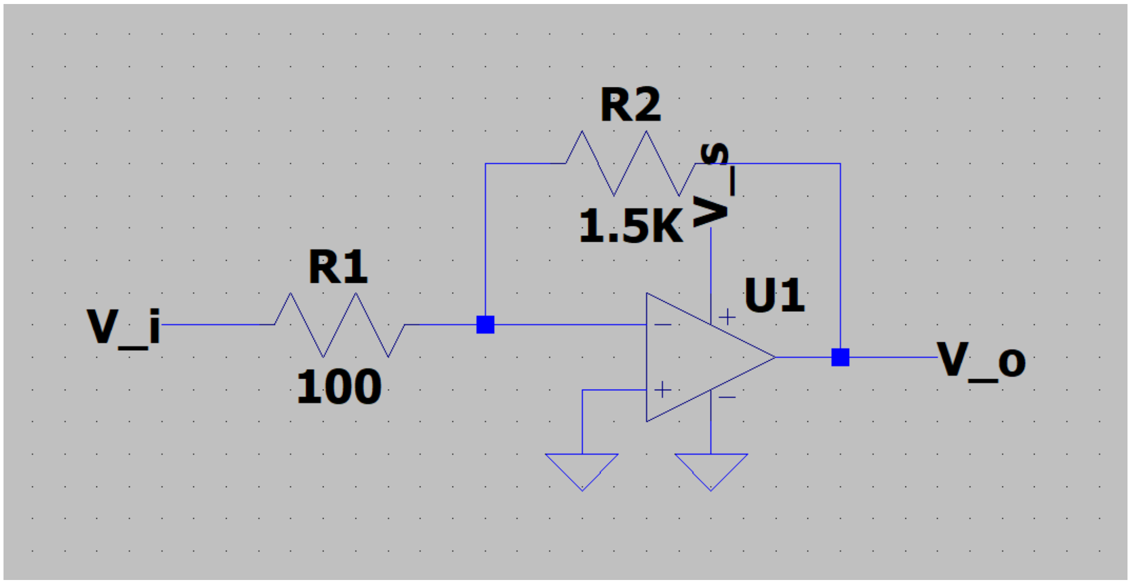

Figure 4: Amplifier Circuit Diagram

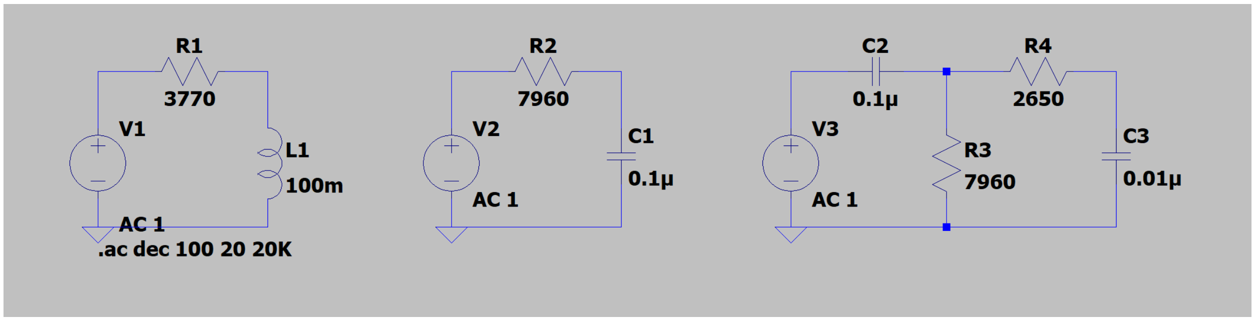

Figure 5: Filter Circuit Diagrams in LTSpice

3 Simulation

Figure 5 shows the LTSpice circuit diagrams for the high pass (left), low pass (center), and band pass (right) filters with the calculated component values.

Figures 6, 7, and 8 show that all three filter designs function as intended. The measurements at the cursors show that the corner frequencies are aligned with the $-3\,\mathrm{dB}$ point.

Figure 9 demonstrates that all three filters together make a crossover which covers all frequencies.

4 Measured Results

A function generator supplying $8\,\mathrm{V_{pp}}$ was used to provide a signal to each filter. An oscilloscope was used to measure the output voltage at each filter over a range of input frequencies from $10\,\mathrm{Hz}$

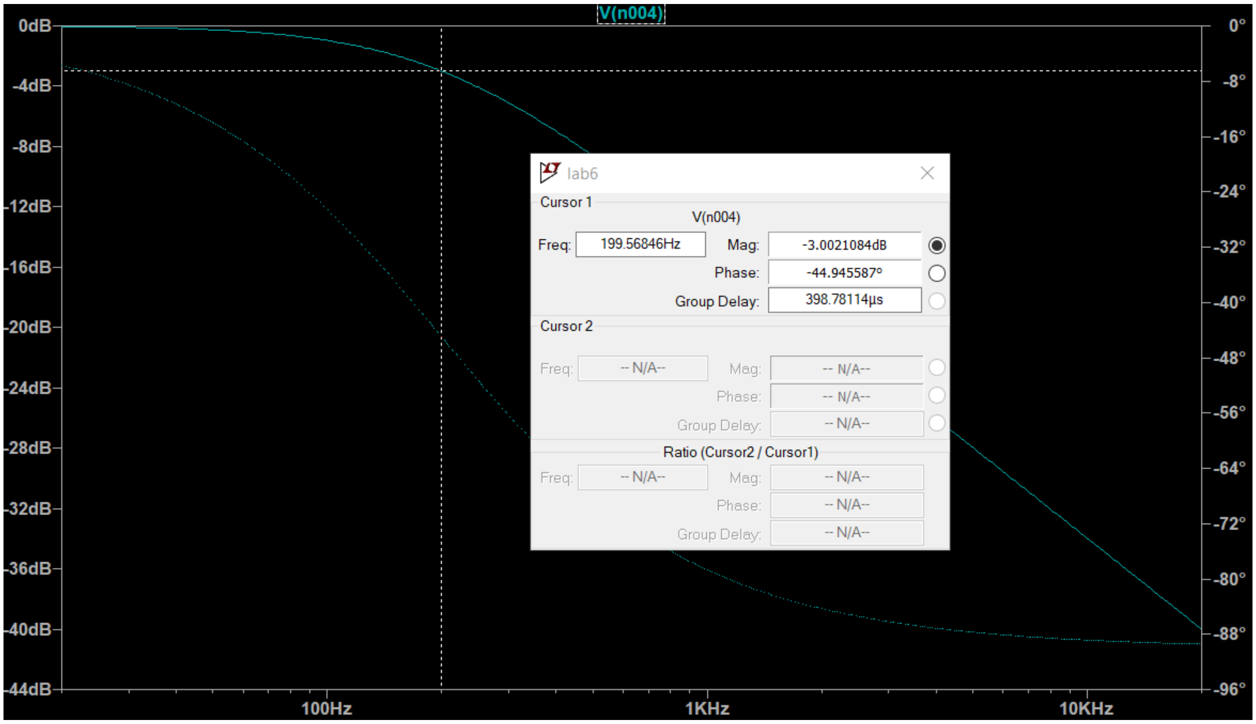

Figure 6: Low Pass Filter Simulation in LTSpice

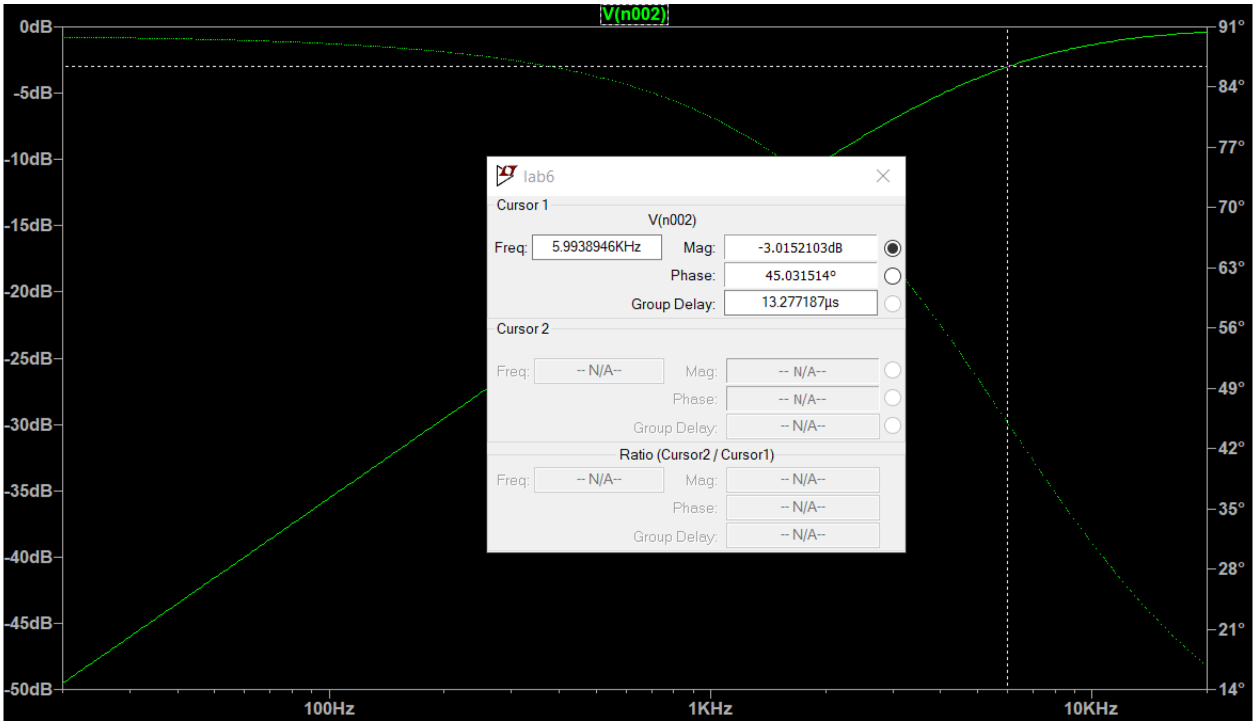

Figure 7: High Pass Filter Simulation in LTSpice

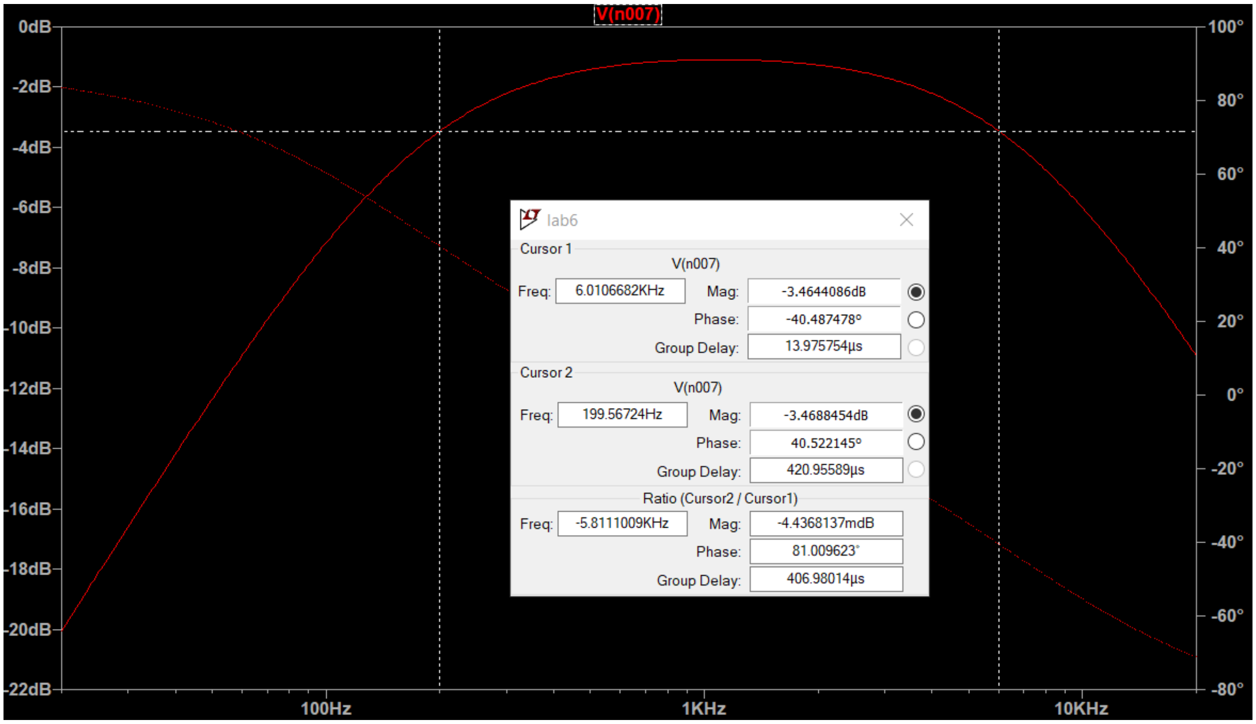

Figure 8: Band Pass Filter Simulation in LTSpice

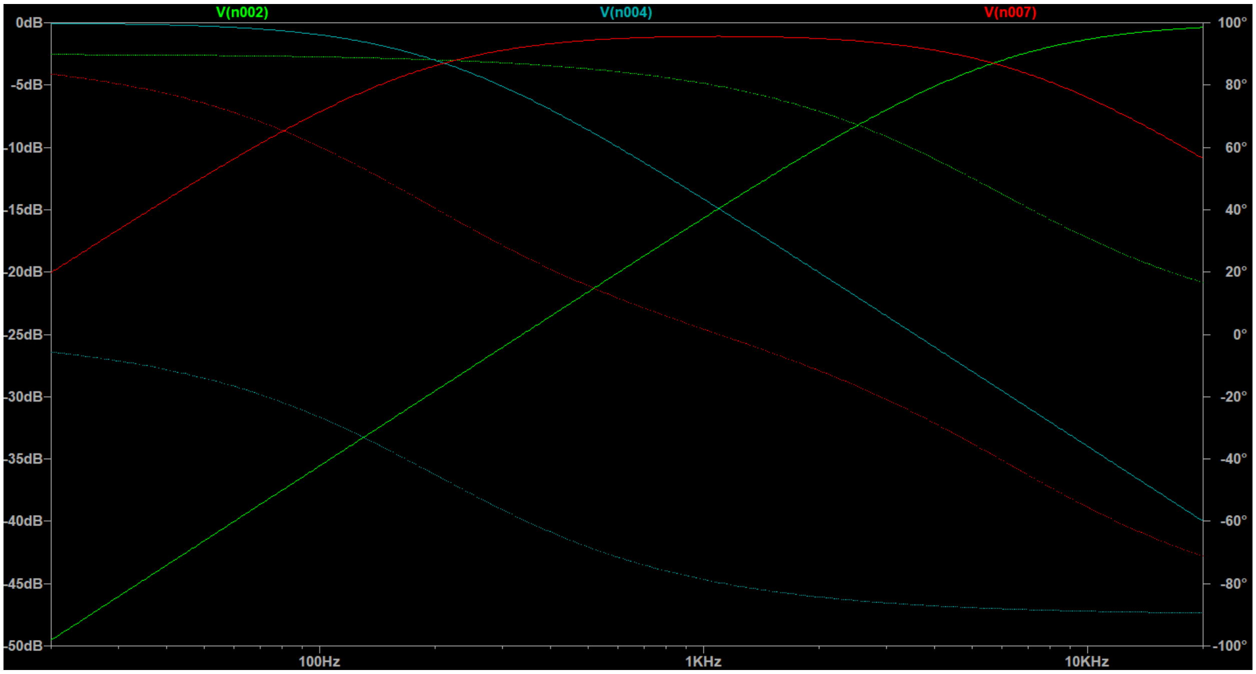

Figure 9: Full Crossover Simulation in LTSpice

to 30 kHz. The measured results recorded in Table 1 show that the physical implementation of the crossover functions as intended. The low pass output is close to the input frequency at frequencies lower than 300 Hz. The high pass output is close to the input frequency at frequencies greater than 10 kHz. The band pass output covers the frequencies in between the low pass and high pass outputs.

Freq (Hz)	Input (V_{pp})	Low (V_{pp})	Mid (V_{pp})	High (V_{pp})
10	8.00	7.76	0.40	0.17
30	8.00	7.76	1.08	0.17
100	8.00	6.96	3.40	0.21
300	8.00	4.56	5.72	0.41
1k	8.00	1.68	6.70	1.24
3k	8.00	0.64	6.40	3.12
10k	8.00	0.20	4.04	6.52
30k	8.00	0.075	1.70	7.48

Table 1: Crossover Measurements

5 Conclusion

In this lab, a three-way crossover speaker system was designed, tested, and implemented. Each filter in the crossover was designed using frequency response analysis (ee Figure 5). The signal was amplified and produced using operational amplifiers and three types of speakers that cover a wide range of frequencies. The filter designs were simulated using LTSpice (see Figures 6, 7, and 8). A physical implementation of the crossover on a breadboard was tested using a function generator and an oscilloscope to measure the output signals (see Table 1).

The process of designing and implementing the crossover was a great first step in AC circuit design and a foundation for future projects related to audio engineering.

6 Implementation

See Figure 10 for the full crossover implementation on a breadboard. See Figure 11 for the soldered implementation of the low pass section.

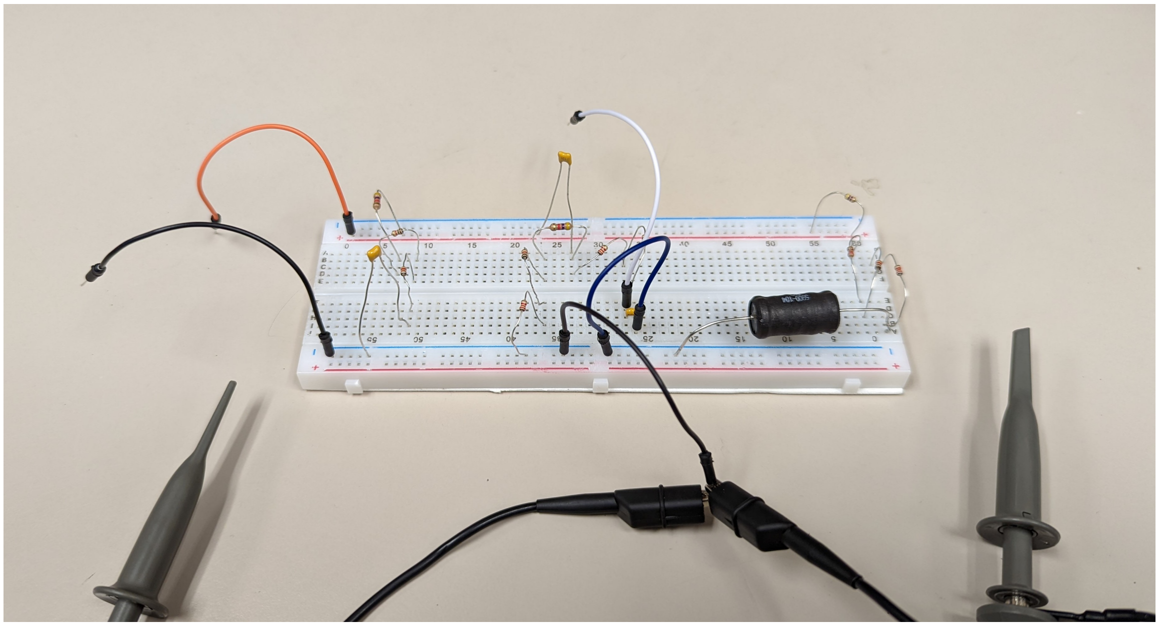

Figure 10: Crossover implementation on breadboard

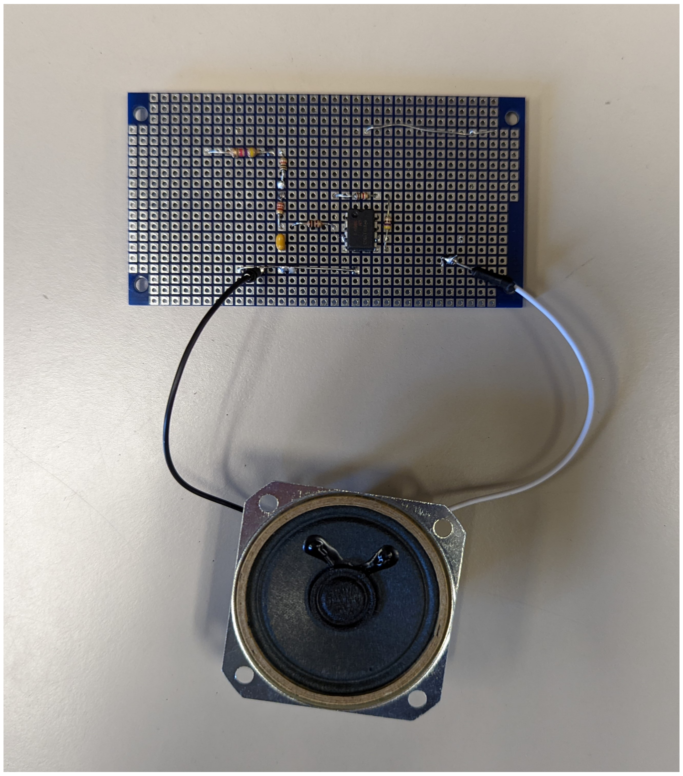

Figure 11: Low pass section soldered onto prototype board