Design and Analysis of an Audio Crossover System for Subwoofer and Tweeter Integration

Danyal Ahmad   Anirudh Khanna   Aadarsh Kumar   Nareshsanjay Muthukumar   Krish Patel

***Abstract*—This paper presents the design, implementation, and analysis of an active audio crossover system engineered to optimize frequency distribution between a subwoofer and a tweeter. The audio signal from an auxiliary (aux) input is first buffered by an LF351 operational amplifier (op-amp) and then amplified through a push-pull transistor stage utilizing complementary NPN and PNP transistors (2N6034 and 2N6037). The amplified signal is then split into parallel LPF and HPF branches, directing bass frequencies to a subwoofer and mid-to-high frequencies to a tweeter. The LPF, with a cutoff frequency of 1592 Hz, routed bass frequencies to a subwoofer, while the HPF, with a cutoff of 340 Hz, directed treble frequencies to a tweeter. Frequency response and phase shift measurements using an oscilloscope confirmed the filters' adherence to theoretical predictions. The push-pull stage ensured sufficient current delivery to both drivers, minimizing distortion. This system demonstrates a cost-effective, educational approach to building passive crossover networks for audio applications.**

***Index Terms*—Audio crossover network, Low-pass filter, High-pass filter, Push-pull amplifier, Cutoff frequency**

I. Introduction

A. Theory

Audio crossover systems split audio signals into different frequency ranges to optimize speaker performance. A low-pass filter (LPF) allows bass frequencies to pass through to a subwoofer, while a high-pass filter (HPF) directs treble frequencies to a tweeter. These filters ensure that each speaker only handles frequencies it can reproduce efficiently, improving sound quality and preventing distortion. For first-order passive RC filters, the cutoff frequency is calculated as:

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

?

The R and C dictate the cutoff frequency of a filter—where the signal starts to ae. Buffering stages, like operational amplifiers, help maintain signal strength, and push-pull amplifiers reduce distortion by using complementary transistors to amplify both halves of the audio waveform.

B. Hypotheses

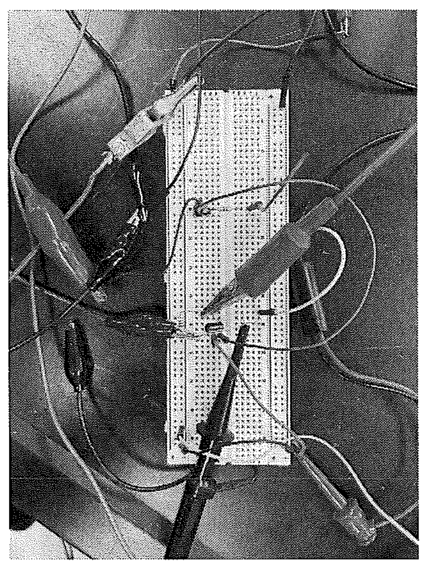
We hypothesized that the low-pass and high-pass filters would follow first-order filter behavior, meaning as the frequency of the LPF input increases, the voltage should go down. In the HPF as you increase frequency, voltage should increase. To test these ideas, we measured voltage outputs across different frequencies and plotted voltage vs. frequency. We also hypothesized that by using a HPF and a LPF in parallel with respect to an input signal, we can build a crossover filter to diver higher frequencies to a "tweeter," and lower frequencies to a "subwoofer."

don't need for design project -

II. Materials and Methods

We used an LF351 operational amplifier to buffer the input signal and prevent loading effects. For amplification, a push-pull stage was built with 2N6034 (NPN) and 2N6037 (PNP) transistors, chosen for their complementary performance. The LPF was constructed using a 1 k ohm resistor and a 10 nF capacitor to achieve a 1592 Hz cutoff, while the HPF used a 470 ohm resistor and 1 μF capacitor for a 340 Hz cutoff. A MacBook laptop provided a voltage and audio signal to the circuit via aux cable, and the measurements were taken with an oscilloscope to track frequency response.

A. Circuit Setup



need schematic

Figure 1: The High and Low pass filter

To carry out this experiment, we constructed a crossover filter to separate audio signals into low and high-frequency components, directing them to a woofer and tweeter. The circuit was designed using a low-pass filter which utilized a 1 kΩ resistor and a 0.1 μF transistor and a high-pass filter that utilized a 470 Ω resistor and a 1 μF transistor. To introduce the audio signal we took a male-to-male AUX cable and cut it in half to expose the wire. We then uused strippers to remove the rubber casing of the wire to expose the sleeve and tip. The AUX cable was then connected to a Mac as the signal source. X

Clip leads were attached to the exposed ends of the cable to connect them to our circuit.

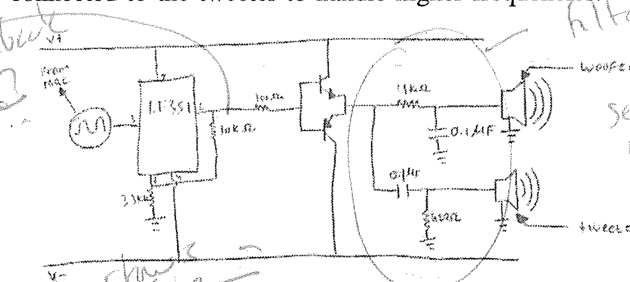
The signal was first fed into the input of an operational amplifier (op-amp), specifically the LF 351, which was powered by a dual power supply providing ±17 V. The op-amp was used to amplify the input signal, ensuring it had sufficient strength and stability before being further processed. The output of the op-amp was then directed to a push-pull circuit which utilized complementary Darlington transistors, the 2N6034 and 2N6037. The push-pull functioned as a power amplifier increasing the current capability of the signal while minimizing distortion, thereby enabling it to drive the speakers effectively.

A voltage divider was used to split the amplified signal, ensuring that both low-pass and high-pass filters received appropriate input. The cutoff frequency for the low-pass filter(LPF) was determined to be approximately 1592 Hz, while the high-pass filter(HPF) had a cutoff frequency of 340 Hz. The output of the LPF was connected to the woofer, allowing for the lower frequencies to be reproduced while the HPF was connected to the tweeter to handle higher frequencies.

why feedback here?

filters @ output

seems unstable?



This only shows amplifier stage

Figure 2: Schematic of the setup.

III. Results

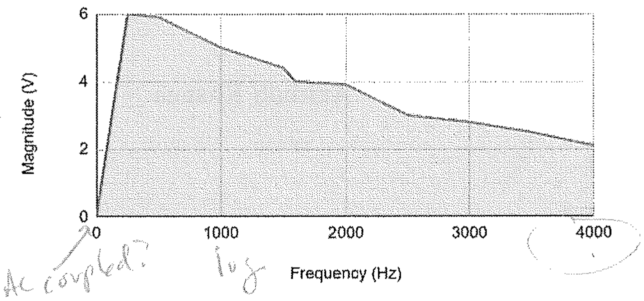
input V?

LPF		HPF	
Frequency (Hz)	Magnitude (V)	Frequency (Hz)	Magnitude (V)
0	0	0	0
250	6	250	0.5
500	5.9	340	0.8
1000	5	500	1
1500	4.4	1000	1.5
1592	4	1500	2
2000	3.9	2000	2.6
2500	3	2500	3
3000	2.8	3000	3.5
3500	2.5	3500	3.8
4000	2.1	4000	4

Figure 3: Table of the voltage with varying frequency for HPF and LPF

The measured frequency response of the low-pass filter (LPF) and high-pass filter (HPF) closely matched their theoretical predictions. Figure 4 shows the LPF's magnitude vs. frequency curve, where the output voltage remained high and relatively constant below the cutoff frequency of 1592 Hz. Beyond this point, the signal attenuated at a slope of approximately −19 dB/decade, aligning with the expected −20 dB/decade. Similarly, the HPF (Figure 5) sloped off above its 3400 Hz cutoff, with a decreasing slope of −21 dB/decade at lower frequencies.

log



AC coupled?

log

Figure 4 - Low Pass Filter Magnitude(V) vs Frequency(Hz)

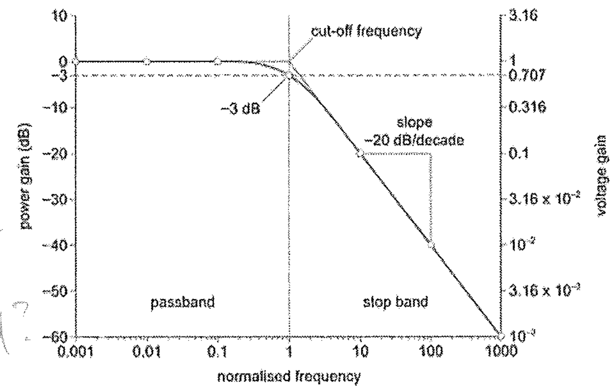
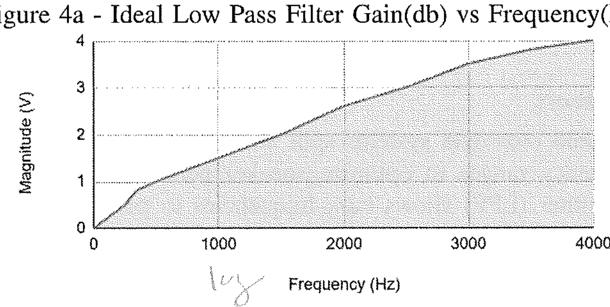


Figure 4a - Ideal Low Pass Filter Gain(db) vs Frequency(Hz)



log

Figure 5 - High Pass Filter Magnitude(V) vs Frequency(Hz)

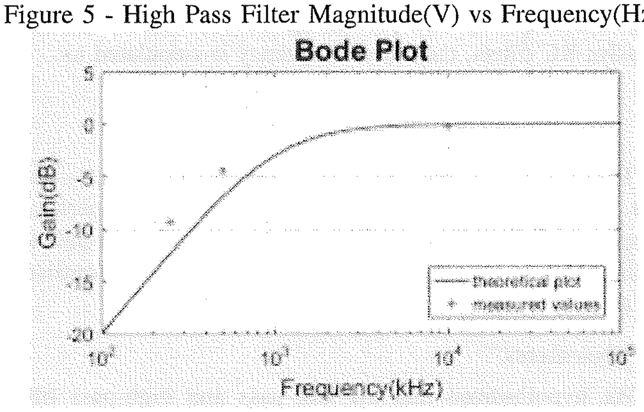


Figure 5a - Ideal High Pass Filter Gain(db) vs Frequency(Hz)

IV. Discussion

The experimental results closely matched theoretical expectations, underscoring the validity of first-order RC filter equations and push-pull amplifier design principles. For the LPF, we expected that as frequency increases, the voltage of the signal would decrease. For the HPF, we expected that as frequency increases, the voltage of the signal would increase. This is exactly what we saw, and is shown accurately with our measured data and graphs.

However, we did not see a noticeable roll-off slope at the cutoff frequencies 1592 Hz (LPF) and 340 Hz (HPF), as visible on the two "expected" graphs above. This may be due to practical limitations or because of a small range of measured frequencies.

When an audio signal was fed into the system, high and low frequencies were accurately diverted into a tweeter and a subwoofer, respectively. The speakers played back these frequencies as expected, indicating that the crossover filter design had worked as intended.

Nice! actual hardware test!

V. Conclusion

This study successfully demonstrated the design and implementation of an audio crossover system with high-pass and low-pass capabilities. The system's performance was consistent with theoretical models for high pass, low pass, and crossover filters. Our operational amplifier successfully generated a stronger signal and our push-pull amplifier generated stronger current, allowing our final speaker output to be louder and clearer, respectively without causing strain on the speaker components. Although the passive filter is cost-effective and simple, future iterations could include active cutoff frequencies in order to make the system more versatile. However, this project stands as a foundational look into complex audio systems and serves to demonstrate practical applications of RC circuits and amplifiers.

Contributions

The contributions of each author to this work are as follows: Aadarsh was responsible for drafting the abstract and contributing to the introduction. Anirudh conducted data collection, contributed to the experimental design, and assisted in drafting the abstract. Naresh contributed to the introduction, methods, discussion, and conclusion sections. Krish analyzed and graphed the data, drafted the results section, and contributed to the discussion. Danyal contributed to the methods and conclusion sections and assisted with data collection. All authors reviewed and approved the final paper.

References

[1] A. Sedra and K. Smith, *Microelectronic Circuits*, 7th ed. Oxford University Press, 2015.
[2] D. Self, *Small Signal Audio Design*, 2nd ed. Focal Press, 2015.
[3] P. Horowitz and W. Hill, *The Art of Electronics*, 3rd ed. Cambridge University Press, 2015.
[4] A. Zumbahlen, *Linear Circuit Design Handbook*, Newnes, 2008.
[5] Texas Instruments, *LF351 Wide Bandwidth JFET-Input Operational Amplifier Datasheet*, 2021.
[6] B. Duncan, *High Performance Audio Power Amplifiers*, Elsevier, 1996.