SUBWOOFERS: LOW-PASS FILTERS

Introduction

One thing that appears to be important to our generation is music. To obtain the maximum music experience, whether it is in our cars or in a home theater system, is bass or “bumps”. You often see drivers adding big subwoofers to their vehicles to over amplify these low tones. An audio system with good bass can be compared to watching a movie on a 60-inch flat-screen HDTV (high definition television) screen or watching it on your friend’s 20-inch SDTV (standard definition television).

Bass is actually achieved by passing the audio signal through a low-pass filter. A low-pass filter is a filter that passes and amplifies low-frequency signals but cuts out high-frequency or higher sounds such as vocals. This lab will introduce you to the frequency and gain characteristics of a low-pass filter and how to utilize it to filter out high frequency audio signals and amplify the low sounds, bass. You will gain insight on how your home stereo and car audio system function (i.e. what happens when you push volume up or down, hit the bass boost button, etc.)

Items needed for this lab:

- Breadboard
- 1 - TL074CN 8-pin chip
- Resistors, capacitors, and various wires
- 2 - 9-Volt batteries connected to snap connectors
- A pair of powered speakers (with power adapter)
- Digital Multimeter

Procedure

Figure 1 shows the pin layout of the TL074CN chip. We will use this figure to create a simple high-pass filter. We will pass an audio signal (song) through the filter and observe how the signal at the output of the op-amp differs from the one at the input. Also, how changing resistor and capacitor values in the circuit change the filter quality.

Figure 1: TL074CN 8-pin chip
You can find more information about the specification of the TL074CN op-amp circuit at:  

**Note on the speakers:**
Make sure to use powered speakers for this lab, we are using powered speakers so you won’t have to worry about impedance matching, where the input impedance of the audio source matches the output impedance of the speakers. Impedance matching maximizes the power transferred to the load but requires a more complicated circuit. Using powered speakers allows you to focus more on the theory of signals and not the subwoofer design process.

**Step 1: Powering the filter**

1. Place the TL074CN chip on your protoboard. Notice on one side of the chip is a half-circle; this lets you know the location of each pin. Refer to Figure 1 for pin descriptions and locations, notice chip in the picture posses the same half-circle.

2. Using one of the 9V batteries, connect the positive terminal (Vcc+) to Pin 4 of the TL074CN chip and use the negative terminal to create part of the **Ground connection** similar to the one in Figure 2.

3. Using the second 9V battery, connect the negative terminal (Vcc−) to Pin 11 of the chip and use the positive terminal to complete the **Ground connection**. Your circuit should now look similar to Figure 2.

![Figure 2: Battery & Power setup for TL074CN](image-url)
Step 2: Constructing Low-pass filter

1. Leaving the power setup you created in the previous step, using Figures 3 & 4, build the low-pass filter as pictured in Figure 4. Figure 3 is the diagram of the low-pass filter and Figure 4 is its physical representation. As you can see from Figure 1, there are 4 op-amps in the chip, CHOOSE ONE. Referring to Figure 1, looking at the half-circle on the edge of the chip, we will use the first op-amp (op-amp at the top, just left of the half-circle) to create the low-pass filter.

Figure 3: Diagram of low-pass filter

Figure 4: Low-Pass filter on protoboard
2. Look at the speaker wires in Figure 5 and identify the left and right speaker wires as well as the speaker ground. Connect the left and right speakers to the output pin of op-amp 1 (Pin1). This plays the audio signal produced by the filter through the speakers. Also don’t forget to connect the green cable (ground) to the ground connection on your board. Your connection should look similar to Figure 4.

![Figure 5: Speaker wires](image)

3. Look at Figure 6 this is the audio cord that connects to the headphone jack of your MP3 player or computer and the stripped wires that connect to the input of the filter. This is what enables the song from your device to be passed through the filter. Identify the ground connection for the audio source and the audio input for the op-amp. Connect the audio input to the filter, like in Figure 4. Connect the ground wire to the same ground connection that you created in Step 1. Connect the headphone plug to the headphone jack of the mp3 player or computer.

4. Play a song. If you don’t have any music files on your computer or MP3 player, visit an online radio station or Pandora.com.

![Figure 6: Audio cord](image)
NOTE: Your circuit should look very similar to the one constructed in Figure 4. If your circuit does not appear to be working properly try setting up the circuit exactly as pictured in Figure 4.

5. Listen to the song that you have playing. Now replace R2 with a 0→22KΩ potentiometer (resistor that’s able to vary its resistance). Set the potentiometer to the previous value $R_2 = 10KΩ$. Now increase the resistance value of your filter by changing to $R_2 = 20KΩ$ (20,000Ω). What happens to bass/subwoofer quality? Does it appear to increase or decrease?

6. Now vary the potentiometer between 0→9KΩ. Does the bass appear to increase or decrease?

7. Change $R_2$ back to 10KΩ. Now increase the capacitance by changing $C_2 = 150nF$ ($100 \times 10^{-9} F$). What happens to bass/subwoofer quality? Does it appear to increase or decrease?

**Circuit Theory (Low-pass filter):**

The purpose of this section is to give a little intuition about how subwoofer speakers cutout high frequencies in order to just output bass, low frequencies. We know that you may not understand everything or anything in this upcoming section and that is ok. The overall goal of this lab is to show how engineering principles are applied in creating low-pass and high-pass filters which are utilized in making tweeters and subwoofers.

Amplifiers do just that; they amplify the signals that are inputted. The amplified signal is displayed the result at the output of the op-amp (the output pins of the op-amps can be seen in Figure 1). The “gain/amplification” of the low-pass filter is a ratio of the output signal to the input signal. It tells you how much the filter amplifies the signal inputted, in this case, the song from your device. Let's label the audio input signal $[A_{in}]$ and the output signal by $[A_{out}]$. The gain is, $|G| = \frac{A_{out}}{A_{in}} = \frac{1}{\sqrt{1^2 + (\omega \tau)^2}}$; $\omega$ is the frequency of the input signal to the op-amp and $\tau$ is the time constant of the circuit (you will learn more about ($\omega$ and $\tau$) mean shortly).

**Filter cutoff frequency ($\omega_c$):** is the boundary of all filters, not just low-pass, where the input signal (audio signal $[A_{in}]$) is no longer amplified. If the frequencies of the input signal, $\omega$, are larger than the filter cutoff frequency, thus ($\omega > \omega_c$), that input frequency will be cutout. Also, this input frequency does not receive amplification. In music vocals are compositions of high frequencies just as low tones like drums are composed of low frequencies. Listen to the song that has been passed through the low-pass filter you constructed. Notice that the vocals from
the song on your MP3 player or computer appear to be cutout, that’s because these frequencies exceed the filter cutoff frequency. The low tones, bass, amplified and easily heard, this is because the frequency of the low tones are below the filter cutout frequency.

\[ \omega_c = \frac{1}{\tau} \]

**Time constant (\( \tau \))**: tells you how long it takes for the filter to reach the outputed amplified signal.

\[ \tau = R_2C \quad \text{[seconds]} \]

**Questions:**

With \( C = 100\text{nF} = (100 \times 10^{-9}) \), where \( F = \text{farads} \), which is the unit capacitance is measured in

1. What is the cutoff frequency of the your low pass filter _________

2. What is the time constant of your filter________ seconds

3. Compute the gain of your filter at the following frequencies:

   Gain equation: \( |G| = \frac{1}{\sqrt{1^2 + (\tau \omega)^2}} \)

   *substitute \( \omega_1, \omega_2, \omega_3 \) into the gain equation for \( \omega \)*

   a). \( \omega_1 = \omega = 50 \)

   \( |G_1| = \)

   b). \( \omega_2 = 110 \)

   \( |G_2| = \)

   c). \( \omega_3 = 150 \)

   \( |G_3| = \)
4. From your gain calculations above, does it appear that your filter is operating properly, in that the gains $\omega_1 > \omega_2 > \omega_3$. Explain. (HINT: Think of what low-pass filters do to audio pitches that are within and that exceed the cutoff-frequency.)

Conclusion

You have witnessed that Bass is actually achieved by passing the audio signal through a low-pass filter which amplifies low-frequency signals (drums, tubas etc.) but cuts out high-frequency or high pitch sounds such as vocals. This lab introduced you to the frequency and gain characteristics of a low-pass filter and how to utilize it to filter out high frequency audio signals and amplify the low sounds, bass. Hopefully you gained insight on how your home stereo and car audio systems function (i.e. what happens when you push volume up or down, hit the bass boost button, etc.)