Pre-Lab

1. Color Organ Filter Design

In the fourth lab, we will design low-pass, band-pass, and high-pass filters for color organ. There are Red, Green, and Blue LEDs. Each color will correspond to a specified frequency range of the input audio signal. The intensity of the light emitted will correspond to the amplitude of the audio signal.

(a) First, you realized that you can build simple filters using a resistor and a capacitor. Design the first-order passive low and high pass filter with following frequency ranges for each filter using only 1 uF capacitors. ("Passive" means the circuit does not require any power supply)

• Low pass filter – 3-dB frequency at 100 Hz
• High pass filter – 3-dB frequency at 2400 Hz

Please draw the schematic-level representation of your designs, and show your work for the values for resistors. Also, please mark $V_{in}$, $V_{out}$, and ground nodes in your schematic. Round your results to two significant figures.

(b) Based on the previous problem, one may decide to build a band pass filter by simply cascading them. Connect your low pass filter $V_{out}$ to $V_{in}$ of your high pass filter. What is $H_{BPF}$, a transfer function from $V_{in}$ of the low pass filter to $V_{out}$ of the high pass filter? Please use $R_L$, $C_L$, $R_H$, and $C_H$ for low pass filter and high pass filter components, respectively. Show your work.

(c) Plug component values into the transfer function $H_{BPF}$. Using MATLAB or python, draw a bode plot from 0.1 Hz to 1 GHz. What are the frequency of poles and zeros? What is the magnitude of $H_{BPF}$ in dB at pass band? Is that something that you wanted? If not, explain why and suggest a simple way (either adding passive or active components) to fix it.

(d) Now that you know how to make filters and amplifiers, we can finally build a system for color organ circuit below. Before going into actual schematic design, the first thing you have to do is to set specifications for each block. The goal of the circuit is to divide the input signal into three frequency bands and turn the LEDs on based on the input signal’s frequency.

In this problem, assume that the microphone is a 3-pole 2-zero system. Poles are located at 10 Hz, 100 Hz, and 10000 Hz. Zeros are at DC and 200 Hz. This means that frequency response at the microphone output can be modeled as follow.

$$V_{MIC} = K_{MIC} \frac{jw(1+jw/w_{1})}{(1+jw/w_{p1})(1+jw/w_{p2})(1+jw/w_{p3})}$$

where $K_{MIC}$ is a constant gain, $w_{z1}$, $w_{p1}$, $w_{p2}$, and $w_{p3}$ are zero and poles. Note that $jw$ term in the numerator denotes the zero at DC. The magnitude of the voltage at the microphone output is 1 V peak-to-peak at 40 Hz. (Hint: you can use this information to calculate $K_{MIC}$)
Suppose that three filters have transfer functions as below.

- Low pass filter
  \[ H_{LPF} = \frac{2}{1 + jw/200\pi} \]

- Band pass filter
  \[ H_{BPF} = \frac{4.54 \times 10^{-4}jw}{(1 + jw/400\pi)(1 + jw/4000\pi)} \]

- High pass filter
  \[ H_{HPF} = \frac{jw}{1 + jw/8000\pi} \]

What are the frequency responses in voltage peak to peak at the output of each filter? Please write the responses in jw domain. For example, \( \frac{3(1+jw(1.5 \times 10^3))}{1+jw(2 \times 10^4)} \). Assume there are ideal voltage buffers before and after each filter. (Do not forget \( w = 2\pi f \)).

(e) What are the voltage gain of each non-inverting amplifier that makes the output peak to peak voltage measured right before the 10 \( \Omega \) resistor is 5 \( V_{pp} \) at 50 Hz, 1000 Hz, and 8000 Hz for each path?

**Problems**

2. **RLC Circuit**

In this question, we will take a look at an electrical systems described by second order differential equations and analyze it using the phasor domain. Consider the circuit below, where \( R = 8 \text{k}\Omega, L = 1 \text{mH}, C = 200\text{nF}, \) and \( V_s = 2\cos \left( 2000t + \frac{\pi}{4} \right) \).
(a) What are the impedances of the resistor $Z_R$, inductor $Z_L$, and capacitor $Z_C$?
(b) Solve for $V_{\text{out}}$ in phasor form.
(c) What is $V_{\text{out}}$ in the time domain?
(d) Solve for the current $i(t)$.
(e) Solve for the transfer function $H(\omega) = \frac{V_{\text{out}}}{V_s}$

Leave your answer in terms of $R$, $L$, $C$, and $\omega$.

3. Op-Amp Circuits
In this question, we’ll be looking at op-amp circuits using the phasor domain and how different components in the feedback path affect the output. For this question, assume that $V_s$ is a sinusoidal input.

(a) Find the transfer function for this circuit.

(b) What type of filter is the circuit shown in Figure 1?
(c) Sketch the Bode plot for the magnitude $|H(\omega)|$ and phase $\angle H(\omega)$ of the transfer function of the circuit in Figure 1.
(d) Now instead of a capacitor, we add an inductor in parallel with $R_f$, seen in Figure 2. What is the new transfer function?
(e) What type of filter is the circuit shown in Figure 2?

(f) Sketch the Bode plot for the magnitude $|H(\omega)|$ and phase $\angle H(\omega)$ of the transfer function of the circuit in Figure 2.

(g) Now we have both a capacitor and inductor in parallel with $R_f$, seen in Figure 3. Find the new transfer function.

(h) What type of filter is the circuit shown in Figure 3?

(i) Sketch the Bode plot for the magnitude $|H(\omega)|$ and phase $\angle H(\omega)$ of the transfer function of the circuit in Figure 3.
4. Bode Plots and Transfer Functions

(a) Find the transfer function $H(\omega)$ that corresponds to the magnitude plot below. The phase of $H(\omega)$ is $180^\circ$ at $\omega = 0$.

(b) Sketch the Bode plot (magnitude and phase) for the transfer function:

$$H(\omega) = \frac{(30 + j\omega)(10^2 + j\omega)^3}{(j\omega)(10^3 + j\omega)^2}$$

Contributors:

- Kyoungtae Lee.
- Nikhil Shinde.
- Varun Mishra.
- Kyle Tanghe.