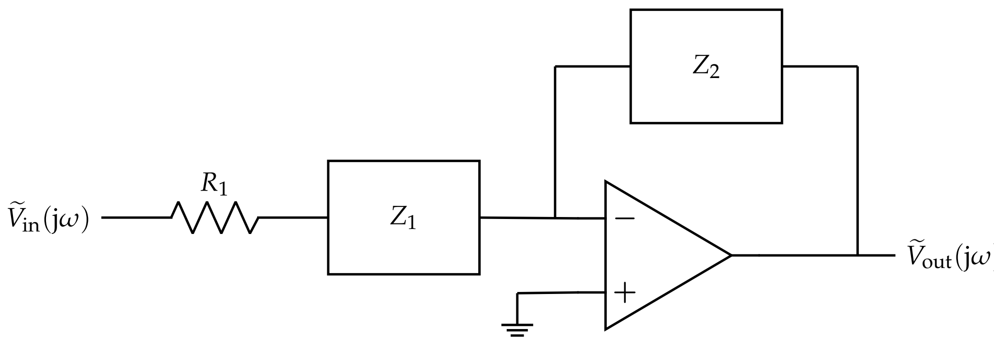
EECS 16B   Designing Information Systems and Devices II   UC Berkeley   Spring 2024

Homework 5

This homework is due on Saturday, February 24, 2024, at 11:59PM.

1. Circuit Design Part 2

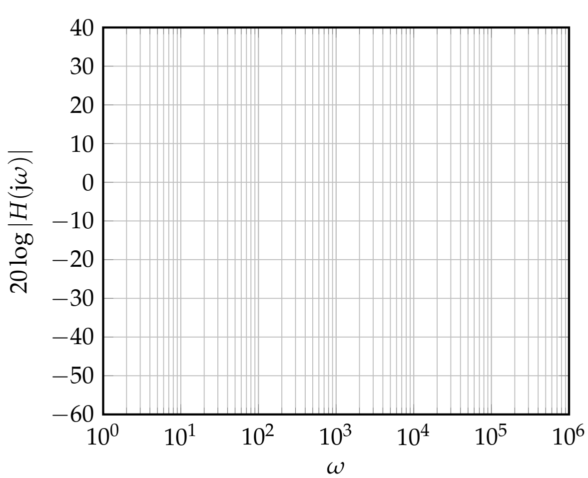
In the previous homework, you analyzed the following circuit in phasor domain:

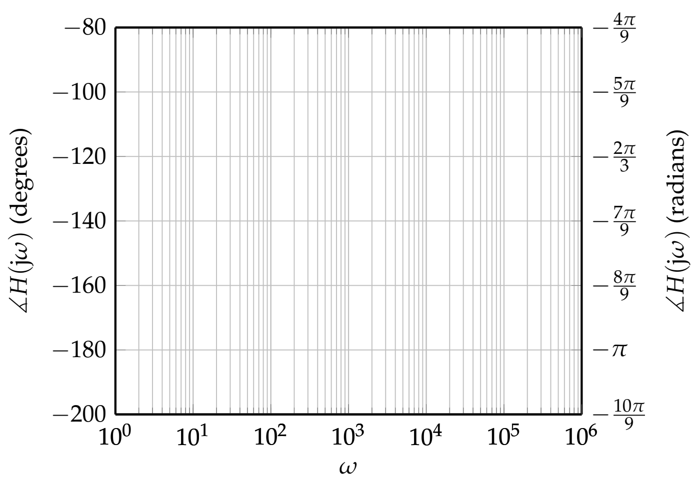


You (hopefully) determined that $Z_2 = R = 10\,\text{k}\Omega$ and $Z_1 = \frac{1}{j\omega C}$ with $C = 1\,\mu\text{F}$ and $R_1 = 1\,\text{k}\Omega$. This gave you the following transfer function:

$$H(j\omega) = -\frac{R}{R_1} \cdot \frac{1}{1 - \frac{j}{\omega C R_1}} \tag{1}$$

Draw the magnitude and phase Bode plots (straight-line approximations of the transfer function) of this transfer function. Blank plots are provided here for you to use.





2. Bode Plots 1

A transfer function is given by

$$H(\mathrm{j}\omega) = \frac{100}{1 + \mathrm{j}\frac{\omega}{1000}} \tag{2}$$

Sketch the asymptotic magnitude and phase Bode plots to scale. What is the value of the half-power frequency?

3. Bode Plots 2

Sketch the asymptotic magnitude and phase Bode plots to scale for the transfer function

$$H(\mathrm{j}\omega) = 10\frac{1-\mathrm{j}\frac{\omega}{100}}{1+\mathrm{j}\frac{\omega}{100}} \tag{3}$$

4. Bandpass Filter: Lowpass and Highpass Cascade

Consider an input signal that is composed of the superposition of:

- $A_p := 20\,\mathrm{mV}$ level pure tone at frequency $f_p := 60\,\mathrm{Hz}$ and phase ϕ_p corresponding to power line noise.
- $A_v := 1\,\mathrm{mV}$ level pure tone at frequency $f_v := 600\,\mathrm{Hz}$ and phase ϕ_v corresponding to a voice signal.
- $A_f := 10\,\mathrm{mV}$ level pure tone at frequency $f_f := 60\,\mathrm{kHz}$ and phase ϕ_f corresponding to fluorescent light control electronics noise.

We would like to keep the 600 Hz tone, which could correspond to a voice signal.

NOTE: The phases ϕ are symbolic – we do not provide numerical values – but the amplitudes A are not symbolic.

(a) **Write the $V_{\text{in}}(t)$ that describes the above input in time domain, in the following format:**.

$$V_{\text{in}}(t) = A_p \cos(2\pi f_p t + \phi_p) + A_v \cos(2\pi f_v t + \phi_v) + A_f \cos\left(2\pi f_f t + \phi_f\right) \tag{4}$$

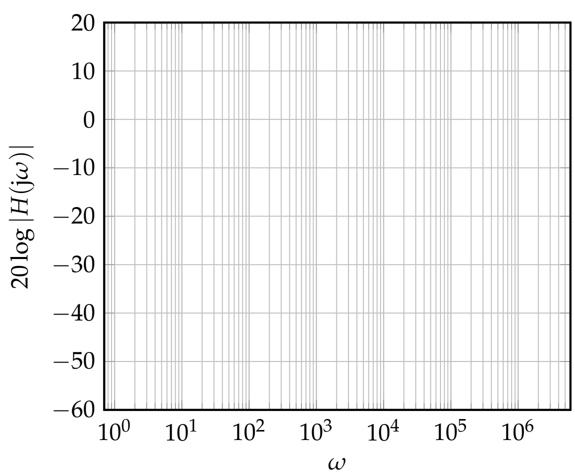
(b) **What are the angular frequencies (i.e., $\omega_p, \omega_v, \omega_f$) involved and the phasors associated with each tone?** Remember that the frequencies of the tones are provided in Hz. To convert these frequencies to angular frequencies, we use $\omega = 2\pi f$.

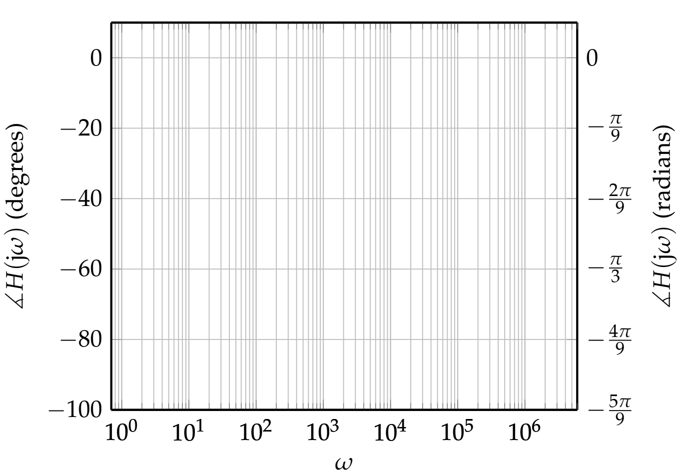
NOTE: This scenario is common in applications; usually, the data collected is in "regular" frequencies, but the analysis requires angular frequencies.

(c) To achieve your goal of keeping the voice tone but rejecting the noise from the power-lines and fluorescent lights, **at what frequency do you want to have the cutoff frequency for the lowpass filters**?

(HINT: To arrive at a unique solution consider computing the geometric mean (the analogous quantity to the arithmetic mean on a log scale) of the two frequencies of interest.)

(d) **Draw the Bode plots (straight-line approximations of the transfer function) for the magnitude (using $20 \log |H(\mathrm{j}\omega)|$) and phase of the lowpass filter.**





(e) To achieve your goal of keeping the voice tone but rejecting the noise from the power-lines and fluorescent lights, **at what frequency do you want to have the cutoff frequency for the highpass filters**?

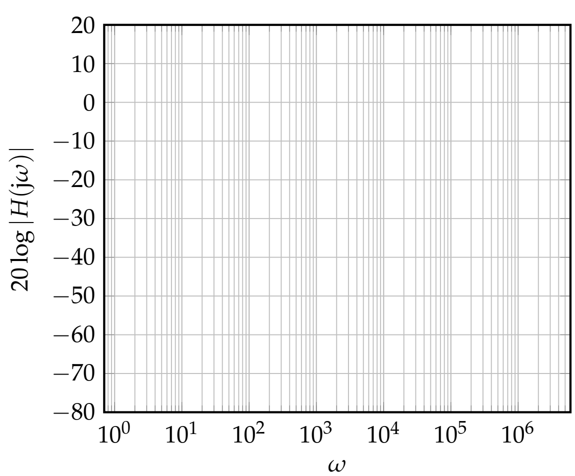
(HINT: To arrive at a unique solution consider computing the geometric mean (the analogous quantity to the arithmetic mean on a log scale) of the two frequencies of interest.)

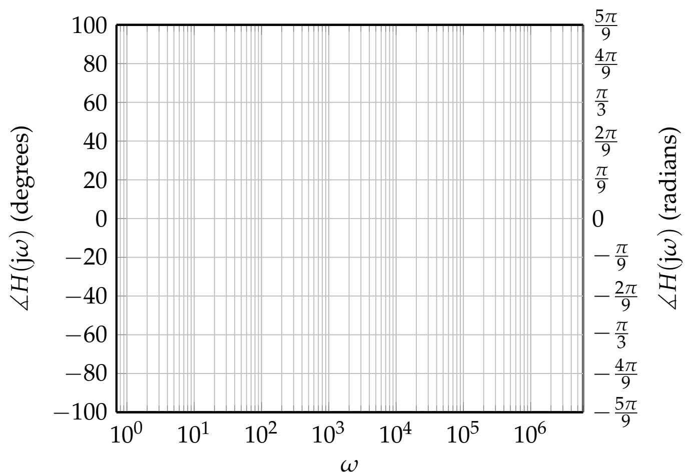
(f) **Draw the Bode plot (straight-line approximations to the transfer function) for the magnitude (using $20\log|H(\mathrm{j}\omega)|$) and phase of the highpass filter.**

(g) For the following questions, assume your cut-off frequencies for lowpass and highpass are 6 kHz and 189 Hz respectively. Suppose that you only had 1 µF capacitors to use. **What resistance values would you choose for your highpass and lowpass filters so that they have the desired cutoff frequencies?**

(h) The overall bandpass filter that is created by cascading the lowpass and highpass with ideal buffers in between. **Draw the Bode plot (straight-line approximations to the transfer function) for the magnitude and phase of the overall bandpass transfer function.**

(HINT: You should think about how the Bode plot of a cascade of two filters can be derived based on the Bode plots of the lower-level filters.)





(i) Suppose that the bandpass filter does not have enough suppression at 60 Hz and 60 kHz. You decide to use a cascade of three bandpass filters (with unity-gain buffers in between) (as shown in Figures 1 and 2). **What are the phasors for each of the frequency tones after all three bandpass filters?**

(HINT: Remember how you determined the transfer function of the bandpass filter from the transfer functions of the lowpass and highpass filters.)

Feel free to use a computer to help you evaluate both the magnitudes and the phases here.

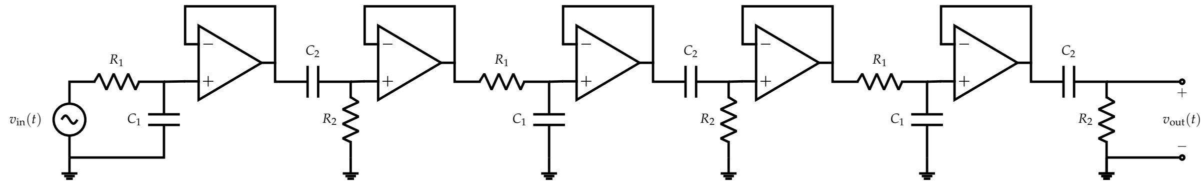


Figure 1: "Time-domain" circuit: Cascade of the three bandpass filters, using buffers to avoid loading.

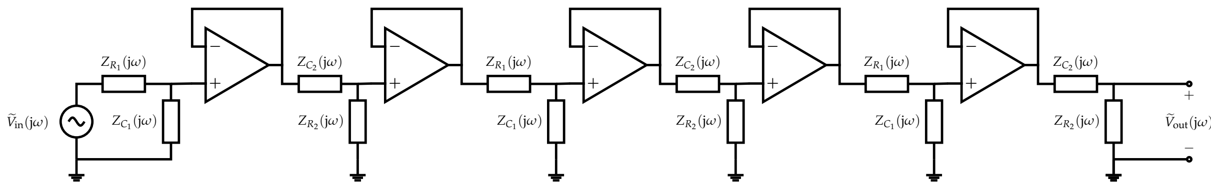
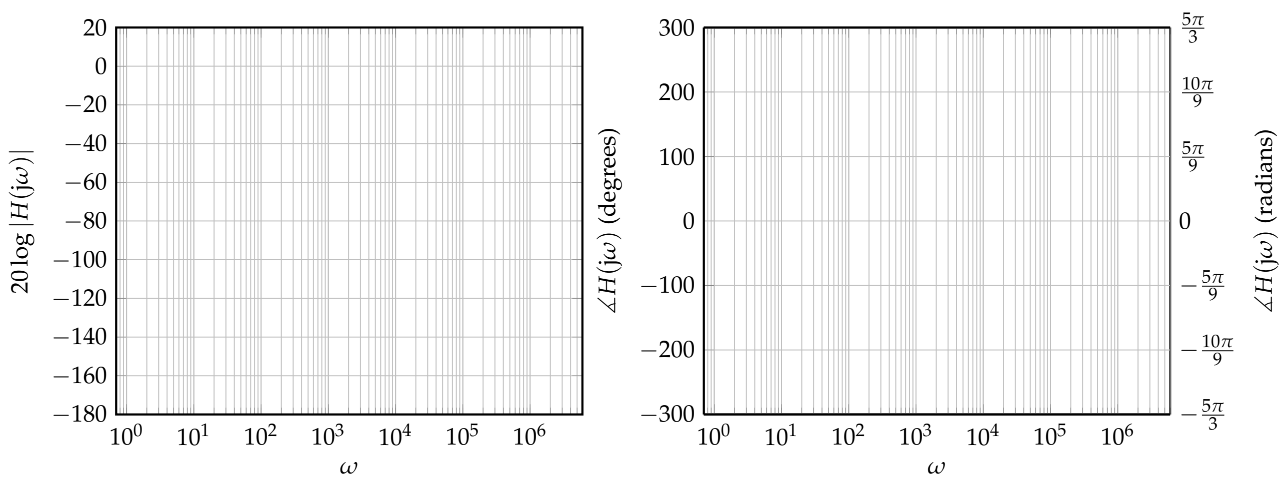


Figure 2: "Phasor-domain" circuit: Cascade of the three bandpass filters, using buffers to avoid loading.

(j) **Draw the Bode plots (straight-line approximations to the transfer function) for the magnitude and phase of the** 3^{rd} **order bandpass filter.** To highlight the difference between the 3^{rd} and 1^{st} order filters, please draw both Bode plots on a single figure.



(k) **Write the final time domain voltage waveform that would be present after the filter.**

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