BME354L (Palmeri)

Spring 2013

Exam #1: Solutions

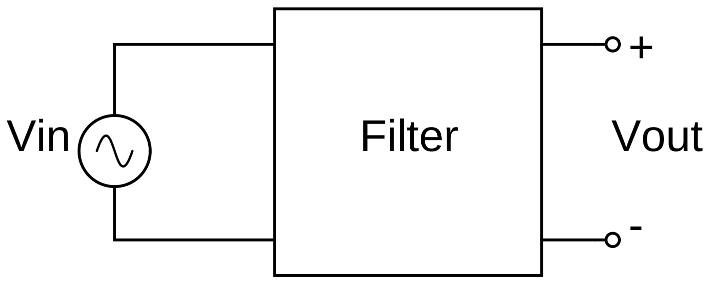
Instructions:

- Write your name at the top of each page.
- **Show all work (this is *critical* for partial credit!)**.
- Remember to include units with all answers and label all plot axes.
- Clearly box all answers.
- Assume that all components are ideal unless otherwise stated.
- Please keep your answers brief for questions where I ask 'why?'.

In keeping with the Duke Community Standard, I have neither given nor received aid in completion of this examination.

Signature:______________________________________

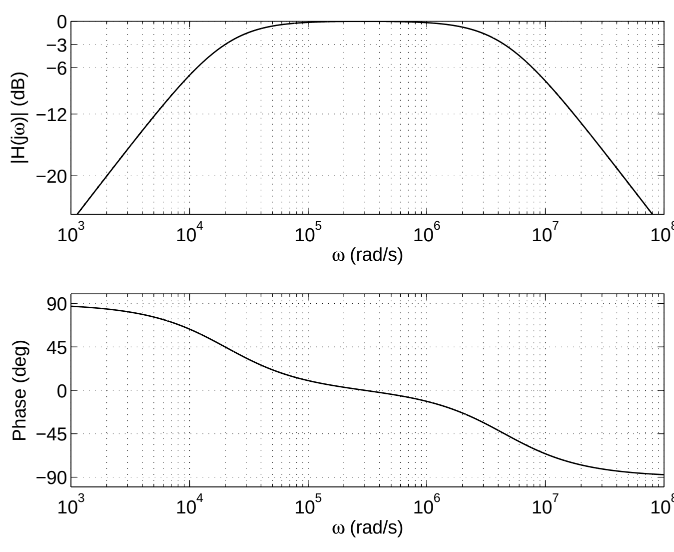
Problem #1 [50 points]



You build the generalized circuit above in lab, and you measure the following V_{out} signals for the specified V_{in} signals (all measurements have $\pm 10\%$ tolerance on them):[1]

V_{in} (V)	$V_{\text{out}}(V)$
$15\sin(2000t)$	$1.5\sin(2000t+\frac{\pi}{2})$
$10\sin(20000t+\frac{\pi}{2})$	$\frac{10\sqrt{2}}{2}\sin(20000t+\frac{3\pi}{4})$
$2.5\cos(300000t)$	$2.5\cos(300000t)$
$1.2\sin(4500000t)$	$\frac{1.2\sqrt{2}}{2}\sin(4500000t-\frac{\pi}{4})$
$0.5\sin(45000000t+\frac{\pi}{2})$	$0.05\sin(45000000t)$

(a) Sketch Bode plots for the amplitude and phase transfer functions for your filter. Label everything important, including cut-off / resonance frequencies, if applicable.[2] [15 points]



[1]It may help to think of these V_{in} : V_{out} pairs in terms of phasors.
[2]I have only given you 5 discrete data points for your filter, but you can assume that all circuit behavior between these points is smooth and monotonic.

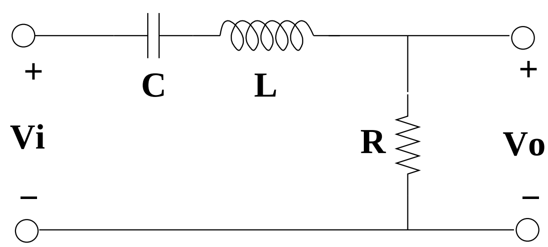
(b) You need to design a **[low-pass / high-pass / bandpass / bandstop]** filter for these $V_{\text{in}} : V_{\text{out}}$ relationships? Why? [5 points, choose one answer]

Bandpass filter

(c) Does your filter need to be active, or could you design a passive filter to achieve this $V_{\text{in}} : V_{\text{out}}$ behavior? Why? [5 points]

Passive filter is possible since there is only unity gain in the passband.

(d) Draw the circuit diagram for your filter with all key components labeled with specified values. If you are using op amps, then please specify their rail voltages. [10 points]



See the bandpass filter problem in Problem Set #1 for way to solve for R, C, and L using the center frequency and cutoff frequencies (bandwidth) of the filter.

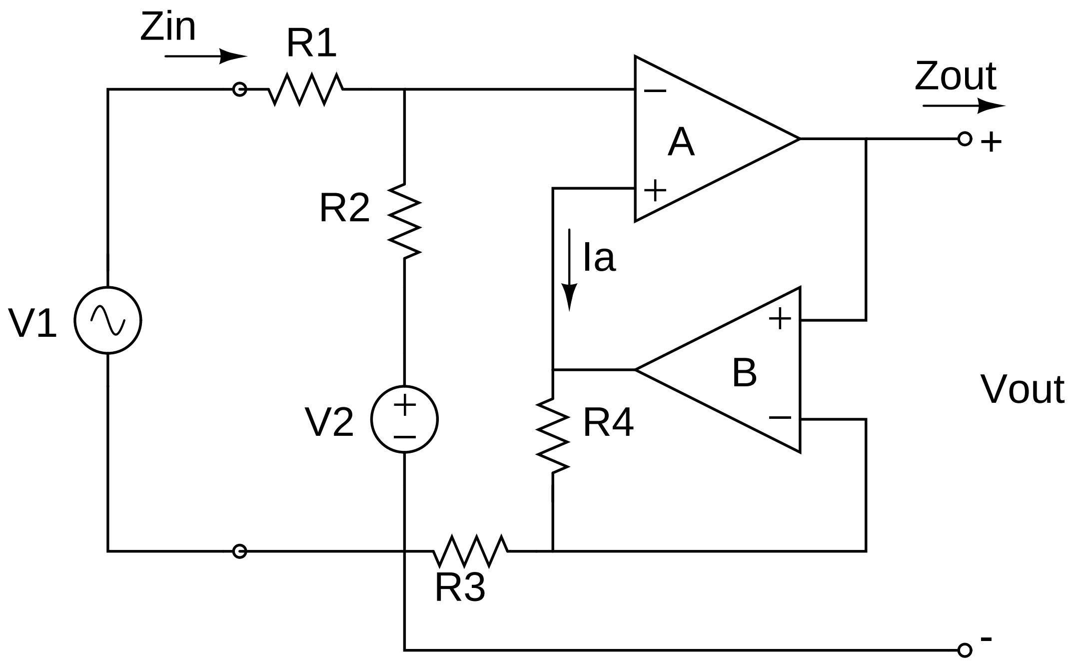
(e) What is the input impedance of your filter? [5 points]

Given the circuit above, $Z_{\text{in}} = R + Z_{\text{L}} + Z_{\text{C}}$; answer was adjusted to match the circuit you designed.

(f) Design an amplifier for your filter output that can generate a maximum output voltage of $\pm$ 12 V and does not saturate ("rail") for filter output voltages (V_{out}) as large as $\pm$ 2.5 V. Make sure that your amplifier does not corrupt the phase of the filter output (V_{out}). Remember to consider the impedance relationship between your filter and your amplifier. [10 points]

One potential solution was a non-inverting amplifier (high input impedance!) that had a gain $\leq \frac{12}{2.5}$, and setting the resistors appropriately to achieve that gain. Inverting amplifier solutions were accepted if they were then inverted again to preserve phase and something was done in increase the finite input impedance.

Problem #2 [50 points]



All of the components in the circuit above should be considered ideal and have the following values:

- Component Values: $R_1 = R_2 = R_3 = R_4 = 10$ kΩ; V_2 = -1 V
- Rail voltages for op amp A: $\pm$ 2 V
- Rail voltages for op amp B: $\pm$ 12 V

(a) What is the input impedance (Z_{in}), as indicated on the circuit diagram (as "seen" by V_1). [5 points]

$Z_{\text{in}} = R_1 + R_2$. Why? Using the $\frac{\Delta v_{\text{in}}}{\Delta i_{\text{in}}}$ approach, think of adding a Δv by adding a new DC power supply in series with V_i; then by superposition, you could solve for Δi by "removing" the original voltage source (i.e., they all become shorts), leaving you with a simple look with R_1 in series with R_2 to dicate the current.

(b) Op amp A is configured with **[no / negative / positive]** feedback. Why? [5 points, choose one answer]

Positive feedback exists since the output of op amp A goes through the non-inverting amplifier in the feedback look and affects the non-inverting input of op amp A.

(c) Op amp B is configured with **[no / negative / positive]** feedback. Why? [5 points, choose one answer]

Negative feedback; this is a non-inverting amplifier.

(d) Write an expression for I_a, as indicated on the circuit diagram. [5 points]

I_a = 0 since no current flow in / out of the input terminals of an op amp under ideal assumptions.

(e) What is the purpose of V_2 in this circuit? [5 points]

V_2 acts as V_{ref} for the comparator (op amp A).

(f) Sketch V_{out} for V_1 = -12:12 V. Please be sure to indicate the overall function of this circuit and show your steps in solving for V_{out} to maximize partial credit!! [15 points]

This is a standard hysteresis curve, with rails at $\pm$ 2V. The center of the hysteresis window is at $-V_{\text{ref}}$ = 1 V. The gain of the non-inverting feedback amp is 2, so V_+ for op amp A is $\pm$4 V, and using our rules of thumb that the transition points are "2 V_+" away from the center of the hysteresis window, we know that we transition at 9 V (+2 $\rightarrow$ -2 V) and -7 V (-2 V $\rightarrow$ +2 V).

(g) Sketch V_{out} for 2 cycles of V_1 = 12 $\cos(100t)$ V, starting at t = 0. [5 points]

This is a rect output going switch between -2 and 2 V. It starts at -2 V since V_i is 12 V at t = 0, and V_{out} = -2 V in that state; then jumps when V_i hits the transition voltages appropriate for its current state.

(h) What is the output impedance, Z_{out}, as indicated on the circuit diagram? [5 points]

Ideally, Z_{out} = 0.