ASSIGNMENT 5

Due date: Oct 28, 2025 (4 PM)

Unless otherwise specified all op amps are ideal.

Relevant Class Notes	**Assessment Criteria**
Transfer Functions §7, 9.1 Operational Amplifiers (§ 2.4, 3, 4, 5.1, 8.1)	Apply one or more procedure(s) to a problem. Analyze a problem and obtain a correct result. Write a MATLAB script to analyze a problem. Interpret observations / results.
References to Prior Assignments	
Q3 builds upon Assignment 3 Q4 & Assignment 4 Q3.	

Manage your time. Having problems with the assignment? Discuss them with the instructor!

Attachment05.zip accompanies this assignment and contains needed MATLAB files.

1. (2.5/10)

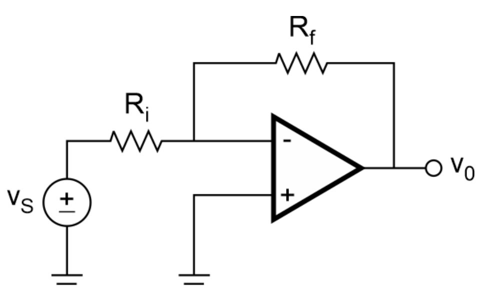


Figure 1

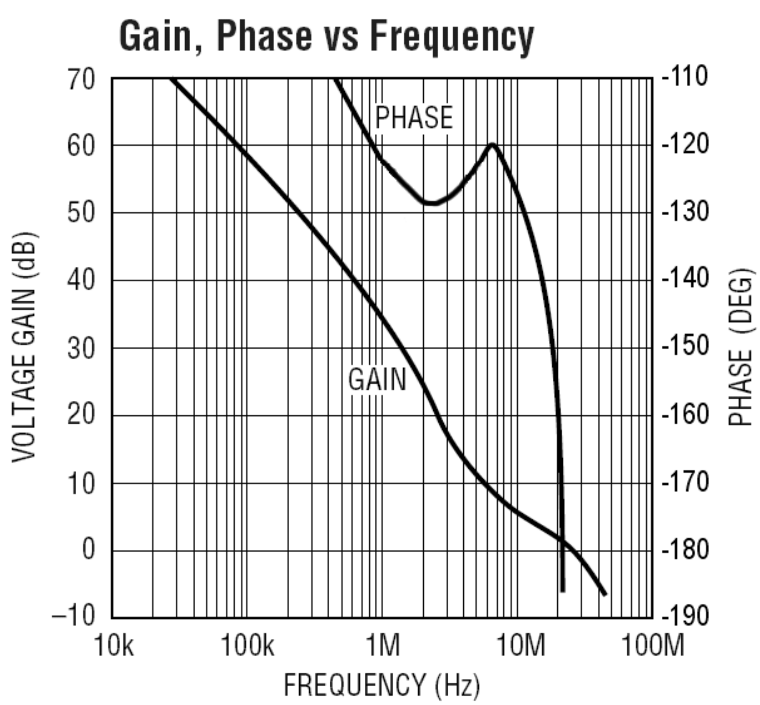


Figure 2

You need to build the amplifier (operational circuit) shown in Figure 1 and are considering using an op amp having the open-loop frequency response shown in Figure 2.

You may assume that at frequencies below 30kHz that:

- The system loop gain is very large (>>1)
- The op-amp phase response monotonically → 0° as frequency → 0

What are the restrictions on the amplifier gain[1] for the system to be stable with a minimum phase margin of 45°?

Recall:

- Amplifier gain is a low-frequency characteristic. Given the above information, you do not need to see the open-loop frequency response down to low frequency.
- Questions of stability are high-frequency phenomenon. Hence the frequency range shown in Figure 2.
- Stability analysis involves analyzing the system loop gain. In actuality, the op-amp frequency response is the loop-gain frequency response when $\beta = 1$.)

2. (2/10)

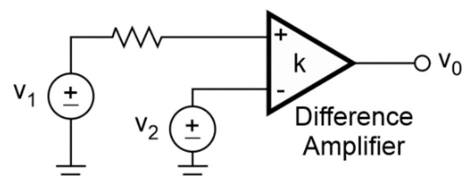


Figure 3

Q2.p, which accompanies this assignment, simulates a realistic difference amplifier with finite common mode rejection, as shown in Figure 3. Determine the amplifier's common-mode rejection (CMR) by performing two experiments, where you excite the amplifier with a differential signal then with a common-mode signal. Attach your MATLAB code.

3. (4.5/10)

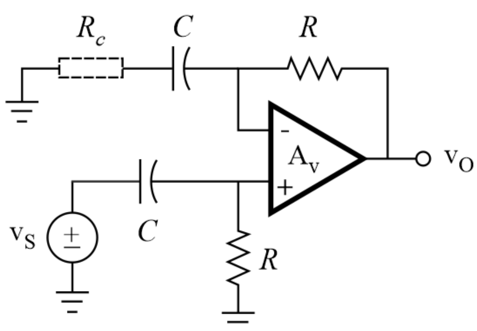


Figure 4. Differentiator (Noninverting)

A *differentiator*, shown in Figure 4, followed by a *comparator* is useful for detecting an event for which the slope exceeds a given value – for example, detection of the R-wave in an electrocardiogram, as shown in Figure 5.

Unfortunately, the differentiator circuit exhibits stability problems but can be stabilized by inserting a compensating resistance (R_C).

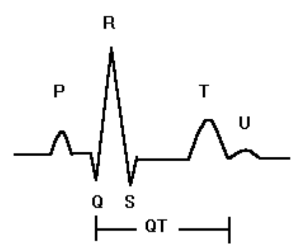


Figure 5. ECG Signal

a)

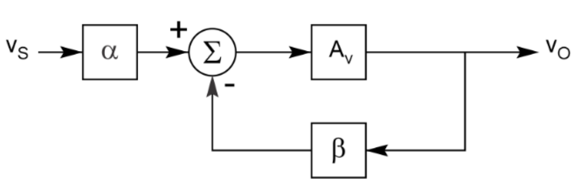


Figure 6

The circuit may be represented with the block diagram shown in Figure 6, which is the classical negative-feedback diagram, augmented with the α block, which accounts for V_S not going directly to the op-amp '+' terminal. The resulting closed-loop response is:

$$A_{CL}(s) = \frac{V_O(s)}{V_S(s)} = \frac{\alpha(s)A_v(s)}{1 + A_v(s)\beta(s)}$$

---

[1] Do not confuse the amplifier gain with the op-amp gain. The amplifier gain is the operational circuit's closed-loop static gain, when the system loop gain is >> 1, and is expressed as a single real number.

Use the feedback-analysis approach to:

i) Determine α and β in Figure 6 for the system in Figure 4 when R_c in series with C is represented as an equivalent impedance, Z. (Leave your answer in terms of Z.)

ii) Setting $R_c = 0$, use the results from (i) to determine the ideal operational equation (i.e., assuming an ideal op amp) as a function of R and C.

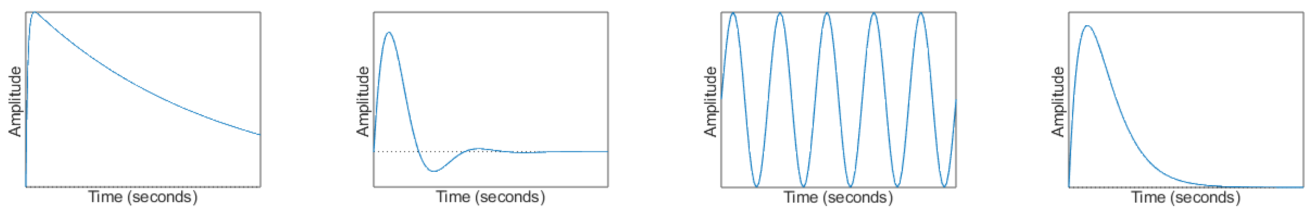
b) With $R_c = 0$ and $A_v(s) = \frac{A_0}{s\tau_0+1}$, the system transfer function is

$$A_{CL}(s) = \frac{sRCA_0}{(sRC+1)(s\tau_0+1)+A_0}$$

i) Show that the transfer function damping ratio → 0 as $A_0 \to \infty$. (Refer to class notes on *Transfer Functions* and the section on 2nd-order systems.)

ii) In terms of the natural modes of response of a system, which of the following cases corresponds with the scenario in (i)? (Select all that apply.)

(a) (b) (c) (d)



c) *Q3c.p*, which accompanies this assignment, evaluates the system transfer function for a set of component values. Let C = 560nF, R = 243kΩ, $A_0 = 1\times10^5$V/V, and $\tau_o = 1/(20\pi)$ seconds. Using MATLAB, find a compensating resistance, R_c, that yields the fastest step response without making the system be underdamped.

- Use *pzmap* to assess your choice of R_c.
- Plot the system step response over 3ms for the uncompensated and compensated cases.
- Limit your component selection to standard resistor values from the 1% line. (See the Appendix in the class notes on *Electronic Circuits* for standard passive component values.) I recommend that you find the correct value by probing values using a manual and systematic approach. Tip: R_c controls the system damping ratio.

d) Use *Q3d_primer.m* to help you get started. Plot superimposed frequency responses of:

- The ideal system transfer function ($A_{CL\text{ ideal}}$)
- The op-amp gain (A_v)
- The loop gain ($A_v\beta$)
- The transfer function of the compensated system (A_{CL})

Briefly comment on how $|A_{CL}(j\omega)|$ compares to $|A_{CL\text{ ideal}}(j\omega)|$ in relation to the loop-gain magnitude response and $|A_v(j\omega)|$. In particular:

- Under what condition is the desired $|A_{CL}(j\omega)|$ achieved?
- What determines the high-frequency performance of $|A_{CL}(j\omega)|$?

e) Over what frequency range does the compensated circuit act as a differentiator? Briefly justify your conclusion.

4. (1/10)

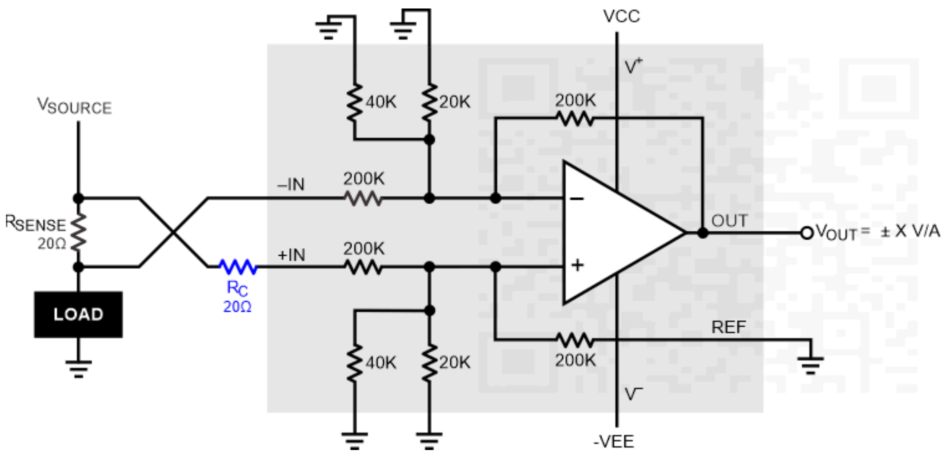


Figure 7. Precision Current Monitor

Op Amp Parameters	
Av	Not available
GBW	8 MHz
V_{os}	5 mV (max)
I_B	±2nA (max)
CMR	83 dB (min)
SR	4 V/µs
V_{SAT}	Rail-to-rail

The I.C. show in Figure 7 is a voltage difference amplifier incorporating a precision op amp and a matched resistor network. The circuit illustrates an application of the I.C. in a precision current monitor. Op amp parameters are shown in the accompanying table.

Circuit operation: current through the load is determined by monitoring the voltage drop across R_{SENSE}. Assuming zero source resistance the output voltage is proportional to current with sensitivity X volts per ampere of load current.

Question: Assuming zero source resistance, what is the purpose of R_C on the +IN input? (No formal circuit analysis necessary.) Assume that the load resistance >> R_{SENSE}. Select one of the following options.

a) To maintain op-amp CMR

b) To maintain circuit CMR

c) To allow the output to swing at the op-amp SR specification

d) To allow the output voltage to swing beyond +/- V_{SAT}

e) To minimize output offset error due to V_{OS}

f) (a) and (b)

g) None of the above

5. (0.5/10) Bonus

Report the amount of time spent on this assignment.

Relevant MATLAB function(s):

You will have to use functions introduced in previous assignments.