

# Exercises for Module 5

of

Micro and Smart Systems NPTEL Course

(Some of the following problems are taken from instructors' book entitled "Micro and Smart Systems", John Wiley, 2012.)

5.1 A non-inverting amplifier was designed to have a gain of 100 with an ideal op-amp and suitable feedback resistors. The power supply voltages are  $V_{CC} = 10\text{ V}$  and  $V_{EE} = 10\text{ V}$ . The gain-bandwidth product of the op-amp is  $10^6\text{ Hz}$ . Determine the output voltage  $V_o$  of this amplifier when the input voltage is

- (a) 150 mV.
- (b)  $0.01\sin(10^5t)$ .

5.2 Using Fig. 5.1 for the circuit diagram of a noninverting op-amp, design the resistor  $R_2$  if  $R_1 = 1\text{ k}\Omega$  such that the voltage gain of the amplifier is 100. Assume that the openloop gain  $A_0$  of the op-amp is infinite.

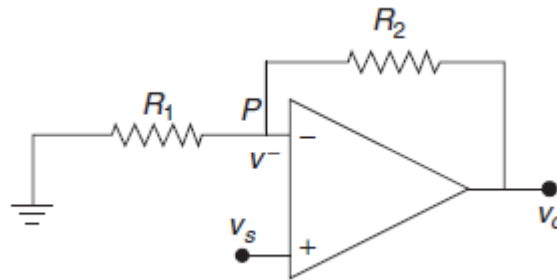


Fig. 5.1 A non-inverting op-amp

5.3 Determine the input voltage  $V_s$  when the output voltage of the amplifier in Problem 5.2 is 1 V. Assume that  $V_{CC} = 10\text{ V}$  and  $V_{EE} = 10\text{ V}$ . Also, determine the input voltage  $V_s$  when the output voltage is 1 V and the open-loop gain of the op-amp is finite with a value  $A_0 = 10^5$ .

5.4 (a) Draw the circuit diagram of a precision half-wave rectifier using an op-amp and sketch the input and output waveforms one below the other, taking the input as a sine wave. (b) Explain the working of this rectifier.

5.5 The sensitivity of a piezoresistive pressure sensor operating at 5 V power supply was found to be 100 mV/bar ( $1\text{ bar} = 10^5\text{ N/m}^2$ ). It gives linear output up to 10 bar pressure.

- (a) Design a differential amplifier circuit with differential gain  $A_d = 5$  using an op-amp to amplify the signal output. Choose appropriate power supply voltage for the op-amp.
- (b) The Wheatstone bridge of the sensor is perfectly balanced with zero offset voltage. However, the amplified output gives an offset voltage when its input terminals are connected to the output of the pressure sensor. This is attributed to the finite CMRR of the amplifier whose differential gain is 5. Determine the above output offset voltage if the CMRR of the amplifier is 500.

5.6 The open-loop transfer function of a unity feedback system is given by  $G(s) = K/[s(Ts + 1)]$  where  $K$  and  $T$  are positive constants. The unit step response of this system has overshoot, which can be controlled with amplifier gain. By what factor should the gain be changed to reduce the overshoot from 75% to 25%?

5.7 Check the stability of a system whose characteristic equation is given by

(a)  $s^4 + 6s^3 + 12s^2 + 18s + 3 = 0$

(b)  $3s^4 + 5s^3 + 2s^2 + 10s + 3 = 0$

5.8 Consider a system with open-loop transfer function given below.

$$G(s)H(s) = \frac{4s + 1}{s^2 + (s + 1)(2s + 1)}$$

Sketch the Nyquist contour for this and determine its closed-loop stability.

5.9 For a third-order process with open-loop transfer function as  $G(s) = 250/[(s+10)(s+5)^2]$ , use a Routh array to determine the critical gain.

5.10 A piezoresistive pressure sensor is realized by ion implantation of boron onto a n-type silicon diaphragm having dimensions  $0.5 \text{ mm} \times 0.5 \text{ mm}$  and thickness  $5 \text{ }\mu\text{m}$ . Piezoresistors are arranged in the conventional manner on the membrane so that two of them experience maximum longitudinal tensile stress (connected in the opposite arms of a Wheatstone bridge) and other two experience maximum transverse tensile stress.

(a) Determine the burst pressure, ignoring stress crowding at corners.

(b) Determine the sensitivity of this pressure sensor for an input voltage of 1 V.

Assume that the Young's modulus of silicon is 170 GPa, the yield strength is 5 GPa, and Poisson's ratio is 0.2 (note that  $1 \text{ bar} = 10^5 \text{ Pa}$ ). Note that the gauge factor  $G_L = -G_T = 100$  for boron-implanted single-crystal piezoresistors.

5.11 The offset voltage of a piezoresistive pressure sensor is found to be 5 mV when the input voltage is 1 V. The sensitivity of the pressure sensor is 50 mV/bar for an input

voltage of 5 V. Determine the output voltage when the pressure is 3 bar and the input is 5 V.

5.12 What is the significance or error signals in the design of feedback control systems?

5.13 How do you define a transfer function of a control system? How do you obtain the transfer function of system from the finite element analysis?

5.14 Reduce the following differential equation in a state space form.

$$\frac{d^3 y}{dt^3} + a_1 \frac{d^2 y}{dt^2} + a_2 \frac{dy}{dt} + a_3 y = b_0 \frac{d^3 u}{dt^3} + b_1 \frac{d^2 u}{dt^2} + b_2 \frac{du}{dt} + b_3 u$$

5.15 Obtain the transfer function for the system shown below.

$$\begin{cases} \frac{dx_1}{dt} \\ \frac{dx_2}{dt} \end{cases} = \begin{bmatrix} -5 & -1 \\ 3 & -1 \end{bmatrix} \begin{cases} x_1 \\ x_2 \end{cases} + \begin{cases} 2 \\ 5 \end{cases} u,$$
$$y = \begin{bmatrix} 1 & 2 \end{bmatrix} \begin{cases} x_1 \\ x_2 \end{cases}$$

5.16 A given vibration signal has an amplitude of 90 mm and a period of 2 s. Determine the maximum velocity and acceleration.

5.17 A vibration measuring instrument indicate that a body vibrating harmonically at a frequency of 480 cycles per minute with a maximum acceleration of 1000 mm/sec<sup>2</sup>. Determine the amplitude of vibration.

5.18 A spring mass system with a viscous damping is displaced a distance  $x_0$  and released. Determine the equation of motion when (a)  $\xi=2$  (b)  $\xi=0.20$  and (c)  $\xi=1.0$  and compare the three cases by plotting the results.

5.19 From the record of damped vibration of an airplane wing, the ratio of succeeding amplitudes was found to be 1.16. Determine the damping factor  $\xi$ .