National Exams December 2009

04-Env-B8, Instrumentation and Process Control

Duration of Examination: 3 hours

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is an CLOSED BOOK EXAM. Any Casio or Sharp approved model calculator is permitted. Three aids sheets 81/2" x 11" written on both sides are permitted.

3. All Five (5) questions constitute a complete exam paper.

4. Each question is of equal value.

5. Certain questions require an answer in essay format. Clarity and organization of the answer are important.

Problem #1: (10 points)

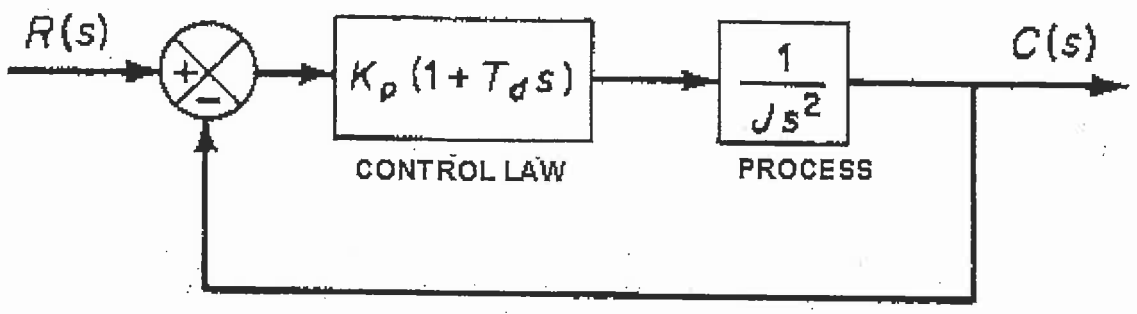


Figure 1

The closed-loop process control system illustrated in Figure 1 is subjected to a step input of magnitude 1; i.e., R(t)=1u(t) or R(s)=1/s.

a) Identify the control strategy implemented in Figure 1 (e.g. P, PI, PID).

b) Find the transfer function C(s)/ R(s).

c) Find the coordinates of the closed-loop system poles for J=2 kg-m^2, K_p=1 and T_d=2. Repeat for T_d=4.

d) What effect does the parameter T_d have on the position of the poles and on the dynamic behavior of the system?

Problem #2: (10 points)

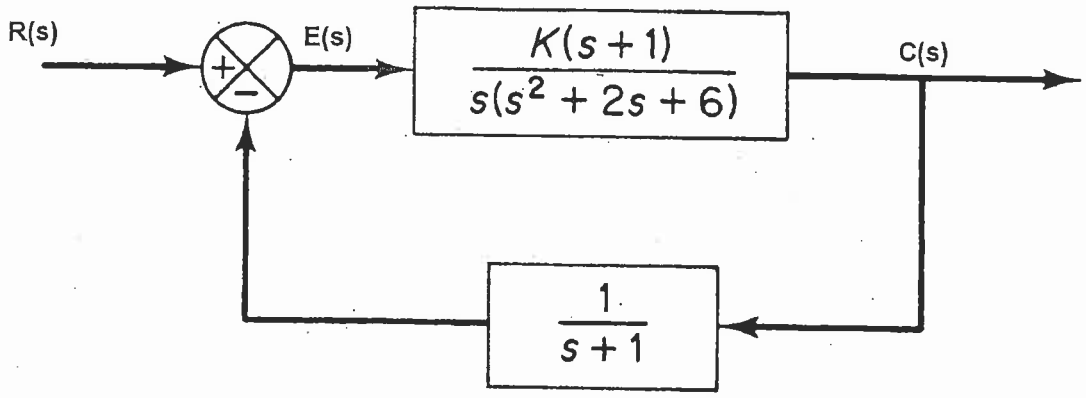


Figure 2

a) Apply the final value theorem to determine the steady-state error, E(∞), as a function of the gain K for a ramp input of amplitude 5 (i.e. R(t)=5t u(t) or $R(s)=5/s^2$).

b) What would the steady-state error be for a step input?

c) Using the Routh-Hurwitz stability criterion, determine the range of K corresponding to a stable system.

Problem #3: (10 points)

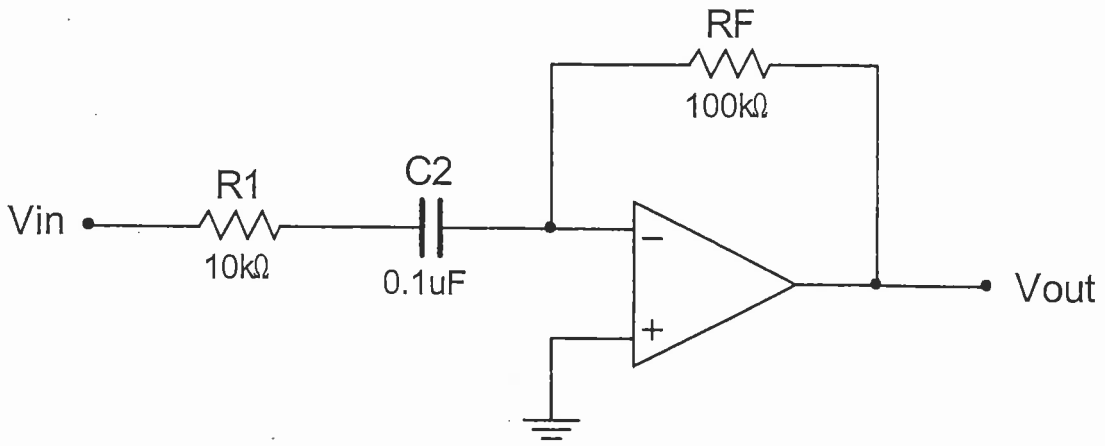


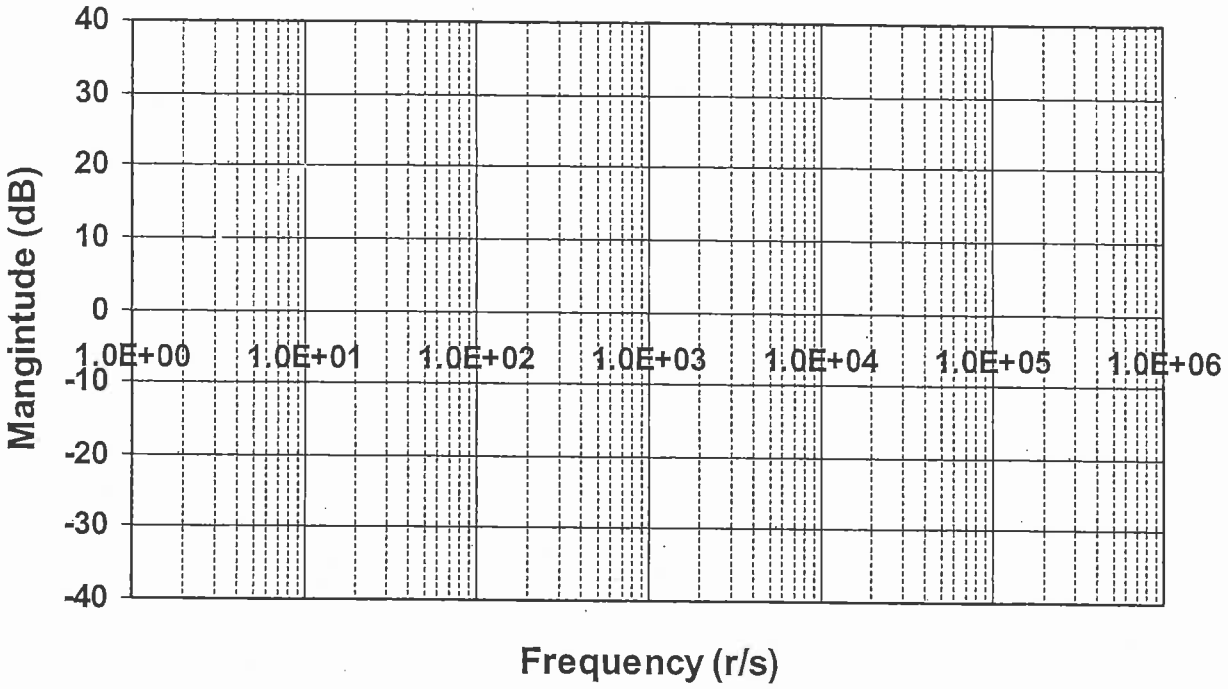
Figure 3

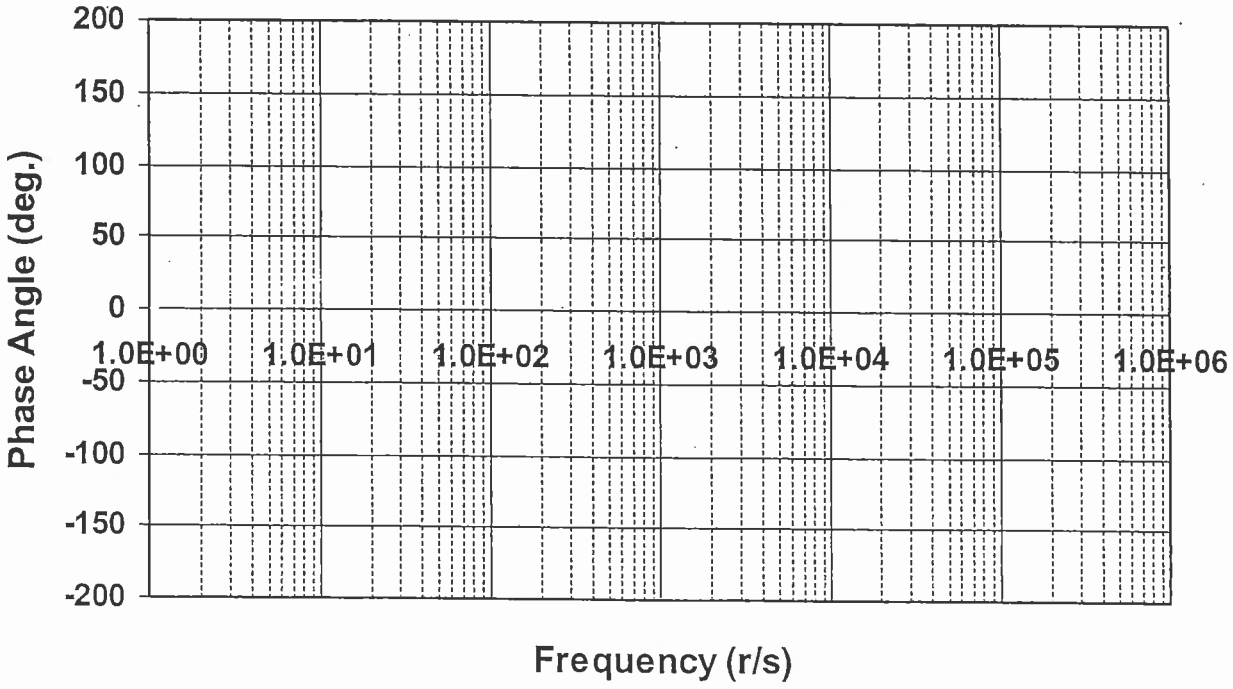
a) Determine the transfer function V_{out}/V_{in} in terms of R_1, R_F, and C for the operational amplifier circuit shown in Figure 3.

b) **In the space provided on the following page**, sketch the frequency response (i.e., Bode Diagram including magnitude and phase) directly from the transfer function assuming R_1=10KΩ, R_F=100KΩ, and C=0.1 μF.

c) Based on the Bode Diagram, is the circuit a low-pass filter, a high-pass filter, or a band-pass filter? What is the cutoff frequency, ω_c? What is the gain of the circuit in the passband, i.e., at the frequencies being passed by the filter? Use the same values of R_1, R_F, and C specified in part b.

Problem 3c: Sketch the frequency response to scale on the graph below.

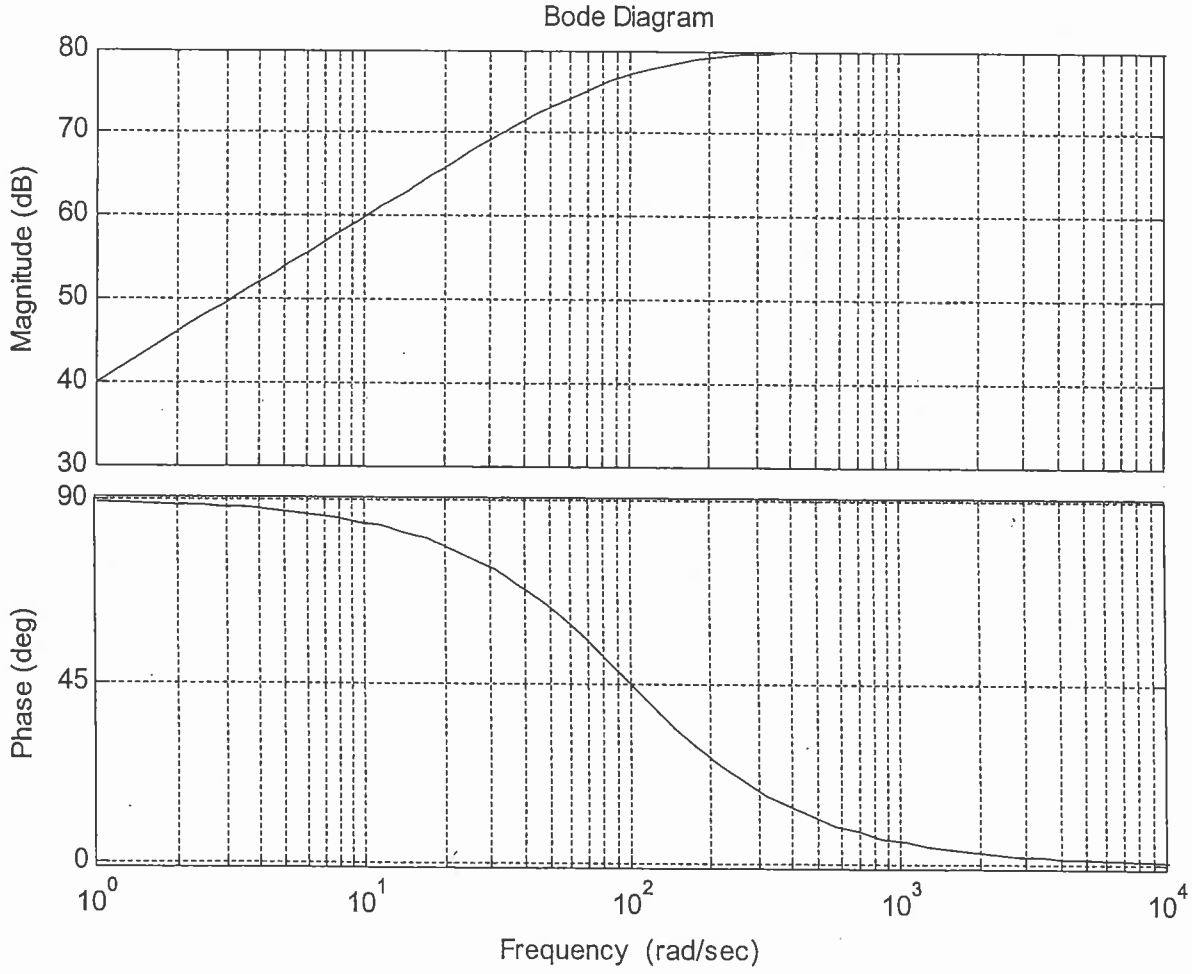




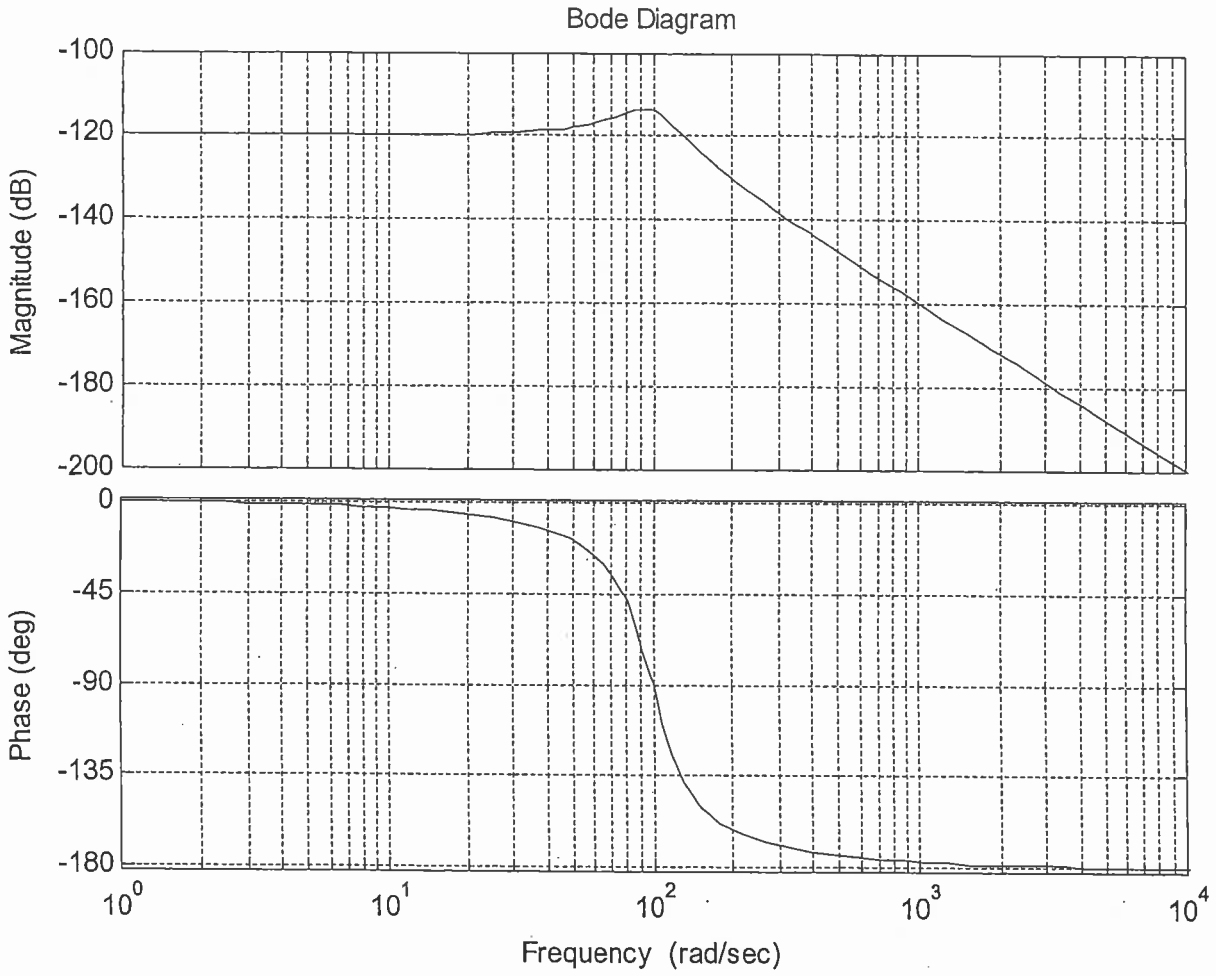
Problem #4: (10 points)

In process control "system identification" refers to a systematic procedure for determining the system model from measurements of the input and output. For the two frequency response diagrams shown below ("a" and "b") estimate the system transfer function directly from the graphs. Clearly explain how you arrived at your answers.

a)



b)


Bode Diagram
Magnitude (dB)
-100
-120
-140
-160
-180
-200
Phase (deg)
0
-45
-90
-135
-180
10^0
10^1
10^2
10^3
10^4
Frequency (rad/sec)

Problem #5: (10 points)

a) Describe the three components of a PID controller. How does each component affect the overall performance of a typical process control system? Briefly describe a systematic procedure for tuning PID controllers in a temperature control application.

b) Sketch the optimal location of the 4 strain gauges (i.e., full Wheatstone bridge) for three load cell configurations; an axial (tension/compression) load cell, a load cell based on a cantilever beam, and a shear beam load cell. Assume that in each case the load cell consists of a rectangular block of aluminium. Include the direction and point of application of force as well as the constraints (where applicable).

c) What are the primary advantages of a Resistance Temperature Detector (RTD) over a thermocouple? What is the primary advantage of a 4-wire RTD measuring circuit over a 2-wire circuit?