NATIONAL EXAMS

16-Elec-B2 Advanced Control Systems – May 2018

3 hours duration

NOTES:

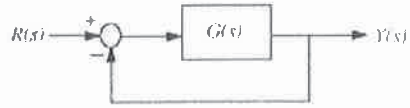
1. This is an open book exam. Tables of Laplace are attached.
2. If a doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
3. Any non-communicating calculator is permitted.
4. Any four questions constitute a complete paper. Only the first four questions as they appear in your answer book will be marked.
5. All questions are of equal value (25%).
6. The exam booklet contains 17 pages.

Question 1. Choose the best answer.

1. A chemical process is designed to follow a desired path described by (parabola)

$$r(t) = (5 - t + 0.5t^2)u(t)$$

where $r(t)$ is the desired response and $u(t)$ is a unit step function. Consider a unity feedback system.



What is the steady-state error $E(s) = R(s)\text{-}Y(s)$ with the following open-loop transfer function? **[1]**

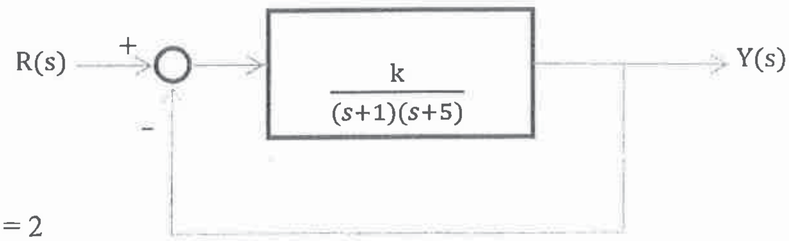
$$G(s) = \frac{10(s+1)}{s^2(s+5)}.$$

(a) $ee_{ss} = \lim_{t\to\infty} e(t) = 0.5$
(b) $e_{ss} = \lim_{t\to\infty} e(t) \to \infty$
(c) $e_{ss} = \lim_{t\to\infty} e(t) = 1$
(d) $e_{ss} = \lim_{t\to\infty} e(t) = 0$

2. What is the type of the system when the steady-state error of a feedback control system with an acceleration (parabola) input becomes finite? **[1]**

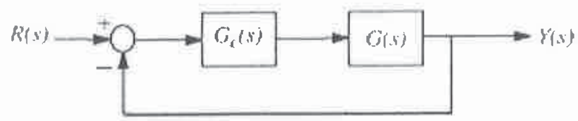
(a) Type 0 system
(b) Type 1 system
(c) Type 2 system
(d) Type 3 system

3. For the system shown below, what is the value of the k that yields a stable system with critically damped response? **[2]**



(a) k = 2
(b) k = 4
(c) k = 8
(d) k = 16

4. Consider the feedback control system block diagram

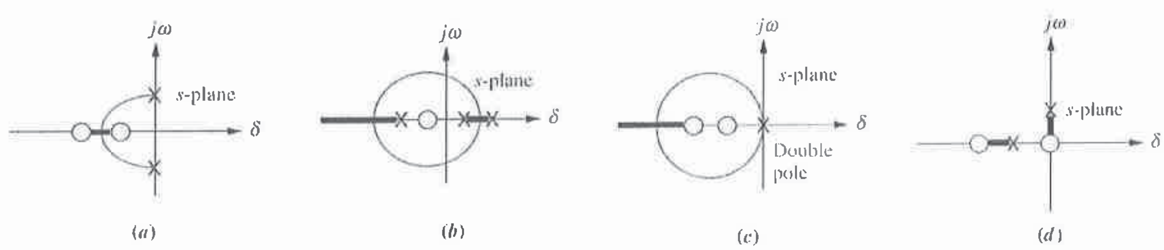


Which condition holds for the closed-loop stability with the following transfer functions? **[2]**

$$G_c(s) = K(s+1) \qquad \text{and} \qquad G(s) = \frac{1}{(s+2)(s-1)}.$$

(a) Unstable for $K = 1.10$ and unstable for $K = 3$
(b) Stable for $K = 1.10$ and stable for $K = 3$
(c) Unstable for $K = 1.10$ and stable for $K = 3$
(d) Stable for $K = 1.10$ and unstable for $K = 3$

5. Which one of the following sketches can be a root locus? **[1]**



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

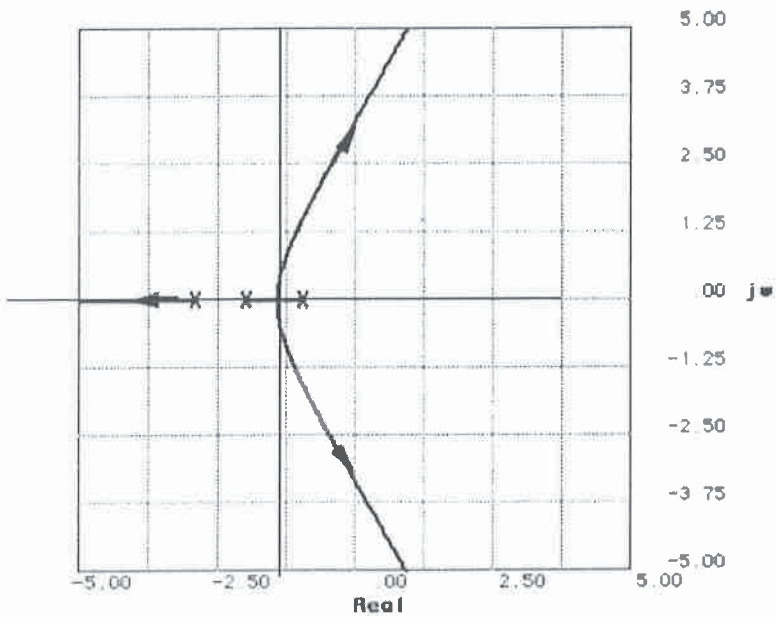
6. For the following root locus (with open loop poles at -1, -2 and -3), what are the coordinates of closed loop system poles for 20% overshoot? **[2]**

   (a) $-1.25 \pm 0.8j$

   (b) $-1 \pm 1.25j$

   (c) $-0.86 \pm 1.69j$

   (d) $-0.5 \pm 2.5j$



7. What is the gain (K) value corresponding to those poles providing 20% overshoot in the previous problem? **[2]**

   (a) 6.342

   (b) 9.398

   (c) 7.301

   (d) 3.221

8. What is the peak time (T_p) associated with those poles in the same problem? **[1]**

    (a) 3.92

    (b) 2.51

    (c) 1.85

    (d) 1.26

9. What is the settling time (T_s) associated with those poles in the same problem? **[2]**

    (a) 3.2

    (b) 4.0

    (c) 4.6

    (d) 8.0

10. Consider a forward path transfer function $G(s)$ with gain K. Which statements are true for this system? **[1]**

    1) The zeros of the closed loop system change with changing gain K.

    2) The poles of the closed loop system change with changing gain K.

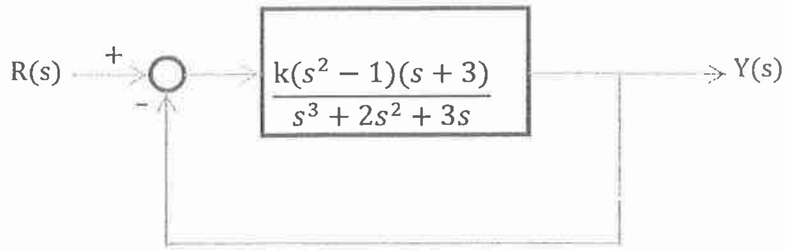
    (a) None of them is true

    (b) Only 1 is true

    (c) Only 2 is true

    (d) Both are true

11. How many asymptotes of the root locus are there for the system shown below? [1]



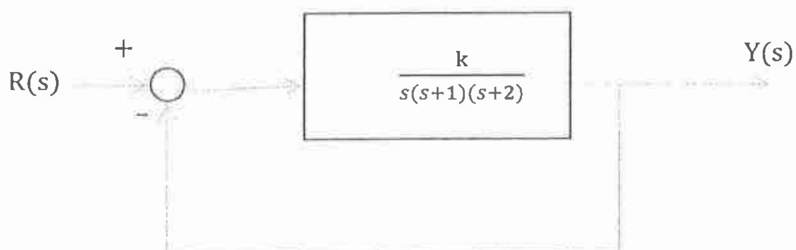
(a) There are no asymptotes

(b) There is one asymptote

(c) There are two asymptotes

(d) There are three asymptotes

12. What are the angles of the asymptotes in degrees for the system shown below? [2]



(a) 90 and -90

(b) 90, 180 and 270

(c) 60, -60 and 180

(d) 0, 60 and 180

13. In the previous problem, which one is the real-axis intercept for the asymptotes? [1]

(a) $s = -0.423$

(b) $s = -1$

(c) $s = -2$

(d) $s = -3.54$

14. A transfer function has a second order denominator and constant gain as the numerator. Which statement is true for this system? [1]

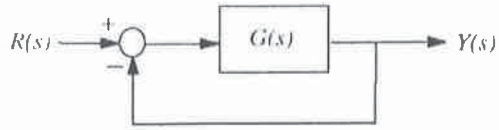
(a) The system has one zero at infinity

(b) The system does not have a zero

(c) The system has two zeros at origin

(d) The system has two zeros at infinity

15. Consider the unity feedback control system



where

$$G(s) = \frac{K}{s(s+5)}.$$

The design specifications are:

(i) Peak Time $T_p \le 1.0$ sec

(ii) Percent overshoot $PO \le 10\%$

with K as the design parameter. Which one is true? [1]

(a) Both specifications can be satisfied.

(b) Only the second specification $PO \le 10\%$ can be satisfied.

(c) Only the first specification $T_p \le 1.0$ can be satisfied.

(d) Neither specification can be satisfied.

16. While designing a PD controller, a zero has to be added to the system in order for the root locus to pass through the desired point of $-1 + j$. The two poles of the system make angles of 22.5° and 45° whereas the zero of the system makes an angle of 60° with the real axis. What will be the angular contribution of the compensator zero? **[1]**
    (a) 62.5°
    (b) 92.5°
    (c) 132.5°
    (d) 172.5

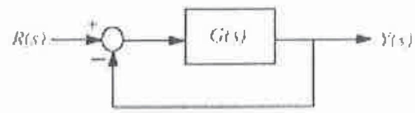
17. What is the location of the compensator zero for the previous problem? **[1]**
    (a) -1.52
    (b) -0.96
    (c) -0.08
    (d) +6.59

18. For an under-damped system, the resonant frequency peak in the Bode magnitude plot **[1]**
    (a) Increases by decreasing the damping ratio
    (b) Increases by increasing the damping ratio
    (c) Is independent of the change in damping ratio
    (d) None of the above

19. While making the Bode phase plot for the first-order pole of a system, the frequency is scaled to **[1]**
    (a) Obtain a phase of -45° at break frequency of $\omega_n = 1$ rad/sec
    (b) Obtain a phase of 45° at break frequency of $\omega_n = 1$ rad/sec
    (c) Obtain a phase of 0° at break frequency of $\omega_n = 1$ rad/sec
    (d) Obtain a phase of 90° at break frequency of $\omega_n = 1$ rad/sec

Question 2.

(Part A). Consider the unity feedback system



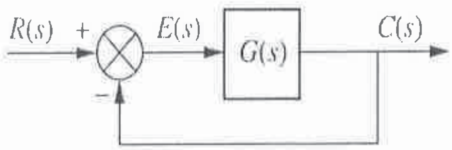
$$G(s) = \frac{K(s+1)}{s^2 + 5s + 17.33}.$$

(a) What are the approximate angles of departure of the root-locus from the complex poles?

(b) For the open loop transfer function $\frac{K(s+1)}{s^2+5s+10}$, what is the break-in point?

(c) What is the gain value at break-in point for the open loop transfer function given in the above problem?

(Part B) For the open-loop pole-zero plot in the following figure (with unity feedback):



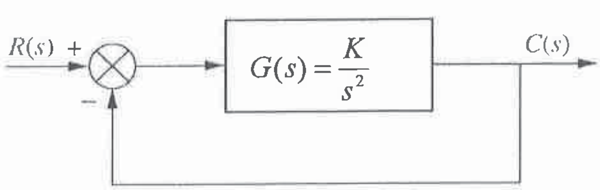
$$G(s) = \frac{K}{(s+1)(s+2)(s+3)}$$

(a) What are the intercept and angles of the asymptotes?

(b) What is the range of K for stability?

(c) Where is the crossing with the imaginary axis?

Question 3. The unity feedback system shown in the following figure with



is to be designed for a settling time of 1.667 seconds and a 16.3% overshoot. If a compensator zero is placed at -1, do the following:

(a) Find the coordinates of the dominant poles.

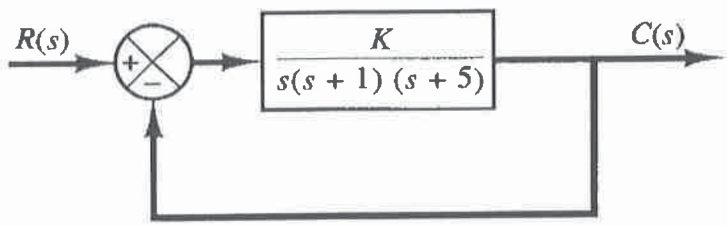
(b) Find the compensator pole.

(c) Find the compensated system gain.

(d) Find the location of all nondominant poles of the closed loop system.
(e) Discuss the accuracy your second-order approximation.
(f) Evaluate the steady state error of the system to unit step, ramp and parabola inputs.

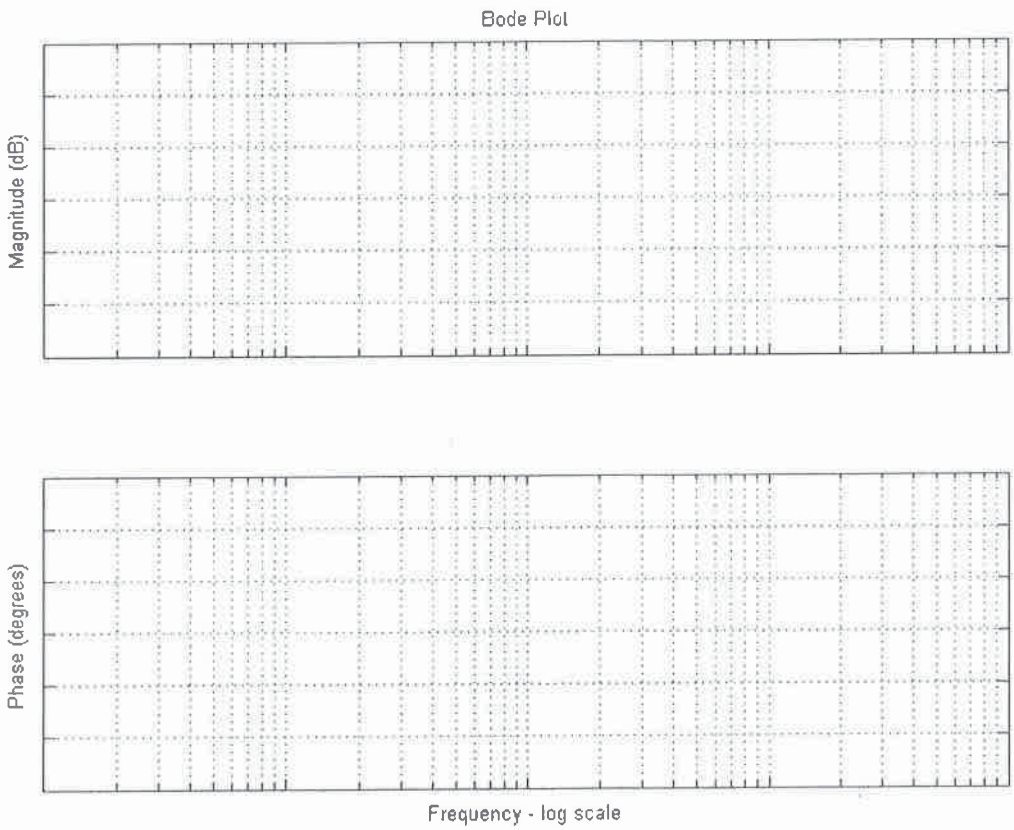
Question 4. For the system shown in the following figure,

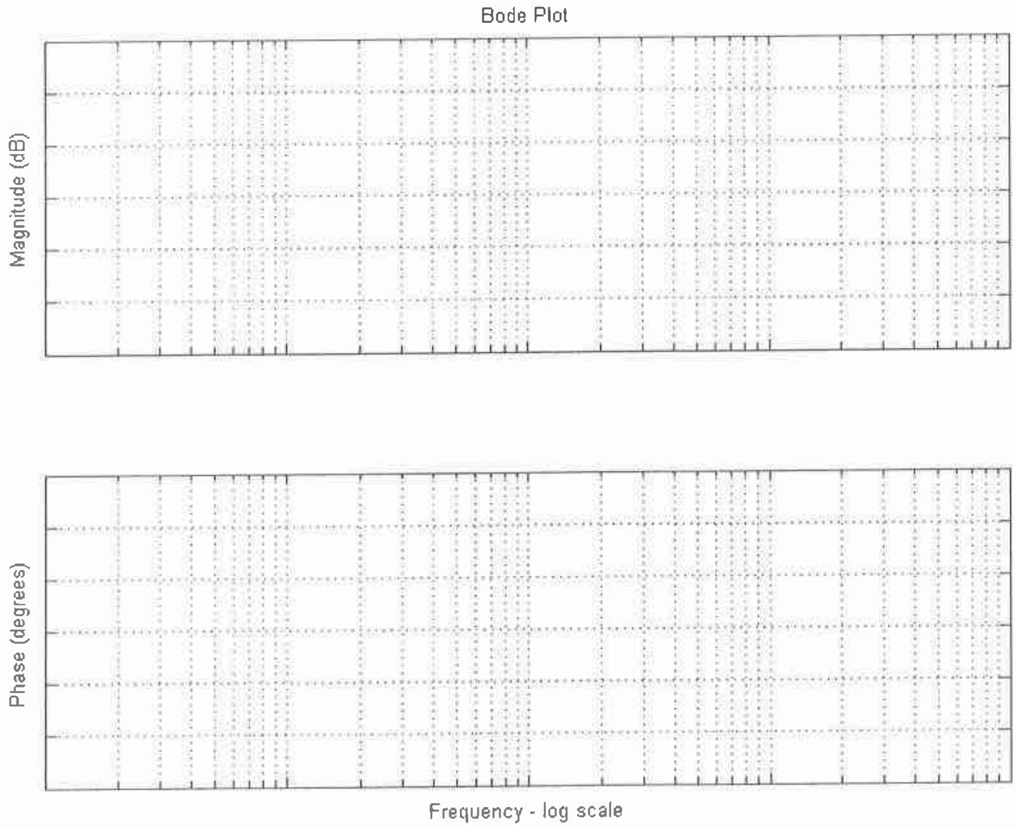
(a) Use the transfer function G(s) of the system to sketch the approximate Bode log-magnitude and phase plots for each component of the unity feedback system given the open-loop transfer function when K = 5:

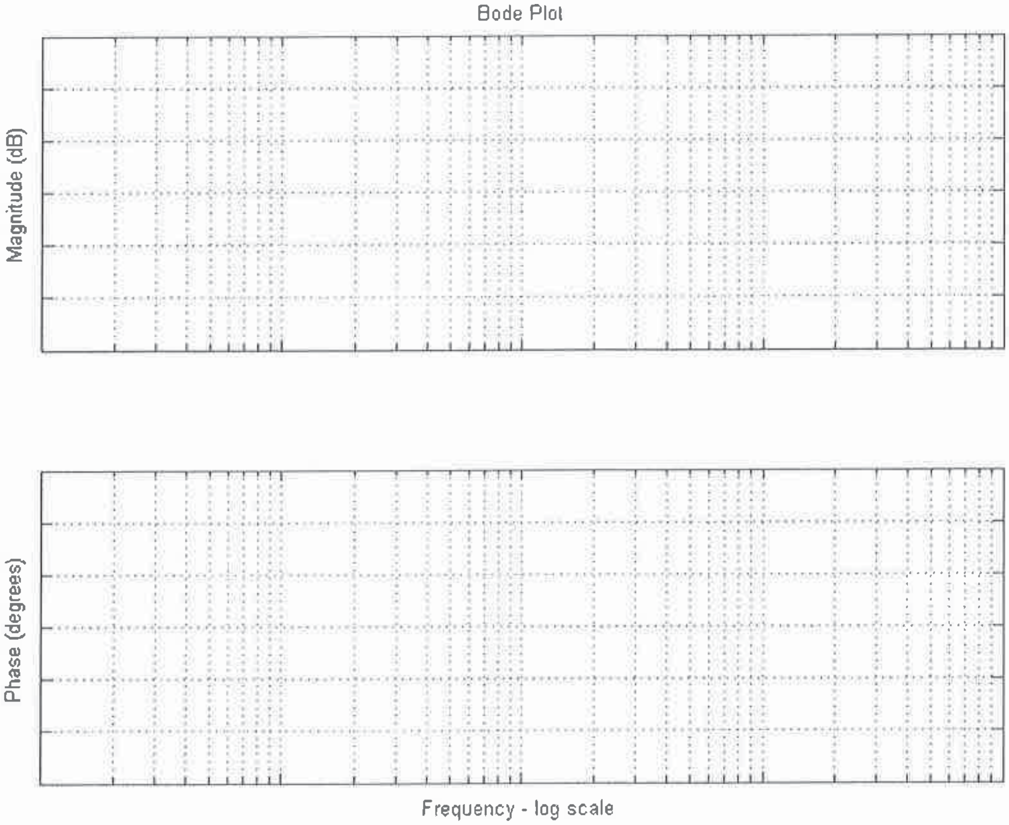


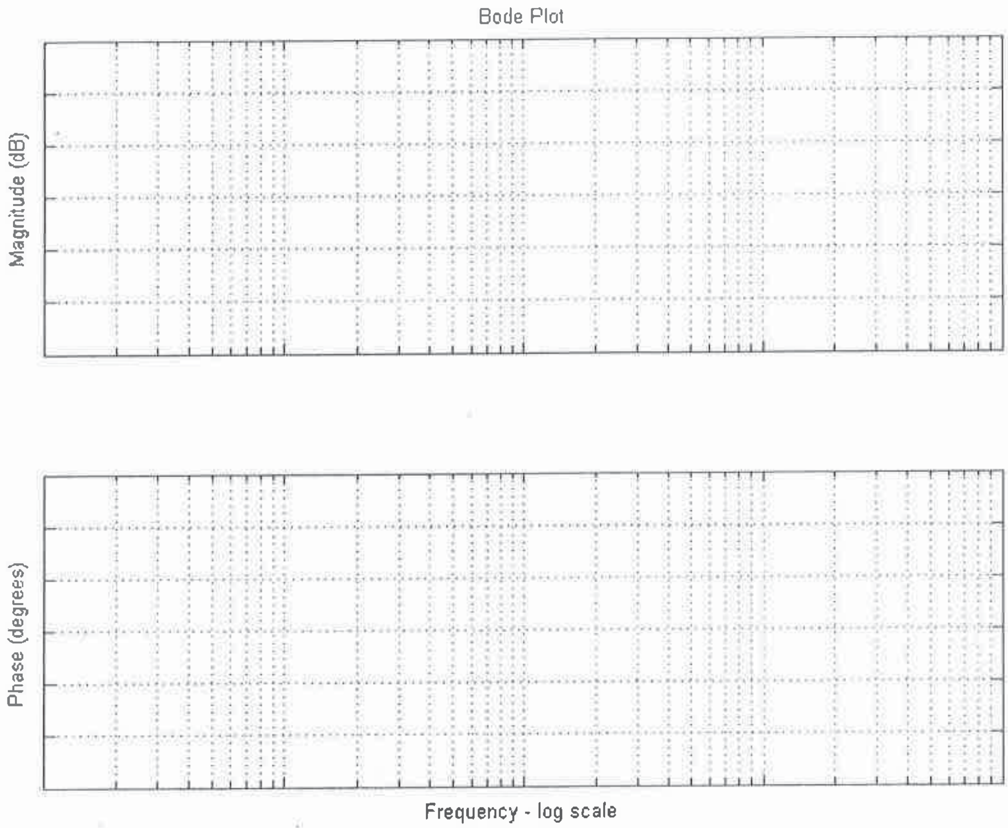
after normalizing the given transfer function. You need to sketch magnitude and phase plots for each component first (i.e., overall gain after normmalization, and three poles). Then you need to show the overall Bode diagram.

(b) Find the gain margin, phase margin and their frequencies for the system when K = 5.
(c) What would be the maximum gain (K) to keep the system stable?

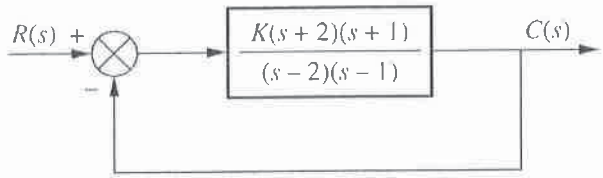

Bode Plot
Magnitude (dB)
Phase (degrees)
Frequency - log scale

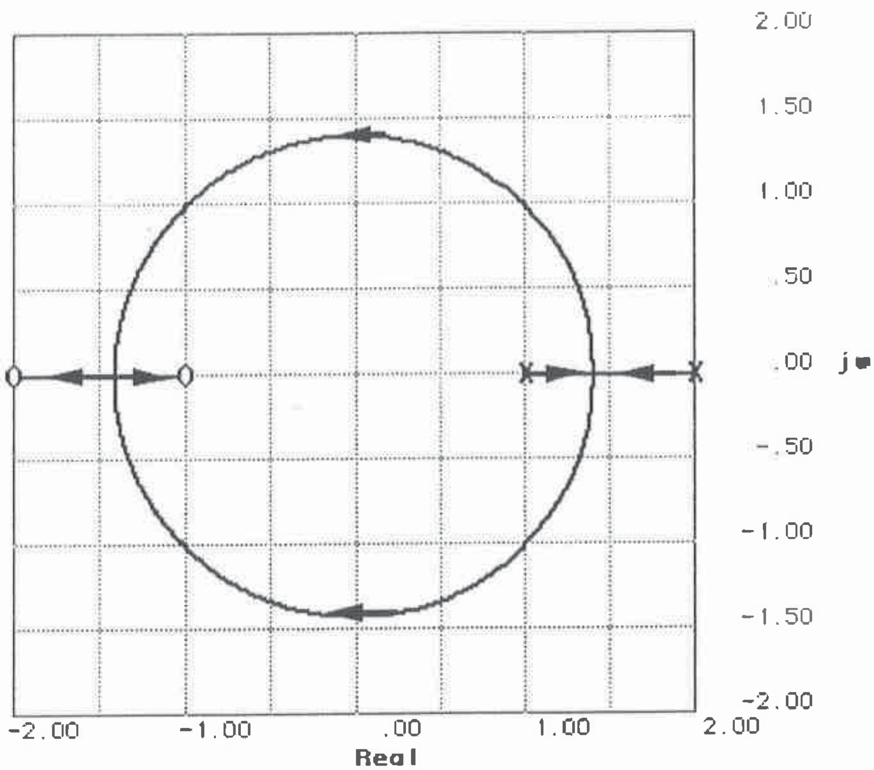

Bode Plot
Magnitude (dB)
Phase (degrees)
Frequency - log scale


Bode Plot
Magnitude (dB)
Phase (degrees)
Frequency - log scale


Bode Plot
Magnitude (dB)
Phase (degrees)
Frequency - log scale

Question 5. The root locus of a system is provided in the following figure.





(a) Find the location of closed-loop system poles (design poles) to provide $\varsigma = 0.707$ (use the provided scaled graph to avoid numerical calculations).

(b) Find the value of K corresponding to the design poles.

(c) Find the value of settling time corresponding to the design poles.

(d) It is desired to make the system faster (by factor of 3, i.e., one third of the existing settling time) but to have the same damping ratio. What would be the new design poles location?

(e) Calculate the summation of the angles to the new design pole?

(f) An engineer claims to design a PD compensator to achieve the new design poles. Calculate the angle contribution of z_c of PD controller. Discuss in ONE line the validity of the claim.

(g) Design a PI controller to make steady state error diminish (choose zero location at 0.1).

Inverse Laplace Transforms	
$F(s)$	$f(t)$
$\dfrac{A}{s+\alpha}$	$Ae^{-\alpha t}$
$\dfrac{C+jD}{s+\alpha+j\beta}+\dfrac{C-jD}{s+\alpha-j\beta}$	$2e^{-\alpha t}\left(C\cos\beta t+D\sin\beta t\right)$
$\dfrac{A}{(s+\alpha)^{n+1}}$	$\dfrac{At^n e^{-\alpha t}}{n!}$
$\dfrac{C+jD}{(s+\alpha+j\beta)^{n+1}}+\dfrac{C-jD}{(s+\alpha-j\beta)^{n+1}}$	$\dfrac{2t^n e^{-\alpha t}}{n!}\left(C\cos\beta t+D\sin\beta t\right)$

Table of Laplace and z-Transforms (*h* denotes the sample period)		
$f(t)$	$F(s)$	$F(z)$
unit impulse	1	1
unit step	$\frac{1}{s}$	$\frac{hz}{z-1}$
$e^{-\alpha t}$	$\frac{1}{s+\alpha}$	$\frac{z}{z-e^{-\alpha h}}$
t	$\frac{1}{s^2}$	$\frac{hz}{(z-1)^2}$
$\cos \beta t$	$\frac{s}{s^2+\beta^2}$	$\frac{z(z-\cos\beta h)}{z^2-2z\cos\beta h+1}$
$\sin \beta t$	$\frac{\beta}{s^2+\beta^2}$	$\frac{z\sin\beta h}{z^2-2z\cos\beta h+1}$
$e^{-\alpha t}\cos \beta t$	$\frac{s+\alpha}{(s+\alpha)^2+\beta^2}$	$\frac{z(z-e^{-\alpha h}\cos\beta h)}{z^2-2ze^{-\alpha h}\cos\beta h+e^{-2\alpha h}}$
$e^{-\alpha t}\sin \beta t$	$\frac{\beta}{(s+\alpha)^2+\beta^2}$	$\frac{ze^{-\alpha h}\sin\beta h}{z^2-2ze^{-\alpha h}\cos\beta h+e^{-2\alpha h}}$
$t\,f(t)$	$-\frac{dF(s)}{ds}$	$-zh\frac{dF(z)}{dz}$
$e^{-\alpha t}f(t)$	$F(s+\alpha)$	$F(ze^{\alpha h})$