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Director's Message

B. Singh (Ex. IES)

Engineering is one of the most chosen graduating field. Taking engineering is usually a matter of interest but this eventually develops into "purpose of being an engineer" when you choose engineering services as a career option.

Train goes in tunnel we don't panic but sit still and trust the engineer, even we don't doubt on signalling system, we don't think twice crossing over a bridge reducing our travel time; every engineer has a purpose in his department which when coupled with his unique talent provides service to mankind.

I believe *"the educator must realize in the potential power of his pupil and he must employ all his art, in seeking to bring his pupil to experience this power".* To support dreams of every engineer and to make efficient use of capabilities of aspirant, MADE EASY team has put sincere efforts in compiling all the previous years' ESE-Pre questions with accurate and detailed explanation. The objective of this book is to facilitate every aspirant in ESE preparation and so, questions are segregated chapterwise and topicwise to enable the student to do topicwise preparation and strengthen the concept as and when they are read.

I would like to acknowledge efforts of entire MADE EASY team who worked hard to solve previous years' papers with accuracy and I hope this book will stand up to the expectations of aspirants and my desire to serve student fraternity by providing best study material and quality guidance will get accomplished.

B. Singh (Ex. IES)
CMD, MADE EASY Group

Volume-II

ELECTRONICS & TELECOM. ENGG.

Objective Solved Questions

of UPSC Engineering Services Examination

Contents

■■■■

UNIT

I

Control Systems

Syllabus

Signal flow graphs, Routh-Hurwitz criteria, root loci, Nyquist/Bode plots; Feedback systems-open &close loop types, stability analysis, steady state, transient and frequency response analysis; Design of control systems, compensators, elements of lead/lag compensation, PID and industrial controllers.

Contents

2 Time Domain Analysis

2.1 The response $c(t)$ of a system is described by the differential equation

$$\frac{d^2c(t)}{dt^2} + 4\frac{dc(t)}{dt} + 5c(t) = 0$$

The system response is

(a) undamped (b) underdamped
(c) critically damped (d) oscillatory

[ESE-1999]

2.2 The system with the open-loop transfer function

$$G(s)\,H(s) = \frac{1}{s(1+s)} \text{ is}$$

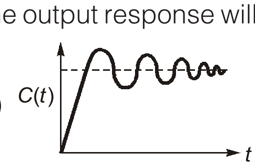
(a) type 2 and order 1
(b) type 1 and order 1
(c) type 0 and order 0
(d) type 1 and order 2

[ESE-1999]

2.3 A step input is applied to a system with the transfer function

$$G(s) = \frac{e^{-s}}{1+0.5s}$$

The output response will be

(a)


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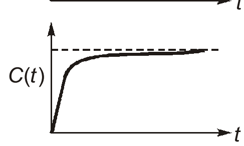

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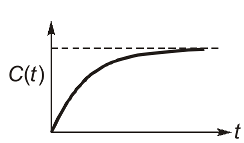

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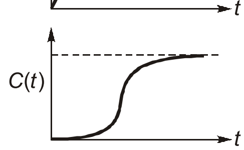


[ESE-1999]

2.4 **Assertion (A):** The largest undershoot corresponding to a unit step input to an underdamped second order system with damping ratio ξ and undamped natural frequency of oscillation ω_n is $e^{-2\xi\pi/\sqrt{1-\xi^2}}$.

Reason (R): The overshoots and undershoots of a second order underdamped system is

$$e^{-\xi n\pi/\sqrt{1-\xi^2}},\, n = 1, 2, \ldots\ldots$$

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE-2000]

2.5 Which one of the following transfer functions represents the critically damped system?

(a) $H_1(s) = \dfrac{1}{s^2 + 4s + 4}$

(b) $H_2(s) = \dfrac{1}{s^2 + 3s + 4}$

(c) $H_3(s) = \dfrac{1}{s^2 + 2s + 4}$

(d) $H_4(s) = \dfrac{1}{s^2 + s + 4}$

[ESE-2000]

2.6 A second order system has the damping ratio ξ and undamped natural frequency of oscillation ω_n. The settling time at 2% tolerance band of the system is

(a) $2/\xi\omega_n$ (b) $3/\xi\omega_n$
(c) $4/\xi\omega_n$ (d) $\xi\omega_n$

[ESE-2000]

2.7 Two identical first-order systems have been cascaded non-interactively. The unit step response of the systems will be

(a) overdamped (b) underdamped
(c) undamped (d) critically damped

[ESE-2001]

2.8 Which one of the following is the response $y(t)$ of a causal LTI system described by

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

for a given input $x(t) = e^{-t}\,u(t)$?

(a) $y(t) = e^{-t} \sin t\, u(t)$
(b) $y(t) = e^{-(t-1)} \sin(t-1)\, u(t-1)$
(c) $y(t) = \sin(t-1)\, u(t-1)$
(d) $y(t) = e^{-t} \cos t\, u(t)$

[ESE-2001]

2.9 Which one of the following is the steady-state error for a step input applied to a unity feedback system with the open loop transfer function

$$G(s) = \frac{10}{s^2+14s+50}?$$

(a) $e_{ss} = 0$ (b) $e_{ss} = 0.83$
(c) $e_{ss} = 1$ (d) $e_{ss} = \infty$

[ESE-2001]

2.10 The unit step response of a particular control system is given by $c(t) = 1 - 10e^{-t}$. Then its transfer function is

(a) $\frac{10}{s+1}$ (b) $\frac{s-9}{s+1}$
(c) $\frac{1-9s}{s+1}$ (d) $\frac{1-9s}{s(s+1)}$

[ESE-2001]

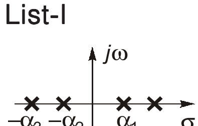
2.11 A third-order system is approximated to an equivalent second order system. The rise time of this approximated lower order system will be

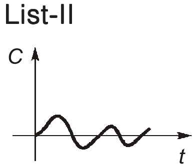
(a) same as original system for any input
(b) smaller than the original system for any input
(c) larger than the original system for any input
(d) larger or smaller depending on the input

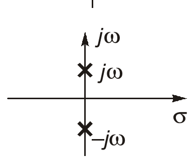
[ESE-2001]

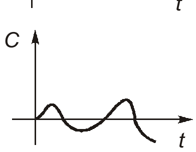
2.12 Match **List-I** (Pole-zero plot of linear control system) with **List-II** (Responses of the system) and select the correct answer:

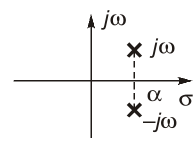
List-I **List-II**

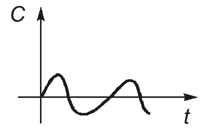
A. 

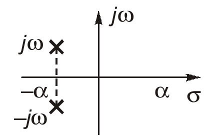
1. 

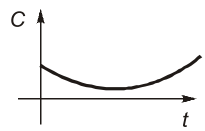
B. 

2. 

C. 

3. 

D. 

4. 

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	4	3	2	1
(c)	3	4	2	1
(d)	3	4	1	2

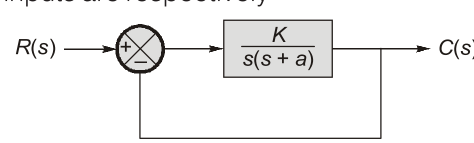
[ESE-2002]

2.13 A system has a single pole at origin. Its impulse response will be

(a) constant
(b) ramp
(c) decaying exponential
(d) oscillatory

[ESE-2002]

2.14 Consider the unity feedback system as shown below. The sensitivity of the steady state error to change in parameter K and parameter a with ramp inputs are respectively



(a) 1, –1 (b) –1, 1
(c) 1, 0 (d) 0, 1

[ESE-2003]

2.15 Which one of the following is the transfer function of a linear system whose output is t^2e^{-t} for a unit step input?

(a) $\frac{s}{(s+1)^3}$ (b) $\frac{2s}{(s+1)^3}$

(c) $\frac{1}{s^2(s+1)}$ (d) $\frac{2}{s(s+1)^2}$

[ESE-2003]

2.16 Assuming unit ramp input, match **List-I** (System Type) with **List-II** (Steady State Error) and select the correct answer using the codes given below the lists:

List-I	List-II
A. 0	1. K
B. 1	2. ∞
C. 2	3. 0
D. 3	4. $1/K$

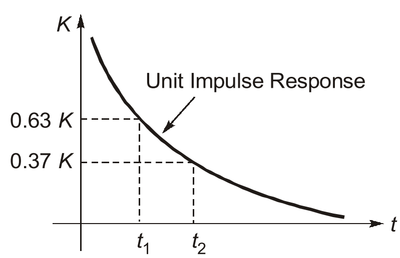
Codes:

	A	B	C	D
(a)	2	4	3	3
(b)	1	2	2	4
(c)	2	1	4	3
(d)	1	2	4	3

[ESE-2003]

2.17 When the time period of observation is large, the type of the error is
(a) Transient error
(b) Steady state error
(c) Half-power error
(d) Position error constant [ESE-2003]

2.18 The unit impulse response of a system having transfer function $K/(s + \alpha)$ is shown below. The value of α is



(a) t_1 (b) $1/t_1$
(c) t_2 (d) $1/t_2$

[ESE-2003]

2.19 What is the unit step response of a unity feedback control system having forward path transfer function $G(s) = \frac{80}{s(s+18)}$?
(a) Overdamped
(b) Critically damped
(c) Underdamped
(d) Undamped oscillatory

[ESE-2004]

2.20 Consider the following statements:
Feedback in control system can be used
1. to reduce the sensitivity of the system to parameter variations and disturbances
2. to change time constant of the system
3. to increase loop gain of the system

Which of the statements given above are correct?
(a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1 and 3

[ESE-2004]

2.21 Which one of the following statements is correct?
A second-order system is critically damped when the roots of its characteristic equation are
(a) negative, real and unequal
(b) complex conjugates
(c) negative, real and equal
(d) positive, real and equal

[ESE-2004]

2.22 A linear network has the system function

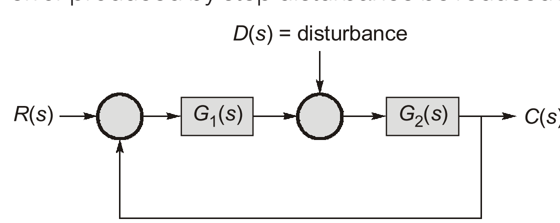
$$H\frac{(s+c)}{(s+a)(s+b)}$$

The outputs of the network with zero initial conditions for two different inputs are tabled as

Input $x(t)$	Output $y(t)$
$u(t)$	$2+De^{-t}+Ee^{-3t}$
$e^{-2t}u(t)$	$Fe^{-t}+Ge^{-3t}$

Then the values of c and H are, respectively
(a) 2 and 3 (b) 3 and 2
(c) 2 and 2 (d) 1 and 3 [ESE-2005]

2.23 For the given system, how can be steady state error produced by step disturbance be reduced?



(a) By increasing dc gain of $G_1(s)G_2(s)$
(b) By increasing dc gain of $G_2(s)$
(c) By increasing dc gain of $G_1(s)$
(d) By removing the feedback [ESE-2005]

2.24 Which one of the following expresses the time at which second peak in step response occurs for a second order system?

(a) $\frac{\pi}{\omega_n\sqrt{1-\xi^2}}$ (b) $\frac{2\pi}{\omega_n\sqrt{1-\xi^2}}$

(c) $\frac{3\pi}{\omega_n\sqrt{1-\xi^2}}$ (d) $\frac{\pi}{\sqrt{1-\xi^2}}$

[ESE-2005]

2.25 With negative feedback in a closed loop control system, the system sensitivity to parameter variations:
(a) Increases (b) Decreases
(c) Becomes zero (d) Becomes infinite
[ESE-2005]

2.26 An underdamped second order system with negative damping will have the two roots:
(a) On the negative real axis as real roots
(b) On the left hand side of complex plane as complex roots
(c) On the right hand side of complex plane as complex conjugates
(d) On the positive real axis as real roots
[ESE-2005]

2.27 Match **List-I** (System $G(s)$) with **List-II** (Nature of Response) and select the correct answer using the code given below the Lists:

List-I	**List-II**
A. $\frac{400}{s^2+12s+400}$	1. Undamped
B. $\frac{900}{s^2+90s+900}$	2. Critically damped
C. $\frac{225}{s^2+30s+225}$	3. Underdamped
D. $\frac{625}{s^2+625}$	4. Overdamped

Codes:

	A	B	C	D
(a)	3	1	2	4
(b)	2	4	3	1
(c)	3	4	2	1
(d)	2	1	3	4

[ESE-2005]

2.28 Given a unity feedback system with $G(s) = \frac{K}{s(s+4)}$, what is the value of K for a damping ratio of 0.5?
(a) 1 (b) 16
(c) 4 (d) 2
[ESE-2005]

2.29 What is the steady state error for a unity feedback control system having $G(s) = \frac{1}{s(s+1)}$, due to unit ramp input?
(a) 1 (b) 0.5
(c) 0.25 (d) $\sqrt{0.5}$ **[ESE-2005]**

2.30 What is the value of K for a unity feedback system with $G(s) = \frac{K}{s(1+s)}$ to have a peak overshoot of 50%?
(a) 0.53 (b) 5.3
(c) 0.6 (d) 0.047 **[ESE-2006]**

2.31 Consider the following statements:
For the first order transient systems, the time constant is
1. a specification of transient response
2. reciprocal of real-axis pole location
3. an indication of accuracy of response
4. an indication of speed of the response

Which of the statements given above are correct?
(a) Only 1 and 2 (b) Only 1, 2 and 4
(c) Only 3 and 4 (d) 1, 2, 3 and 4
[ESE-2006]

2.32 The unit step response of a second order system is = $1 - e^{-5t} - 5t\,e^{-5t}$
Consider the following statements:
1. The undamped natural frequency is 5 rad/s.
2. The damping ratio is 1.
3. The impulse response is $25t\,e^{-5t}$.

Which of the statements given above are correct?
(a) Only 1 and 2 (b) Only 2 and 3
(c) Only 1 and 3 (d) 1, 2 and 3
[ESE-2006]

2.33 The unit step response of a system is $1 - e^{-t}(1+t)$. Which is this system?
(a) Unstable (b) Stable
(c) Critically stable (d) Oscillatory
[ESE-2006]

2.34 **Assertion (A):** The impulse response is only a function of the terms in natural response.
Reason (R): The differentiation and differencing operations eliminate the constant terms associated with the particular solution in the step response and change only the constants associated with exponential terms in the natural response.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true **[ESE-2006]**

2.35 The relation between input $x(t)$ and output $y(t)$ of a continuous-time system is given by

$$\frac{dy(t)}{dt} + 3y(t) = x(t)$$

What is the forced response of the system when $x(t) = k$ (a constant)?

(a) k (b) $k/3$
(c) $3k$ (d) 0 **[ESE-2007]**

2.36 How can the steady-state error in a system be reduced?
(a) By decreasing the type of system
(b) By increasing system gain
(c) By decreasing the static error constant
(d) By increasing the input **[ESE-2007]**

2.37 For second-order system

$$2\frac{d^2y}{dt^2} + 4\frac{dy}{dt} + 8y = 8x$$

what is the damping ratio?
(a) 1 (b) 0.25
(c) 0.333 (d) 0.5 **[ESE-2007]**

2.38 For a second-order system, ξ is equal to zero in the transfer function given by

$$\frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

Which one of the following is correct?
(a) Closed-loop poles are complex conjugate with negative real part
(b) Closed-loop poles are purely imaginary
(c) Closed-loop poles are real, equal and negative
(d) Closed-loop poles are real, unequal and negative

[ESE-2007]

2.39 For the unity feedback system with $G(s) = \dfrac{10}{s^2(s+4)}$, what is the steady state error resulting from an input $10t$?
(a) 10 (b) 4
(c) Zero (d) 1

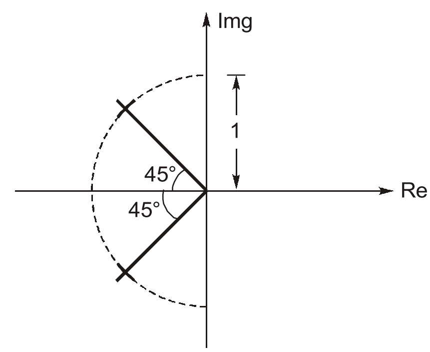
[ESE-2007]

2.40 **Assertion (A):** The system having characteristic equation $4s^2 + 6s + 1 = 0$ gives rise to under-damped oscillations for a step input.
Reason (R): The un-damped natural frequency of oscillation of the system is $\omega_n = 0.5$ rad/s.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE-2008]

2.41 A diaphragm type pressure sensor has two poles as shown in the figure below. The zeros are at infinity. What is its steady state deformation for a unit step input pressure?



(a) 0.25 (b) 0.5
(c) 0.707 (d) 1 **[ESE-2008]**

2.42 A second order control system has a transfer function $\dfrac{16}{s^2 + 4s + 16}$. What is the time for the first overshoot?

(a) $\dfrac{2\pi}{\sqrt{3}}$ s (b) $\dfrac{\pi}{\sqrt{3}}$ s
(c) $\dfrac{\pi}{2\sqrt{3}}$ s (d) $\dfrac{\pi}{4\sqrt{3}}$ s

[ESE-2008]

2.43 The closed loop transfer function of a control system has the following poles and zeros

Poles	**Zeros**
$p_1 = -0.5$	$z_1 = -6$
$p_2 = -1.0$	$z_2 = -8$
$p_3 = -5$	
$p_4 = -10$	

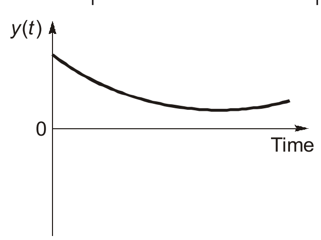
The closed loop response can be closely approximated by considering which of the following?
(a) p_1 and p_2 (b) p_3 and p_4
(c) p_3 and z_1 (d) p_4 and z_2

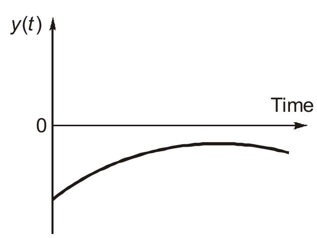
[ESE-2008]

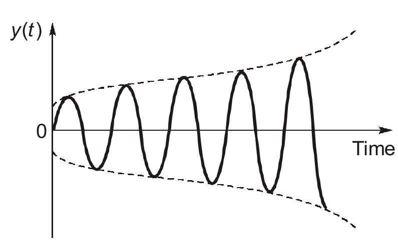
2.44 Consider the function $F(s) = \dfrac{\omega}{s^2 + \omega^2}$ where $F(s)$ is the Laplace transform of $f(t)$. What is the steady-state value of $f(t)$?
(a) Zero
(b) One
(c) Two
(d) A value between –1 and +1 **[ESE-2009]**

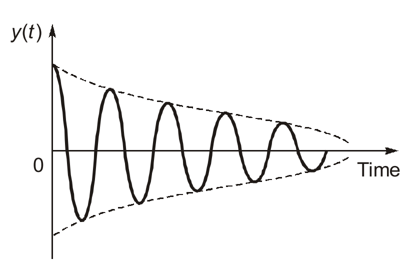
2.45 In a unity feedback control system with $G(s) = \dfrac{4}{s^2 + 0.4s}$ when subjected to unit step input, it is required that system response should be settled within 2% tolerance band; the system settling time is
(a) 1 sec (b) 2 sec
(c) 10 sec (d) 20 sec **[ESE-2010]**

2.46 Which of the following is the response of a spring-mass-damper with under-damping?

(a)


(b)


(c)


(d)


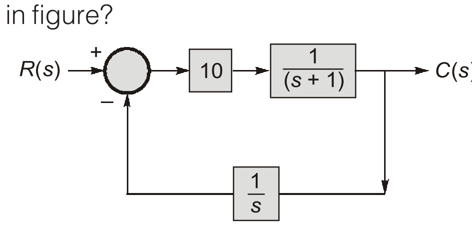
[ESE-2010]

2.47 From the point of view of stability and response speed of a closed loop system, the appropriate range for the value of damping ratio lies between
(a) 0 to 0.2 (b) 0.4 to 0.7
(c) 0.8 to 1.0 (d) 1.1 to 1.5
[ESE-2010]

2.48 **Assertion (A):** Steady state error can be reduced by increasing integral gain.
Reason (R): Overshoot can be reduced by increasing derivative gain.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true **[ESE-2010]**

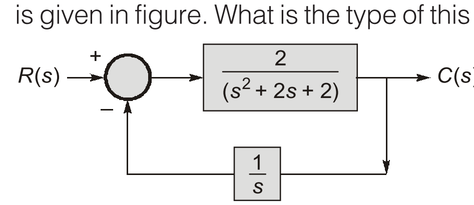
2.49 **Assertion (A):** A linear system gives a bounded output if the input is bounded.
Reason (R): The roots of the characteristic equation have all negative real parts and response due to initial conditions decay to zero as time t tends to infinity.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true **[ESE-2010]**

2.50 What is the steady-state value of the unit-step response of a closed-loop control system shown in figure?



(a) –0.5 (b) 0
(c) 2 (d) ∞ **[ESE-2011]**

2.51 The block diagram of a closed-loop control system is given in figure. What is the type of this system?



(a) Zero (b) One
(c) Two (d) Three **[ESE-2011]**

Answers Time Domain Analysis

2.1	(b)	2.2	(d)	2.3	(d)	2.4	(a)	2.5	(a)	2.6	(c)	2.7	(d)	2.8	(a)	2.9	(b)
2.10	(c)	2.11	(a)	2.12	(b)	2.13	(a)	2.14	(b)	2.15	(b)	2.16	(a)	2.17	(b)	2.18	(d)
2.19	(a)	2.20	(b)	2.21	(c)	2.22	(a)	2.23	(c)	2.24	(c)	2.25	(b)	2.26	(c)	2.27	(c)
2.28	(b)	2.29	(a)	2.30	(b)	2.31	(b)	2.32	(d)	2.33	(b)	2.34	(a)	2.35	(b)	2.36	(b)
2.37	(d)	2.38	(b)	2.39	(c)	2.40	(d)	2.41	(d)	2.42	(c)	2.43	(a)	2.44	(d)	2.45	(d)
2.46	(d)	2.47	(b)	2.48	(b)	2.49	(d)	2.50	(b)	2.51	(b)	2.52	(b)	2.53	(b)	2.54	(c)
2.55	(d)	2.56	(a)	2.57	(b)	2.58	(b)	2.59	(d)	2.60	(b)	2.61	(c)	2.62	(a)	2.63	(a)
2.64	(c)	2.65	(c)	2.66	(d)	2.67	(d)	2.68	(c)	2.69	(c)	2.70	(d)	2.71	(d)	2.72	(a)
2.73	(b)	2.74	(b)	2.75	(a)	2.76	(c)	2.77	(d)	2.78	(b)	2.79	(c)	2.80	(a)	2.81	(c)
2.82	(c)	2.83	(a)	2.84	(c)	2.85	(c)	2.86	(*)	2.87	(d)	2.88	(*)	2.89	(c)	2.90	(a)
2.91	(b)	2.92	(d)	2.93	(b)	2.94	(*)	2.95	(a)	2.96	(c)	2.97	(a)	2.98	(c)	2.99	(d)
2.100	(a)	2.101	(d)	2.102	(b)	2.103	(b)	2.104	(d)	2.105	(a)	2.106	(d)	2.107	(d)	2.108	(a)
2.109	(a)	2.110	(d)	2.111	(b)	2.112	(b)	2.113	(d)	2.114	(c)	2.115	(d)				

Explanations Time Domain Analysis

2.1 (b)

$$\omega_n = \sqrt{5}\ \text{rad/s}$$

$$2\xi\omega_n = 4 \Rightarrow \xi = \frac{4}{2\sqrt{5}} < 1$$

$\Rightarrow$ System response is underdamped.

2.2 (d)

In the pole zero form,

$$G(s)\,H(s) = \frac{K(s+z_1)(s+z_2)\,...}{s^n(s+p_1)(s+p_2)\,...}$$

the type of the system is 'n' and order of the system is the highest power of s in the denominator.

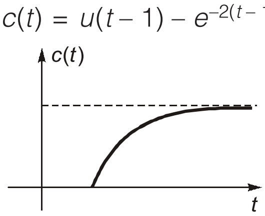
2.3 (d)

$$C(s) = G(s)\cdot R(s) = \frac{e^{-s}}{1+0.5s}\cdot\frac{1}{s}$$

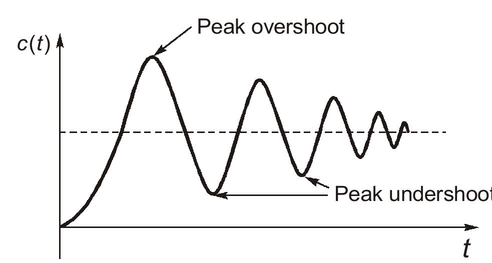
$$\Rightarrow \quad C(s) = \frac{2e^{-s}}{s(s+2)}$$

$$\Rightarrow \quad C(s) = \frac{e^{-s}}{s} - \frac{e^{-s}}{s+2}$$

$$\Rightarrow \quad c(t) = u(t-1) - e^{-2(t-1)}\,u(t-1)$$



2.4 (a)



$$M_P = e^{-\xi n\pi/\sqrt{1-\xi^2}} \quad \text{for } n = 1, 2, 3, ...$$

2.5 (a)

$$H_1(s) = \frac{1}{s^2+4s+4} = \frac{1}{(s+2)^2}$$

since both roots are negative real and equal, it is a critically damped system.

2.6 (c)

Settling time at 2% of tolerance band of the system,

$$t_s = \frac{4}{\xi\omega_n}$$

Settling time at 5% of tolerance band of the system,

$$t_s = \frac{3}{\xi\omega_n}$$

2.7 (d)

$$\left(\frac{1}{s+\tau}\right)\cdot\left(\frac{1}{s+\tau}\right) = \frac{1}{(s+\tau)^2}$$

Since both are cascaded non-interactively, the overall unit step response will be as shown above. It is clear that the above response is critically damped.

Alternate Solution:

Transfer function of first order system is $\frac{1}{1+sT}$

when two such are cascaded overall transfer function is (TF_1)

$$TF_1 = \frac{1}{1+sT}\cdot\frac{1}{1+sT}$$

$$= \frac{1}{s^2T^2+2sT+1} = \frac{1/T^2}{s^2+\frac{2s}{T}+\frac{1}{T^2}}$$

Comparing with standard second order transfer function, we get

$$\omega_n = \frac{1}{T}$$

and $2\xi\omega_n = \frac{2}{T}$

$$\xi = 1$$

∴ Critically underdamped.

2.8 (a)

$$X(s) = \frac{1}{s+1}$$

$$Y(s) = X(s)H(s)$$

$$= \frac{1}{(s+1)}\cdot\frac{(s+1)}{\{(s+1)^2+1\}} = \frac{1}{(s+1)^2+1}$$

$$\Rightarrow y(t) = e^{-t}\sin t\, u(t)$$

2.9 (b)

$$G(s) = \frac{10}{s^2+14s+50}$$

It is type 0 system. Input is step input.

$$e_{ss} = \frac{1}{1+K_p}$$

where $K_p = \lim_{s\to 0} G(s)H(s)$

$$K_p = \lim_{s\to 0}\frac{10}{s^2+14s+50}$$

$$= \frac{10}{50} = 0.2$$

$$e_{ss} = \frac{1}{1+0.2} = \frac{1}{1.3} = 0.83$$

2.10 (c)

$$\text{TF} = s\,L[\text{Step response}] = \frac{1-9s}{s+1}$$

2.13 (a)

$$G(s) = \frac{1}{s} \Rightarrow g(t) = 1$$

The impulse response of the system is constant.

2.14 (b)

$$R(s) = \frac{1}{s^2}$$

Steady state error

$$e_{ss} = \lim_{s\to 0}\frac{sR(s)}{1+G(s)H(s)}$$

$$\Rightarrow \quad e_{ss} = \lim_{s\to 0}\frac{s.1/s^2}{1+\frac{K}{s(s+a)}.1}$$

$$\Rightarrow \quad e_{ss} = \lim_{s\to 0}\frac{s+a}{s(s+a)+K}$$

$$\Rightarrow \quad e_{ss} = \frac{a}{K}$$

Sensitivity of e_{ss} to change in K is

$$S_K^{e_{ss}} = \frac{de_{ss}}{dK}\times\frac{K}{e_{ss}} = \frac{-a}{K^2}\times\frac{K}{a/K}$$

$$\Rightarrow \quad S_K^{e_{ss}} = -1$$

Now, $S_a^{e_{ss}} = \frac{de_{ss}}{da}\times\frac{a}{e_{ss}} = \frac{1}{K}\times\frac{a}{a/K}$

$$\Rightarrow \quad S_a^{e_{ss}} = 1$$

2.15 (b)

$$c(t) = t^2 e^{-t}$$

$$C(s) = \frac{2}{(s+1)^3}$$

$$R(s) = \frac{1}{s}$$

Transfer function

$$G(s) = \frac{C(s)}{R(s)} = \frac{2/(s+1)^3}{1/s}$$

$$\Rightarrow \quad G(s) = \frac{2s}{(s+1)^3}$$

2.16 **(a)**

Table for steady state error

Input / Type	Unit step	Unit Ramp	Unit Parabola
Type 0	$\frac{1}{1+K_p}$	∞	∞
Type 1	0	$\frac{1}{K_v}$	∞
Type 2	0	0	$\frac{1}{K_a}$

Where $K_p = \lim_{s\to 0} G(s)\,H(s)$

$K_v = \lim_{s\to 0} sG(s)\,H(s)$

$K_a = \lim_{s\to 0} s^2G(s)\,H(s)$

2.17 **(b)**

Steady state error is the error at $t \to \infty$.

2.18 **(d)**

$$G(s) = \frac{C(s)}{R(s)} = \frac{K}{s+\alpha}$$

$$\Rightarrow \quad C(s) = \frac{K}{s+\alpha} \text{ since } R(s) = 1$$

$$\Rightarrow \quad c(t) = Ke^{-\alpha t}$$

Time constant $\tau = 1/\alpha$

Time constant is the time at which

$$c(t) = Ke^{-1} = 0.37\text{ K}$$

So, $\tau = t_2 = \frac{1}{\alpha} \Rightarrow \alpha = \frac{1}{t_2}$

2.19 **(a)**

$$\frac{G(s)}{1+G(s)} = \frac{80}{s^2+18s+80} \qquad \omega_n = \sqrt{80}$$

$$\xi = \frac{18}{2\sqrt{80}} = 1.00623$$

So, the system is overdamped.

2.20 **(b)**

(i) In open-loop system, transfer function $T = G$

Sensitivity of open-loop system is

$$S_G^T = \frac{\partial T}{\partial G}\times\frac{G}{T} = 1 \qquad [\because T = G]$$

In closed-loop system, transfer function

$$T = \frac{G}{1+GH}$$

$$S_G^T = \frac{\partial T}{\partial G}\times\frac{G}{T}$$

$$= \frac{1+GH-GH}{(1+GH)^2}\times\frac{G}{G/(1+GH)}$$

$$S_G^T = \frac{1}{1+GH}$$

Thus feedback is used to reduce the sensitivity of the system.

(ii) Feedback is the fraction of output. It reduces the loop gain.

2.21 **(c)**

(i) Roots of 2nd order underdamped system are complex conjugates.

(ii) Roots of 2nd order critically damped system are negative, real and equal.

(iii) Roots of 2nd order overdamped system are negative, real and unequal.

2.22 **(a)**

$$T(s) = H\frac{(s+c)}{(s+a)(s+b)} \qquad \text{...(i)}$$

When input is $u(t)$ output is

$$= 2 + De^{-t} + Ee^{-3t}$$

When input is $e^{-2t}u(t)$ output is

$$= Fe^{-t} + Ge^{-3t}$$

Using equation (i) when input is $u(t)$ output is

$$\frac{H(s+c)}{s(s+a)(s+b)} = \frac{K_1}{s}+\frac{D}{s+a}+\frac{E}{s+b}$$

Taking inverse Laplace transform

$$= 2 + De^{-t} + Ee^{-3t}$$

So, $a = 1$ and $b = 3$

Using final value theorem

$$\lim_{s\to 0}\frac{s\cdot H(s+c)}{s(s+a)(s+b)} = \lim_{t\to\infty} 2+De^{-t}+Ee^{-3t}$$

$$\frac{Hc}{ab} = 2 \quad\text{and}\quad Hc = 6$$

Using equation (i) when input is $e^{-2t}u(t)$ output is

$$\frac{H(s+c)}{(s+2)(s+a)(s+b)}$$

Only two terms are present in the response.

Hence $s + c = s + 2$

$\Rightarrow \quad c = 2$

$H = 3 \qquad (\because HC = 6)$

2.23 (c)

Output due to disturbance $D(s)$ is

$$C_D(s) = \frac{G_2}{1+G_1G_2} \cdot D(s)$$

$$C_D(s) \equiv \frac{G_2}{G_1G_2} \cdot D(s) \qquad [\because\ G_1G_2 >> 1]$$

$$C_D(s) \approx \frac{1}{G_1(s)} \cdot D(s)$$

Thus effect of disturbance can be reduced by increasing $G_1(s)$.

2.24 (c)

Time for peak overshoots are

$$t_p = \frac{n\pi}{\omega_n\sqrt{1-\xi^2}} \qquad n = 1, 3, 5, ...$$

For first peak overshoot, $n = 1$

$$t_{p1} = \frac{n\pi}{\omega_n\sqrt{1-\xi^2}}$$

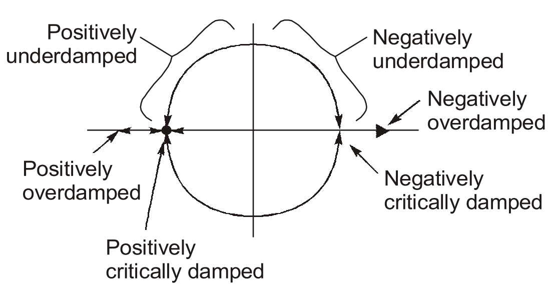
For second peak overshoot, $n = 3$

$$t_{p2} = \frac{3\pi}{\omega_n\sqrt{1-\xi^2}}$$

2.25 (b)

With negative feedback, stability of the system increases and as stability is inversely proportional to sensitivity, therefore sensitivity decreases.

2.26 (c)



2.27 (c)

$s^2 + 12s + 400 = 0$

$$\Rightarrow \xi = \frac{12}{2\sqrt{400}} = \frac{12}{40} < 1$$

$\Rightarrow$ underdamped $s^2 + 90s + 900 = 0$

$$\Rightarrow \xi = \frac{90}{2\sqrt{900}} = \frac{90}{2 \times 30} > 1$$

$\Rightarrow$ overdamped $s^2 + 30s + 225 = 0$

$$\Rightarrow \xi = \frac{30}{2\sqrt{225}} = \frac{30}{2 \times 15} = 1$$

$\Rightarrow$ critically damped

$s^2 + 625 = 0$

$\Rightarrow \xi = 0 \Rightarrow$ undamped.

2.28 (b)

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

$$\xi = \frac{4}{2\sqrt{K}} = 0.5$$

$$\Rightarrow \quad \sqrt{K} = \frac{4}{2 \times 0.5} = 4$$

$$\Rightarrow \quad K = 16$$

2.29 (a)

For type 1, ramp input

$$e_{ss} = \frac{1}{K_v}$$

where $K_v = \lim_{s \to 0} sG(s)$

$$= \lim_{s \to 0} s \cdot \frac{1}{s(s+1)} = 1$$

So, $e_{ss} = \frac{1}{K_v} = 1$

2.30 (b)

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

$$\xi = \frac{1}{2\sqrt{K}}$$

$$\frac{-\frac{1}{2\sqrt{K}}.\pi}{\sqrt{1-\frac{1}{4K}}} = ln(0.5) = -0.693$$

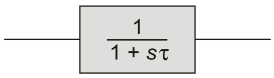
$$\Rightarrow \quad \frac{\pi^2}{4K} = 0.48\left(1-\frac{1}{4K}\right)$$

$$\Rightarrow \quad 4K - 1 = \frac{\pi^2}{0.48}$$

$$\Rightarrow \quad 4K = 21.56$$

$$\Rightarrow \quad K = 5.39$$

2.31 (b)



(i) Time constant is a specification of transient response.
(ii) $s = -1/\tau$
(iii) The time constant τ also affect the steady state value of the system. Hence the accuracy is also governed by it.
(iv) Time constant is an indication of speed of the response.

2.32 (d)

$$C(s) = \frac{1}{s} - \frac{1}{s+5} - \frac{5}{(s+5)^2}$$

$$= \frac{(s+5)^2 - (s+5)s - 5s}{s(s+5)^2}$$

$$= \frac{25}{s(s+5)^2}$$

$$C(s) = \frac{25}{s(s^2+10s+25)}$$

$$R(s) = \frac{1}{s}$$

$$G(s) = \frac{C(s)}{R(s)} = \frac{25}{s^2+10s+25}$$

$$\omega_n = \sqrt{25}$$

$$\Rightarrow \quad \omega_n = 5 \text{ rad/s}$$

$$\xi = \frac{10}{2\times 5} = 1$$

$$\text{Impulse response} = \frac{d}{dt}(1 - e^{-5t} - 5te^{-5t})$$

$$= 5e^{-5t} - 5e^{-5t} + 25te^{-5t} = 25te^{-5t}$$

2.33 (b)

$$C(s) = \frac{1}{s} - \frac{1}{s+1} - \frac{5}{(s+1)^2}$$

$$= \frac{(s+1)^2 - s(s+1) - s}{s(s+1)^2} = \frac{1}{s(s+1)^2}$$

$$R(s) = \frac{1}{s}$$

$$G(s) = \frac{C(s)}{R(s)} = \frac{1}{(s+1)^2} = \frac{1}{s^2+2s+1}$$

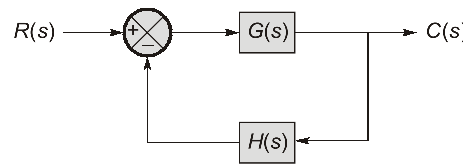
$\therefore \quad \xi = 1$

So given system is critically stable.

2.36 (b)

Steady state error,

$$e_{ss} = \lim_{s\to 0} \frac{sR(s)}{1+G(s)H(s)}$$



(i) By increasing the input $R(s)$, e_{ss} increases.
(ii) By decreasing the type of system, e_{ss} increases.

(iii) $e_{ss} \propto \dfrac{1}{\text{Static error constant}}$

Therefore, by decreasing the static error constant (K_p, K_v or K_a), e_{ss} increases.

2.37 (d)

$$2\frac{d^2y}{dt^2} + 4\frac{dy}{dt} + 8y = 8x$$

$$\text{or} \quad \frac{d^2y}{dt^2} + 2\frac{dy}{dt} + 4y = 4x$$

Taking Laplace transform,

$$(s^2 + 2s + 4)\, y(s) = 4X(s)$$

$$\text{or} \quad \frac{Y(s)}{X(s)} = \frac{4}{s^2+2s+4}$$

Comparing the transfer function with

$$\frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

$$\omega_n^2 = 4$$

$$\Rightarrow \quad \omega_n = 2$$

$$2\xi\omega_n = 2$$

$$\Rightarrow \quad \xi = \frac{2}{2\omega_n} = \frac{2}{2\times 2} = 0.5$$

Therefore, the damping ratio, $\xi = 0.5$.

2.38 (b)

Characteristic equation

$s^2 + 2\xi\,\omega_n s + \omega_n^2 = 0$

If $\xi = 0$, then $s_2 + \omega_n^2 = 0$

$\Rightarrow \quad s = \pm j\omega_n$

It is clear that the closed-loop poles are purely imaginary.

2.39 (c)

$$e_{ss} = \lim_{s\to 0} \frac{sR(s)}{1+G(s)H(s)}$$

Given that,

$$\text{input } r(t) = 10t$$

$$\Rightarrow \quad R(s) = 10/s^2$$

$$G(s) = \frac{10}{s^2(s+4)}, \quad H(s) = 1$$

$$\because \quad e_{ss} = \lim_{s\to 0} \frac{s\cdot 10/s^2}{1+\frac{10}{s^2(s+4)}}$$

$$= \lim_{s\to 0} \frac{10s(s+4)}{s^2(s+4)+10} = 0$$

2.40 (d)

Characteristic equation = $4s^2 + 6s + 1 = 0$

$$s^2 + \frac{6}{4}s + \frac{1}{4} = 0$$

Comparing with standard characteristic equation

$$s^2 + 2\xi\omega_n s + \omega_n^2 = 0$$

$$\omega_n = \frac{1}{2} = 0.5 \text{ rad/sec}$$

$$2\xi\omega_n = \frac{3}{2}$$

$$\xi = \frac{3}{4} \times 2 = 1.5$$

$\therefore$ System is overdamped.

2.41 (d)

$$C(\infty) = \lim_{s\to 0} s \times \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} \times \frac{1}{s} = 1$$

2.42 (c)

Comparing the transfer function

$$\frac{16}{s^2+4s+16} \text{ with } \frac{\omega_n^2}{s^2+2\xi\omega_n\, s+\omega_n^2}$$

$$\omega_n^2 = 16 \qquad \Rightarrow \omega_n = 4 \text{ rad/s}$$

$$2\xi\omega_n = 4 \qquad \Rightarrow = \frac{4}{2\omega_n}$$

$$\Rightarrow \qquad \xi = \frac{4}{2\times 4}$$

Time for first overshoot

$$t_p = \frac{\pi}{\omega_n\sqrt{1-\xi^2}} = \frac{\pi}{4\sqrt{1-\frac{1}{4}}} = \frac{\pi}{2\sqrt{3}} s$$

2.43 (a)

The response of an amplifier with three (or more) poles is determined approximately by the two lowest poles, p_1 and p_2, provided that $|p_3/p_2| \geq 4$.

2.44 (d)

This is the Laplace transform of sin t.

So, $f(t) = \sin t$

Steady-state value of $f(t)$ is undetermined because poles of $F(s)$ are not in LHS of s-plane. Therefore, steady-state value will vary between – 1 and +1.

2.45 (d)

$$G(s) = \frac{4}{s^2+0.4s}; \; H(s) = 1$$

Characteristic equation

$$1 + G(s)\,H(s) = 0$$

$$\Rightarrow \quad 1+\frac{4}{s^2+0.4s}\cdot 1 = 0$$

$$\Rightarrow \quad s^2 + 0.4s + 4 = 0 \qquad ...(1)$$

Comparing equation (1) with standard equation of second order system i.e.

$$s^2 + 2\xi\omega_n s + \omega_n^2 = 0$$

we have

$$2\xi\omega_n = 0.4 \Rightarrow \boxed{\xi\omega_n = 0.2}$$

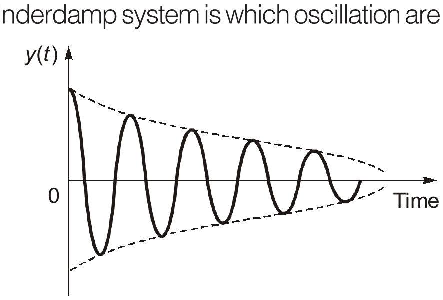
settling time within 2% tolerance band

$$t_s = \frac{4}{\xi\omega_n} = \frac{4}{0.2}$$

$$\Rightarrow \quad t_s = 20 \text{ sec}$$

2.46 (d)

Underdamp system is which oscillation are damped.



2.48 (b)

Integral controller improves steady state performance while derivative controller improves transient state response.

2.50 (b)

$$\frac{C(s)}{R(s)} = \frac{10\left(\frac{1}{s+1}\right)}{1+\frac{1}{s}\cdot\frac{10}{(s+1)}}$$

$$\Rightarrow \quad C(s) = \frac{10s}{s(s+1)+10}R(s)$$

Given $r(t) = u(t)$

So $R(s) = \frac{1}{s}$

$$\therefore \quad C(s) = \frac{10s}{s(s+1)+10}\cdot\frac{1}{s}$$

$$\Rightarrow \quad C(s) = \frac{10}{s(s+1)+10}$$

Steady state value of response

$$= \lim_{s\to 0} sC(s) = \lim_{s\to 0} s\cdot\frac{10}{s(s+1)+10} = 0$$

2.51 (b)

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

Since $G(s)H(s)$ has one pole at origin, so given system is type-1 system.

2.52 (b)

$$40\frac{dx}{dt}+2x = f(t)$$

$$\Rightarrow \quad X(s)\,(40s+2) = F(s)$$

$$\therefore \quad \frac{X(s)}{F(s)} = \frac{1}{40s+2}$$

Pole will be at $s = -\frac{1}{20}$

Time constant is reciprocal of location of pole for a first order system.

2.53 (b)

Given, $\xi = 0.707 = \frac{1}{\sqrt{2}}$

Settling time $= \frac{3}{\xi\,\omega_n} = 0.60$ sec.

$$\xi\omega_n = \frac{3}{0.6} = \frac{30}{6} = 5$$

Poles are given as

$$s = -\xi\,\omega_n \pm j\omega_n\sqrt{1-\xi^2}$$

$$s = -5 \pm j5\sqrt{2}\,\sqrt{1-\frac{1}{2}}$$

$$= -5 \pm j\,5\sqrt{2}\cdot\frac{1}{\sqrt{2}} = -5 \pm j5$$

2.54 (c)

$$G(s) = \frac{K}{s(s+6)}$$

Characteristics equation

$$1 + G(s)\,H(s) = 0$$

$$\Rightarrow \quad 1+\frac{K}{s(s+6)} = 0$$

$$\Rightarrow \quad s(s+6)+K = 0$$

$$\Rightarrow \quad s^2+6s+K = 0$$

Comparing above equation with standard equation i.e.

$$s^2+2\xi\,\omega_n\,s+\omega_n^2 = 0$$

We have, $\omega_n = \sqrt{K}$ and $2\xi\,\omega_n = 6$

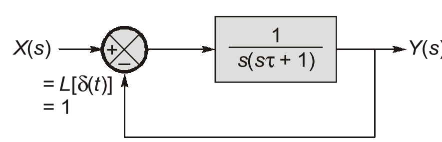
It is given that $\xi = 0.75$; so

$$2\times 0.75\times\sqrt{K} = 6$$

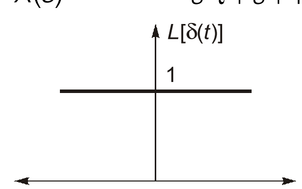
$$\therefore \quad \sqrt{K} = \frac{6}{1.5} = 4$$

$$K = 16$$

2.55 (d)



$$\frac{Y(s)}{X(s)} = H(s) = \frac{1}{s^2\tau+s+1}$$



2.56 (a)

- As we know from the formulae

  Rise time, $t_r = \frac{0.35}{\text{Bandwidth}}$

  Thus it can be seen that rise time is inversely proportional to bandwidth.

- Also $\omega_d = \omega_n\sqrt{1-\xi^2}$

  Increasing ω_n causes increase in ω_d and thus bandwidth increases and rise time reduces.