WINTER – 2022 EXAMINATION
Model Answer

Subject Name: Control System **Subject Code: 22541**

Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills.
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.
8) As per the policy decision of Maharashtra State Government, teaching in English/Marathi and Bilingual (English + Marathi) medium is introduced at first year of AICTE diploma Programme from academic year 2021-2022. Hence if the students in first year (first and second semesters) write answers in Marathi or bilingual language (English +Marathi), the Examiner shall consider the same and assess the answer based on matching of concepts with model answer.

Q. No.	Sub Q.N.	Answer	Marking Scheme
Q.1		**Attempt any Five of the following**	**10 M**
	a)	**State the transfer function of open loop and closed loop system.**	**2M**
	Ans	Transfer Function is defined as the ratio of Laplace transform of Output to that of Laplace transform of input under the assumption that all initial conditions are zero. Transfer function of open loop system: $C(S) / R(S) = G(s) H(S)$ Transfer function of closed loop negative / positive feedback system: $\frac{C(s)}{R(s)} = \frac{G(s)}{1 \pm G(s) H(s)}$	
	b)	**List standard test inputs. Draw their graphical representation.**	**2M**

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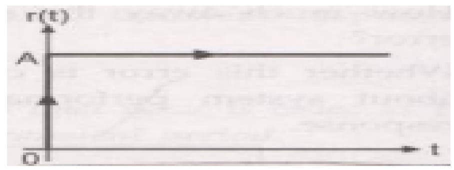
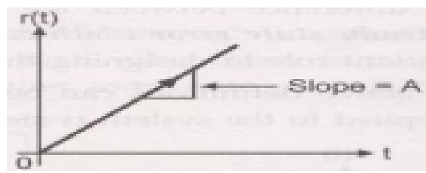
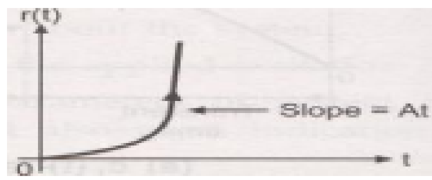
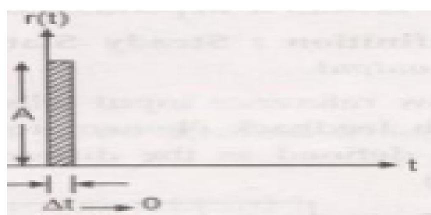
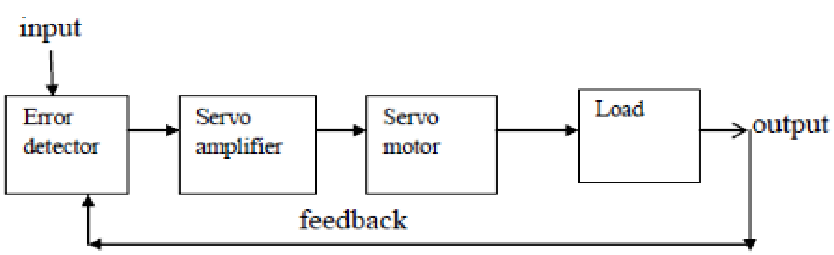
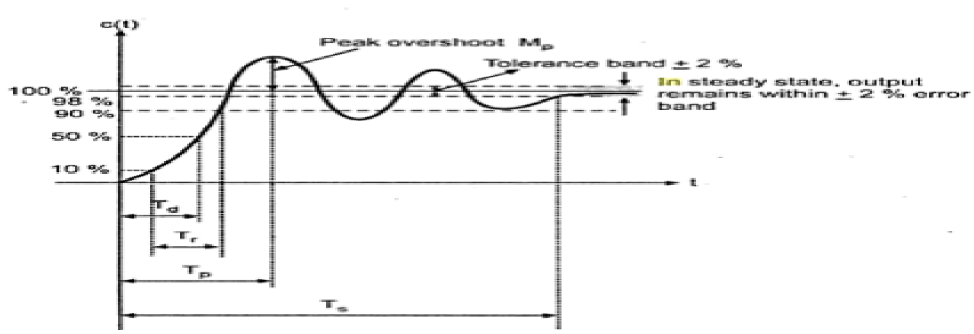
<table>
<tr><td></td><td>Ans</td><td>Standard test inputs and their graphical representation is given as:
<table>
<tr><th>Test Input</th><th>Graphical Representation</th></tr>
<tr><td>Unit Step Input</td><td>
</td></tr>
<tr><td>Unit Ramp Input</td><td>
</td></tr>
<tr><td>Unit Parabolic Input</td><td>
</td></tr>
<tr><td>Unit Impulse Input</td><td>
</td></tr>
</table>
</td><td>½ M to each input and its representa tion</td></tr>
<tr><td></td><td>c)
i)
ii)</td><td>Define
Gain Margin
Phase Margin</td><td>2M</td></tr>
<tr><td></td><td>Ans</td><td>Gain Margin: Margin in the gain allowable by which gain can be increased till system reaches on the verge of instability.

Phase Margin: The amount of additional phase lag which can be introduced in the system till system reaches on the verge of instability.</td><td>1 M to each defination.</td></tr>
<tr><td></td><td>d)</td><td>Define offset. State the methods to eliminate it.</td><td>2M</td></tr>
</table>

	Ans	**Offset: The** proportional controller produces a permanent residual error in the controlled variable, when a change in load occurs. This is referred to as offset. **Methods of eliminating offset:** It can be minimized by the large proportional gain Kp, by doing manual resetting and by using integral controller.	**definition 1 M and method of elimination 1 M**
	e)	**Classify Servo System. Draw the generalized block diagram of a servo system.**	**2M**
	Ans	**Servo system is classified as:** 1. Based on nature of components of system Electrical Servo System, Hydraulic Servo system, electro hydraulic Servo system. 2.Based of driving system AC Servo System, DC Servo System 3. Based on control methods Open loop Servo System, Closed loop Servo System. **Generalized block diagram of a servo system is given as:**  	**Classification 1 M and block diagram 1 M**
	f)	**Draw and label the time response of 2nd order control system for unit step input.**	**2M**
	Ans	 	**neat labeled diagram 2 M**

	g)	**State with justification if AC two phase induction motor can be used as AC servo motor.**	**2M**
	Ans	AC servo motor should have less inertia than 2 phase induction motor since it is used in feedback applications to regulate the speed of the load. This is achieved by reducing the diameter of the rotor and increasing its length compared to 2 phase induction motor. To achieve this, special designs of rotor like drag-cup rotor or squirrel cage rotor are used. The characteristic of 2 phase induction motor is nonlinear with initial positive slope. But the characteristic of AC servo motor is made linear with negative slope to improve the stability since it is used in servo system which is a feedback system. This is achieved by small X/R ratio which is obtained by increasing the resistance of the rotor winding. The increase in rotor resistance may cause heat dissipation and power loss and reduction in the speed. Therefore, by considering these two points, AC two phase induction motor can be used as AC servo motor.	**2M** **(brief explanation)**
Q.2		**Attempt Any THREE of the following**	**12M**
	a)	**Find the state space representation for the transfer function** $\frac{C(S)}{R(S)} = \frac{25}{(S^2 + 9S + 25)}$	**4M**

	Ans	After cross-multiplying, $$(S^2 + 9S + 25)C(S) = 25R(S)$$ Taking inverse Laplace Transform after opening the bracket, $$\frac{d^2}{dt^2}c(t) + 9\frac{d}{dt}c(t) + 25c(t) = 25r(t)$$ $Input = r(t) = u(t)$ $Output = y(t) = c(t)$ Therefore, first state variable $x_1 = c(t) = y(t)$ Second state variable $x_2 = \frac{d}{dt}c(t) = \dot{x_1}$ $\dot{x_2} = \frac{d^2}{dt^2}c(t) = 25r(t) - 9\frac{d}{dt}c(t) - 25c(t)$ $$\dot{x_2} = 25u(t) - 9x_2 - 25x_1$$ SSR: $$\dot{X} = AX + BU$$ $$Y = CX + DU$$ $\begin{bmatrix} \dot{x_1} \\ \dot{x_2} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -25 & -9 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + [0 \quad 25]\, u$ $$Y = [1 \quad 0] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$	2M 1M 1M
	b)	**Find the type of the system and steady. State error for a unity feedback system with** $G(S) = \frac{10}{S(1+25)}$ **for input r(t) = 5t.**	4M

	Ans	For unity feedback system ∴ $H(s) = 1$ To determine type of system, it is required to bring $G(s) \cdot H(s)$ into its time constant form. $\therefore G(s)H(s) = \frac{10}{s(1+2s)}$ comparing with standard form the type of system is '1' (ii) $r(t) = 5t$ —— (input) $\therefore A = 5$ $K_p = \lim_{s\to 0} G(s) \cdot H(s)$ $K_p = \lim_{s\to 0} \frac{10}{s(1+2s)}$ $K_p = \infty$ $K_v = \lim_{s\to 0} s \cdot G(s)H(s)$ $K_v = \lim_{s\to 0} s \cdot \frac{10}{s(1+2s)}$ $K_v = 10$ $K_a = \lim_{s\to 0} s^2 \cdot G(s)H(s)$ $K_a = \lim_{s\to 0} s \cdot s \cdot \frac{10}{s(1+2s)}$ $K_a = 0$ Steady state error (ess) $= \frac{A}{K_v} = \frac{5}{10} = 0.5$ $e_{ss} = 0.5$	**type of system =1 M** **rest all step = 3M**
	c)	**Compare AC servomotor & DC servomotor (any four points).**	**4M**

Ans

Sr.No	AC Servomotor	DC Servomotor
1	Low power output High power o/p	Low power output High power o/p
2	Maintenance is less	Maintenance is more
3	No Brushes / commutators absent	Brushes / problem, commutators present.
4	Stable and smooth operation	Noisy operation
5	Less problem of stability	More problem of stability
6	No RF noise because of absence of brushes	Brushes produce RF noise.
7	Non – linear characteristics	Linear characteristics
8	No voltage supply to rotor, Rotor current is supplied inductively by rotating magnetic field of stator.	Voltage is given through power supply to rotor.
9	Applications:- low power(computer peripherals, recorders etc.)	Application: high power (machine tools, robotics)

each point 1 mark Any 4 points

d)	**For a given transfer function** $\frac{C(S)}{R(S)} = \frac{(S^2 + 16)}{S^2 + 7S + 16}$ **Find**	**4M**
i)	**Pole**	
ii)	**Zero**	
iii)	**Pole – Zero plot**	
iv)	**Characteristic equation.**	
Ans	**(i) Poles:**	

Poles are obtained by equating the denominator of the transfer function to zero therefore:

$S^2 + 7S + 16 = 0$ Which is a quadratic equation .

For the quadratic equation ax2+bx+c=0, a=1, b=7, c=16

the poles are =[-b±√(b^2-4ac) / 2a]

= -7 ±√(49-(4*1*16)) / 2*1

= -7 ±√(49-(64)) / 2

= -7 ±√(-15) / 2

= -7 ±j√ (15) / 2

Therefore:

S = -7 + j√ (15) /2   and S = -7 - j√ (15) /2

Poles are :

1. -3.5 - 1.93j
2. -3.5 + 1.93j

(ii) Zeros:

$S^2 + 16 = 0$

$S^2 = -16$

$S = \pm 4j$

S = +4j , -4j

(iii)Pole – Zero plot:

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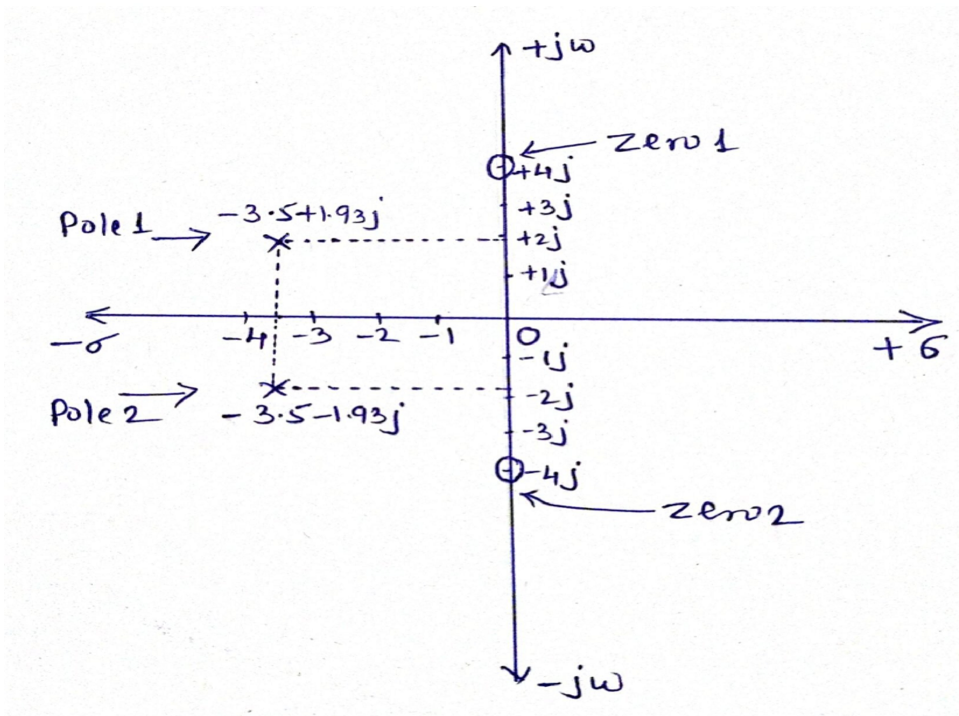
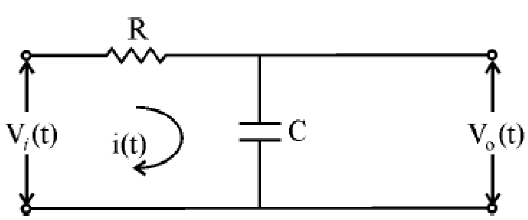


(iv)Characteristic equation:

$$(S^2 + 7S + 16) = 0$$

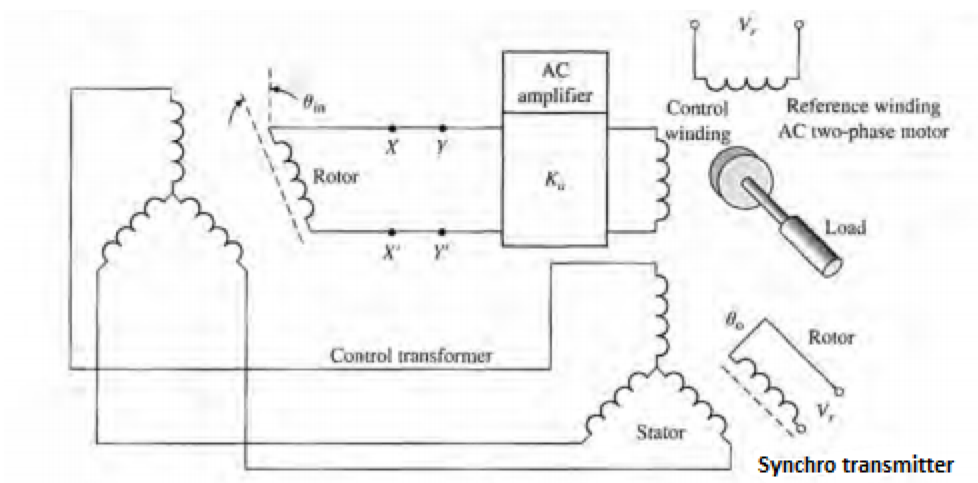
Q.3		**Attempt any THREE of the following.**	**12M**
	a)	**Derive the transfer function for RC network.**	**4M**
	ANS.	(see circuit below)	**1M**



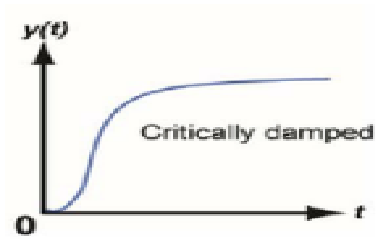
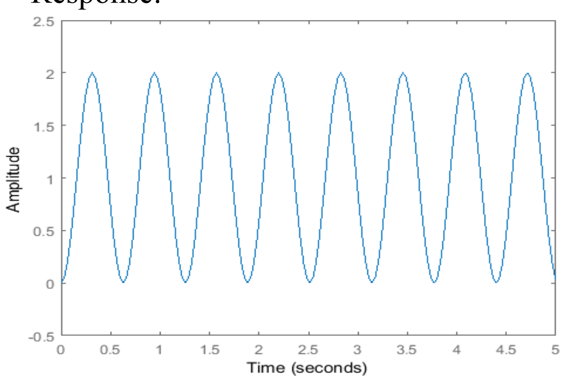
Input equation :

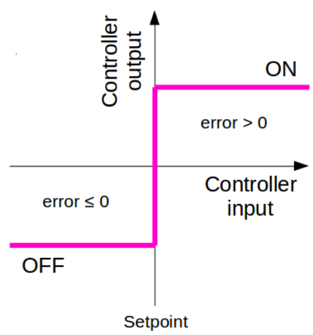
$$V_i(t) = Ri(t) + \frac{1}{C}\int i(t)dt$$

		Output equation: $$V_0(t) = \frac{1}{C}\int i(t)dt$$	2M
		Taking Laplace of Input and Output equations: $$V_i(S) = R\,I(S) + \frac{I(S)}{CS}$$ $$V_0(S) = \frac{I(S)}{CS}$$ $$\text{TF} = \frac{V_0(S)}{V_i(S)} = \frac{\frac{I(S)}{CS}}{R\,I(S) + \frac{I(S)}{CS}} = \frac{1}{RCS+1}$$	1M
	b)	**For a unity feedback system whose open loop transfer function is** $$G(S) = \frac{50}{(1 + 0.1S)(1 + 2S)}$$ **Find position, velocity and acceleration error constant.**	**4M**
	Ans	$$Type\ of\ the\ system = 0$$ $$K_P = \lim_{s\to 0} G(S)H(S) = K_P = \lim_{s\to 0} \frac{50}{(1+0.1S)(1+2S)} = 50$$ $$K_V = \lim_{s\to 0} S\,G(S)H(S) = \lim_{s\to 0} S\frac{50}{(1+0.1S)(1+2S)} = 0$$ $$K_A = \lim_{s\to 0} S^2\,G(S)H(S) = \lim_{s\to 0} S^2\frac{50}{(1+0.1S)(1+2S)} = 0$$	**1M** **1M** **1M** **1M**
	c)	**Using Routh's stability criteria, determine the stability for the system with characteristic equation** $3S^4 + 10S^3 + 5S^2 + 5S + 2 = 0.$	**4M**
	Ans	Routh's array: S^4 3 5 2	**3m**

		S^3 10 5 0 S^2 3.5 2 0 S -5/7 0 0 S^0 2 0 0 Conclusion: There are two sign changes in the first column. Therefore, two poles are on the right side of S-plane. So the system is unstable.	1M
	d)	**Explain different components of AC servo system with neat diagram.**	**4M**
	Ans		**2M**
		• AC position control system consists of components such as Synchro as error detector, AC servo amplifier and AC servo motor which is connected to the load. • The load is connected to the rotor of synchro transmitter as feedback. • The rotor of synchro control transformer is kept constant at the reference position. • The differential output of the synchro error detector is the error voltage which is given to the AC servo amplifier. • The amplifier output which is the error voltage is given to the control winding of AC servo motor.	**2M**

		• Thus, the speed of the motor is adjusted according to the error voltage and feedback signal. • Thus, the load is positioned according to the reference signal.	
Q.4		**Attempt any THREE of the following.**	**12M**
	a)	**Find the transfer function of the following differential equation.** $\frac{d^2y(t)}{dt^2} + 4\frac{dy(t)}{dt} + 8y(t) = 8\,x(t).$	**4M**
	ANS.	$\frac{d^2y(t)}{dt^2} + 4\frac{dy(t)}{dt} + 8y(t) = 8\,x(t)$ Taking Laplace, $S^2Y(S) + 4SY(S) + 8Y(S) = 8X(S)$ $Y(S)[S^2 + 4S + 8] = 8X(S)$ $TF = \frac{Y(S)}{X(S)} = \frac{8}{S^2+4S+8}$	**2m** **2m**
	b)	**Draw the response of second order system for critically damped case, for unit step input.**	**4M**
	Ans.	When damping factor $\zeta = 1$, system is called critically damped system $Poles = -\omega_n, -\omega_n$ The o/p response $y(t) = A + Bte^{-\omega_n t}$ It can be seen that the critically damped response is exponential. The response:	**2m**

			2m
	c)	**State the concept of marginal stability.**	**4M**
	ANS.	Marginal stability:-If the poles (non -repeated) are located purely on imaginary axis of s-plane, system is said to be critically stable. Here the output amplitude neither increase nor decrease but the system oscillates with constant amplitude. Response: 	2M 2M
	d)	**Explain ON-OFF controller with equation. State any two of its application.**	**4M**
	ANS.	It has only two fixed positions such as on (1) and off (0). The output signal P remains either 0% or 100% depending upon whether the error is negative or positive. So the equation of On-Off controller is: P = 100% (on) for positive error P = 0% (off) for negative error . Consider a practical example of temperature control system with Set Point "x". When the temperature is more than "x" the on - off controller will be off and when it is less than "x" ,on - off controller will be on. Output diagram:	2m



Example:- Relays, Thermostat

Applications: temperature control systems for houses (heating and cooling), freezers and other home appliances are using on-off control

2 m

e) **Using Routh's criteria, determine the range of K for the system to be stable for the characteristics equation**

$S^4 + 4S^3 + 13S^2 + 36S + K = 0.$

Ans. Routh's array: **2m**

S^4	1	13	K
S^3	4	36	0
S^2	4	K	0
S	$\frac{144-4K}{4}$	0	0
S^0	K	0	0

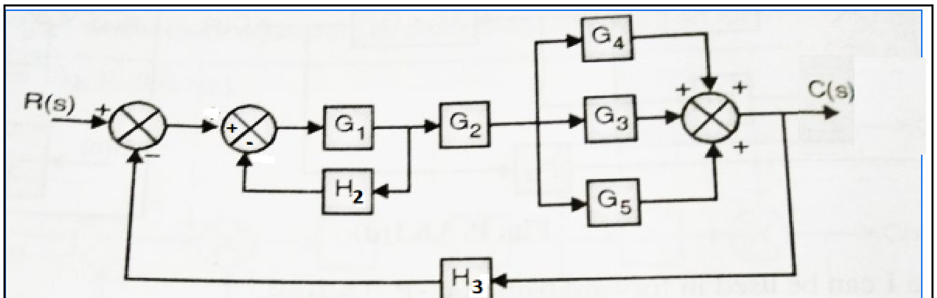
To satisfy the condition for stability, **2M**

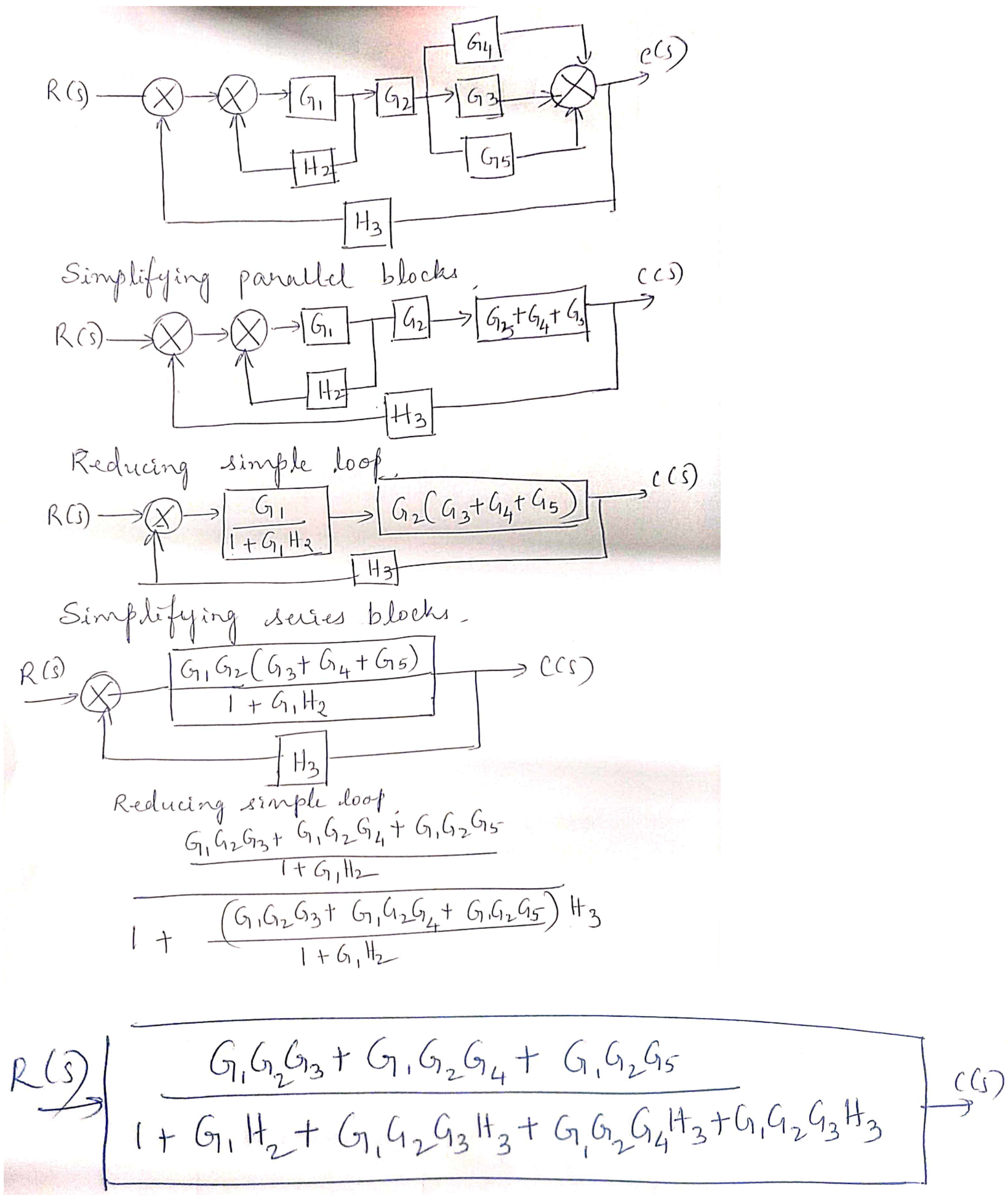
$$K > 0,$$

$$\frac{144-4K}{4} > 0$$

Or $144 - 4K > 0$, $144 > 4K$, $36 > K$

Therefore, the range of K for the system to be stable is,

		$0 < K < 36$	
Q. 5		**Attempt any TWO of the following.**	**12M**
	a)	**Derive the transfer function of the system shown below using block diagram reduction techniques in Fig. No. 1.**  Figure no. 1	**6M**

	Ans		
	b)	**Draw Bode plot for the system with open loop transfer function.** $G(S)\ H(S) = \frac{10}{S(1+2S)\ (1+0.2S)}$	**6M**

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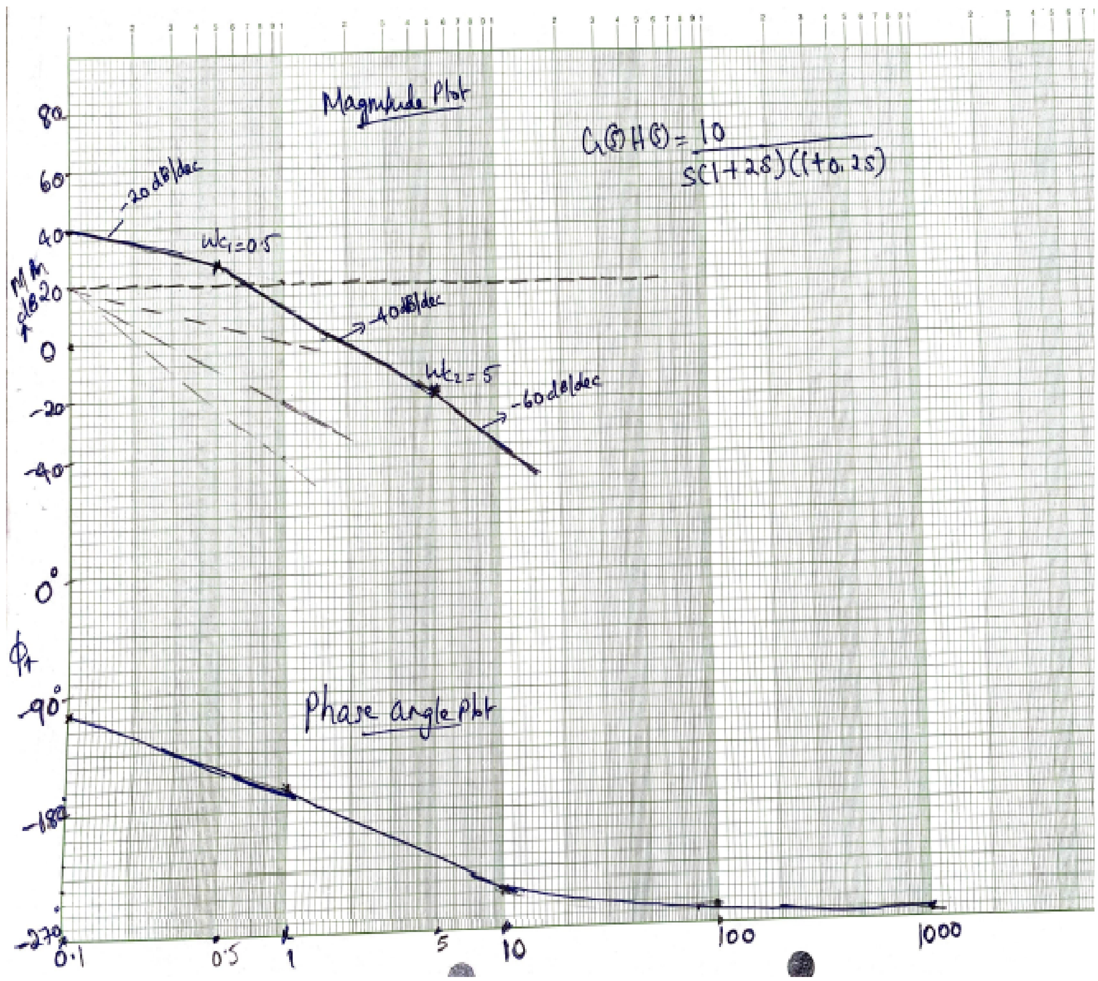
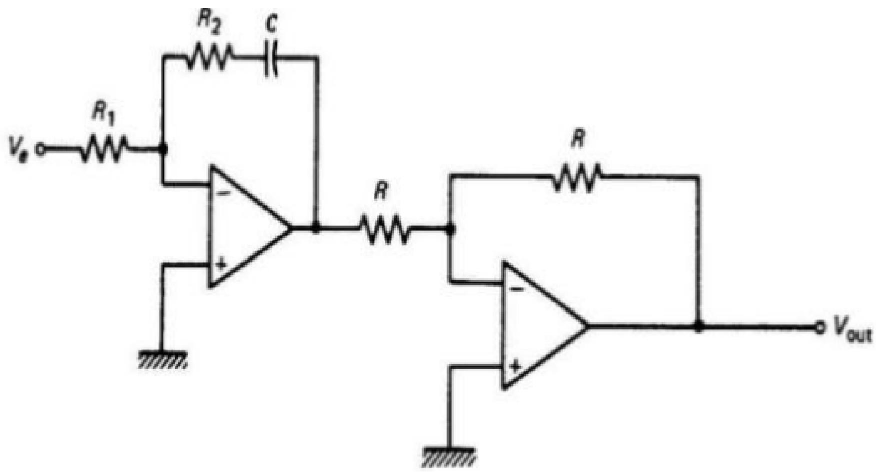
	Ans	Step 1: The given open loop transfer function is already in the time constant form $G(S)H(S) = \frac{10}{S(1+2S)(1+0.2S)}$ Step 2: Identify the factors; 1. Open loop gain $K = 10$, $M\ in\ dB = 20\ log\ K = 20\ log\ 10 = 20\ dB$ 2. Pole at origin (1/S) which has a magnitude plot with slope of $-20dB/decade$. $For\ \omega = 0.1$, $M\ in\ dB\ for\ (1/S) = -20\ log 0.1 = 20\ dB$ 3. First order poles are $\frac{1}{(1+2S)}$ and $\frac{1}{(1+0.2S)}$. The corner frequencies of them are $\omega_{c1} = \frac{1}{2} = 0.5$, $\omega_{c2} = \frac{1}{0.2} = 5$ Frequency in Bode plot at which the magnitude plots of low and high frequency ranges meet is called corner frequency. Till the corner frequencies the magnitude plot's slope will be $0\ dB/decade$ and from the corner frequencies it changes to $-20dB\ /decade$. Step 3: Phase angle ϕ :	2M 2M 2M

Frequency =w	For Factor1, K=2 ϕ_1	For Factor 2, 1/S ϕ_2	For Factor 3, 1/ (1+2S) $\phi_3 = -\tan^{-1} 2w$	For Factor 4, 1/(1+0.2S) $\phi_4 = -\tan^{-1} 0.2\,w$	Total phase angle $\phi = \phi_1 + \phi_2 + \phi_3 + \phi_4$
0.1	0^0	-90^0	-11.3^0	-1.1^0	-102.4^0
1	0^0	-90^0	-63.4^0	-11.3^0	-164.7^0
10	0^0	-90^0	-87.1^0	-63.4^0	-240.5^0
100	0^0	-90^0	-89.7^0	-87.1^0	-266.8^0
1000	0^0	-90^0	-89.97^0	-89.7^0	-269.67^0



	c)	**Draw the circuit diagram of the electronic PI controller and state its equation. Compare the proportional and integral control action on the basis of** **1) Output** **2) Equation** **3) Stability** **4) Speed of response**	**6M**

Ans



Electronic PI controller

$$P_{out} = K_p E_p + K_p K_1 \int_0^t E_p dt + P_0$$

Where P0 is the controller output when time t=0

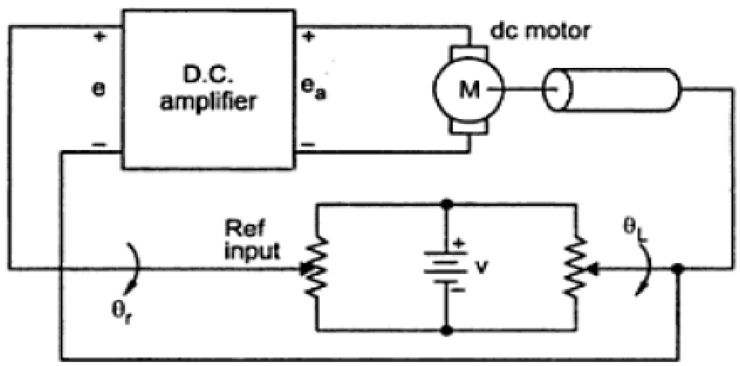
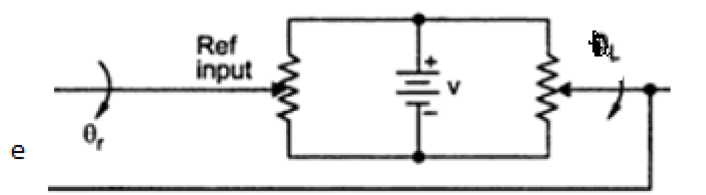
Parameters	**Proportional**	**Integral**
Output	Output is proportional to the present error	Output is proportional to the past history of errors.
Equation	P = KpEp + Po P= Controller output Ep=Error Percentage Kp=Proportionality constant Po= Controller Output at SP	Pout = $K_i \int_0^t E_p dt + P_0$ Pout =Controller output Ep=Error Percentage Ki =Integral constant P0=Controller Output at t=0
Stability	Moderate Stability	Less stability
Speed of response	Moderate speed	Slow speed

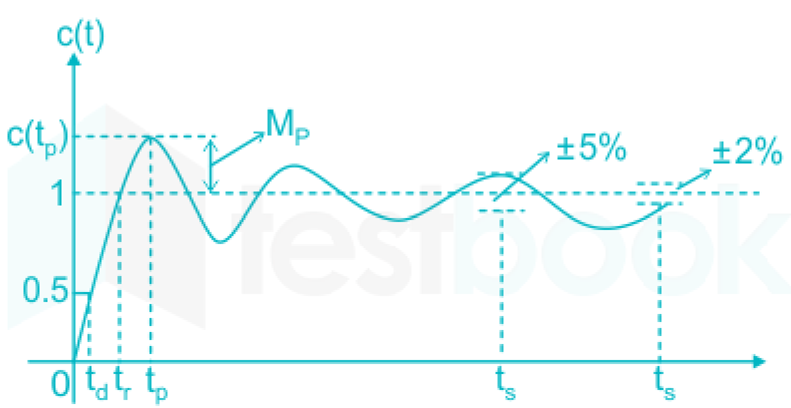
Circuit Diagram and equation 2M

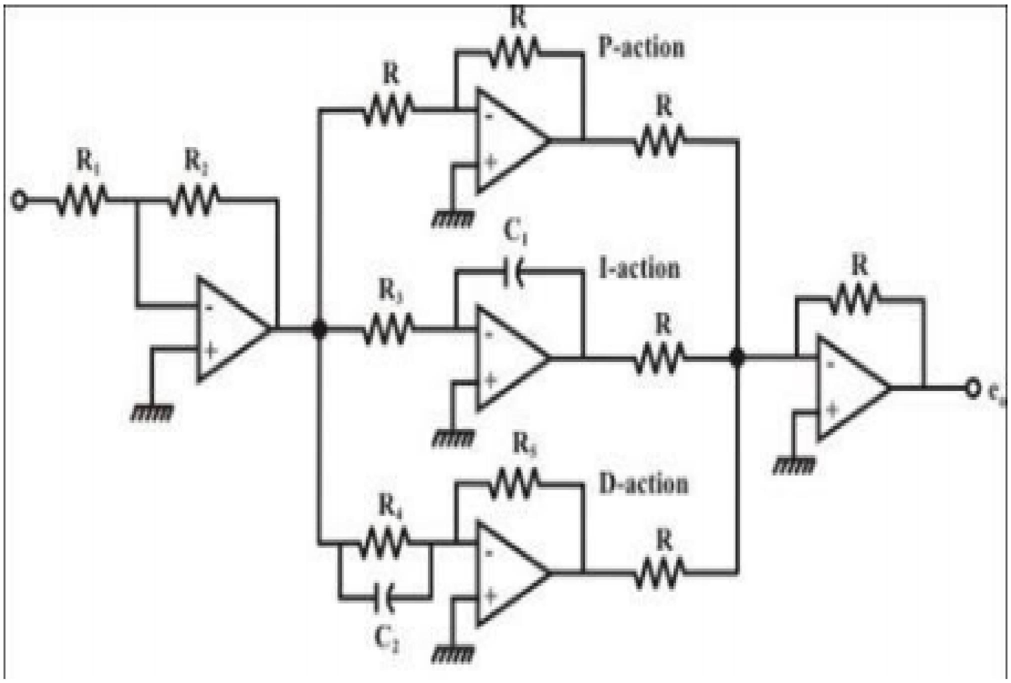
Comparison 1 M each

Q. 6 **Attempt any TWO of the following:** **12M**

a) Draw the functional diagram of DC servo system and explain the use of each element. Describe the error detector used in it with suitable diagram. **6M**

	Ans.	 DC Servo System Dc position control system consists of 2 potentiometers in parallel as an error detector, DC servo amplifier and DC servo motor which is connected to the load. The load is connected to the wiper of one the potentiometer as feedback. The other potentiometer wiper is kept constant at the reference position. The differential output of the 2 potentiometers is the error voltage which is given to the servo amplifier. The amplifier output, which is the error voltage, is given to the motor. Thus the speed of the motor is adjusted according to the error voltage and feedback signal. Thus the load is positioned according to the reference signal. **Potentiometer as error detector:**  An assembly of two potentiometers in parallel is used as an error detector in DC servo systems. This type of arrangement allows comparison of two separately located shaft positions. The output voltage is taken across the variable terminals of the two potentiometers. It gives the output voltage proportional to the difference in the positions of both the wipers of potentiometers. It is given to a servo amplifier. The motor, in turn moves and the shaft connected to the load potentiometer moves with it in such a way as to make the output voltage zero. That is, the output (Load) potentiometer shaft moves in accordance with the shaft of the input (reference) potentiometer.	**Block Diagram 2M** **Explanation 2M** **Error detector 2M**

	b)	**The open loop transfer function of a unity feedback system is given by** $G(S)\ H(S) = \frac{16}{S(S+4)}$ **Find the settling time and peak overshoot. Draw its response.**	**6M**
	Ans.	$G(S)\ H(S) = \frac{16}{S(S+4)}$ Closed loop Transfer function in $\frac{G}{1+GH} = \frac{\frac{16}{S(S+4)}}{1+\frac{16}{S(S+4)}}$ $\frac{C(S)}{R(S)} = \frac{\frac{16}{S(S+4)}}{\frac{S(S+4)+16}{S(S+4)}}$ $= \frac{16}{S^2+4S+16}$ Comparing this with standard equations, $\frac{C(S)}{R(S)} = \frac{Wn^2}{S^2+2\xi Wn^s+Wn^2}$ $Wn^2=16 \Rightarrow Wn=4$ rad/sec. $2\xi Wn=4$ So, $\xi = \frac{4}{2(4)} = 0.5$ i) settling Time $Ts=\frac{4}{\xi Wn} = \frac{4}{(0.5)(4)} = 2\ sec.$ ii)Peak overshoot $\%Mp=e^{\frac{-\pi\xi}{\sqrt{1-\xi 2}}} * 100$ $=e^{\frac{-\pi(0.5)}{\sqrt{1-(0.5)^2}}} * 100$ $\%Mp=16.31\%$ 	**Settling Time 2M** **Peak overshoot 2M**

	c)	**Draw the circuit diagram of electronic PID controller. State the effect of integral and derivative control action on the system performance.**	**6M**
	Ans.	 PID Controller Derivative controller responds to the rate at which the error is changing. It improves damping and reduces maximum overshoot. It reduces rise time and settling time. It increases bandwidth. Integral controller corrects for any offset between set point and process variable automatically. Integral action is provided by summing the error over time, multiplying that by a gain and adding the result to the present controller output. The control action is slow. It removes the offset by allowing the controller to adapt to changing external conditions by changing the zero-error output.	**Diagram 3M** **Integral 1.5 M** **Derivative 1.5 M**