CLASS TEST

S.No. : 01SK_221221

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CONTROL SYSTEMS

EC | EE

Date of Test : 22/12/2021

ANSWER KEY

1.	(b)	7.	(d)	13.	(c)	19.	(d)	25.	(a)
2.	(d)	8.	(b)	14.	(c)	20.	(b)	26.	(d)
3.	(b)	9.	(d)	15.	(a)	21.	(b)	27.	(b)
4.	(d)	10.	(a)	16.	(b)	22.	(b)	28.	(b)
5.	(b)	11.	(a)	17.	(c)	23.	(b)	29.	(b)
6.	(c)	12.	(d)	18.	(c)	24.	(c)	30.	(a)

Detailed Explanations

1. (b)

As the three blocks are connected in cascade the overall transfer function is given by the multiplication of individual blocks.

$$\therefore \quad x_1 \times x_2 \times x_3 = \frac{(s+1)}{s(s+2)(s+3)}$$

$$\frac{1}{s(s+2)} \times \frac{(s+2)}{(s+3)} \times x_3 = \frac{(s+1)}{s(s+2)(s+3)}$$

$$x_3 = \frac{(s+1)}{(s+2)}$$

2. (d)

At ω = 0, the plot for system I, started from –270° hence it represents a type 3 system.

At ω = 0, the plot for system II has slope of 0 dB/dec and therefore it is a type 0 system.

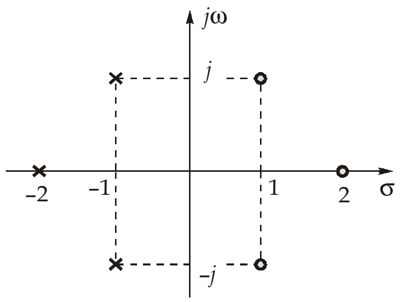
3. (b)

The Routh's table can be formed as

s^3	4	4
s^2	$3(s^2)$	$3(0)$
s^1	$(0)6$	(0)
s^0	$\frac{18-0}{6} = 3$	

as there is no sign change in the first column of Routh array thus, there will be no pole lie on the RHS of s-plane. Also the row of zero occurs that indicates the complex conjugate poles exists on $j\omega$ axis.

4. (d)



5. (b)

Here, the encirclement to the critical point is 1 (in clock wise direction) and 2 (in counter clockwise direction).

$$\therefore \quad N = -1 + 2 = 1$$

6. (c)

Closed loop transfer function $\frac{C(s)}{R(s)} = \frac{K}{s^2 + 10s + K}$

Here, $2\xi\omega_n = 10$

$\xi\omega_n = 5$

Therefore, $\omega_n = \frac{5}{0.75}$

$\because \quad K = \omega_n^2 = \left(\frac{5}{0.75}\right)^2 = 44.44$

7. (d)

$$T(s) = \frac{C(s)}{R(s)} = \frac{10(s+2)}{(s^2+4s+8)}$$

$\therefore$ The step response $C(s)$ is,

$$C(s) = \frac{10(s+2)}{(s^2+4s+8)} \times R(s) = \frac{10(s+2)}{s(s^2+4s+8)}$$

and the steady state response is,

$$\lim_{t\to\infty} c(t) = \lim_{s\to 0} sC(s) = \lim_{s\to 0} s\frac{10(s+2)}{s(s^2+4s+8)} = \frac{10}{4} = 2.5$$

8. (b)

The roots of the characteristic equation are given by,

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

Here, $-\xi\omega_n = -3$

$\Rightarrow \quad \omega_n = \frac{3}{\xi}$ ...(i)

and $\omega_n\sqrt{1-\xi^2} = 2 = \omega_d$ ...(ii)

By putting the value of ω_n in equation (ii), we get,

$$\frac{3}{\xi}\sqrt{1-\xi^2} = 2$$

$$\frac{9}{\xi^2}\times(1-\xi^2) = 4$$

or $9(1 - \xi^2) = 4\xi^2$

$9 - 9\xi^2 - 4\xi^2 = 0$

or $13\xi^2 = 9$

or $\xi = \sqrt{\frac{9}{13}} = \frac{3}{\sqrt{13}}$

9. (d)

The steady state offset is given by,

$$e_{\text{off}} = \lim_{s\to 0} sC(s)\Big|_{R(s)=0}$$

When $R(s) = 0$,

$$C(s) = D(s) - C(s)\left[\frac{4K}{(2s+1)}\right]$$

$$C(s) = \frac{D(s)}{1+\dfrac{4K}{(2s+1)}}$$

$\therefore$

$$e_{\text{off}} = \lim_{s\to 0} \frac{s\cdot\dfrac{0.3}{s}(2s+1)}{(2s+1)+4K}$$

or

$$e_{\text{off}} = \frac{0.3}{4K+1}$$

For $e_{\text{off}} = 0$, $K = \infty$

10. (a)

The characteristic equation is given by,

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

Here,

$$G(s) = \frac{4}{s(s+0.2)} \text{ and } H(s) = (1+2s)$$

$\therefore$

$$1+\frac{4(1+2s)}{s(s+0.2)} = 0$$

$$s^2 + 0.2s + 8s + 4 = 0$$

$$s^2 + 8.2s + 4 = 0$$

11. (a)

The transfer function of the above circuit is,

$$\frac{E_0(s)}{E_i(s)} = \frac{R_2R_4(R_1C_1s+1)}{R_1R_3(R_2C_2s+1)} = \frac{R_4C_1}{R_3C_2}\left(\frac{s+\dfrac{1}{R_1C_1}}{s+\dfrac{1}{R_2C_2}}\right)$$

$$= K\alpha\left(\frac{1+sT}{1+\alpha sT}\right) = K_c\left(\frac{s+\dfrac{1}{T}}{s+\dfrac{1}{\alpha T}}\right)$$

Here, $T = R_1C_1$ and $\alpha T = R_2C_2$

If $R_1C_1 > R_2C_2$ then $\alpha < 1$.

Thus, it represents a phase lead network.

12. (d)

The CE of the given system is,

$$1 + G(s) = 0$$

$$1+\frac{2s^2+as+50}{(s+1)^2(s+2)} = 0$$

$(s^2 + 2s + 1)(s + 2) + 2s^2 + as + 50 = 0$

$s^3 + 2s^2 + s + 2s^2 + 4s + 2 + 2s^2 + as + 50 = 0$

$s^3 + 6s^2 + (5 + a)s + 52 = 0$

For system to be stable

$$(5 + a)6 > 52$$
$$30 + 6a > 52$$
$$6a > (52 - 30)$$
$$a > \frac{22}{6}$$
$$a > 3.667$$

13. (c)

As the system is said to be stable,

Therefore, no open loop pole in the RHS.

$\therefore \quad P = 0$

The intersection point $\left(-\frac{4}{5}K, 0\right)$ and $K > \frac{5}{4}$.

$\therefore \quad \frac{4}{5}K > 1$

or $\quad -\frac{4}{5}K < -1$

That means the Nyquist plot encircles the critical point two times in the clockwise direction

Hence, $\quad N = -2$

$\Rightarrow \quad N = P - Z$

$\Rightarrow \quad -2 = -Z \quad$ or $Z = 2$

14. (c)

The closed loop transfer function of the system is

$$\frac{C(s)}{R(s)} = \frac{4s+1}{4s^2+4s+1} = \frac{1}{4} \times \frac{4s+1}{\left(s+\frac{1}{2}\right)^2}$$

For unit step input, $R(s) = \frac{1}{s}$

$$C(s) = \frac{1}{4} \times \frac{4s+1}{s\left(s+\frac{1}{2}\right)^2} \quad \text{. . . (i)}$$

15. (a)

1st line has slope of 12 dB/oct = 40 dB/dec, thus there is s^2 term in the numerator.

At ω = 0.5 rad/sec, slope changes from +12 dB/oct to +6 dB/oct. Therefore, the term $\left(1+\frac{s}{0.5}\right)$ should be added to the denominator.

At ω = 1 rad/sec, slope changes from +6 dB/oct to 0 dB/oct, thus, a term $(1 + s)$ should be added to the denominator.

At ω = 5 rad/sec, again the slope changes from 0 dB/oct to –6 dB/oct, thus, the term $\left(1+\frac{s}{5}\right)$ should be added to the denominator.

∴ The transfer function can be written as

$$T(s) = \frac{K(s^2)}{\left(1+\frac{s}{0.5}\right)\left(1+\frac{s}{5}\right)(1+s)}$$

Determining the K value, we get,

$$32 = 20\log K + 40\log\omega - 20\log\frac{\omega}{0.5} - 20\log\frac{\omega}{5} - 20\log\omega$$

$$32\big|_{\omega = 5\text{ rad/sec}} = 20\log K + 40\log 5 - 20\log\frac{5}{0.5} - 20\log 1 - 20\log 5$$

$$= 20\log K + 27.95 - 20 - 0 - 13.97$$

$$32 = 20\log K - 6.02$$

$$\log K = \frac{38.02}{20} = 1.901$$

$$K = 79.615$$

∴ The overall transfer function is, $T(s) = \dfrac{79.6s^2}{(2s+1)(s+1)(0.2s+1)}$

16. (b)

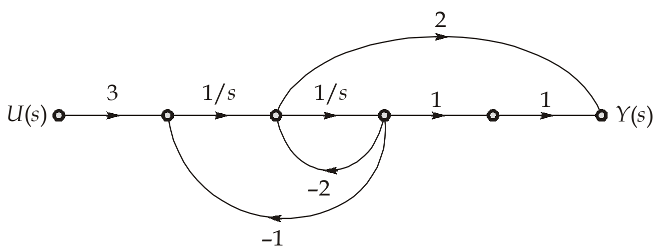
The state equation can be written as.

$$\dot{x}_1 = -2x_1 + x_2$$

$$\dot{x}_2 = -x_1 + 3u$$

and $$y = x_1 + 2x_2$$

∴ The signal flow graph corresponding to the state equations is



17. (c)

For the given system put $s = j\omega$

we get, $$G(j\omega)H(j\omega) = \frac{32}{j\omega\left(j\omega+\sqrt{6}\right)^3}$$

$$|G(j\omega)H(j\omega)| = \frac{32}{\omega\left(\sqrt{\omega^2+6}\right)^3}$$

at $\omega = \sqrt{2}$ rad/sec,

$$|G(\sqrt{2})H(\sqrt{2})| = \frac{32}{\sqrt{2}(\sqrt{2+6})^3} = 1$$

$$\because \quad |G(j\omega)H(j\omega)|_{\omega=\sqrt{2}\frac{\text{rad}}{\text{sec}}} = 1$$

Thus, the gain cross over frequency = $\sqrt{2}$ rad/sec

Also,
$$-180 = -90 - 3\tan^{-1}\frac{\omega_{pc}}{\sqrt{6}}$$

$$\tan^{-1}\frac{\omega_{pc}}{\sqrt{6}} = \frac{-90}{-3}$$

$$\Rightarrow \quad \frac{\omega_{pc}}{\sqrt{6}} = \tan 30°$$

$$\therefore \quad \omega_{pc} = \sqrt{2} \text{ rad/sec}$$

$$\because \quad \omega_{gc} = \omega_{pc}$$

$$\text{GM} = 0 \text{ dB and PM} = 0°$$

The system represents a marginally stable system.

18. (c)

$$\frac{C(s)}{R(s)} = \frac{1}{1+s\tau}$$

The response of the system,

$$C(s) = \frac{1}{1+s\tau} \times R(s)$$

$$C(s) = \frac{1}{1+s\tau} \times \frac{5}{s}$$

Taking inverse Laplace transform, we get,

$$c(t) = 5(1 - e^{-t/\tau})\, u(t)$$

Now, $c(t) = 4.2$ at $t = 0.35$ msec

By putting these values, we get,

$$4.2 = 5(1 - e^{-0.35/\tau})$$

$$0.16 = e^{-0.35/\tau}$$

or $\tau = 0.19$ msec

19. (d)

Given,
$$\frac{C(s)}{R(s)} = \frac{G(s)}{1+G(s)H(s)} = \frac{K+p}{s^2+qs+p}$$

For $H(s) = 1$,
$$\frac{G(s)}{1+G(s)} = \frac{K+p}{s^2+qs+p}$$

or
$$G(s)\,[s^2+qs+p] = (K+p) + G(K+p)$$

or
$$G(s) = \frac{K+p}{s^2+qs+p-K-p} = \frac{K+p}{s^2+qs-K}$$

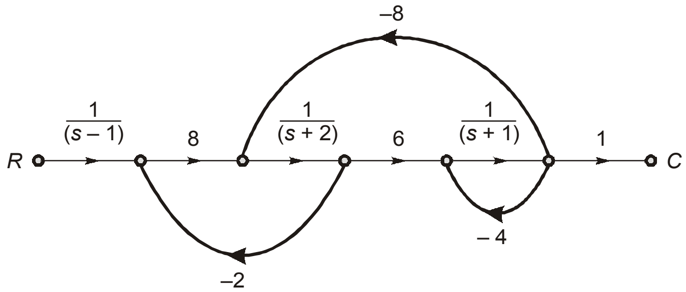
This is a type-0 system.

For a type-0 system, for unit ramp input,

$$e_{ss} = \infty$$

20. (b)

The signal flow graph of the given system can be drawn as,



The forward path, $F_1 = \dfrac{48}{(s-1)(s+2)(s+1)}$

The feedback loops, $L_1 = -\dfrac{16}{s+2}$

$L_2 = -\dfrac{4}{(s+1)}$

$L_3 = -\dfrac{48}{(s+2)(s+1)}$

The non-touching loop pair, $L_{1,\,2} = \dfrac{-(16)\times(-4)}{(s+2)(s+1)}$

∴ The closed loop transfer function using Mason's gain formula is,

$$T(s) = \frac{\dfrac{48}{(s-1)(s+2)(s+1)}}{1+\dfrac{16}{s+2}+\dfrac{4}{s+1}+\dfrac{48}{(s+1)(s+2)}+\dfrac{64}{(s+1)(s+2)}}$$

$$= \frac{\dfrac{48}{(s-1)}}{(s+1)(s+2)+16(s+1)+4(s+2)+112}$$

$$T(s) = \frac{48}{(s-1)[s^2+3s+2+16s+16+4s+8+112]}$$

$$= \frac{48}{s^3+23s^2+138s-s^2-23s-138}$$

$$= \frac{48}{s^3+22s^2+115s-138}$$

∴ The characteristic equation is,

$$s^3 + 22s^2 + 115s - 138 = 0$$

Using Routh's criterion,

s^3	1	115
s^2	22	–138
s^1	121.27	0
s^0	–138	

$\because$ There is a sign change in the first column of Routh's tabular form, the given system is unstable.

21. (b)

Using the Routh's tabular form

s^6	1	8	20	16
s^5	2	12	16	0
s^4	$2(s^4)$	$12(s^2)$	$16(s^0)$	
s^3	8	24	0	
s^2	6	16	0	
s^1	$\frac{16}{6}$	0	0	
s^0	16			

Since there is no sign change in the first column of the Routh array, the system does not have any pole in the RHS of s-plane. However the row of zeros occur which gives the auxiliary equation

$$A(s) \Rightarrow 2s^4 + 12s^2 + 16 = 0$$

$$\Rightarrow s^4 + 6s^2 + 8 = 0$$

and the roots are given by,

$$s = \pm j\sqrt{2}, \pm j2$$

Hence the system is said to be marginally stable.

22. (b)

The open loop transfer function is given as,

$$G(s)\,H(s) = \frac{1}{s(10s-1)}$$

Put, $s = j\omega$

$$G(j\omega)\,H(j\omega) = \frac{1}{j\omega(10j\omega-1)}$$

$$|G(j\omega)\,H(j\omega)| = \frac{1}{\omega\sqrt{100\omega^2+1}}$$

$$\angle G(j\omega)\,H(j\omega) = -90° - 180° + \tan^{-1}(10\omega) = -270° + \tan^{-1}(10\omega)$$

For $\omega = 0$,

$$|G(0)\,H(0)| = \infty$$

and $$\angle G(0)\,H(0) = \left(-270° + \tan^{-1}(10\omega)\right)\Big|_{\omega=0} = -270°$$

For $\omega = \infty$, $$|G(\infty)\,H(\infty)| = 0$$

and $$\angle G(\infty)\,H(\infty) = \left(-270° + \tan^{-1}(10\omega)\right)\Big|_{\omega=\infty} = -180°$$

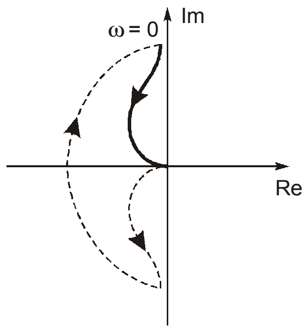
There is an open loop pole at origin. To map this pole,

$$s = re^{j\theta}\Big|_{r\to 0,\ \theta\to -\frac{\pi}{2}\text{ to }\frac{\pi}{2}}$$

$$G(s)\,H(s) = \frac{-1}{s(1-10s)} = \lim_{r\to 0}\frac{e^{j\pi}}{re^{j\theta}(1-10re^{j\theta})}\Bigg|_{\theta\to -\frac{\pi}{2}\text{ to }\frac{\pi}{2}}$$

$$= \lim_{r\to 0}\frac{1}{r}e^{j(\pi-\theta)}\Bigg|_{\theta\to -\frac{\pi}{2}\text{ to }\frac{\pi}{2}} = \infty e^{j\theta}\Big|_{\theta\to \frac{3\pi}{2}\text{ to }\frac{\pi}{2}}$$

Thus, the Nyquist plot can be drawn as,



23. (b)

The gain cross-over frequency ω_{gc} can be calculated as,

$$|G(j\omega)|_{\omega=\omega_{gc}} = 1$$

Here, $$G(j\omega) = \frac{32}{j\omega(j\omega+\sqrt{6})^3}$$

$$|G(j\omega)| = \frac{32}{\omega(\sqrt{\omega^2+6})^3} = 1$$

At $\omega = \sqrt{2}\text{ rad/sec}$

$|G(j\omega)|\ \omega = \sqrt{2}\text{ rad/sec}$

$$\frac{32}{\sqrt{2}\times\sqrt{8}\times\sqrt{8}\times\sqrt{8}} = 1$$

Thus, $\omega = \sqrt{2}\text{ rad/sec}$ is the gain cross-over frequency. Now, the phase cross-over frequency is calculated as

$$\angle G(j\omega)\,H(j\omega) = -180°$$

Here, $$\angle G(j\omega) = -90° - 3\tan^{-1}\frac{\omega}{\sqrt{6}}$$

or $$\frac{\tan^{-1}\omega}{\sqrt{6}} = 30°$$

or $$\frac{\omega}{\sqrt{6}} = \tan 30° = \frac{1}{\sqrt{3}}$$

or $$\omega_{pc} = \sqrt{2}\text{ rad/sec}$$

$$\omega_{gc} = \omega_{pc} = \sqrt{2}\text{ rad/sec}$$

The given system represents a marginally stable system having GM = 0 dB and PM = 0°.

24. (c)

Given that, $$G(s) = \frac{25}{s(s+1)(s+5)}$$

Let the compensator, $$G_c(s) = \frac{(s+\omega_z)}{(s+\omega_p)}$$

The open loop transfer function of the compensated system can be given as,

$$L(s) = G(s)\,G_c(s) = \frac{25(s+\omega_z)}{s(s+1)(s+5)(s+\omega_p)}$$

The velocity error constant of the compensated system will be,

$$K_v = \lim_{s\to 0} sL(s) = \frac{25}{5}\left(\frac{\omega_z}{\omega_p}\right) = 5\left(\frac{\omega_z}{\omega_p}\right)$$

Given that, $$e_{ss} = \frac{1}{K_v} < 0.05$$

So, $$K_v > \frac{1}{0.05} = 20$$

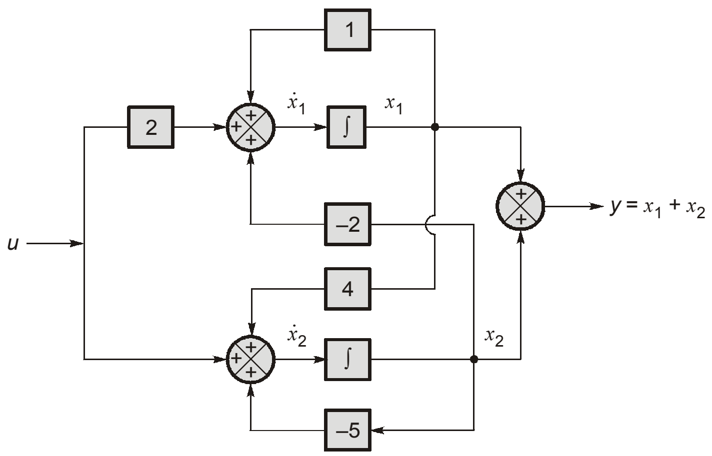
$$5\left(\frac{\omega_z}{\omega_p}\right) > 20$$

$$\frac{\omega_z}{\omega_p} > 4$$

Only option (c) satisfies this.

25. (a)

Redrawing the given block diagram, we get,



As per the block diagram, state equations are,

$$\dot{x}_1 = x_1 - 2x_2 + 2u$$

$$\dot{x}_2 = 4x_1 - 5x_2 + u$$

and $$y = x_1 + x_2$$

∴ State model, $$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix}1 & -2\\ 4 & -5\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}2\\ 1\end{bmatrix}u$$

$$y = [1 \quad 1]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

Check for controllability:

$$Q_c = [B \; : \; AB]$$

$$= \begin{bmatrix} 2 & : & \begin{pmatrix} 1 & -2 \\ 4 & -5 \end{pmatrix}\begin{pmatrix} 2 \\ 1 \end{pmatrix} \\ 1 & : & \end{bmatrix} = \begin{bmatrix} 2 & : & \begin{pmatrix} 2-2 \\ 8-5 \end{pmatrix} \\ 1 & : & \end{bmatrix} = \begin{bmatrix} 2 & 0 \\ 1 & 3 \end{bmatrix}$$

$$|Q_C| \neq 0 \;\Rightarrow\; \text{Controllable}$$

Check for observability:

$$Q_o = [C^T \; : \; A^T C^T]$$

$$= \begin{bmatrix} 1 & : & \begin{pmatrix} 1 & 4 \\ -2 & -5 \end{pmatrix}\begin{pmatrix} 1 \\ 1 \end{pmatrix} \\ 1 & : & \end{bmatrix} = \begin{bmatrix} 1 & 5 \\ 1 & -7 \end{bmatrix}$$

$$|Q_C| \neq 0 \;\Rightarrow\; \text{Observable}$$

26. (d)

As per root locus transfer function

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

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

$$s(s^2 + 2s + 2) + 4\,(s^2 + 2s + 2) + k = 0$$

$$s^3 + 6s^2 + 10s + (8 + k) = 0$$

s^3	1	10
s^2	6	$8 + k$
s^1	$-\dfrac{(8+k)-60}{6}$	0
s^0	$8 + k$	0

Row, $s^1 = 0$

$\Rightarrow$ $8 + k = 60$

$k = 52$

For calculation of intersection points,

$$6s^2 + (8 + k) = 0$$

$$6s^2 + (60) = 0$$

$$s^2 = -10$$

$$s = \pm j\sqrt{10}$$

Thus points of intersection are,

$$s = \pm j\omega = \pm j\sqrt{10}$$

27. (b)

The gain margin of the system can be given as,

$$\text{GM} = 20\log_{10}\frac{1}{|G(j\omega_{pc})|}$$

ω_{pc} is independent of the value of K.

So, $\text{GM} = C - 20\log_{10}(K)$

Where, C is a term independent of "K".

For $K = 2$, $\text{GM} = 32$ dB

So, $C = 32 + 20\log_{10}(2)$

When GM = 25 dB,

$$25 = C - 20\log_{10}(K)$$

$$25 = 32 + 20\log_{10}(2) - 20\log_{10}(K)$$

$$20\log_{10}(K) = 7 + 20\log_{10}(2) = 13.02$$

$$K = 10^{(13.02/20)} = 4.48$$

28. (b)

The maximum phase lead is given by,

$$\phi_m = \sin^{-1}\left(\frac{1-\alpha}{1+\alpha}\right)$$

For high pass filter/lead compensator,

$$\tau = R_1C$$

and

$$\alpha = \frac{R_2}{R_1 + R_2}\ ;\ \alpha < 1$$

By putting the value of α in the above relation, we get,

$$\phi_m = \sin^{-1}\left(\frac{1-\dfrac{R_2}{R_1+R_2}}{1+\dfrac{R_2}{R_1+R_2}}\right)$$

$$= \sin^{-1}\left(\frac{R_1+R_2-R_2}{R_1+R_2+R_2}\right) = \sin^{-1}\left(\frac{R_1}{R_1+2R_2}\right)$$

29. (b)

The characteristic equation is given by,

$$|sI - A| = 0$$

$$\begin{bmatrix} s & 0 & 0 \\ 0 & s & 0 \\ 0 & 0 & s \end{bmatrix} - \begin{bmatrix} 0 & 3 & 1 \\ 2 & 4 & 1 \\ -5 & -2 & -2 \end{bmatrix} = \begin{bmatrix} s & -3 & -1 \\ -2 & s-4 & -1 \\ 5 & 2 & s+2 \end{bmatrix}$$

$$\therefore \quad \begin{vmatrix} s & -3 & -1 \\ -2 & s-4 & -1 \\ 5 & 2 & s+2 \end{vmatrix} = 0$$

$$s[(s-4)(s+2)+2]+3[-2(s+2)+5]-1[-4-5(s-4)] = 0$$

$\Rightarrow$ $s[s^2 - 2s - 8 + 2] + 3[-2s - 4 + 5] - [-4 - 5s + 20] = 0$

$\Rightarrow$ $s[s^2 - 2s - 6] + 3[-2s + 1] - [-5s + 16] = 0$

$\Rightarrow$ $s^3 - 2s^2 - 6s - 6s + 3 + 5s - 16 = 0$

$\Rightarrow$ $s^3 - 2s^2 - 7s - 13 = 0$

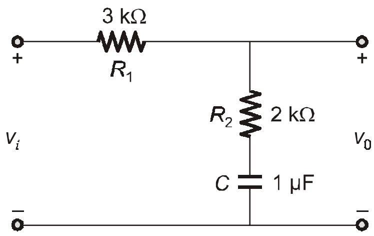
Using Routh's tabular form,

s^3	1	−7
s^2	−2	−13
s^1	−13.5	0
s^0	−13	0

Here, the total number of sign changes in the first column of Routh array is 1, therefore only one pole lie in the RHS of s-plane.

30. (a)

For the circuit shown,



$$G(s) = \frac{V_0(s)}{V_i(s)} = \frac{R_2 + \frac{1}{sC}}{R_1 + R_2 + \frac{1}{sC}}$$

$$= \left(\frac{R_2}{R_1 + R_2}\right) \cdot \frac{\left(s + \frac{1}{R_2C}\right)}{\left[s + \left(\frac{R_2}{R_1 + R_2}\right)\frac{1}{R_2C}\right]}$$

$$\therefore \quad \alpha = \frac{R_1 + R_2}{R_2} = \frac{3\text{ k}\Omega + 2\text{ k}\Omega}{2\text{ k}\Omega} = \frac{5}{2} = 2.50$$

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