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Civil Services Main Examination Previous Solved Papers : Electrical Engg. (Paper-II)

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Preface

Civil Service is considered as the most prestigious job in India and it has become a preferred destination by all engineers. In order to reach this estimable position every aspirant has to take arduous journey of Civil Services Examination (CSE). Focused approach and strong determination are the pre-requisites for this journey. Besides this, a good book also comes in the list of essential commodity of this odyssey.



I feel extremely glad to launch the revised edition of such a book which will not only make CSE plain sailing, but also with 100% clarity in concepts.

MADE EASY team has prepared this book with utmost care and thorough study of all previous years papers of CSE. The book aims to provide complete solution to all previous years questions with accuracy.

On doing a detailed analysis of previous years CSE question papers, it came to light that a good percentage of questions have been asked in Engineering Services, Indian Forest Services and State Services exams. Hence, this book is a one stop shop for all CSE, ESE and other competitive exam aspirants.

I would like to acknowledge efforts of entire MADE EASY team who worked day and night to solve previous years papers in a limited time frame and I hope this book will prove to be an essential tool to succeed in competitive exams and my desire to serve student fraternity by providing best study material and quality guidance will get accomplished.

With Best Wishes

B. Singh (Ex. IES)

CMD, MADE EASY Group

Previous Years Solved Papers of
Civil Services Main Examination

Electrical Engineering : Paper-II

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1

Control Systems

1. Modelling of a Control System & Transfer Function Approach

- 1.1** Show that the feedback reduces the effect of parameter variation on the performance of the control system. Also discuss briefly the effect of feedback on the transient performance of the control system.

[CSE-2002 : 20 marks]

Solution:

Consider an open loop system,

$$T(s) = \frac{C(s)}{R(s)} = G(s)$$

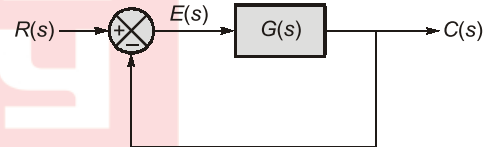


The sensitivity of $T(s)$ with respect to $G(s)$ will be given by

$$S_G^T = \frac{\frac{\partial T}{\partial G}}{\frac{T}{G}} = \frac{\frac{\partial T}{\partial G} \cdot G}{T} = 1$$

Consider a closed loop system,

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



$$\therefore S_G^T = \frac{\frac{\partial T}{\partial G} \cdot G}{T} = \frac{1}{1 + G(s)}$$

Hence, feedback reduce the sensitivity of the transfer function to changes in system parameters.

Effect of feedback on transient performance:

1. Feedback reduces the gain of the system.
2. Feedback reduces the system time constant and thus increases response speed.
3. Feedback shifts the pole of the system to left.
4. Feedback introduces the possibility of instability.
5. Feedback increases the bandwidth of the system.

- 1.2** Explain the effects of negative feedback in control systems on the following :

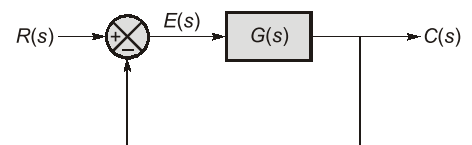
- (i) Stability
- (ii) External disturbances

[CSE-2003 : 20 marks]

Solution:

For closed-loop system with negative feedback,

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

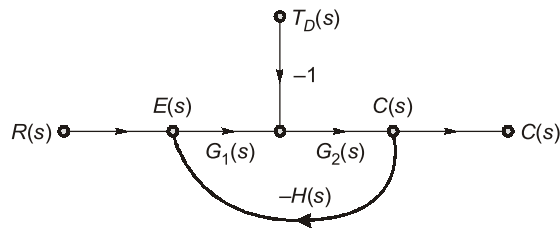


- (i) **Stability:** Negative feedback introduces the possibility of instability.

This is because the characteristic equation of $\frac{C(s)}{R(s)}$ may have roots with positive real parts even if

$G(s)$ itself is stable.

- (ii) **External disturbances:** Negative feedback reduces the effect of external disturbances on output. Consider the closed loop system with disturbances as shown below:



$$\frac{C(s)}{T_D(s)} = \frac{-1}{G_1(s)H(s)} \quad [\text{Considering } R(s) = 0]$$

Thus, feedback reduces the effect of disturbance on a system.

- 1.3** If the roots of characteristic equation of a linear digital control system lie within unity circle in z-plane, the system is stable?

[CSE-2003 : 20 marks]

Solution:

The characteristic equation of z-transfer function is

$$1 + GH(z) = 0$$

The stability region in z-plane corresponding to s-plane is located by mapping from s-plane to z-plane.

z-transform is obtained by substituting $z = e^{sT}$ in the corresponding impulse train Laplace transform.

The imaginary axis ($j\omega$) axis in the s-plane divides stable and unstable regions and the corresponding regions in z-domain can be obtained by putting $s = \pm j\omega$ and plotting the values of 'z' thus obtained in another complex phase called z-plane.

Therefore,

$$z = e^{\pm j\omega T}$$

$$z = (\cos \omega T \pm j \sin \omega T)$$

Magnitude,

$$|z| = 1$$

Angle,

$$\angle z = \pm \omega T$$

Thus the variation of the dependent variable 'z' in the z-plane as the independent variable 'ω' varied along the imaginary axes in s-plane is given by a circle of unit radius central at origin of z-plane.

Let,

$$s = -\alpha \pm j\omega \quad [\text{a point in the L.H.S. of s-plane}]$$

$$z = e^{(-\alpha \pm j\omega)T} = e^{-\alpha T} (\cos \omega T \pm j \sin \omega T)$$

$$|z| = e^{-\alpha T}$$

$$\angle z = \pm \omega T$$

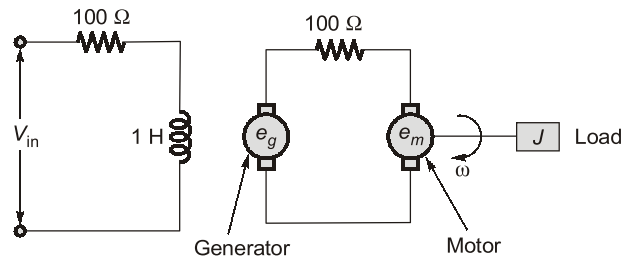
α and T being positive

Therefore,

$$|z| < 1 \quad [\text{region represents L.H.S. of s-plane}]$$

Hence if the roots of characteristic equation of a linear control system lie within unit circle in z-plane the system is stable.

1.4 The diagram of a speed control system is given below :

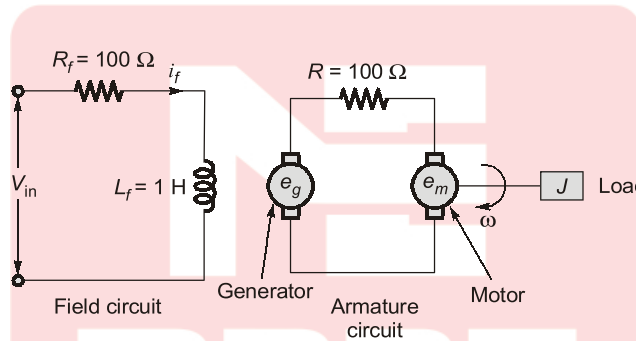


The generator e.m.f. e_g is 2000 volts per field ampere. The motor e.m.f. e_m is $1.5 \text{ volts rad}^{-1} \text{ sec}$. The motor torque K_T is $0.5 \text{ N-m per armature ampere}$ and the inertia of motor and load is

10^{-4} kg.m^2 . Assuming negligible friction, determine the transfer function $\frac{\omega(s)}{V_{in}(s)}$.

[CSE-2011 : 20 marks]

Solution:



Applying KVL in field circuit,

$$V_{in} = R_f i_f + L_f \frac{di_f}{dt}$$

Generated emf,

$$V_{in}(s) = R_f I_f(s) + sL_f I_f(s) \quad \dots(1)$$

$$e_g = K_g i_f$$

$$E_g(s) = K_g I_f(s) \quad \dots(2)$$

Applying KVL in armature circuit,

$$e_g = R i_a + e_m$$

$$E_g(s) = R I_a(s) + E_m(s) \quad \dots(3)$$

Counter emf of motor,

$$e_m = K_M \omega$$

$$E_m(s) = K_M \omega(s) \quad \dots(4)$$

Developed Torque on motor,

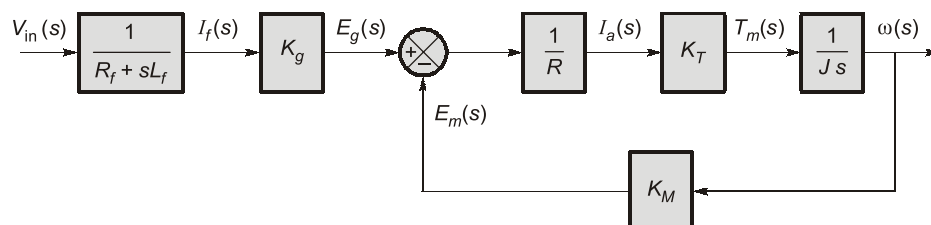
$$T_M = K_T i_a$$

$$T_M(s) = K_T I_a(s) \quad \dots(5)$$

$$T_M = \frac{J d\omega}{dt} \quad \{\text{Neglecting friction on motor}\}$$

$$T_M(s) = Js \omega(s) \quad \dots(6)$$

Block diagram from above equations can be drawn as



On reduction of block diagram we transfer function,

$$\frac{\omega(s)}{V_{in}(s)} = \left(\frac{K_T}{JRs + K_M K_T} \right) \left(\frac{K_g}{R_f + sL_f} \right) = \frac{K_T K_g}{(R_f + sL_f)(JRs + K_M K_T)}$$

From given data we have,

$$K_T = 0.5 \text{ N-m/A}$$

$$K_g = 2000 \text{ V/A}$$

$$K_M = 1.5 \text{ Volts rad}^{-1} \text{ sec}$$

$$J = 10^{-4} \text{ Kg. m}^2$$

$$\frac{\omega(s)}{V_{in}(s)} = \frac{0.5 \times 2000}{(10^{-4} \times 100s + 1.5 \times 0.5)(100 + s)} = \frac{1000}{(10^{-2}s + 0.75)(s + 100)}$$

Hence, transfer function is,

$$\frac{\omega(s)}{V_{in}(s)} = \frac{10^5}{(s + 75)(s + 100)}$$

1.5 The transfer function of a thermocouple relating output voltage to temperature is given by

$\frac{0.625 \times 10^{-4}}{s + 0.125} \text{ V/}^\circ\text{C}$. Put the transfer function in standard format and find the values of characterising parameters of the thermocouple. Determine the thermocouple output voltage at $t = 8 \text{ s}$, when the thermocouple kept at ambient temperature of 20°C at $t = 0 \text{ s}$ is taken to a water bath kept at 80°C . [CSE-2012 : 3 + 4 = 7 marks]

Solution:

Standard format of transfer function is $\frac{K}{(Ts + 1)}$.

$$\text{So, } \frac{V(s)}{T(s)} = \frac{0.625 \times 10^{-4}}{s + 0.125} = \frac{5 \times 10^{-4}}{(8s + 1)}$$

For

$$T(t) = Tu(t)$$

$$T(s) = \frac{T}{s}$$

T = Temperature difference between junctions

$$\Rightarrow V(s) = \frac{T}{s} \times \frac{0.625 \times 10^{-4}}{s + 0.125} = T \times \frac{0.625 \times 10^{-4}}{0.125} \left(\frac{1}{s} - \frac{1}{s + 0.125} \right)$$

$$= 5T \times 10^{-4} \left(\frac{1}{s} - \frac{1}{s + 0.125} \right)$$

$$\Rightarrow V(t) = 5T \times 10^{-4} (u(t) - e^{-t/8} u(t))$$

$$\Rightarrow V(t) = 5T(1 - e^{-t/8}) \times 10^{-4} \text{ V}$$

Thermocouple time constant = 8 secs.

Steady state output of the thermocouple for $T^\circ\text{C}$

$$= 5T \times 10^{-4} \text{ V}$$

$$T = 80^\circ - 20^\circ = 60^\circ\text{C}$$

Now,

$$T = 60^\circ\text{C and } t = 8 \text{ sec}$$

$\therefore$

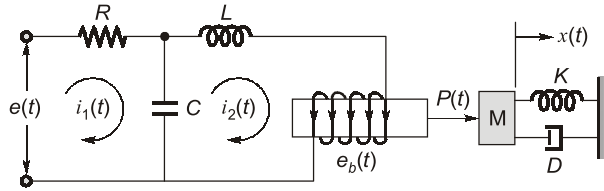
$$V(t) = 5 \times 60 [1 - e^{-8/8}] \times 10^{-4} \text{ V}$$

$$= 300 \left(\frac{e - 1}{e} \right) \times 10^{-4}$$

$$= 189.636 \times 10^{-4} \text{ V} = 18.963 \text{ mV}$$

1.6 Find the transfer function $X(s)/E(s)$ for the electromechanical system shown in the following figure.

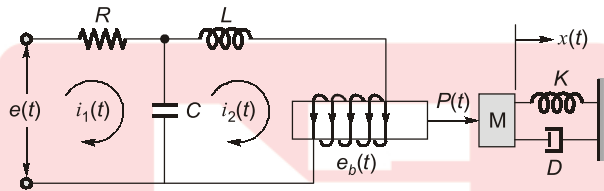
Consider (1) the force acting on mass $P(t) = K_2 i_2(t)$ and (2) the back emf of coil $e_b(t) = K_1 \frac{dx(t)}{dt}$, where K_1 and K_2 are constants.



[CSE-2019 : 10 marks]

Solution:

Given electromechanical system:



Now for mechanical part:

$$\frac{M d^2 x(t)}{dt^2} + K x(t) + \frac{D dx(t)}{dt} = P(t) = K_2 i_2(t) \quad \dots(i)$$

For electrical part:

$$e(t) = i_1(t) \cdot R + \frac{1}{C} \int i_1(t) dt \quad \dots(ii)$$

$$\text{Also, } L \frac{di_2(t)}{dt} + K_1 \frac{dx(t)}{dt} + \frac{1}{C} \int (i_2 - i_1) dt = 0 \quad \dots(iii)$$

⇒ Apply Laplace transform,

$$\frac{X(s)}{I_2(s)} = \frac{K_2}{(Ms^2 + Ds + K)} \quad \dots(iv)$$

$$\frac{E(s)}{I_1(s)} = R + \frac{1}{Cs} \quad \dots(v)$$

$$\left(Ls + \frac{1}{Cs} \right) I_2(s) + K_1 X(s) = \frac{1}{Cs} I_1(s) \quad \dots(vi)$$

Using (iv) and (v) in (vi),

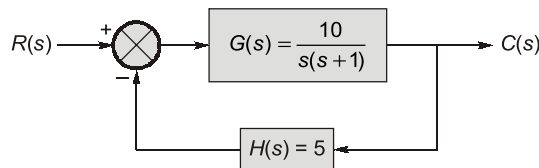
$$\Rightarrow \left\{ \left(Ls + \frac{1}{Cs} \right) \left(\frac{Ms^2 + Ds + K}{K_2} \right) + K_1 \right\} X(s) = \frac{1}{Cs} \times \frac{1}{\left(R + \frac{1}{Cs} \right)} E(s)$$

$$\Rightarrow \frac{X(s)}{E(s)} = \frac{1}{1 + RCs} \times \left[\frac{1}{\left(Ls + \frac{1}{Cs} \right) \left(\frac{Ms^2 + Ds + K}{K_2} \right) + K_1} \right]$$

$$\therefore \frac{X(s)}{E(s)} = \frac{1}{1+RCs} \times \frac{CsK_2}{(LCs^2 + 1)(Ms^2 + Ds + K) + K_1K_2}$$

$$\therefore \frac{X(s)}{E(s)} = \frac{CsK_2}{(1+RCs)[LCs^2 + 1)(Ms^2 + Ds + K) + K_1K_2]}$$

- 1.7** The block diagram of a position control system is shown in the figure. Determine the sensitivity of the closed loop transfer function $T(s)$ with respect to $G(s)$ and $H(s)$ for 1 rad/sec.



[CSE-2024 : 10 marks]

Solution:

$$C(s) = \text{CLTF} = \frac{G(s)}{1+G(s)H(s)}$$

(i)

$$S_C^G = \frac{\partial C}{\partial G} \times \frac{G}{C} = \frac{1+G(s)H(s) - G(s)H(s)}{[1+G(s)H(s)]^2} \times \frac{G(s)[1+G(s)H(s)]}{G(s)}$$

$$\Rightarrow S_C^G = \frac{1}{1+G(s)H(s)} = \frac{1}{1 + \frac{10}{s(s+1)} \times 5}$$

$$S_C^G = \frac{s^2 + s}{s^2 + s + 50} = \frac{-\omega^2 + j\omega}{50 - \omega^2 + j\omega} = \frac{-1 + j1}{49 + j1}$$

$$\Rightarrow S_C^G = \frac{-24}{1201} + j \frac{25}{1201}$$

$$|S_C^G| = 0.02886$$

(ii)

$$S_C^H = \frac{\partial C}{\partial H} \times \frac{H}{C}$$

$$= \frac{(1+GH) \times 0 - G(G)}{(1+GH)^2} \times \frac{H(1+GH)}{G} = \frac{-G^2}{(1+GH)^2} \times \frac{H(1+GH)}{G}$$

$$= \frac{-GH}{1+GH} = \frac{\frac{-10}{s(s+1)} \times 5}{1 + \frac{10 \times 5}{s(s+1)}} = \frac{-50}{s^2 + s + 50} = \frac{-50}{(50 - \omega^2) + j\omega} = \frac{-50}{49 + j1}$$

$$S_C^H = \frac{-1225}{1201} + j \frac{25}{1201}$$

$$\Rightarrow |S_C^H| = 1.0202$$

The closed loop system is more sensitive to disturbances in feedback path than in forward path.

2. Block Diagram and Signal Flow Graph

- 2.1** State and explain the Mason's Gain formula. Determine all input output relationships of the system represented by the set of following linear equations using the Mason's Gain formula:

$$x_1 = a_{11}x_1 + a_{12}x_2 + b_1u_1 \text{ and } x_2 = a_{21}x_1 + a_{22}x_2 + b_2u_2$$

where u_1 and u_2 are the inputs and x_1 and x_2 are the states of the system.

[CSE-2005 : 20 marks]

Solution:

Mason's Gain Formula: The overall transmittance (gain) can be determined by a Mason's gain formula given below:

$$T = \sum_{k=1}^k \frac{P_k \Delta_k}{\Delta}$$

The terms in the Mason's gain formula are explained below:

P_k is the forward path transmittance of K_{th} path from a specified input node to an output node. In asserting P_k no node should be encountered more than once.

Δ is the graph determinant which involves closed-loop transmittances and mutual interaction between non touching loops.

$$\begin{aligned} \Delta = & 1 - [\text{Sum of all individual loop transmittances}] \\ & + [\text{Sum of loop transmittance products of all possible pairs of NON-TOUCHING loops}] \\ & - [\text{Sum of loop transmittance products of all possible triplets of NON-TOUCHING loops}] \\ & + [\text{.....}] - [\text{.....}] \end{aligned}$$

Δ_k is the path factor associated with the concerned path and involves all closed loops in the graph which are isolated from the forward path under consideration.

$$x_1 = a_{11} x_1 + a_{12} x_2 + b_1 u_1$$

$$x_2 = a_{21} x_1 + a_{22} x_2 + b_2 u_2$$

Case 1: Output is taken from x_1 and input is u_1

$$\Delta = 1 - (a_{11} + a_{21}a_{12} + a_{22}) + a_{11}a_{22}$$

$$P_1 = b_1, \Delta_1 = (1 - a_{22})$$

$$\therefore \frac{X_1}{u_1} = \frac{P_1 \Delta_1}{\Delta} = \frac{b_1(1 - a_{22})}{1 - (a_{11} + a_{21}a_{12} + a_{22}) + a_{11}a_{22}}$$

Case 2: Output is taken from x_2 and input is u_1

$$\Delta = 1 - (a_{11} + a_{21}a_{12} + a_{22}) + a_{11}a_{22}$$

$$P_1 = b_1 a_{21}, \Delta_1 = 1$$

$$\frac{X_2}{u_1} = \frac{P_1 \Delta_1}{\Delta} = \frac{b_1 a_{21} \times 1}{1 - (a_{11} + a_{21}a_{12} + a_{22}) + a_{11}a_{22}}$$

Case 3: Output is taken from x_1 and input is u_2

$$\Delta = 1 - (a_{11} + a_{21}a_{12} + a_{22}) + a_{11}a_{22}$$

$$P_1 = b_2 a_{12}, \Delta_1 = 1$$

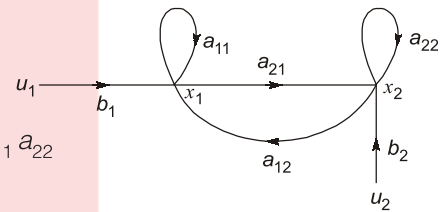
$$\frac{X_1}{u_2} = \frac{P_1 \Delta_1}{\Delta} = \frac{b_2 a_{12}}{1 - (a_{11} + a_{21}a_{12} + a_{22}) + a_{11}a_{22}}$$

Case 4: Output is taken from x_2 and input is u_2

$$\Delta = 1 - (a_{11} + a_{21}a_{12} + a_{22}) + a_{11}a_{22}$$

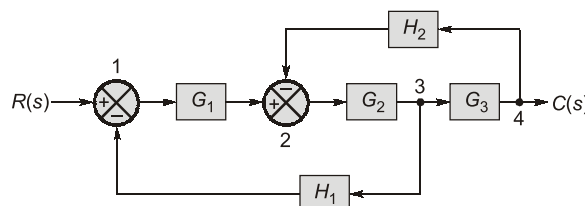
$$P_1 = b_2, \Delta_1 = 1 - a_{11}$$

$$\frac{X_2}{u_2} = \frac{P_1 \Delta_1}{\Delta} = \frac{b_2(1 - a_{11})}{1 - (a_{11} + a_{21}a_{12} + a_{22}) + a_{11}a_{22}}$$



2.2

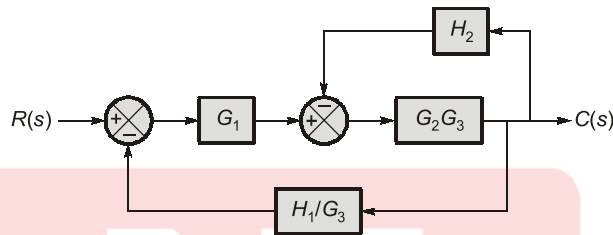
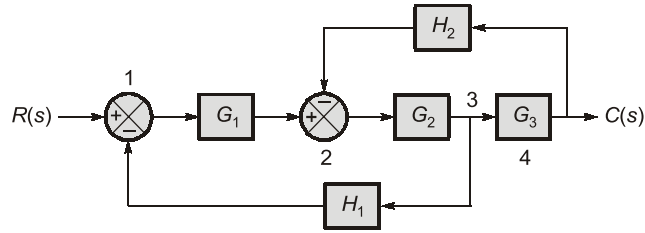
For the block diagram shown in the figure below, find the overall transfer function of the system. Verify the same, using signal-flow graph analysis.



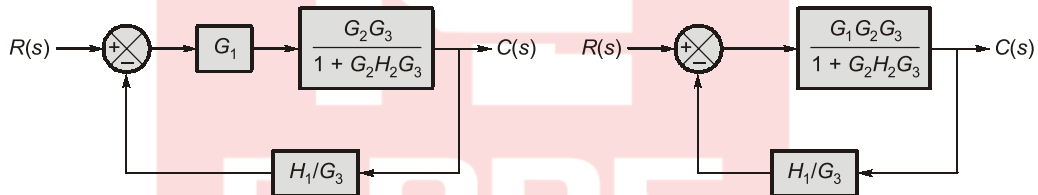
[CSE-2012 : 20 marks]

Solution:

Using block-diagram analysis:

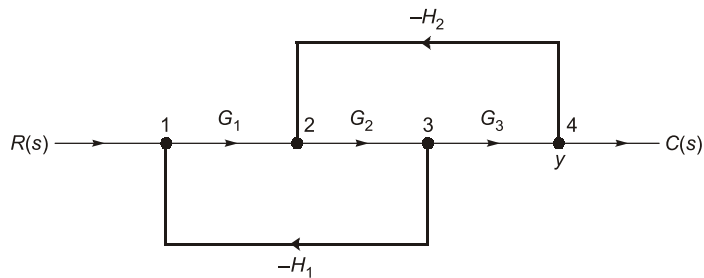


(By moving take-off point from point 3 to point 4)



$$\therefore \frac{C(s)}{R(s)} = \frac{G_1 G_2 G_3}{1 + \frac{G_1 G_2 H_1}{1 + G_2 H_2 G_3}} = \frac{G_1 G_2 G_3}{1 + G_2 G_3 H_2 + G_1 G_2 H_1}$$

Using signal flow graph analysis:



$$P_1 = G_1 G_2 G_3$$

$$L_1 = -G_1 G_2 H_1$$

$$L_2 = -G_2 G_3 H_2$$

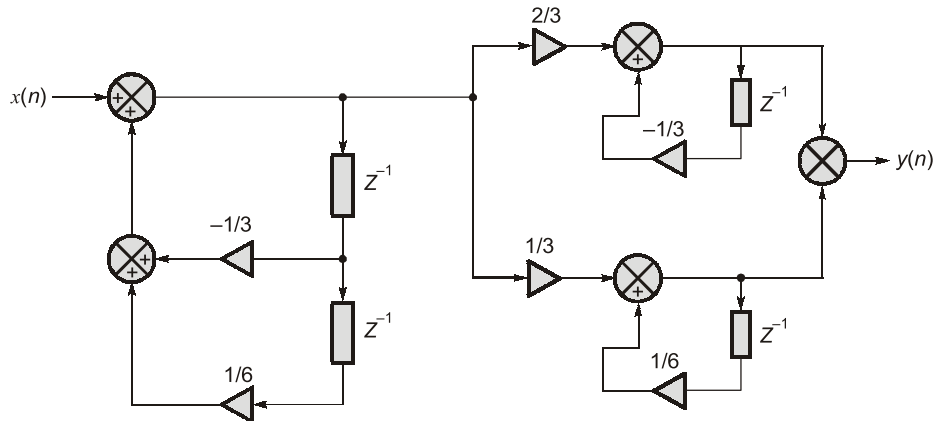
$$\Delta = 1 - (L_1 + L_2) = 1 + G_1 G_2 H_1 + G_2 G_3 H_2$$

$$\Delta_1 = 1$$

and

$$\frac{C(s)}{R(s)} = \frac{P_1 \Delta_1}{\Delta} = \frac{P_1(1)}{\Delta} = \frac{G_1 G_2 G_3}{1 + G_1 G_2 H_1 + G_2 G_3 H_2}$$

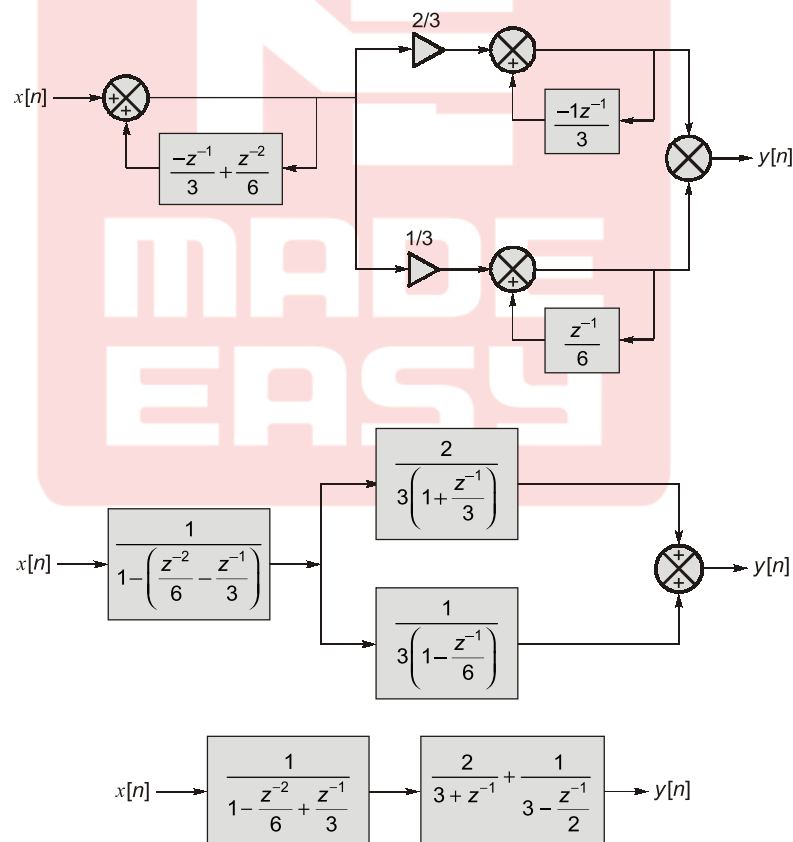
2.3 The block diagram of a discrete time LTI system is given below:



Determine the transfer function $H(z)$.

[CSE-2012 : 20 marks]

Solution:



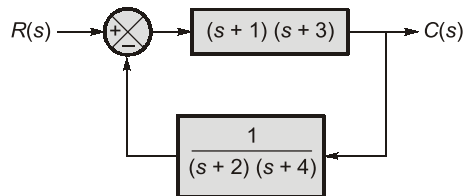
$\therefore$

$$\frac{Y(z)}{X(z)} = \left(\frac{6}{6 - z^{-2} + 2z^{-1}} \right) \left(\frac{2}{3 + z^{-1}} + \frac{2}{6 - z^{-1}} \right)$$

Hence,

$$H(z) = \left(\frac{6}{6 - z^{-2} + 2z^{-1}} \right) \left(\frac{18}{18 + 3z^{-1} - z^{-2}} \right)$$

- 2.4** For the block diagram representation of the figure shown below, determine the system characteristic equation. Is the system represented by this block diagram stable?



[CSE-2012 : 10 marks]

Solution:

Given: $G(s) = (s+1)(s+3)$ and $H(s) = \frac{1}{(s+2)(s+4)}$

Characteristic equation is given by

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

i.e. $1 + \frac{(s+1)(s+3)}{(s+2)(s+4)} = 0$

$$\Rightarrow s^2 + 6s + 8 + s^2 + 4s + 3 = 0$$

$$\Rightarrow 2s^2 + 10s + 11 = 0$$

This is the required system characteristic equation.

Now, for stability:

The Routh table of characteristic equation $2s^2 + 10s + 11 = 0$ is

Routh table:

s^2	2	11
s^1	10	
s^0	11	

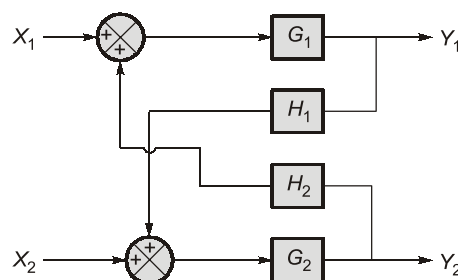
Since, there is no sign changes in first column of the Routh table ; According to Routh Hurwitz criterion, the system is stable.

- 2.5** Some control Systems have more than one inputs applied at different points in the system. How do we find the response of such systems, using block diagram algebra? Illustrate your answer with the help of a simple example.

[CSE-2012 : 10 marks]

Solution:

Consider a control system having more than one input applied at different points in the system as



The response of such system given by

$$\frac{Y}{X} = \frac{Y_1}{X_1} + \frac{Y_2}{X_2} + \frac{Y_2}{X_1} + \frac{Y_1}{X_2}$$

Now,

Case-1, to find $\left. \frac{Y_1}{X_1} \right|_{\text{when } X_2 = Y_2 = 0}$

Then,

$$\text{So, } \frac{Y_1}{X_1} = \frac{G_1}{1 - G_1 G_2 H_1 H_2}$$

Case-2, to find $\left. \frac{Y_2}{X_2} \right|_{\text{when } X_1 = Y_1 = 0}$

Then,

$$\text{So, } \frac{Y_2}{X_2} = \frac{G_2}{1 - G_1 G_2 H_1 H_2}$$

Case-3, to find $\left. \frac{Y_1}{X_2} \right|_{\text{when } Y_2 = X_1 = 0}$

Then,

$$\text{So, } \frac{Y_1}{X_2} = \frac{G_1 G_2 H_2}{1 - G_1 G_2 H_1 H_2}$$

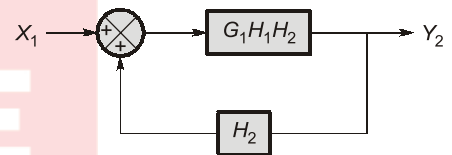
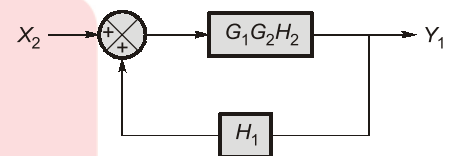
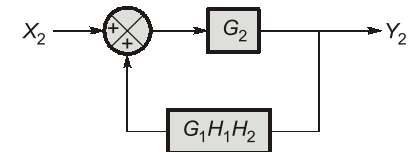
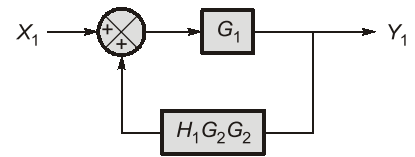
Case-4, to find $\left. \frac{Y_2}{X_1} \right|_{\text{when } Y_1 = X_2 = 0}$

Then,

$$\text{So, } \frac{Y_2}{X_1} = \frac{G_1 G_2 H_1}{1 - G_1 G_2 H_1 H_2}$$

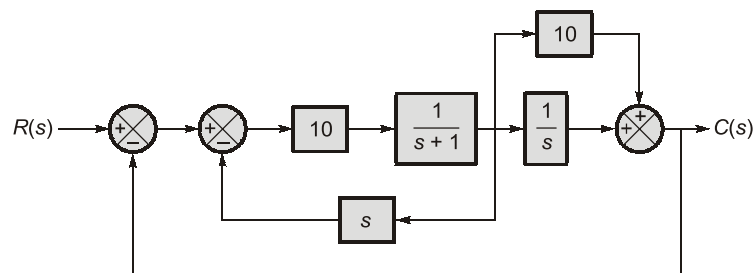
Hence, overall response is given as

$$\begin{aligned} \frac{Y}{X} &= \frac{Y_1}{X_1} + \frac{Y_1}{X_2} + \frac{Y_2}{X_1} + \frac{Y_2}{X_2} \\ \Rightarrow \frac{Y}{X} &= \frac{G_1 + G_2 + G_1 G_2 H_2 + G_1 G_2 H_1}{1 - G_1 G_2 H_1 H_2} \end{aligned}$$

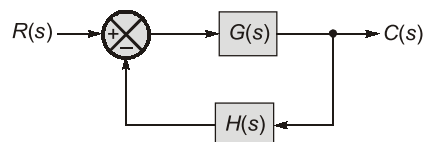


2.6

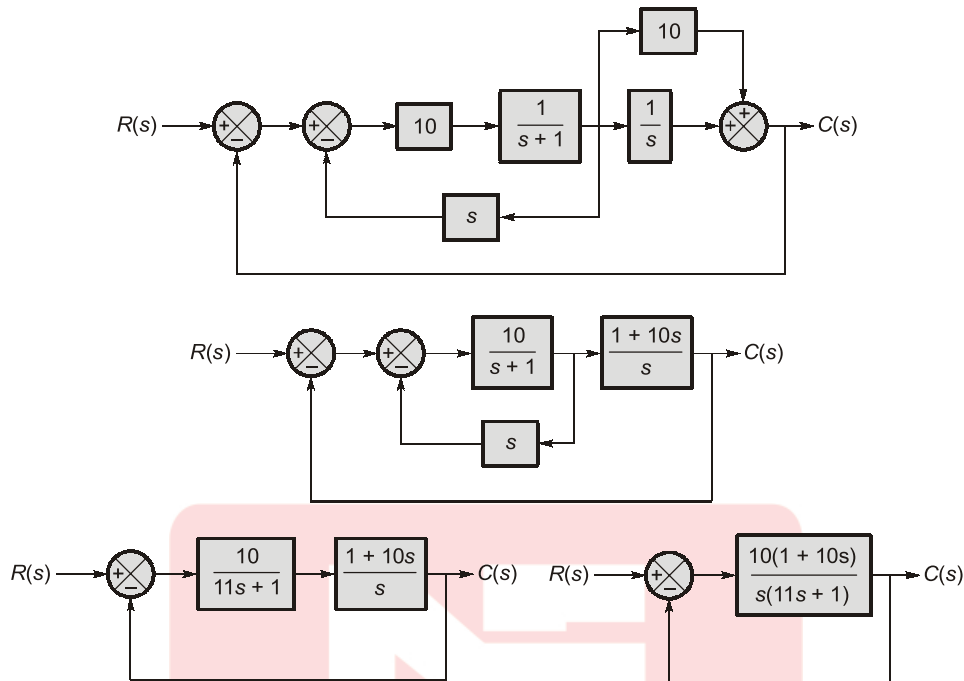
Using the Block diagram simplification method reduce the block diagram of the following control system.



To a block diagram of the following type:



Solution:



$$\therefore G(s) = \frac{10(10s+1)}{s(11s+1)}$$

Therefore,

$$H(s) = 1$$

2.7 A control system is represented by the state space equations:

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = x_3 - u_1$$

$$\dot{x}_3 = -2x_2 - 3x_3 + u_2$$

and the output equations are:

$$y_1 = x_1 + 3x_2 + 2u_1$$

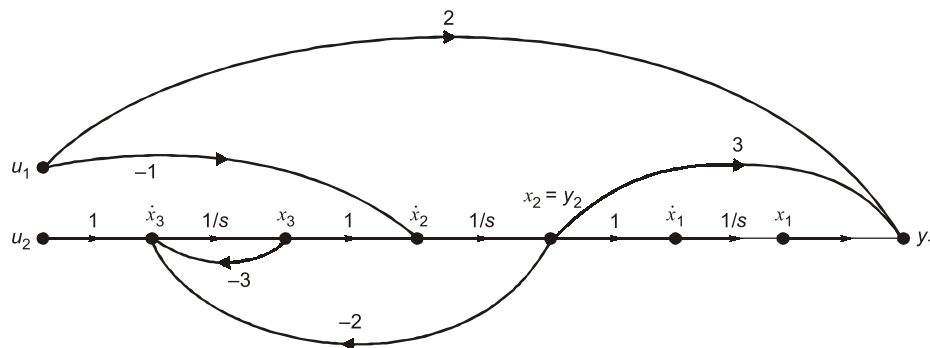
$$y_2 = x_2$$

Draw the state transition signal flow graph and find the characteristic roots of the system.

[CSE-2013 : 20 marks]

Solution:

Signal flow graph,



From the given state space equations,

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & -2 & -3 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ -1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

Here system matrix, $A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & -2 & -3 \end{bmatrix}$

Characteristic roots of system

$$|sI - A| = 0$$

$$\Rightarrow \begin{vmatrix} s & 0 & 0 \\ 0 & s & 0 \\ 0 & 0 & s \end{vmatrix} - \begin{vmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & -2 & -3 \end{vmatrix} = 0$$

$$\Rightarrow \begin{vmatrix} s & -1 & 0 \\ 0 & s & -1 \\ 0 & 2 & s+3 \end{vmatrix} = 0$$

$$\Rightarrow s(s(s+3)+2) = 0$$

$$\Rightarrow s(s^2 + 3s + 2) = 0$$

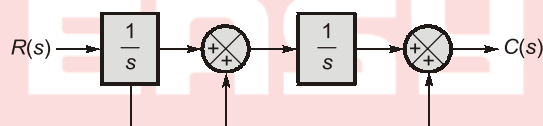
$$\Rightarrow s^3 + 3s^2 + 2s = 0$$

$$\Rightarrow s(s+1)(s+2) = 0$$

$$s = 0, -1, -2$$

Characteristic roots of system are 0, -1, -2.

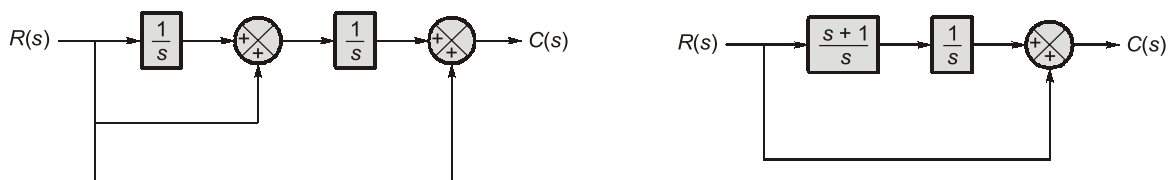
2.8 For the block shown in figure given below, obtain $C(s)/R(s)$ using block diagram reduction technique.



[CSE-2015 : 10 marks]

Solution:

The block diagram shown above can be drawn as

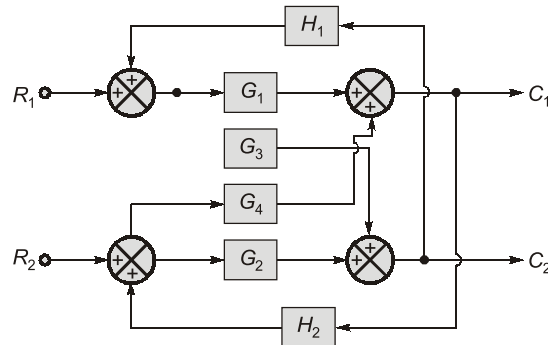


$$R(s) \longrightarrow \left[\frac{s+1}{s^2} + 1 \right] \longrightarrow C(s)$$

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

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

2.9 The block diagram representation of a control system is shown below:



Find C_2/R_1 transfer function using the following:

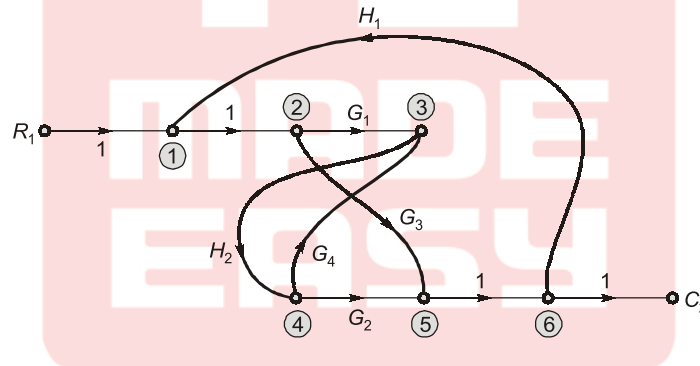
- Block diagram reduction method
- Mason's gain formula

[CSE-2019 : 10 marks]

Solution:

$$\frac{C_2}{R_1}: \text{ (Neglect } C_1, R_2 \text{)}$$

Converting into signal flow graph:



Now by Mason's gain formula, $\frac{C_2(s)}{R(s)} = \frac{\sum P_k \Delta_k}{\Delta}$

Forward paths:

$$P_1 = G_1 H_2 G_2,$$

$$\Delta_1 = 1$$

$$P_2 = G_3,$$

$$\Delta_2 = 1 - G_4 H_2$$

Individual loops:

$$L_1 = G_4 H_2$$

$$L_2 = G_1 H_2 G_2 H_1 \text{ and } L_3 = G_3 H_1$$

Non touching loop:

$$L_1 L_3 = G_4 H_2 G_3 H_1$$

Now,

$$\Delta = 1 - (G_4 H_2 + G_1 H_2 G_2 H_1 + G_3 H_1) + (G_4 H_2 G_3 H_1)$$

$\therefore$

$$\frac{C_2}{R_1} = \frac{G_1 H_2 G_2 + G_3 (1 - G_4 H_2)}{1 - G_4 H_2 - G_3 H_1 - G_1 H_1 G_2 H_2 + G_4 G_3 H_1 H_2}$$