control system :-

control → Regulate, Direct or command

1) Basic concepts of control system.

2) Open loop + Closed loop control system.

3) Time response analysis.
   - → Steady state response analysis.
   - → Transient response analysis.

4) Stability analysis :-
   - → Routh Hurwitz criterion.
   - → Root locus Technique.
   - → ~~Phasor~~ polar plot
   - → Nyquist plot
   - → Bode plot.

5) Compensator

6) PID controller.

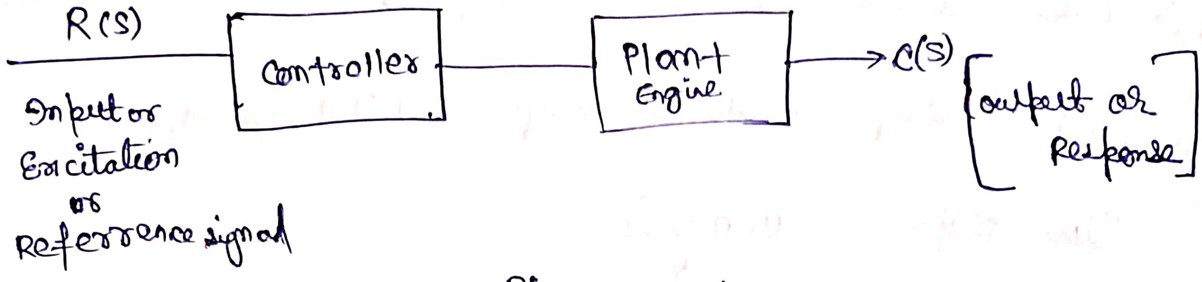


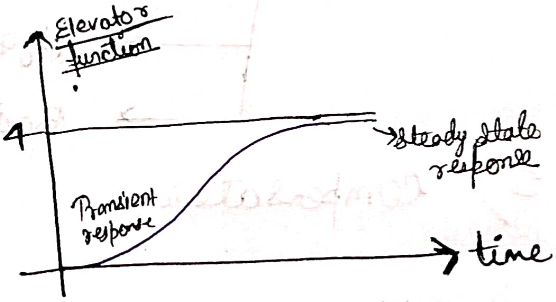
Fig- control system.

→ If the controlling action of a C.S is independent of the output is called as open loop control system.

Classification of control system

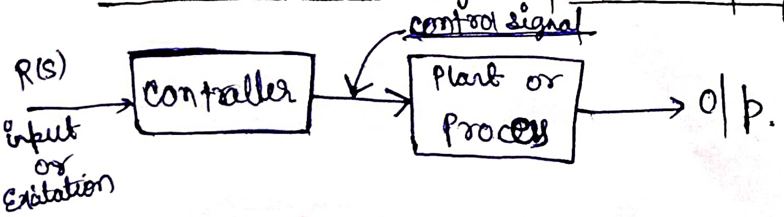
1) Natural control system.
2) Man made control system.

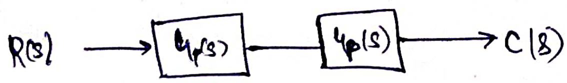
$\cancel{Z_{base} = \frac{(kV_{base})^2}{(MVA_{base})}}$



Elevator response

* Open loop control system | Open loop system :-





→ In the case of open loop control system controlling action is totally independent from the output.

Ex→ Automatic washing machine, Elevator, Bulb with electric switch, traffic control system. Automatic tea/coffee maker, fan regulator, Tv remote, room heater.

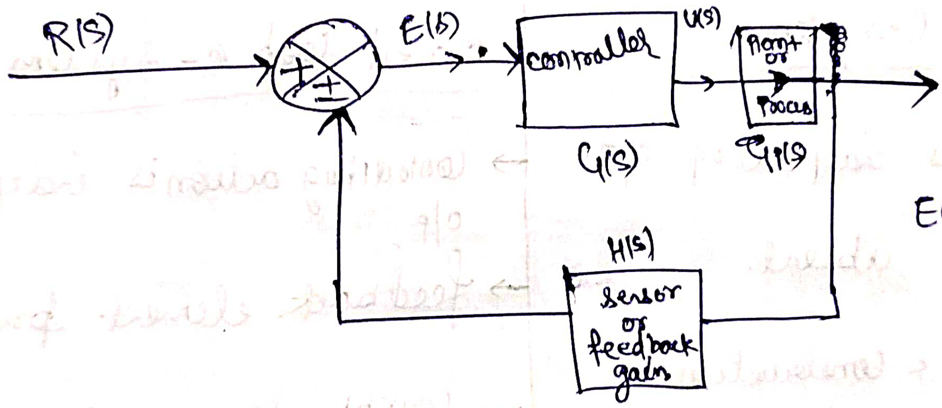
Advantages :-

→ These systems are simple in construction and design.
→ These systems are economical.
→ Less maintainenance required & easy to repair.
→ This is very highly stable system provided that external disturbances are zero.

Disadvantages of open loop control system :-

→ These system are inaccurate and unreliable.
→ It cannot sense internal disturbances
→ Systems are slow.
→ These systems are used in only simple applications.
→ Optimisation are not possible in these systems

closed loop control system :-



$$E(s) = R(s) \pm \underbrace{C(s)\,H(s)}_{B(s)}$$

→ In the case of closed loop control system controlling action dependent on the output or change in output.

eg: Air condition system, missile defense system, water level controller, Automatic electric iron iron, Automatic voltage stabliser, Railway reservation status display, temperature control system etc.

Advantages :-

→ More accurate and reliable.

→ These systems are faster

→ It senses the environmental changes or any disturbances and accordingly modify its error.

→ Optimisation is possible.

Disadvantage :-

→ Complicated and time consuming from design point of view.

→ Problems of stability is there due to feedback and therefore a proper care should be taken in the design of feedback path otherwise it can affect the system stability.

→ In this case maintainance is also difficult.

comparison b/w

Open loop C-system	Closed loop C-system
1) controlling action is independent of o/p	→ controlling action is independent of o/p
2) feedback element absent.	→ feedback element present.
3) Simple in design & construction	→ complicated to design
4) Economical.	→ Costlier
5) Generally stable in nature	→ Stability is the major consideration while designing.
6) Highly sensitive to disturbances	→ ~~Highly~~ Reduce affected by non-linearity
7) Highly affected by non-linearity	→ less sensitive to disturbances.

Transfer function.

laplace transform of Response to excitation assuming initial condition to be zero.

SISO → only valid for single input + single output system.

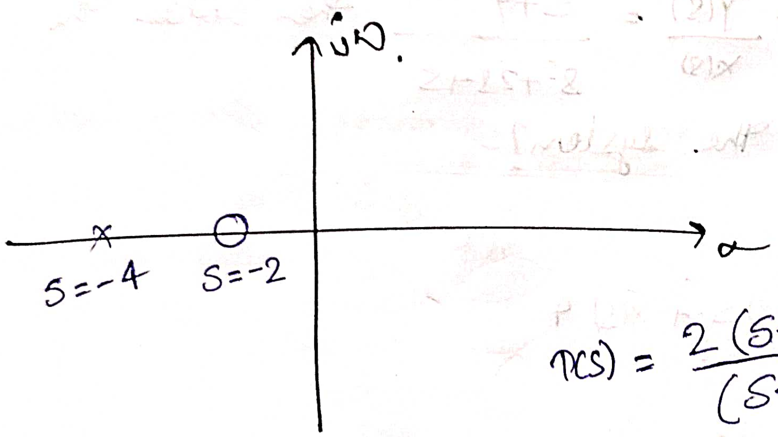
→

$$T(s) = \frac{P(s)}{Q(s)} = \frac{a_0 s^n + a_1 s^{n-1} + a_2 s^{n-2} + \dots + a_n}{b_0 s^n + b_1 s^{n-1} + b_2 s^{n-2} + \dots + b_n}.$$

$$T(s) = \frac{P(s)}{Q(s)} = \frac{K(s-z_1)(s-z_2)(s-z_3)\dots + (s-z_n)}{(s-p_1)(s-p_2)(s-p_3)\dots + (s-p_n)}$$

$c(t) \neq g(t) \times r(t)$

$\boxed{c(t) = g(t) * r(t)}$



zeros → O
poles → X
→ Representation

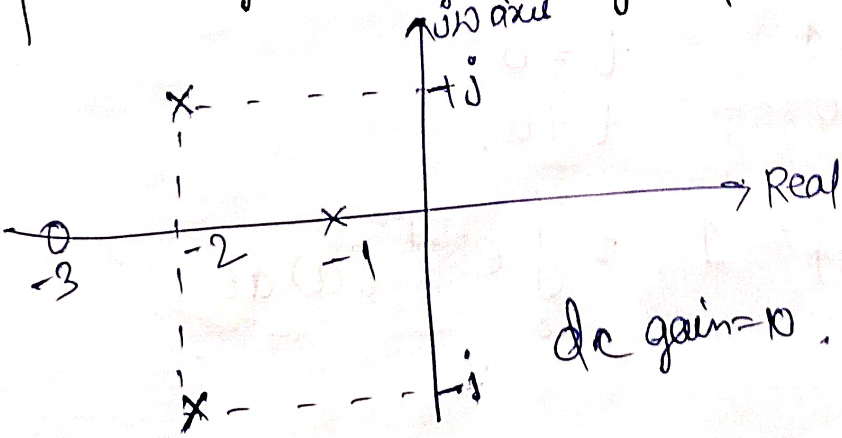
$$T(s) = \frac{2(s+2)^2}{(s+4)}$$

$(s+2)^2 \rightarrow s=-2,-2 \rightarrow$ zeros → Repeated zeros

$(s+4) \rightarrow s=-4 \rightarrow$ poles.

Q) Determine the transfer function if the DC gain = 10 for the system whose pole zero plots are shown in the figure?

Sol



dc gain = 10.

$$T(s) = \frac{K(s+3)}{(s-(-2+j))(s-(-2-j))}$$

$$= \frac{K(s+3)}{s^2+4+4s+1}$$

$$T(s) = \frac{K(s+3)}{(s^2+4s+5)(s+1)} \text{ Ans}$$

$\Rightarrow \boxed{K = 50/3}$

$$T(s) = 50/3\,(s+3)/(s^2+4s+5)(s+1)$$

Q) For a certain system $c(t)$ is the output & $r(t)$ is the input it is represented by the differential eqn

$$\frac{d^2c(t)}{dt^2} + 5\frac{dc(t)}{dt} + 8\,c(t) = 2\frac{dr(t)}{dt} + r(t).$$

Determine Transfer function.

Soln

$$s^2 C(s) + 5sC(s) + 8C(s) = 2 \times s\,R(s) + R(s)$$

$$\Rightarrow \frac{C(s)}{R(s)} = \frac{2s+1}{(s^2+5s+8)} \quad \text{Ans}$$

Q) If the system transfer fn is $\frac{Y(s)}{X(s)} = \frac{s+4}{s^2+2s+5}$ then obtain the differential eqn representing the system?

Soln

$$Y(s)s^2 + 2sY(s) + 5Y(s) = X(s)s + X(s)4$$

$$\frac{d^2y(t)}{dt^2} + 2\frac{dy(t)}{dt} + 5y(t) = \frac{dx(t)}{dt} + 4x(t) \quad \text{Ans}$$

Unit Impulse input :-

$$\delta(t) = 1, \quad t = 0.$$
$$= 0, \quad t \neq 0.$$

$$R(s) \longrightarrow \boxed{G(s)} \longrightarrow C(s)$$

$$L\{\delta(t)\} = 1. = \int_0^\infty e^{-st}\,\delta(t)\,dt$$

$C(s) = R(s)\,G(s)$

$R(s) = 1$

$$\boxed{C(s) = G(s)}$$

→ for a linear time invariant system the transfer function of the system is impulse response.

$L[\delta(t)] = 1 \quad L\{u(t)\} = 1/s \quad L\{t\,u(t)\} = 1/s^2$.

Properties of transfer fn :-

→ Transfer fn of the system is laplace transfer of the impulse response under 0 initial condition.

→ T(s) does not depend on input of the system.

→ System poles & zeros can be determined from its transfer function.

→ Stability can be found from the characteristic eqn. $\boxed{D(s)=0}$ i.e also called roots or poles of system

→ T(s) can not be defined for non-linear system.

→ It can be defined for linear system only.

Mathematical Modelling of a physical system :-

Translational system
- ↳ mass
- ↳ spring
- ↳ damper

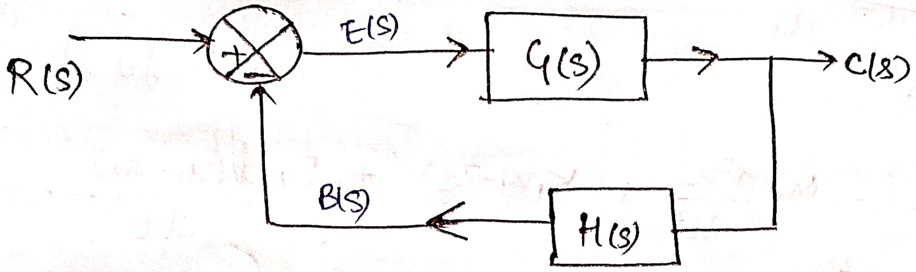
Rotational system.
- ↳ MOI
- ↳ spring (spring)
- ↳ Damper (or friction).

(Prajapati sir ka Pdf)

Concept of feedback :

[C.L.T.F]

→ It is the ratio of output/response $C(s)$ to the input/ Excitation $R(s)$.



CLTF:

$$C(s) = G(s)\,E(s) \quad \text{---} (1)$$

$$E(s) = R(s) - B(s) \quad \text{---} (2).$$

$$\& \quad B(s) = H(s) \cdot C(s) \quad \text{---} (3)$$

$$E(s) = R(s) - H(s)\,C(s)$$

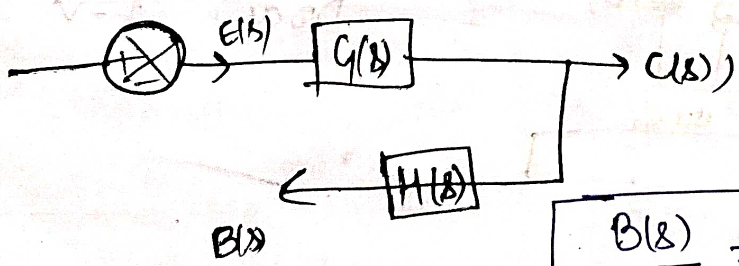
$$C(s) = G(s)\left[R(s) - H(s)\,C(s)\right].$$

$$\Rightarrow C(s)\left[1 + G(s)\,H(s)\right] = G(s)\,R(s)$$

$$\Rightarrow \boxed{\frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)\,H(s)}} \quad \text{---} (4) \; [\text{formula}]$$

[OLTF :-]

* It is the ratio of this feedback signal $B(s)$ to the error signal. $E(s)$



$$\boxed{\frac{B(s)}{E(s)} = G(s)\,H(s)}$$

Effect of transfer function :

→ Negative feedback is used in designing of amplifiers because it significantly lower the noise level in the output signal by feeding a some portion of a output signal in to ~~the phase~~ amplifiers input in a phase opposite to input signal.

→ Positive feedback is used for designing of multivibrator & oscillator in which a portion of output signal is combined in phase of the input signal.

Effect on overall gain :

→ In this case overall gain reduces the in comparison to the open loop system.

→ **Effect of parameter variation**

for open loop system →

$$R(s) \rightarrow \boxed{G(s)} \rightarrow C(s)$$

let $\Delta G(s)$ is the change in open loop gain $G(s)$ due to parameter variations.

Our objective is to see the effect of parameter variation of the output $C(s)$

let $\Delta C(s)$ is the change in the o/p response.

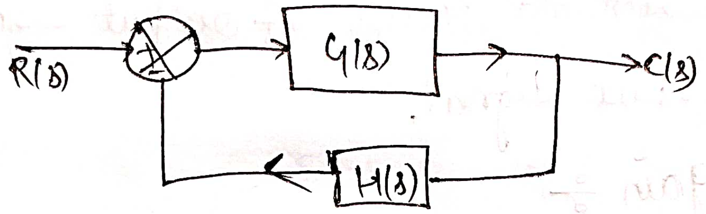
$$C(s) + \Delta C(s) = [G(s) + \Delta G(s)] R(s).$$

$$C(s) + \Delta C(s) = G(s) R(s) + \Delta G(s) R(s)$$

$$\cancel{C(s)} + \Delta C(s) = \cancel{C(s)} + \Delta G(s) R(s)$$

$$\boxed{\Delta C(s) = \Delta G(s) R(s)}$$

<u>for closed loop system :-</u>



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

$$C(s) + \Delta C(s) = \frac{G(s) + \Delta G(s)}{1 + [G(s) + \Delta G(s)] H(s)}$$

$\boxed{\Delta G_s <<< G(s)}$

$$\cancel{C(s)} + \Delta C(s) = \cancel{\frac{G(s)}{1 + G(s) H(s)}} + \frac{\Delta G(s)}{1 + G(s) H(s)}$$

$$\boxed{\Delta C(s) = \frac{\Delta G(s)}{1 + G(s) H(s)}} \quad \text{--- (1)}$$

* the term $\boxed{\Delta G(s) H(s) <<<<< G(s) H(s).}$

→ The change in o/p in the case of closed loop system reduced by the factor of $\frac{1}{1+G(s)H(s)}$ in case of system parameter variations.

Sensitivity of a control system :- [C/S.].

$$A = f(B)$$

$$S_B^A = \frac{\text{Percentage change in } A}{\text{Percentage change in } B} = \frac{\partial(A)/A}{\partial(B)/B} = \left[\frac{B}{A}\right]\left[\frac{\partial(A)}{\partial B}\right].$$

→ It is change in output w.r.t small change in input or some system parameter.

$$\boxed{S_G^T = \frac{\text{fractional change in } T}{\text{fractional change in } G}} = \frac{\Delta o/p}{\Delta i/p}$$

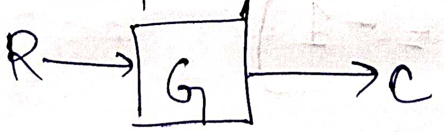
must be minimum.

$$T(s) = \frac{G(s)}{1+H(s)G(s)} \Rightarrow T(s) = \frac{G}{1+GH}.$$

$$\nearrow S_G^T = \left[\frac{\partial T/T}{\partial G/G}\right]$$

$$\searrow S_H^T = \left[\frac{\partial T/T}{\partial H/H}\right]$$

Case 1: For open loop system :-



$$T = C/R = G \quad \text{—} ①$$

$\therefore S_G^T$ = Sensitivity of T w.r.t G.

$$\frac{\partial T/\partial G}{G/T} = \frac{G}{T} \times \frac{\partial T}{\partial G} \quad \text{—} ①.$$

$$S^T_G = 1$$

Case II :-

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

(case a):

$$S^T_G = \frac{G}{T}\left(\frac{\partial T}{\partial G}\right) = \frac{G}{T}\left(\frac{(1+GH) - GH}{(1+GH)^2}\right)$$

$$S^T_G = \frac{G}{T}\left[\frac{1}{(1+GH)^2}\right] = \frac{1}{1+GH} \quad \text{Ans}$$

[Case b]:

$$S^T_H = \frac{H}{T}\left(\frac{\partial T}{\partial H}\right) = \frac{H}{T} \times \frac{G(-G)}{(1+GH)^2}$$

$$S^T_H = \frac{H}{T}\left(\frac{-G \times G}{(1+GH)^2}\right) = \left[\frac{-HG}{(1+GH)}\right] \quad \text{Ans}$$

In this case the sensitivity will reduce by a factor of $1+GH$.

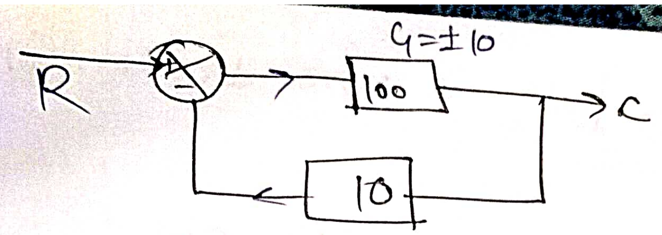
[case b] $\longrightarrow$ if $GH >>> 1$

$$\boxed{S^T_H = -1}$$

In this case the sensitivity is Higher than the previous one. (case a).

→ In this case the ~~value~~ the sensitivity is Higher ~~the~~ w.r.t change in system parameter in forward path.

Q)



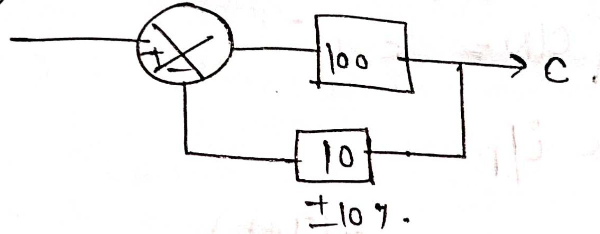
$$S_G^T = \frac{1}{1+1000} = \frac{\partial T/T}{\partial G/G}$$

$$\frac{\partial T}{T} = \frac{0.1}{1000} = 10^{-4}$$

×100

$$\frac{\partial T}{T} = 0.01\ \%$$

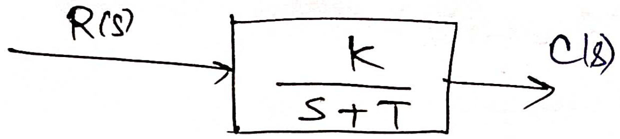
Q)



$$S_H^T = \frac{-\cancel{1000} \times \cancel{10}}{\cancel{1000}}$$

$$\frac{\partial T}{T} = \pm 10\ \%$$ Ans

* Effect of feedback on stability in the case of disturbance :



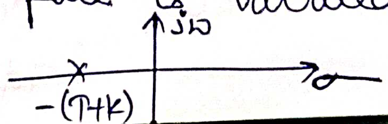
→ let us consider an open loop system in which overall transfer function is $\frac{K}{S+T}$ $S+T=0$ $\boxed{S=-T}$

→ Now consider a unity negative feedback to the original open loop system.

Now overall transfer function of closed loop transfer function is.

$$\frac{C(s)}{R(s)} = \frac{K}{S+(T+K)}$$

In this case closed loop pole is located at $-(T+K)$



→ More negative the pole is more stable will be the system.

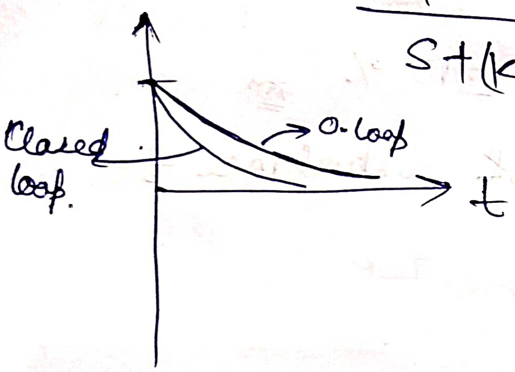
→ $\frac{C(s)}{R(s)} = K/s+T$ $\Rightarrow C(s) = \frac{K \cdot R(s)}{s+T}$

for impulse i/p.

$$\boxed{C(s) = K e^{-T}}$$

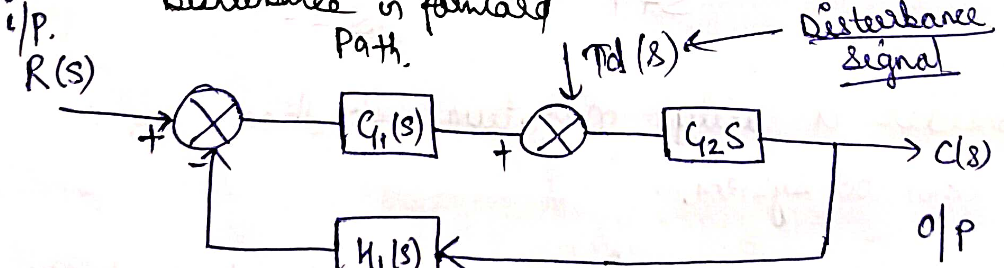
<u>for closed loop:</u> (for impulse i/p).

$$C(s) = \frac{K}{s+(K+T)} \Rightarrow c(t) = K e^{-(T+K)}$$



→ Disturbance may happen in forward path or in feedback path or at the output.

[Case 1:] Disturbance in forward Path.



if put $Td(s) = 0$ $\left.\frac{C(s)}{R(s)}\right|_{Td(s)} = ?$ $\Rightarrow \frac{G_1 G_2}{1+G_1 G_2 H_1}$

if put $R(s) = 0$ $\left.\frac{C(s)}{Td(s)}\right|_{R(s)} = ?$ $\Rightarrow \frac{G_2(s)}{1+G_2(s)G_1(s)H_1(s)}$

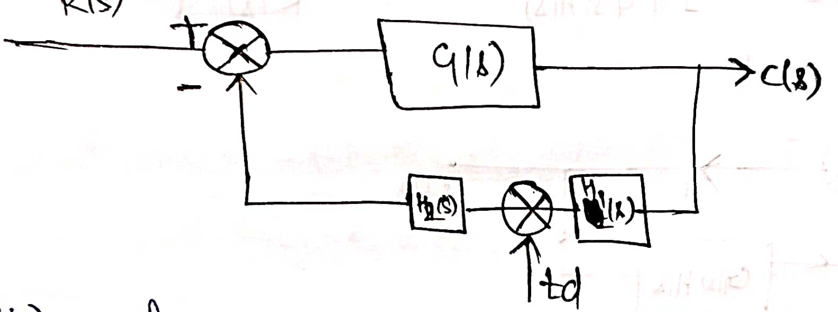
$$\left.\frac{C(s)}{R(s)}\right|_{Td(s)=0} = \frac{G_1 G_2}{G_1 G_2 H_1} = \frac{1}{H(s)}; \qquad G_1 G_2 H_1 >> 1$$

$$\left.\frac{C(s)}{Td(s)}\right|_{R(s)=0} = \frac{1}{G_1(s)\, H(s)} \qquad G_2 G_1 H_1 >> 1.$$

→ In case 1 the effect of disturbance will minimize by selecting a higher value of $G_1(s)$.

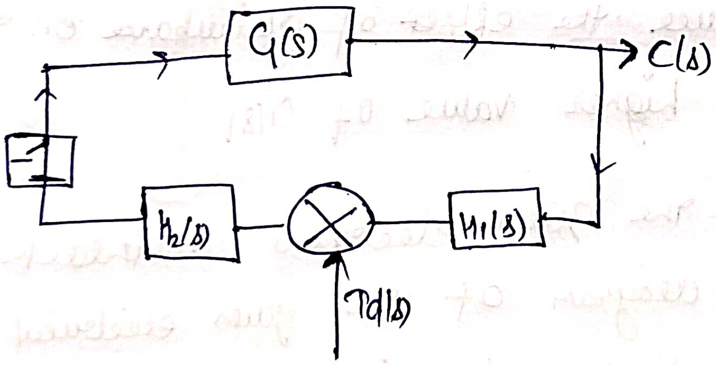
~~In case~~

<u>Case 2</u>



[Disturbance in feedback]

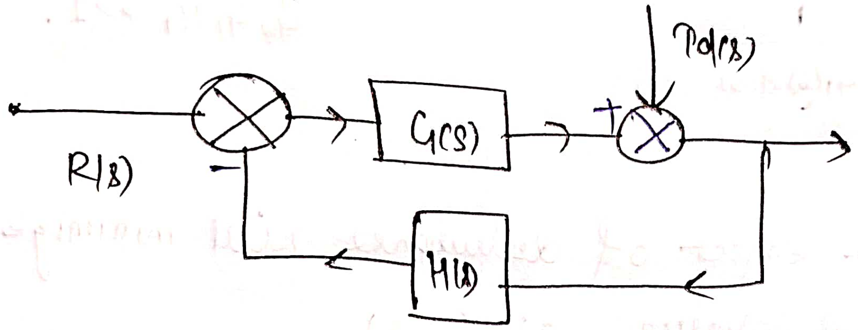
Put R(s)=0 to get the effect of disturbance on o/p.



$$\left.\frac{C(s)}{Td(s)}\right|_{R(s)=0} = \frac{G(s)\, H_2(s)}{1 + G(s)\, H_2(s)\, H_1(s)}$$

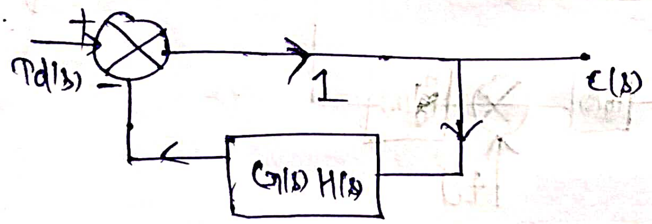
→ In this case the effect of disturbance on o/p will be minimized by selecting higher value of $H_1(s)$.

Case 3: If disturbance acting at the output of the system.



$$\left.\frac{C(s)}{Td(s)}\right|_{R(s)=0} = \frac{1}{1+G(s)H(s)} \qquad \left.\frac{C(s)}{R(s)}\right|_{td(s)=0} = \frac{G(s)}{1+H(s)G(s)}$$

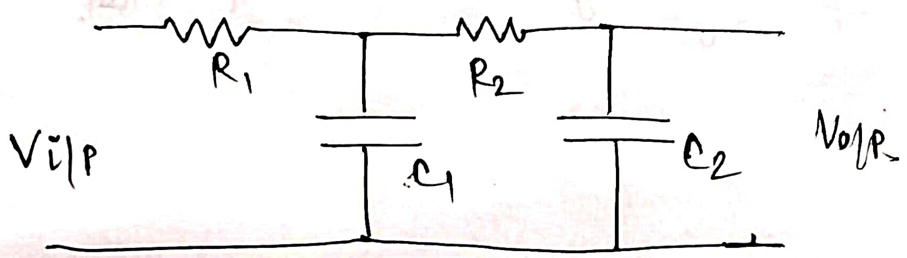
$\Downarrow$



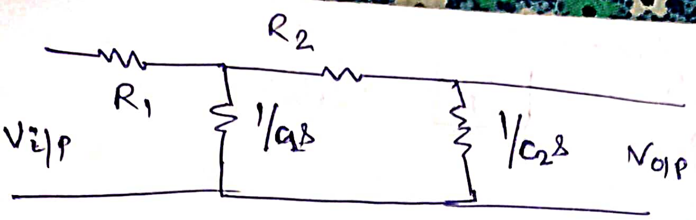
→ In this case to reduce the effect of disturbance on the o/p by selecting the higher value of G(s).

Q) Find the T(s) of the given electrical network?

Q) Draw the block diagram of the given electrical electrical network & find the T(s) by using block diagram reduction technique.



Sol^n 1



$$Z_{Res_1} = \frac{\left(R_2 + \frac{1}{C_2 s}\right) \times \frac{1}{C_1(s)}}{R_2 + \frac{1}{C_2(s)} + \frac{1}{C_1(s)}} = \frac{(R_2 C_2 s + 1)}{s(R_2 C_2 C_1 s + R_2 C_1 + R_2 C_2)}$$

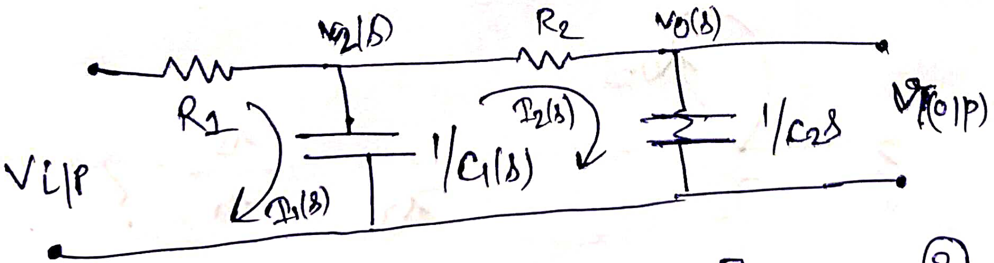
$$V_{1/C_1 s} = \frac{V_{i/p}\left(\frac{R_2 C_2 s + 1}{s(C_2 C_1 R_2 s + R_2 C_1 + R_2 C_2)}\right)}{\left(R_1 + \frac{R_2 C_2 s + 1}{s(C_2 C_1 R_2 s + R_2 C_1 + R_2 C_2)}\right)}$$

$$V_{C_1} = \frac{V_{i/p}\,(R_2 C_2 s + 1)}{\left(R_1 \left[s^2 C_1 C_2 R_2 + R_2 C_1 s + R_2 C_2 s\right) + R_2 C_2 s + 1\right)}$$

$$V_{o/p} = \frac{V_{i/p}\,\cancel{(R_2 C_2 s + 1)}}{\left(R_1 (s^2 C_1 C_2 R_2 + R_2 C_1 s + R_2 C_2 s) + R_2 C_2 s + 1\right)} \times \frac{\cancel{\frac{1}{C_2 s}}}{\cancel{\left(R_2 + \frac{1}{C_2 s}\right)}}$$

$$\frac{V_{o/p}}{V_{i/p}} = \frac{1}{R_1 [s^2 C_1 C_2 R_2 + R_2 C_1 s + R_2 C_2 s) + R_2 C_2 s + 1}$$

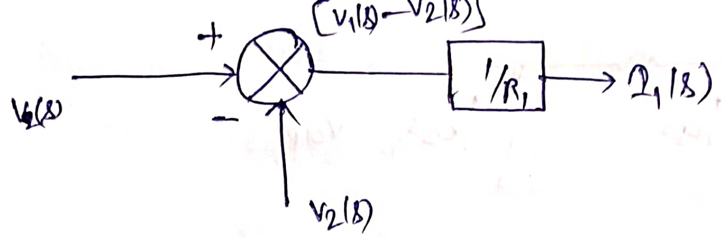
Q)



Sol^n

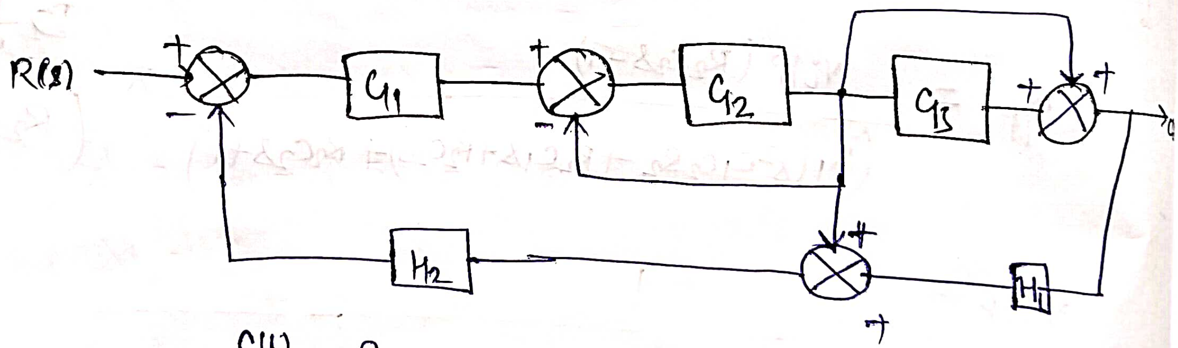
$$V_2(s) = \frac{1}{C_1 s} \times [I_1(s) - I_2(s)] \quad \text{--- (2)}$$

$$I_1(s) = \frac{1}{R_1}[V_1(s) - V_2(s)] \quad \text{--- (1)}$$



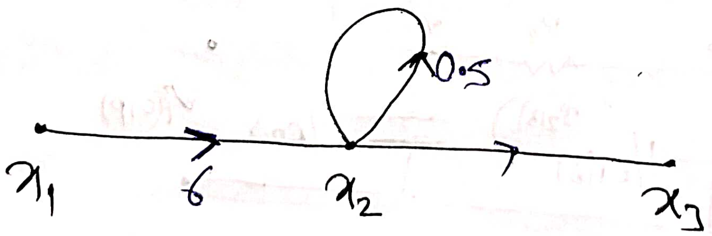
Q) Using signal flow graph & mason's gain formula obtain the overall the overall gain of the given System.

Sol:



$$\frac{C(s)}{R(s)} = ?$$

Q)



$$\frac{x_3}{x_1} = ?$$

Lab

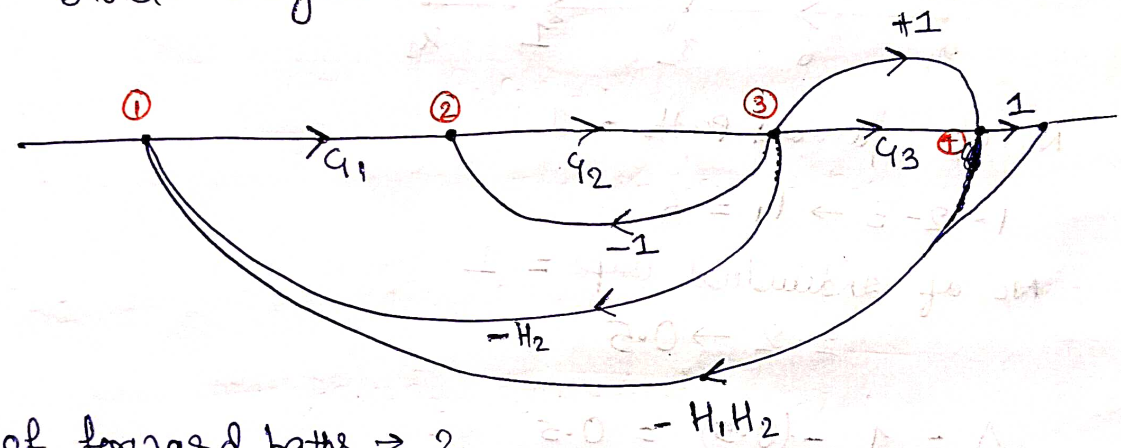
Q1) Find the TF of a system having poles $-1, -1.5, -3 \pm 3j$ & zeros $-5, -3 \pm 3j$ and gain 100.

Q2) Find State space model of the system given in question 1.

Q3) Do EXP 15 in list of experiment chart of the state space Model obtained in question 2.

HOMEWORK SOLUTION :-

1) Forming the signal flow graph of the given Block diagram



No of forward paths → 2

$P_1 \rightarrow G_1G_2G_3$

$P_2 \rightarrow G_1G_2$

No of Individual Loops.

L_1 – 2-3-2 → $-G_2$

L_2 – 1-2-3-1 → $-G_1G_2H_2$

L_3 – 1-2-3-4-1 → $-G_1G_2G_3H_1H_2$

L_4 – 1-2-3-4-1 → $G_1G_2(-H_1H_2)$

No of pair of two non-touching loops

→ zero.

$$\Delta = 1 + G_2 + G_1G_2H_2 + G_1G_2H_1H_2 + G_1G_2G_3H_1H_2 .$$

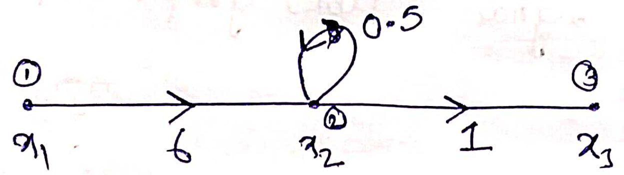
$$\Delta_1 = 1$$

$$\Delta_2 = 1$$

$$\text{Gain} = \frac{P_1\Delta_1 + P_2\Delta_2}{\Delta} = \frac{G_1G_2G_3 + G_1G_2}{\Delta}$$

$$\text{Gain} = \frac{G_1G_2(1+G_3)}{1+G_2+G_1G_2H_2+G_1G_2H_1H_2+G_1G_2G_3H_1H_2} \quad \text{Ans}$$

Q2



$x_3/x_1 = ?$

Soln No of forward path = 1

$1-2-3 \rightarrow P_1 = 6$

No of individual loops = 1

$2-2 \rightarrow 0.5$

$$\Delta = 1 - (0.5) = 0.5$$

$$\Delta_1 = 1$$

$$\text{Gain} = \frac{P_1\Delta_1}{\Delta} = \frac{6 \times 1}{0.5} = 12 \quad \text{Ans}$$

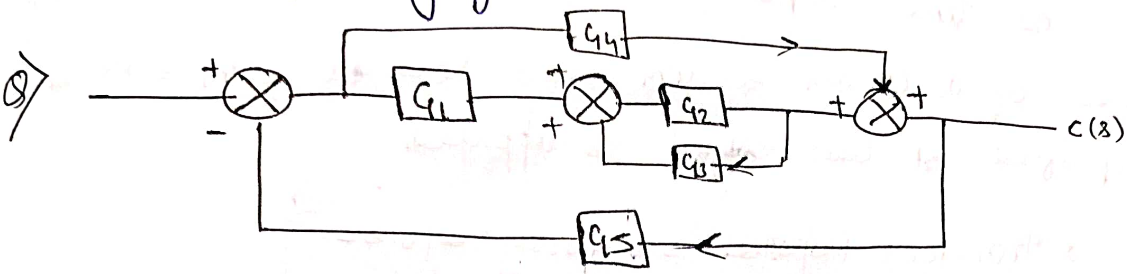
Methods to draw S.F.G from Block diagram :-

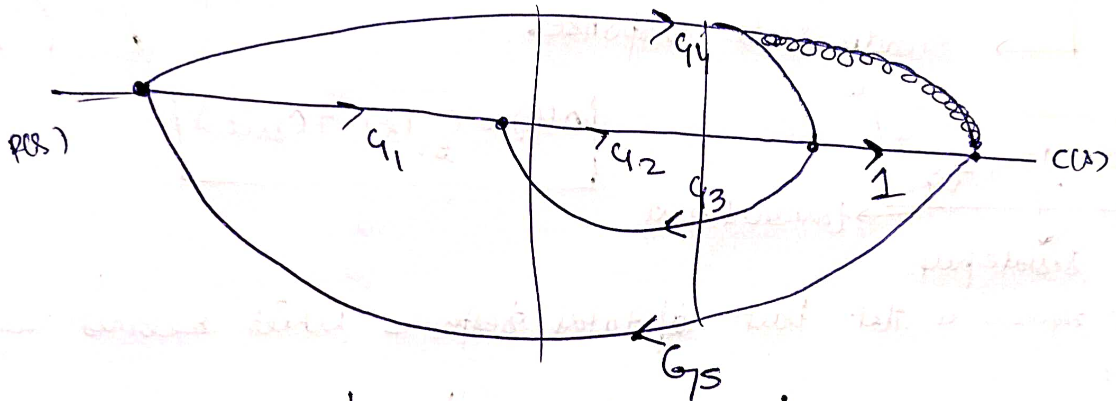
Step 1 → All the variables summing points and takeoff points are represented by nodes. if summing po

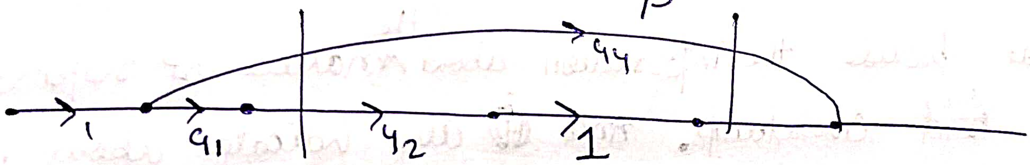
Step 2 → If summing point is placed before a takeoff point in the dirn of signal flow in such case represent the summing point and takeoff point by a single node.

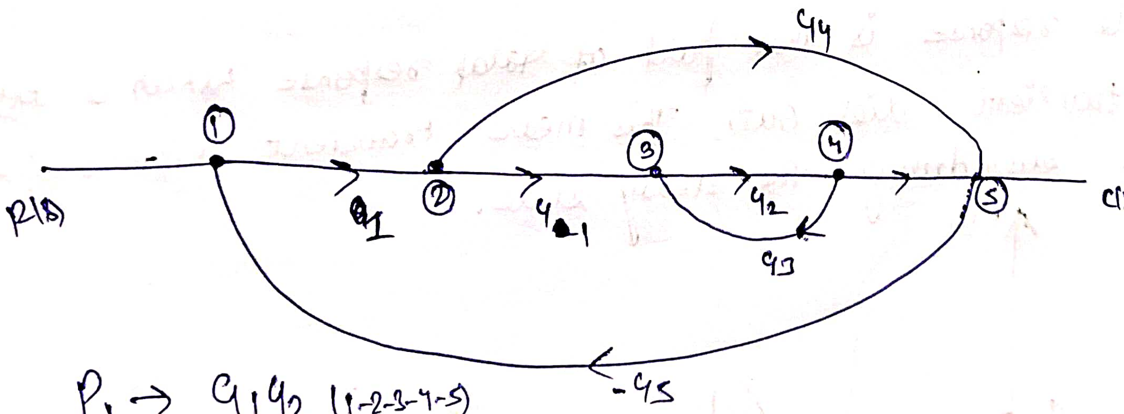
step3 → if a summing point placed after a takeoff point in the direction of signal flow in such case represent the summing point & takeoff point by separate nodes connected by a branch having unity gain.

Q)









$P_1 \rightarrow G_1 G_2$ (1-2-3-4-5)

$P_2 \rightarrow G_4$ (1-2-5)

Individual loop

$L_1 \rightarrow$ 3-4-3 $\rightarrow G_2 G_3$

$L_2 \rightarrow$ 1-2-3-4-5-1 $\rightarrow -G_1 G_2 G_5$

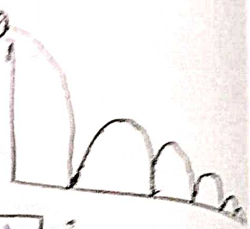
$L_3 \rightarrow$ 1-2-5-1 $\rightarrow -G_4 G_5$

Time response Analysis :

→ Response (or output) of a control system as a function of time (c(t)) is known as time response.

→ Time response of a control system means how the system behaves when time ^ subject specified i/p test signal is applied.

- → Transient Response → temporary response.
- → Steady state response.



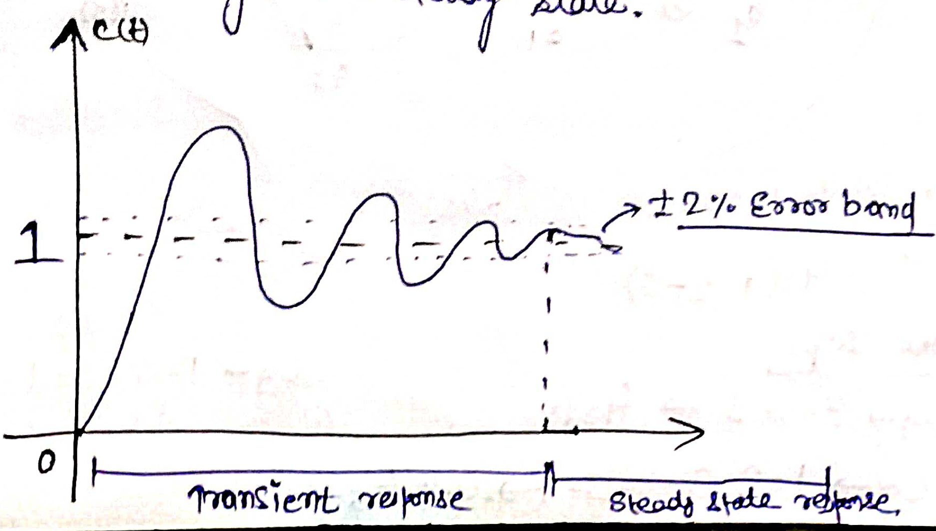
$$\boxed{C(t) = \underbrace{10}_{\text{S. state part}} + \underbrace{5e^{-t}}_{\text{transient part}}}$$

$$\boxed{c(t) = c_{tr}(t) + c_{ss}(t)}$$

→ Transient response is that part of total response which becomes very large (t→∞)

→ Transient part provide the information about the nature of response. i.e underdamp or overdamp. And also indicates about its speed.

→ Steady state response is that part of total response which is left when transient dies out. This means transient response will be zero even during the steady state.



$$x(t) \xrightarrow{\text{Laplace}} X(s).$$

NOTE :- Final value theorem is only applicable for stable system not applicable for marginal & unstable system.