Mechatronics
Semester VI
Mechanical engineering

COURSE CODE: MEDLO6021

CREDITS: 4

Course Objective

- To study key elements of Mechatronics system and its integration
- To familiarize concepts of sensors characterization and its interfacing with microcontrollers.
- To acquaint with concepts of actuators and its interfacing with microcontrollers.
- To study continuous control logics i.e. P,PI, PD and PID
- To study discrete control logic in PLC systems and its industrial applications.

Course Outcomes [CO]

1) Identify the suitable sensor and actuator for a mechatronics system. [CO 1]
2) Select suitable logic controls. [CO 2]
3) Analyze continuous control logics for standard input conditions. [CO 3]
4) Develop ladder logic programming. [CO 4]
5) Design hydraulic/pneumatic circuits. [CO 5]
6) Design a mechatronic system. [CO 6]

MODULE 1

INTRODUCTION TO MECHATRONICS AND ITS BLOCK DIAGRAM REPRESENTATIONS

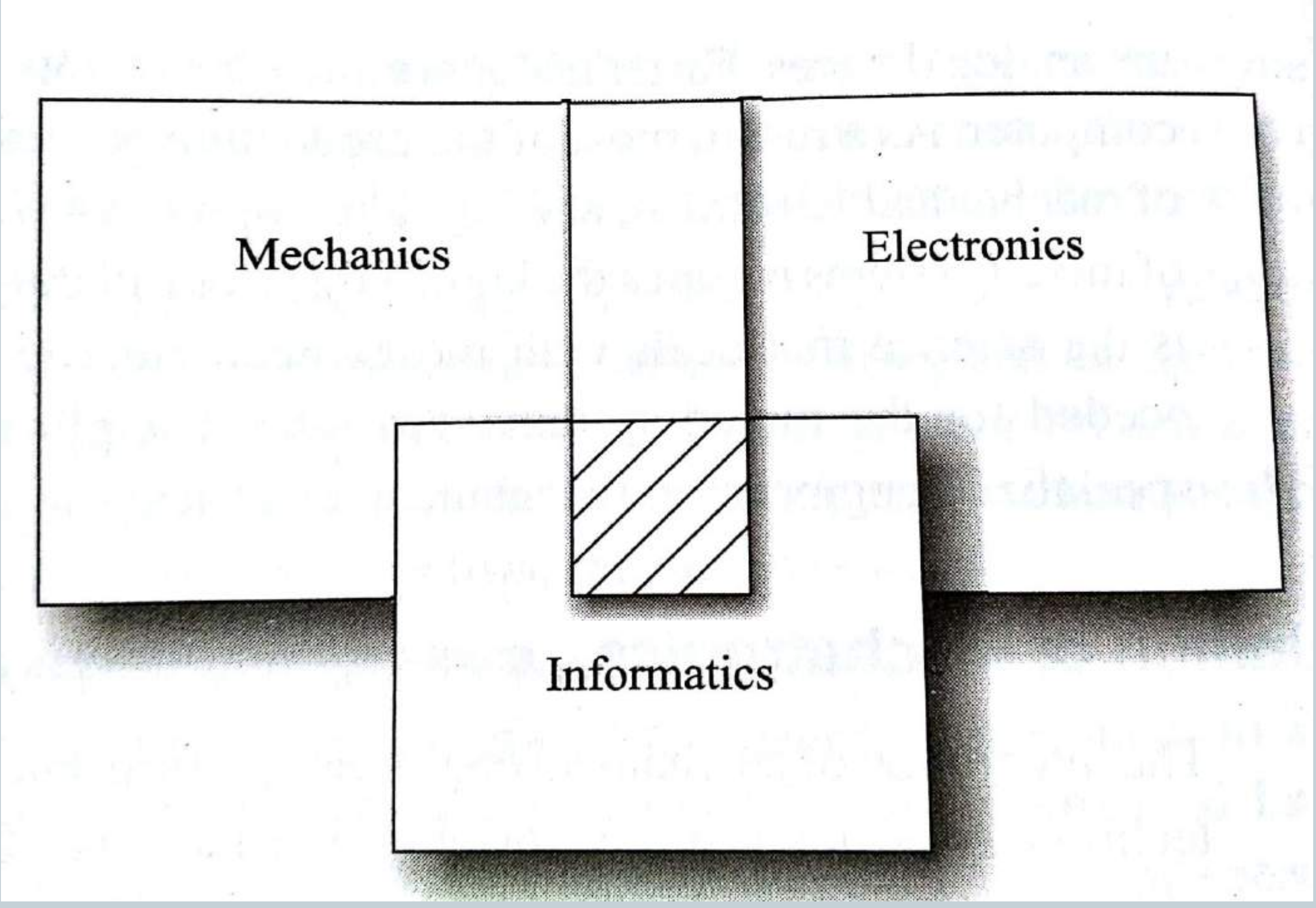
Module	Detailed Contents	Hrs.
1	**Introduction of Mechatronics and its block diagram representation** Key elements of mechatronics, Applications of Mechatronics domestic, industrial etc. Representation of mechatronic system in block diagram and concept of transfer function for each element of mechatronic system, Reduction methods and its numerical treatment for represented block diagram	08

Definition of Mechatronics

"Mechatronics basically refers to mechanical electronic systems and normally described as a synergistic combination of mechanics, electrical electronics, computer and control which, when combined, make possible the generation of simple more economic and reliable systems."

Important for engineers and technicians to adopt interdisciplinary and integrated approach.

Concept of Mechatronics



Concept of Mechatronics contd..

- Mechanics involves,
  - Mechanical engineering subjects like
    - Lubricants, heat transfer, vibration, fluid mechanics, et cetera.
  - Mechanical devices like
    - Simple latches, locks, gear drives, wedge devices.
    - Complicated devices like, harmonic and Norton drives, crank mechanisms, six bar mechanisms.
  - Kinematics and dynamics of machine elements
    - Kinematics determines the position, velocity and acceleration of machine links.
    - Dynamic analysis gives the torque and force required for the motion of link mechanism.

Concept of Mechatronics contd..

- Electronics involves,
  - Measurement systems
    - The sensor, signal conditioner, and display unit.
  - Actuators
    - Elements which are responsible for transforming the output from control system into controlling action of a machine.
  - Power electronics
    - Deals with high power operated devices.
    - Examples of power devices are SCR, DIAC, TRIC, IGBT.
  - Microelectronics
    - Manufacturing microelectronic devices through VLSI circuit design.

Concept of Mechatronics contd..

- Informatics includes,
  - Automation
    - Automated plant reduces burden on human beings in respect of decision making and plant maintenance.
  - Software design
    - Used for solving complex engineering problems.
    - Used in finance system, communication system.
    - Through WAN, Cloud storage, internet data can be accessed easily.
  - Artificial Intelligence (AI)
    - Informatics systems can make decisions using AI.
    - Artificial neural networks, genetic systems, fuzzy logic, hierarchical control systems.

Applications of Mechatronics

- Robotics
  - Uses mechanical, electronic and computer systems
  - Capable of performing operations, assembly, spot welding, spray painting, etc.
    - MS Baleno (18657 units in OCT 2018)*
    - MS Brezza (15832 units in OCT 2018)*
  - Robots used as household servants, Robots for nursing.
- Manufacturing
  - Factory automation include Computer Numerically Controlled (CNC) machines, robots, automation systems and computer integration of all functions.

*https://www.team-bhp.com/forum/indian-car-scene/203575-october-2018-indian-car-sales-figures-analysis.html

Applications of Mechatronics contd…

- Intelligent control
  - Feedback control systems are widespread in industry.
  - Temperature, liquid level, fluid flow, pressure, speed are to be maintained constant by process controllers.
  - Mechatronic systems are used for decision making and controlling the manufacturing.
- Software Integration
  - Different kinds of software are used in manufacturing, design, testing, monitoring and control.
  - Examples of such software includes CAD, CAT, CAE and computer aided process planning (CAPP), CAM or JIT.
  - Used not only for manufacturing but also communication networks.

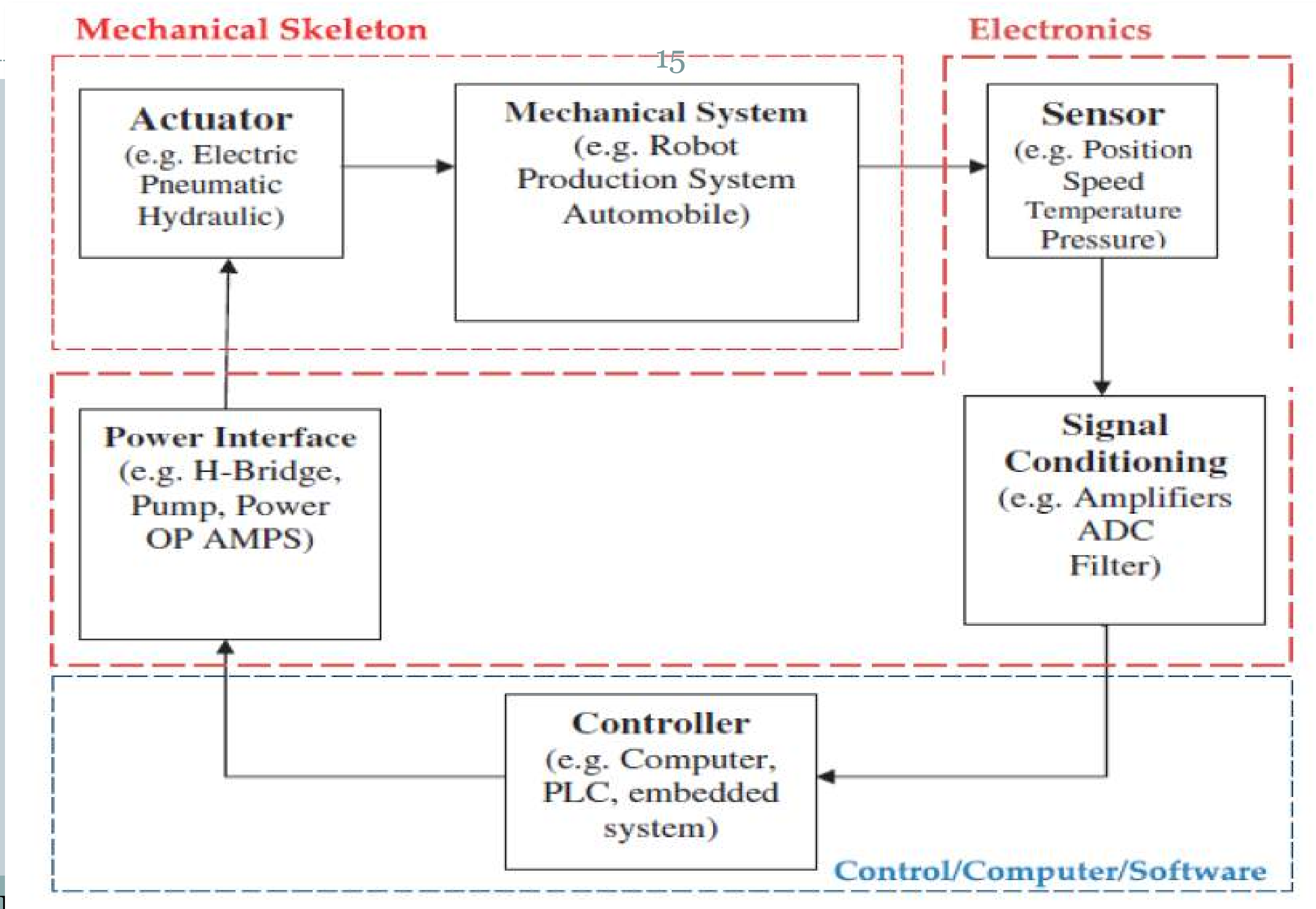
An example of Mechatronic system

- A washing machine
  - Cloths to be washed are put in the machine.
  - Soap, water, bleach are predetermined and poured automatically by machine itself.
  - The microcontroller used for this acts as an informatics system.
  - Washing and wringing cycle time is then set on timer.
  - The electrical motor actuated for wriggling is an electrical system.
  - After completion of cycle machine switches itself off.

Explore more examples

- Thermostatically controlled heater
- Automatic bread toaster

Block diagram of a Mechatronic system



Transfer Functions

- Mathematical model written as output/input, if model turned into function of 's' then it is called as Transfer function.
- Usually denoted as, G(s)

$$G(s) = \frac{Output}{Input}$$

- The outputs and inputs are function of s instead of t.
- What is s then???

Why Transfer Functions

- Differential equations are used to mathematically represent most systems.
- To deal with differential calculus is difficult.
- To make differential equations easy to use, we write,

$$\frac{d\theta}{dt} \text{ becomes } s\theta \text{ and } \frac{d^2\theta}{dt^2} \text{ becomes } s^2\theta$$

- This is called Laplace Transform

Laplace transform

" The purpose of this transform is to allow differential equations to be converted into a normal algebraic equation in which the quantity s is just normal algebraic quantity"

But for electronics engineers s is "Complex Frequency"

Is written as,

$$s = \sigma + j\omega$$

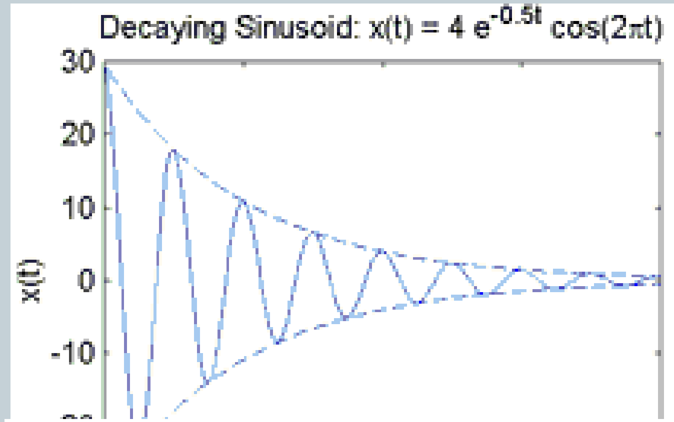
Real frequency with units rad/sec

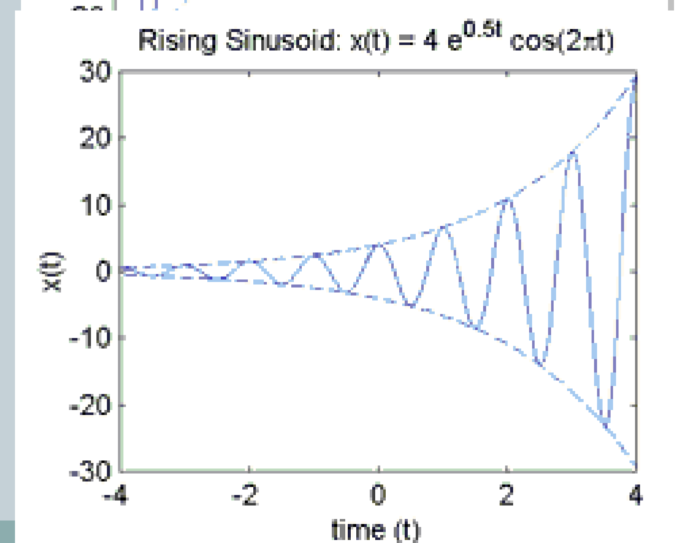
Complex frequency 's'

- Consider a exponentially damped sinusoidal function as,

$$v(t) = V_m e^{\sigma t} \cos(\omega t + \theta)$$

- Where σ is real quantity and is usually negative
- If σ is positive quantity then Sinusoidal amplitude is increasing





DC, Sinusoidal, exponential voltage

$$v(t) = V_m e^{\sigma t} \cos(\omega t + \theta)$$

- Putting σ=ω=0,

$$v(t) = V_m \cos\theta = V_0 \quad \textbf{DC}$$

- If we set only σ=0,

$$v(t) = V_m \cos(\omega t + \theta) = V_m \sin(\omega t + 90 + \theta) \quad \textbf{Sinusoidal}$$

- If we let ω=0,

$$v(t) = V_m e^{\sigma t} \cos\theta = V_0 e^{\sigma t} \quad \textbf{Exponential}$$

Sinusoidal case

- Consider $$v(t) = V_m \cos(\omega t + \theta)$$
- We know,

$$Cos(\omega t + \theta) = \frac{1}{2}\left[e^{j(\omega t+\theta)} + e^{-j(\omega t+\theta)}\right]$$

- We will get,

$$v(t) = \frac{1}{2}V_m\left[e^{j(\omega t+\theta)} + e^{-j(\omega t+\theta)}\right]$$

$$v(t) = \left(\frac{1}{2}V_m e^{j\theta}\right)e^{j\omega t} + \left(\frac{1}{2}V_m e^{-j\theta}\right)e^{-j\omega t}$$

$$v(t) = K_1 e^{s_1 t} + K_2 e^{s_2 t}$$

V(t) sum of complex exponentials

- Two complex frequencies are present in v(t)
- Complex frequency of first term $s=s_1=j\omega$ and that of second term $s=s_2=-j\omega$
- Two values of s are conjugates i.e. $s_2=s_1^*$
- The two values of K are conjugates also,

$$K_1 = \frac{1}{2}V_m e^{j\theta} \qquad K_2 = \frac{1}{2}V_m e^{-j\theta}$$

- Entire first term and entire second term is are therefore conjugates.
- Which we might have expected, as their sum must be a real quantity, v(t)

Relationship of s to reality

- A positive real value of s, e.g. $s=5+j0$,
- Identifies exponentially increasing function Ke^{+5t}
- A negative real value of s, such as $s=-5+j0$ refers to exponentially decreasing function Ke^{-5t}
- Purely imaginary value of s, such as j10 can never be associated with purely real quantity.
- It is necessary to consider conjugate values of s such as $s_{1,2}=\pm j10$
- Which may identify complex frequencies as $s_1=+j10$ and $s_2=-j10$ and with sinusoidal voltage at radian frequency 10 rad/sec

Relationship of s to reality contd…

- The amplitude and phase angle of sinusoidal voltage will depend on choice of K for s_1 and s_2
- Selecting $S_1=j10$ and $K_1=6-j8$, $K_2=K_1^*=6+j8$
- V(t) will become,

$$v(t) = K_1 e^{s_1 t} + K_2 e^{s_2 t}$$

$$v(t) = (6 - j8)e^{j10t} + (6 + j8)e^{-j10t}$$

- The real sinusoid we obtain is $20\cos(10t-53.1^{\circ})$

Relationship of s to reality contd…

- In similar manner, general value of s, such as, 3-j5 can be associated with real quantity only if it is accompanied by its conjugate frequency 3+j5
- We may think either of these two conjugate frequencies describing an exponentially increasing sinusoidal function $e^{3t}\cos(5t)$
- The specific amplitude and phase angle will again depend on values of conjugate complex K

S in general

- In general, complex frequency s describes exponentially varying sinusoid
- The real part of s is associated with it denoted as σ.
- If it is positive, function increases. If it is negative, function decreases. And if it is zero, sinusoidal amplitude is constant.
- Imaginary part of s describes sinusoidal variation by radian frequency i.e. ω

Basic transfer functions

- Basic mechanical models
  - Spring

  - Most springs deflect a distance x in direct proportion to the force .
  - The force may cause spring to get longer or shorter.

Transfer function of spring

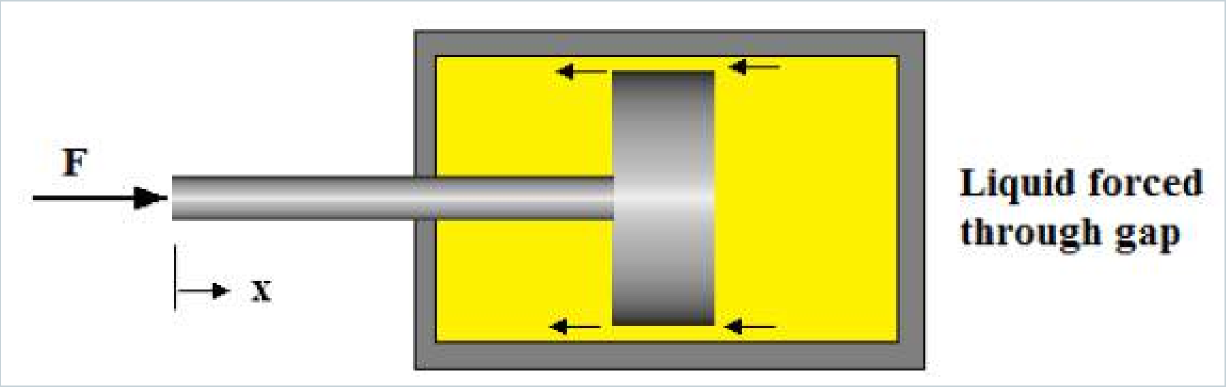
$$\frac{F}{x} = \text{constant} = k$$

- But the transfer function of the system,

$$G(s) = \frac{Output}{Input} = \frac{x}{F} = \frac{1}{k} = C$$

- This is zero order system (No term of s or s^o)

Transfer function of damper



- A damper uses fluid friction to provide resistance to motion
- Force required to move the damper is directly proportional to velocity as,

$$F = velocity \times cons\tan t$$

Transfer function of damper

- Velocity is first derivative of distance x,

$$v = dx/dt$$

- So,

$$F = c\frac{dx}{dt}$$

- The symbol k_d is often used instead of c
- So basic law of damper,

$$F(t) = k_d \frac{dx}{dt}$$

And its Laplace Transform $F(s) = k_d s x$

And its transfer function $\frac{x}{F}(s) = \frac{1}{k_d s}$

So this is first order system

Transfer function of Mass

- When mass is accelerated, the inertia has to be overcome.
- The inertia force is given by Newton's second law of motion,

$$F = mass \times acceleration$$

- Acceleration is second derivative of x
- Newton's second law of motion,

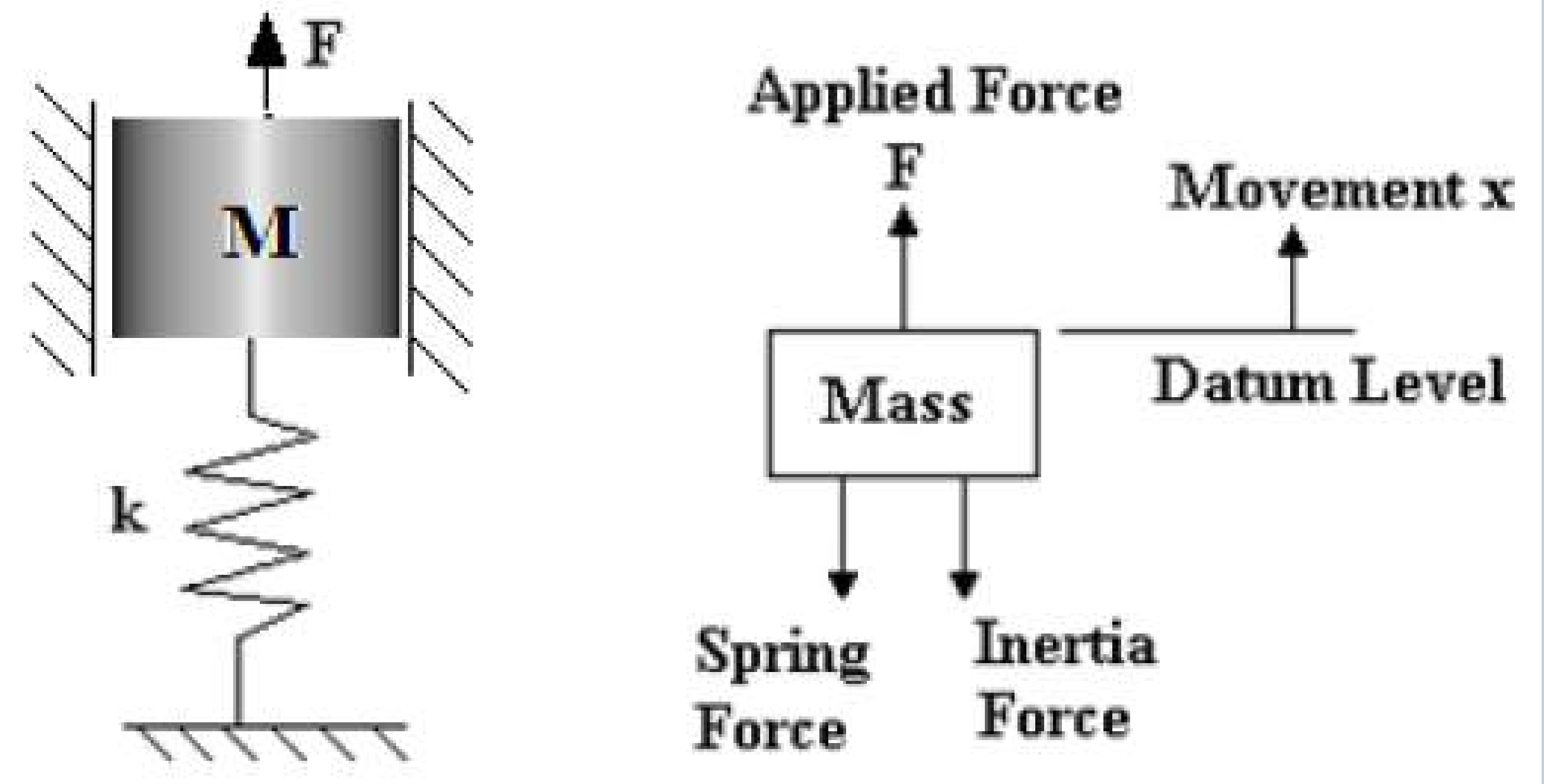
$$F(t) = M\frac{d^2x}{dt^2}$$

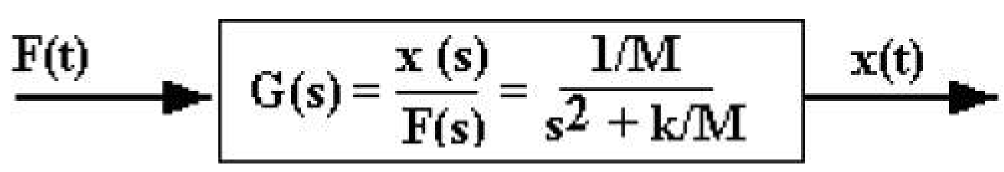
And its Laplace Transform $F(s) = Ms^2x$

And its transfer function $\frac{x}{F}(s) = \frac{1}{Ms^2}$

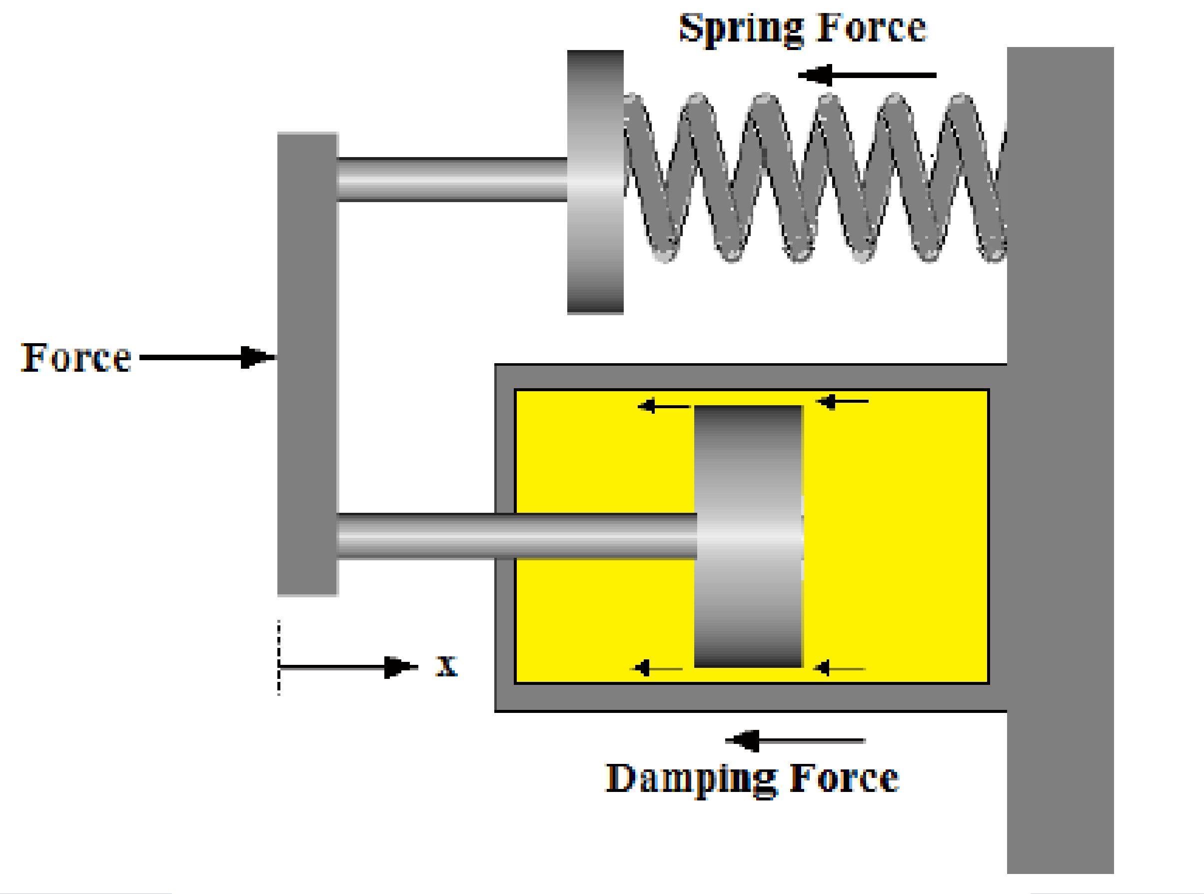
So this is second order system

Transfer function of Mass-spring



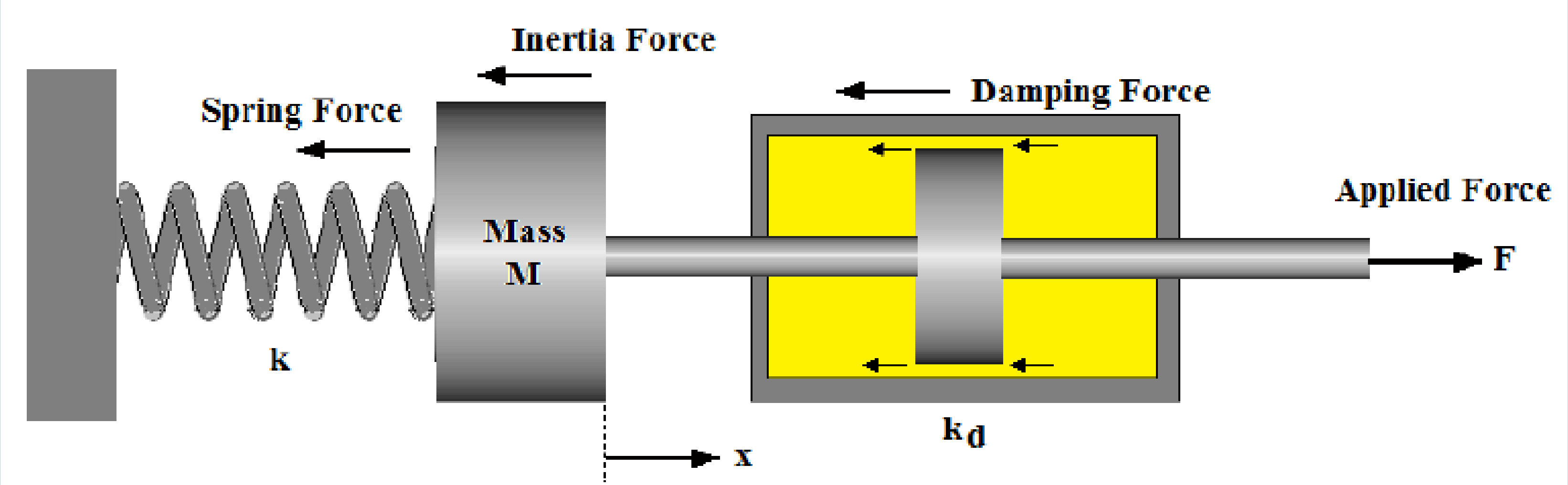


Transfer function of spring-damper



$$F(t) \longrightarrow \boxed{G(s) = \frac{x(s)}{F(s)} = \frac{1/k}{Ts+1}} \longrightarrow x(t)$$

Transfer function of Mass-spring-damper



$$G(s) = \frac{X}{F}(s) = \frac{1/k}{s^2(M/k) + s(k_d/k) + 1}$$

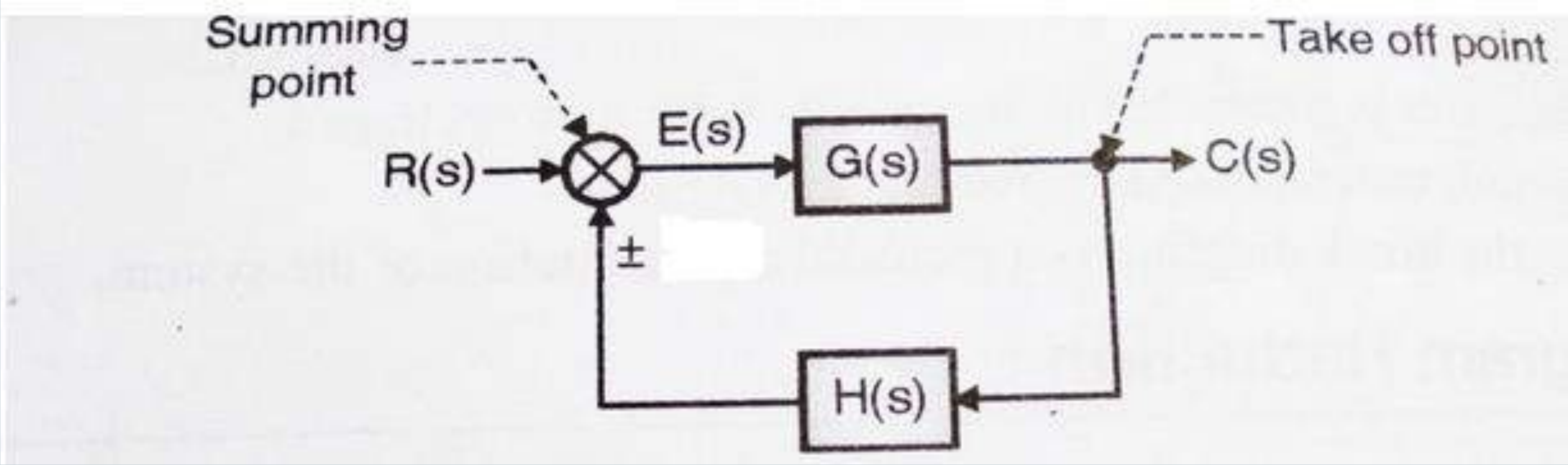
Block diagram reduction

- Control systems consist of mathematical models.
- Transfer function is mathematical representation of individual physical system.
- To show function performed by each component block diagram is used.
- Hence to analyze complex control system i.e. complex block diagram, it is much desirable to reduce the block diagram.

Block diagram terminology

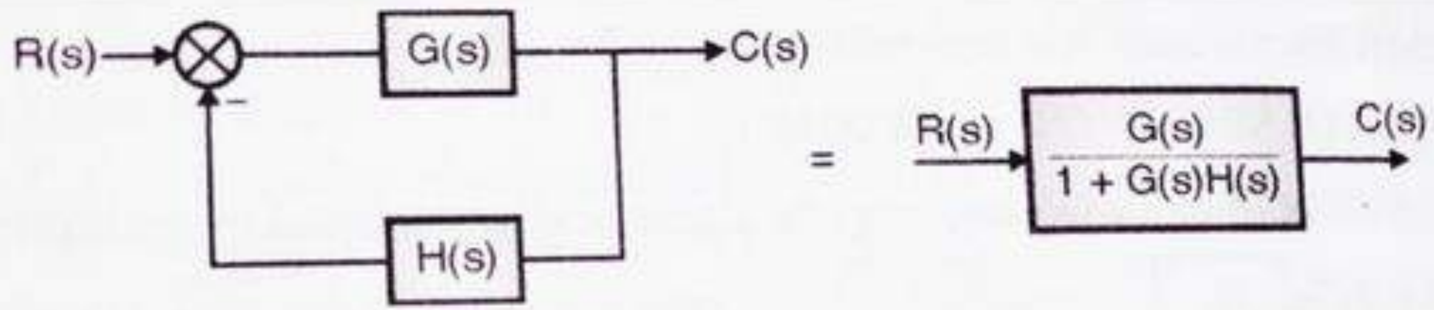
- Block diagram : Pictorial relationship between input and output.
- Summing point : More than one signal can be added or subtracted at a point.
- Take off point : From this point output can be fed to the input
- Forward path : This path represents direction of signal flow from input to output
- Feedback path : This path represents direction of signal flow from output to input.

Block diagram



http://electronicscrunch.com/control-system-block-diagram-reduction-rules/

Feedback



For negative feedback system

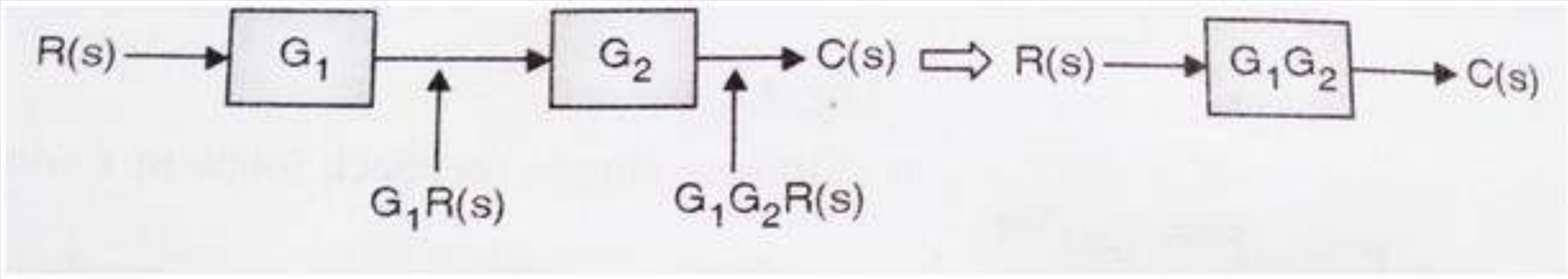
If positive feedback is present in the system,

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

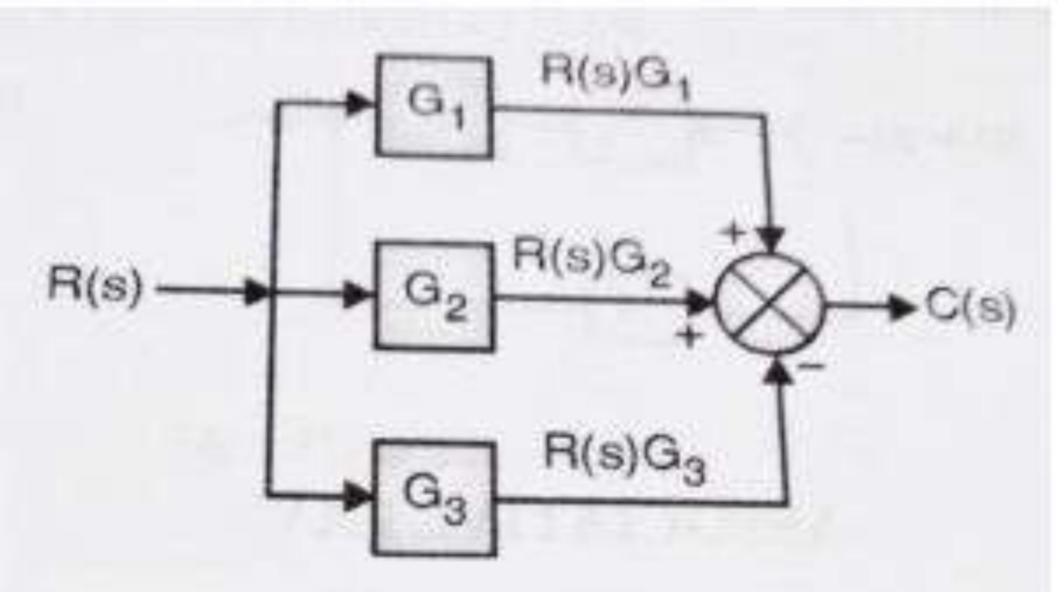
Open loop transfer function

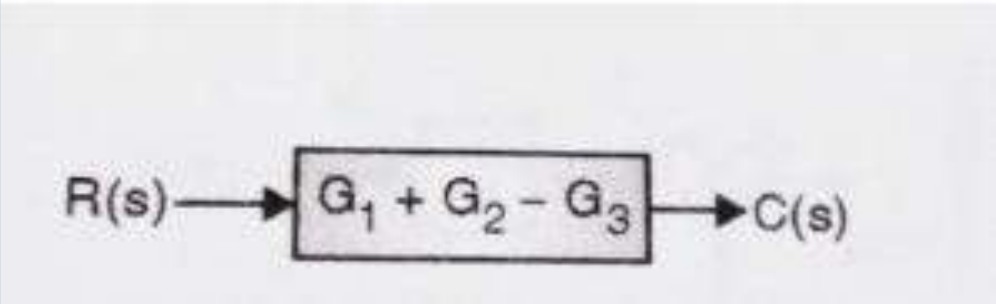
Open loop transfer function= G(s). H(s)

Rule 1: Blocks in series

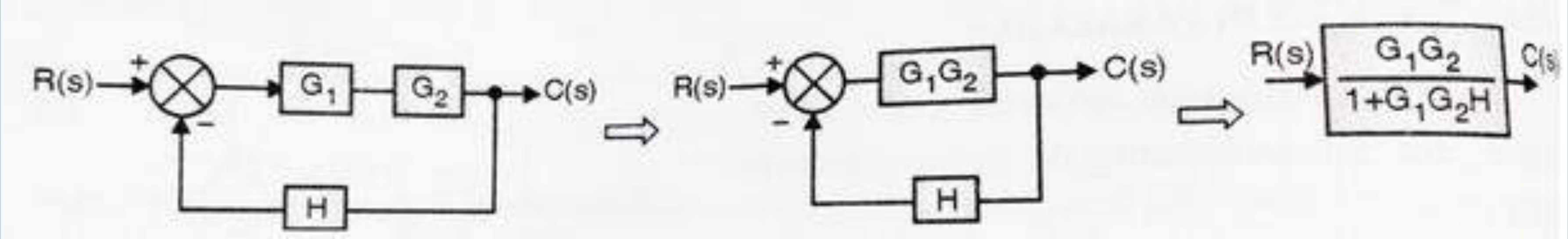


Rule 2: Blocks in parallel

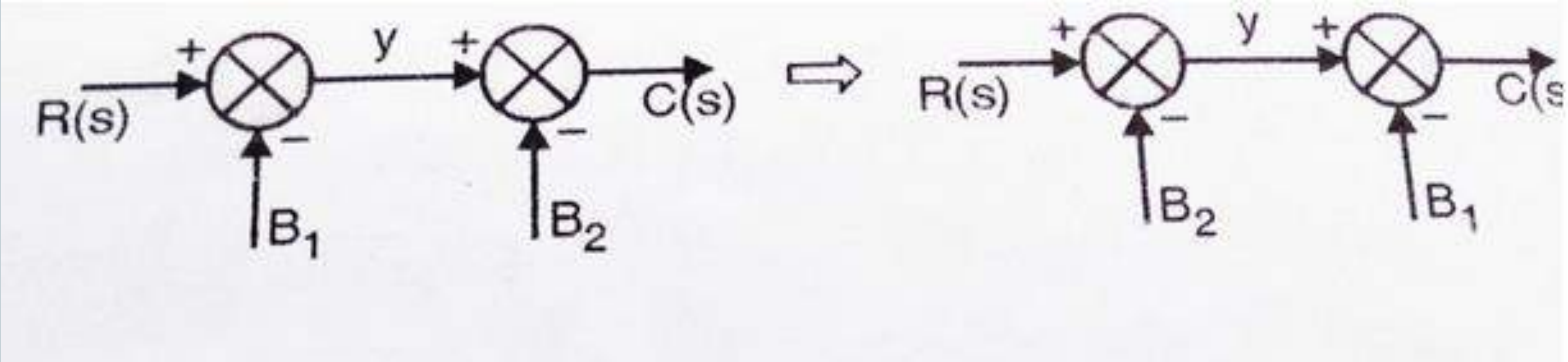




Rule3: Elimination of feedback loop



Rule4 : Associative law for summing point

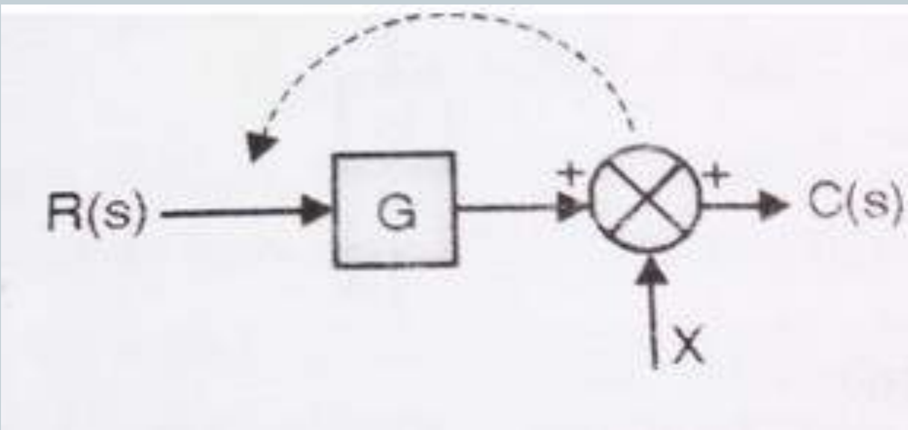


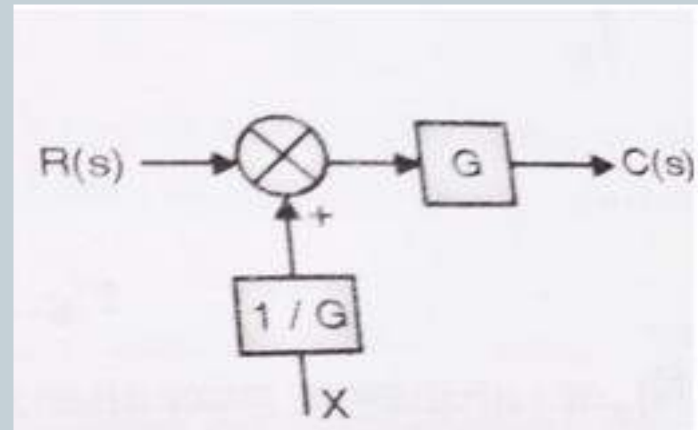
Y= R(s) – B1

C(s) = y – B2 = R(s) – B1 – B2

This law is applicable only to summing points which are connected directly to each other.

Rule5: Shifting of summing point before the block



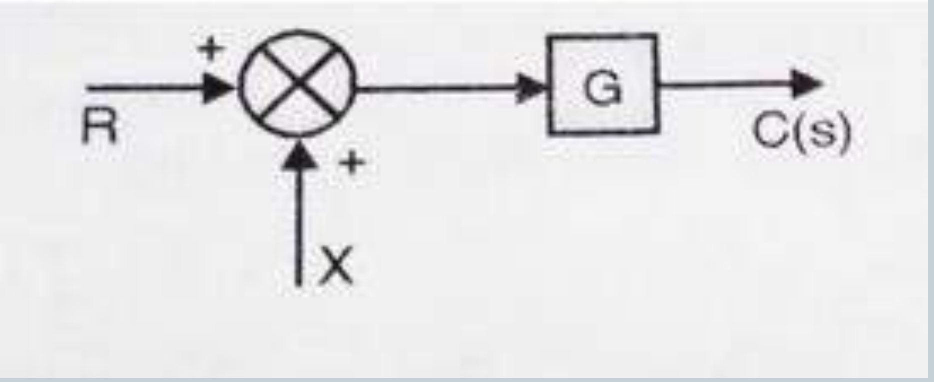


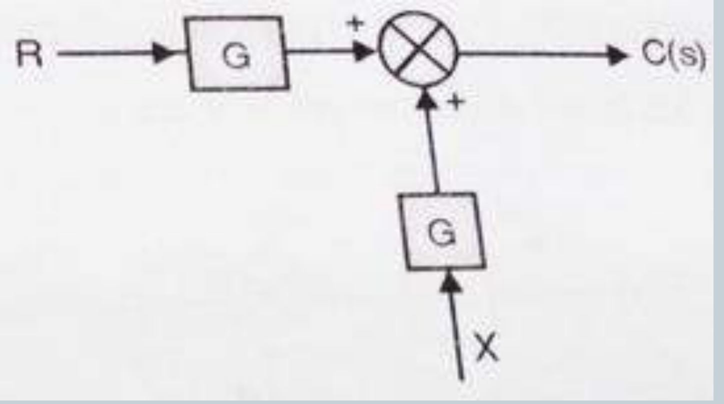
$C(s) = R(s)G + X$

$C(s) = (R(s) + X/G)G = GR(s) + X$

Hence to shift summing point before block , we need to add another block of transfer function 1/G Before the summing point.

Rule6: Shifting of a summing point after a block



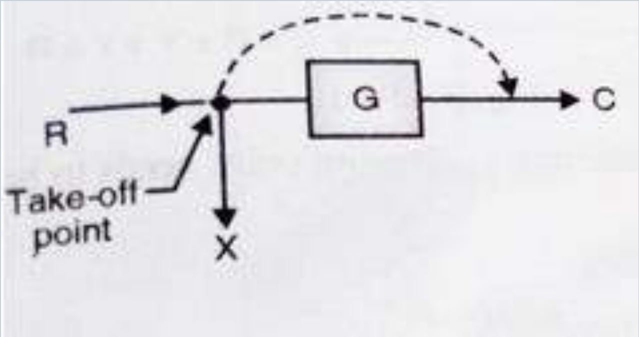


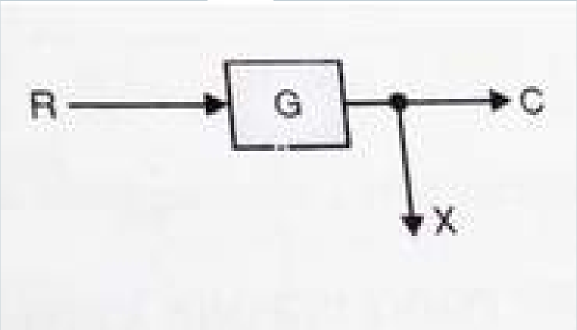
C(s)=(R+X)G

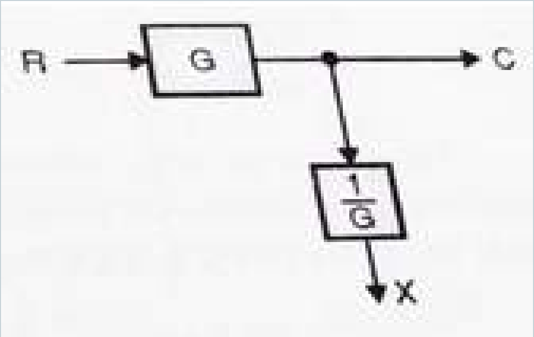
C(s)=RG + XG = (R+X)G

Hence to shift summing point after a block , we need to add another block having same transfer function at the summing point.

Rule7 : Shifting take off point after block



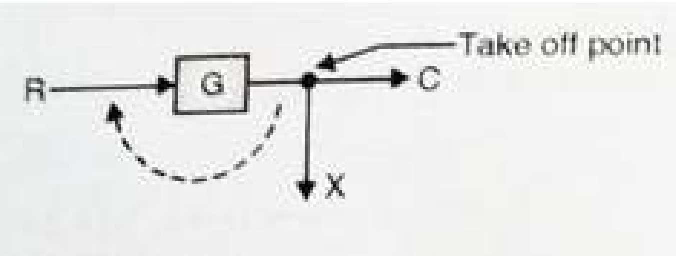


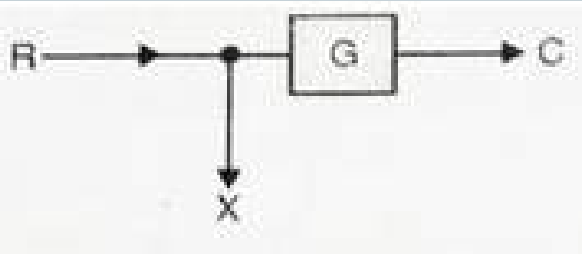


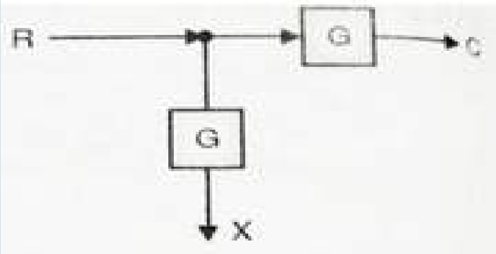
To move X (take off point) after transfer function block G

We need to add a block of transfer function 1/G in series with signal taking off from that point

Rule8: Shifting of take off point before a block



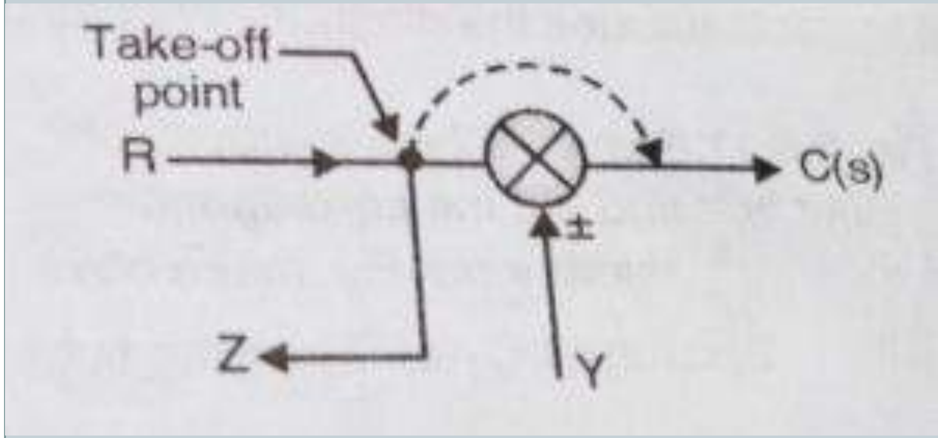


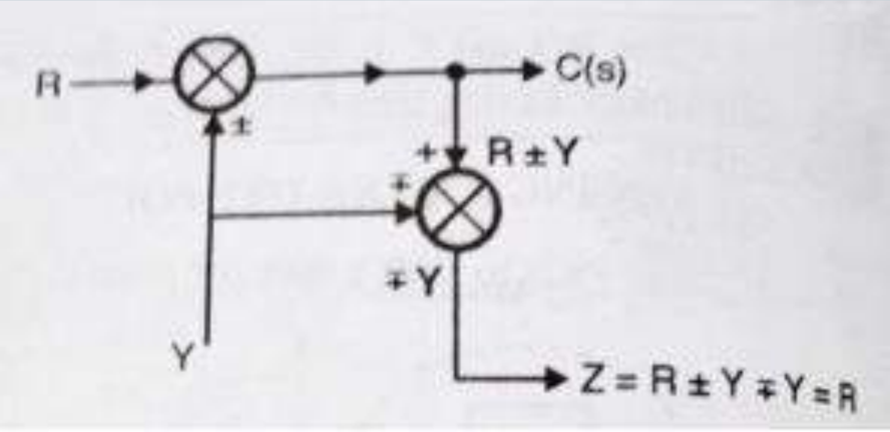


To move X (take off point) before transfer function block G

We need to add a block of transfer function G in series with signal taking off from that point

*Rule9: Shifting take off point after a summing point





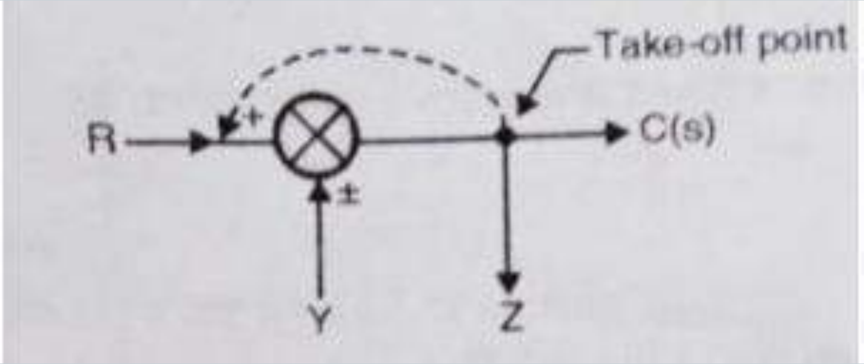
C(s)= R±Y

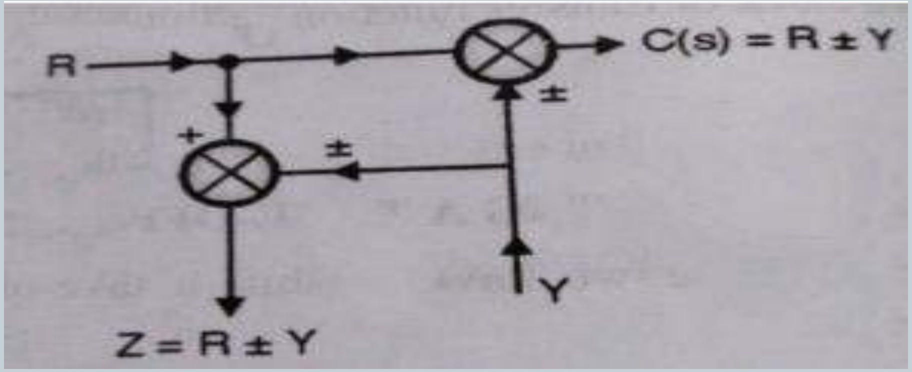
Z= R±Y

If we want to shift a take off point after summing point then another summing is required as shown

* It should be done as a last resort

*Rule10: Shifting take off point before a summing point

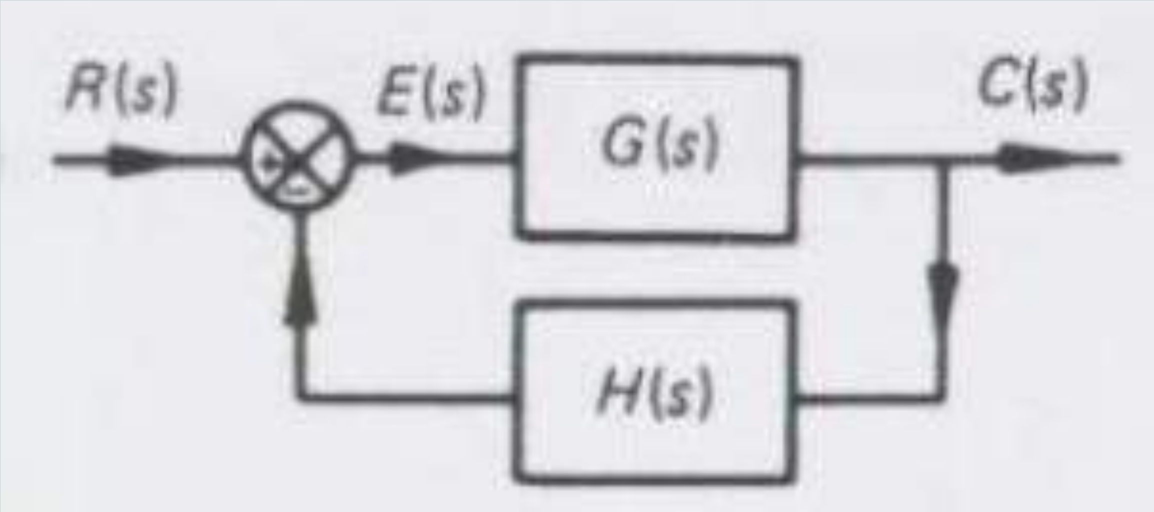




Rule 9 and 10 are critical rules , their usage should be avoided as much as possible

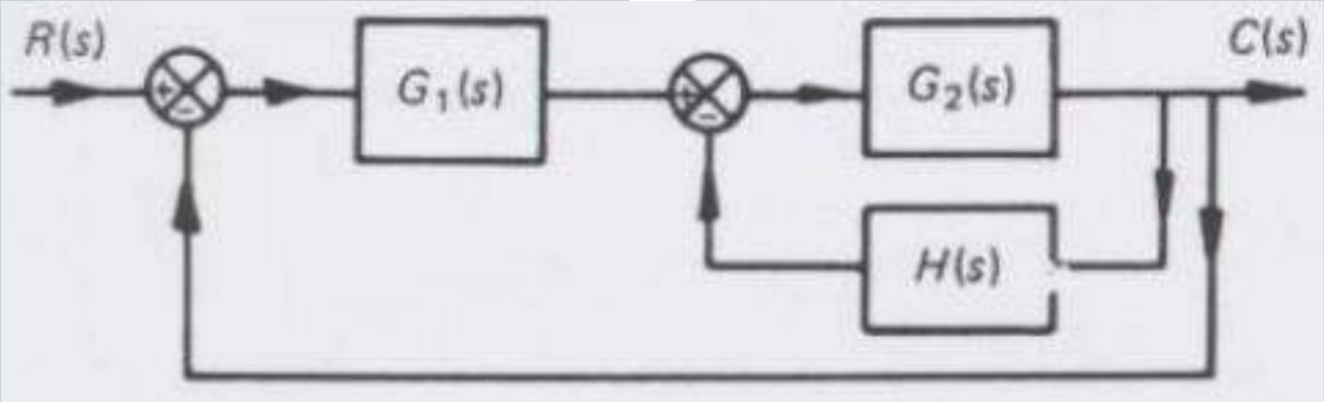
Always try to move take off points towards right and summing points towards left.

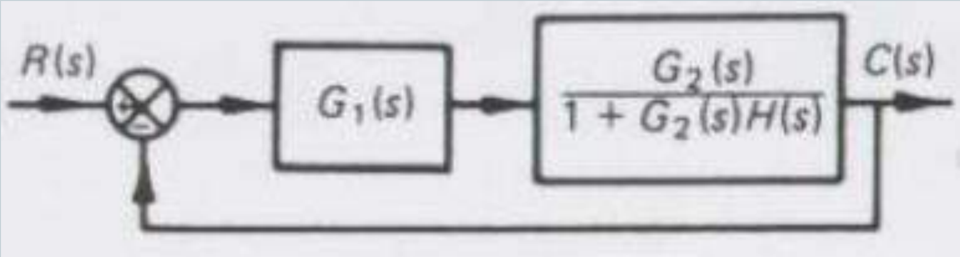
Problem 1

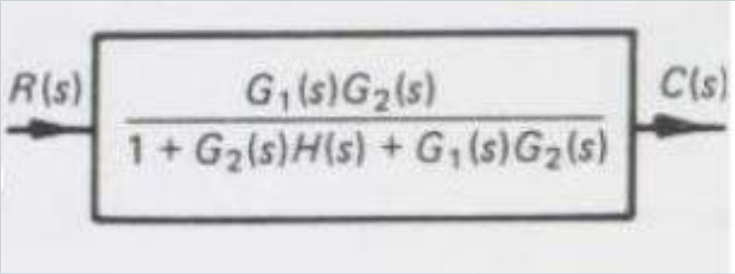


$$\frac{C(s)}{R(s)} = \frac{G(s)}{1+G(s)H(s)}$$

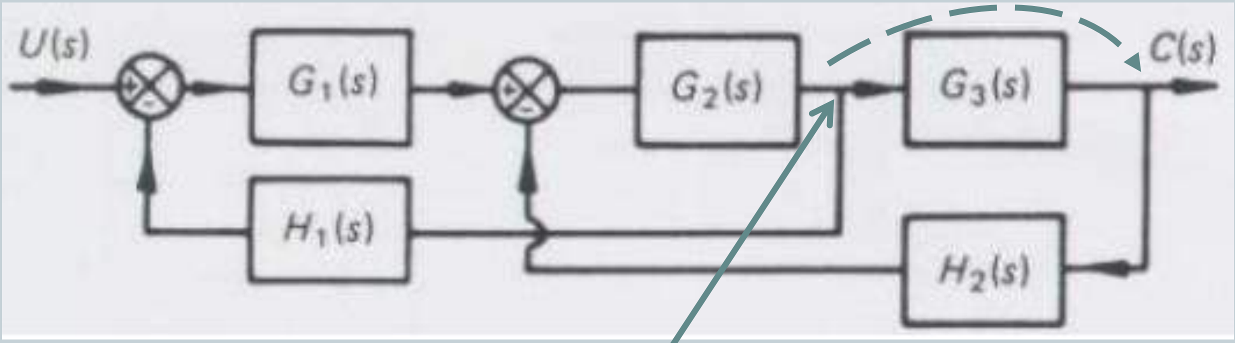
Problem 2


R(s)
G1(s)
G2(s)
C(s)
H(s)

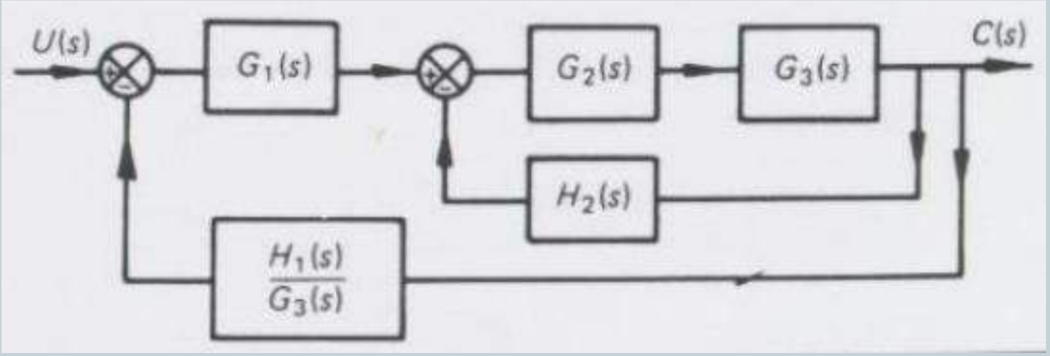

R(s)
G1(s)
$\frac{G_2(s)}{1 + G_2(s)H(s)}$
C(s)


R(s)
$\frac{G_1(s)G_2(s)}{1 + G_2(s)H(s) + G_1(s)G_2(s)}$
C(s)

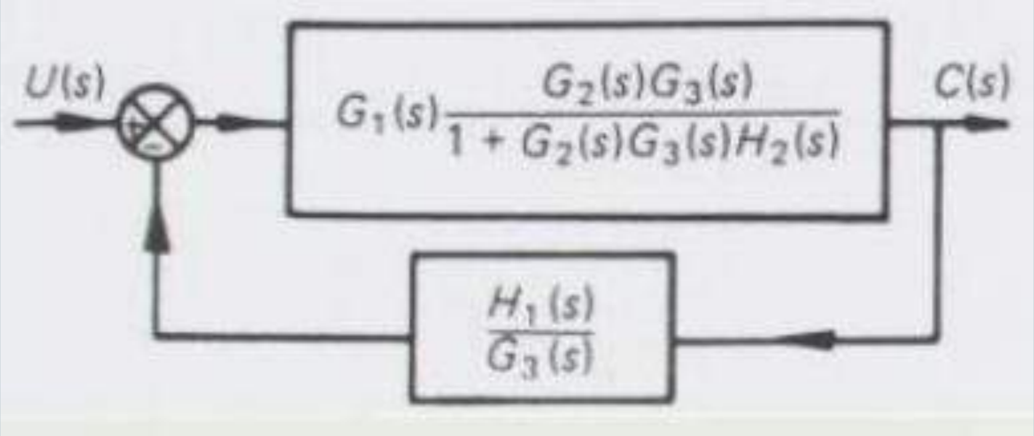
Problem 3

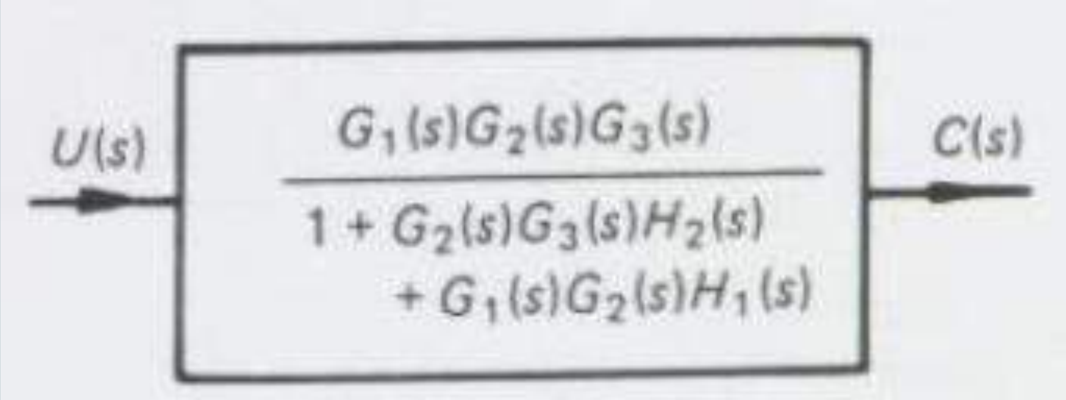


Key here is to move the take off point after the G3

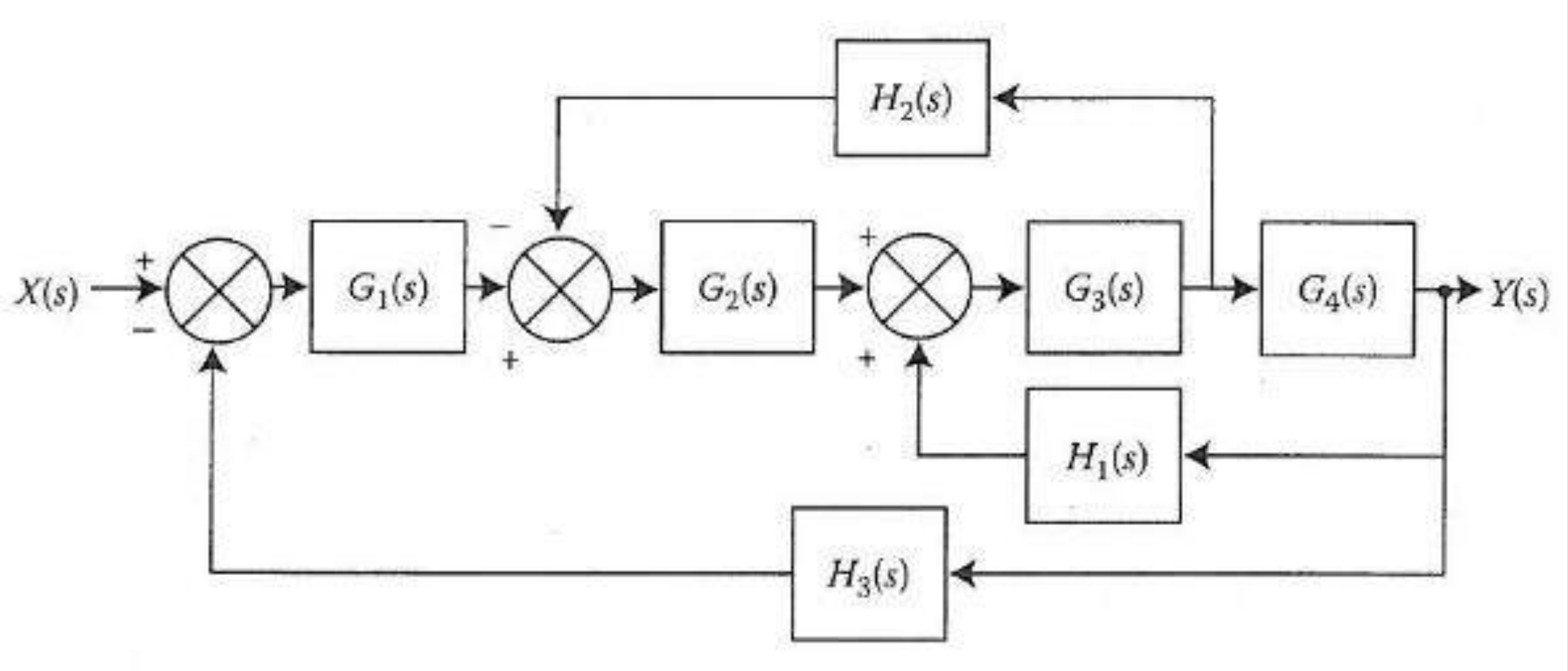


Problem 3 cond...

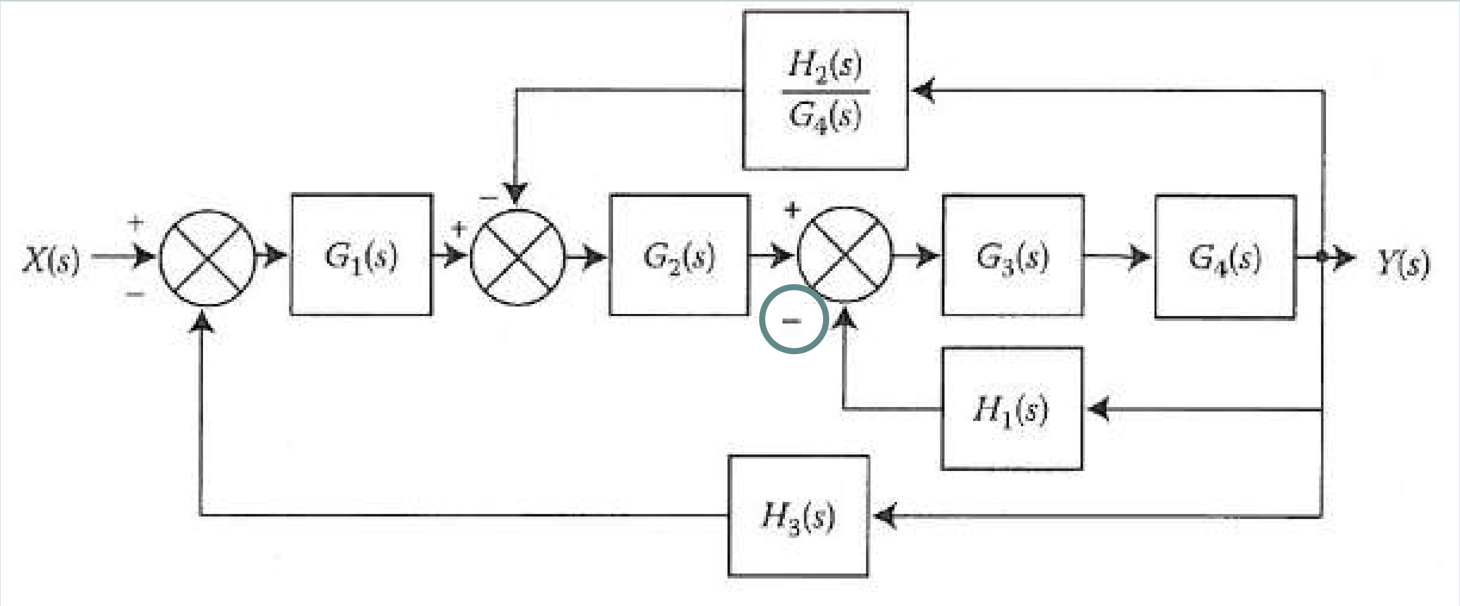




Problem 4



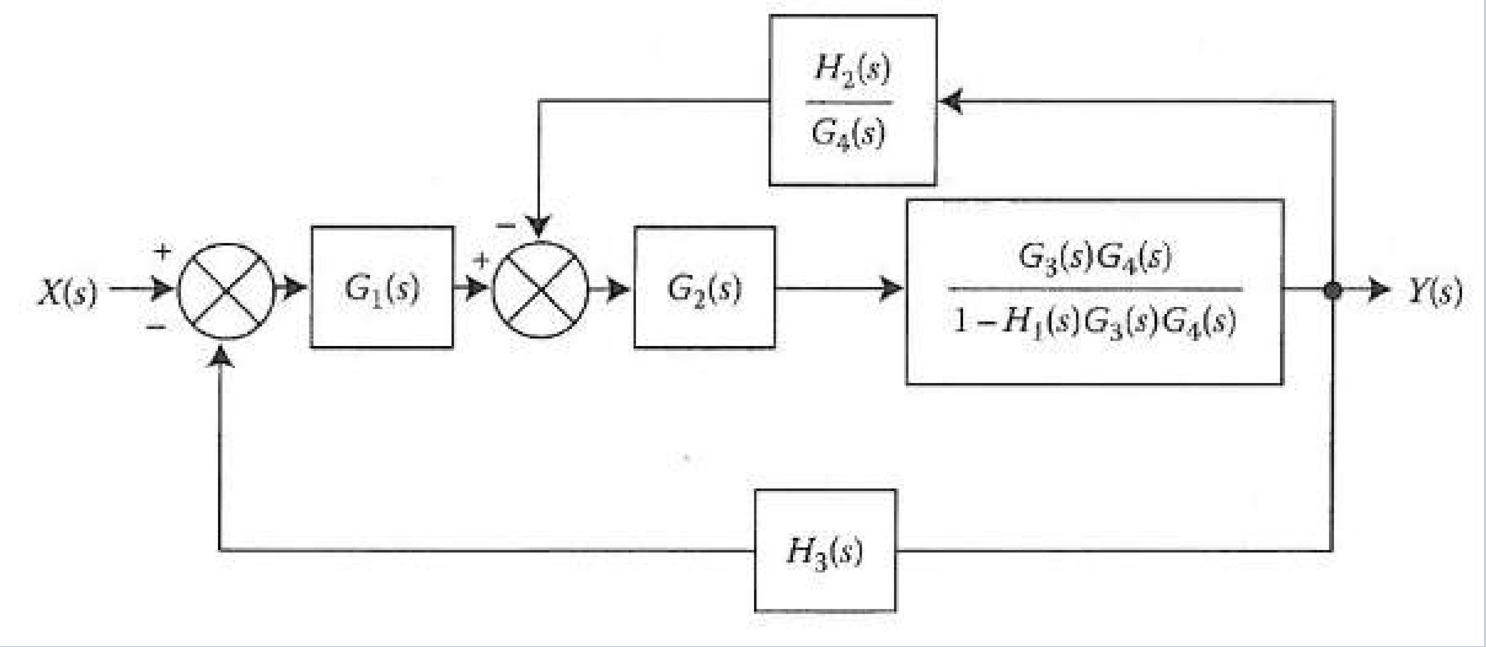
Problem 4 contd…



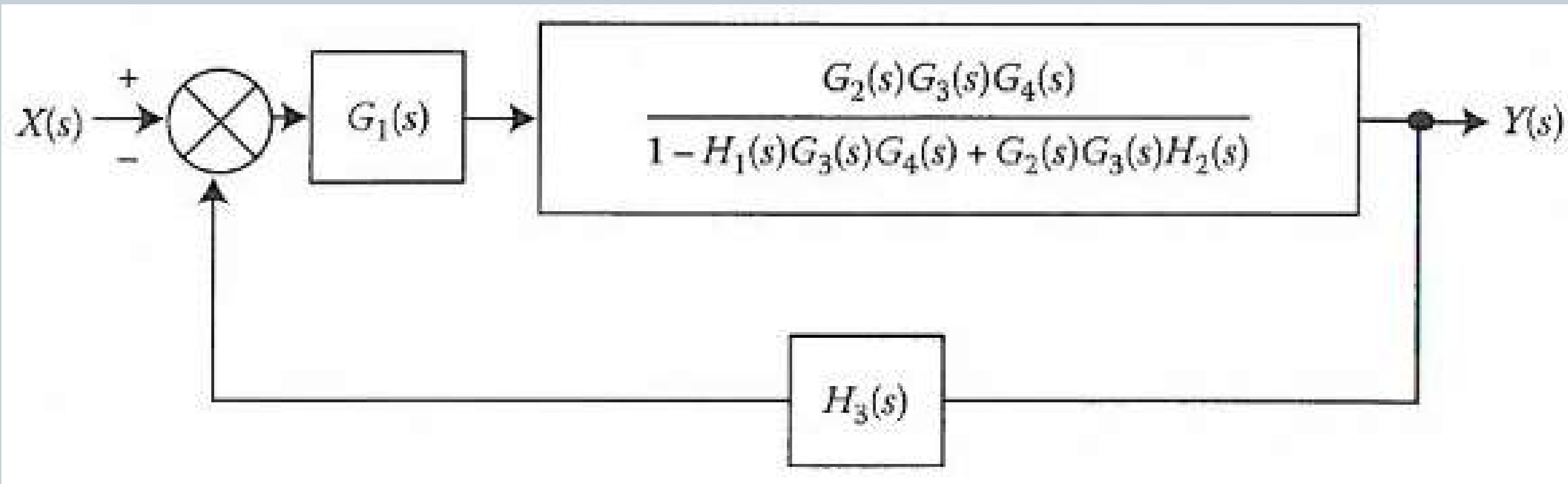
Correction here

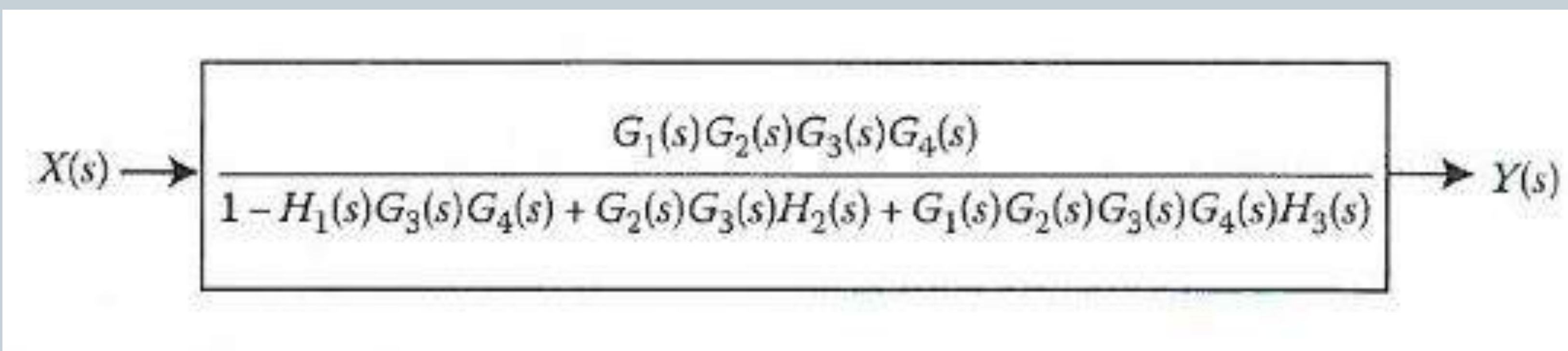
The feedback from H1(s) is positive see the problem

Problem 4 contd...



Problem 4 contd…





Further Reading

Control system by M Gopal