Introduction to control systems

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Introduction

- A control system is a systematically arranged interconnection of components which together act to provide a desired response when excited by an input.

- Control systems are playing a vital role in the advancement of science and technology and influence every aspect of modern life.

- Automatic controls in heating and air conditioning regulate the temperature and humidity for comfortable living.

- Thermostats and alarm clock are other examples.
- Automatic control system in industries speed up the production by way of quality control, inventory control, machine tooling etc.
- Successful operation of space vehicles, satellites, war planes, radars, humans travel to other planets etc, depend on proper functioning of a number of control systems.

- Today control systems are cheaper and more sophisticated , because computers are used as integral parts of control systems and also due to recent development of semiconductor devices and availability of inexpensive microprocessors.

- Control system engineers are concerned with understanding the nature and to control the environment and its effects upon the life of human beings.

Terminology:

- Plant: The dynamic unit or equipment containing components to perform a specified operation.

Example: A electrical machine, a CRO, an aircraft, a chemical reactor etc.

Process: A progressive continuing operation with gradual changes leading towards a specified result. Normally plant and process are used in the same sense.

- Command input (desired output): motivating input signal having full control on the system and is independent of the output.

- Reference input: form of input directly usable by the system. Also called as actuating signal.

- Reference selector: unit that establishes the reference input, also called comparator or controller.

- Disturbance : a signal which tends to adversely affect the output. It may be internally generated in the system or may be externally generated and behaves as an input.

Types of control systems

- Control systems are classified into two types depending on the quantity of actuating signal.
- They are

    1) open loop system

    2) closed loop system.

<u>Open loop system:</u>

- An open loop control system is that system in which the control action is independent of output.
- It means that actuating signal has no component of the output.
- Example: traffic control signal, toaster, DC generator (voltage control)

Traffic control signal

- Traffic control signal is time dependent.
- The traffic becomes mobile or stationary depending on the duration and sequence of siganl (lamp) glow.
- The duration and sequence are controlled by relays which are predetermined and not dependent on the density of the traffic in any road.

Feedback control

- Feedback control is an operation, which in the presence of disturbances, tends to reduce the difference between the desired output and the actual output.
- This difference is called error.
- The desired output is the input command.
- For comparing the actual output with the desired output, actual output or its function is to be fedback to the input side using feedback elements.

Closed loop control systems:

- A control system in which the output has an effect on the input in such a manner as to maintain the desired output, ie to reduce the error.
- All feedback systems are closed loop systems.
- Actuating signal: in the case of openloop systems, the reference input is called the actuating signal.
- In the case of closed loop systems, it is the difference between the reference input and feedback signal. This is the input to the controller.
- The actuating signal in the case of unity feedback system is the error signal.

	Open loop	Closed loop
1	Construction and design are simple, hence less expensive	Complicated design more expensive.
2.	Generally stability is not a problem	Designer should be careful as there is tendency for less stability
3	Less accurate and less reliable	Highly accurate and more reliable
4	No feedback, output has no effect on input	Feedback is present, output affects input.
5	Sensitive to disturbances and environmental changes	Almost insensitive to both
6.	Small bandwidth	Larger bandwidth
7	Nonlinearities affect the response	Effect of nonlinearities is not to a greater extent

General considerations in the design of control systems:

- Stability
- Accuracy
- The speed of response

Stability:

Control systems must be stable .

For a given input, whether it is a reference change or a disturbance, the response must attain and maintain some useful value within a reasonable period of time.

An unstable system is useless.

accuracy

- A system must be accurate within specified limits.
- That is the system must be capable of reducing errors to zero or to some small tolerable value.
- All control systems must provide the demanded degree of accuracy.

Differential equations of physical systems:

- The term mechanical translation is used to describe motion with a single degree of freedom or motion in a straight line.
- the basis for all translation motion analysis is newton's second law of motion which states that the net force F acting on a body is related to its mass M and acceleration a by the equation $\Sigma F = ma$
- The three basic elements used in linear mechanical translational systems are i) Masses

  ii) springs

  iii) dashpot or viscous friction units

Outline of the procedure for writing differential equtions:

1. Assume that the system originally is in equilibrium in this way the often-troublesome effect of gravity is eliminated.
2. assume then that the system is given some arbitrary displacement if no distributing force is present.
3. Draw a free body diagram of the forces exerted on each mass in the system. There should be a separate diagram for each mass.
4. Apply newtons law of motion to each diagram using the convention that any force acting in the direction of the assumed displacement is positive.
5. Rearrange the equation in suitable form to solve by any convenient mathematical means.

Analogous circuits

- Analogous circuits represent systems for which the differential equations have the same form.
- The corresponding variables and parameters in the two circuits represented by equations of the same form are called analogs.

Advantages of analog electric circuits:

1. An electric analog of a mechanical system can be set up very easily in a laboratory.
2. A change in any electrical parameter (R,L and C) is accomplished more readily in an electric circuit.
3. An electric circuit can readily be adjusted to produce a desired response.

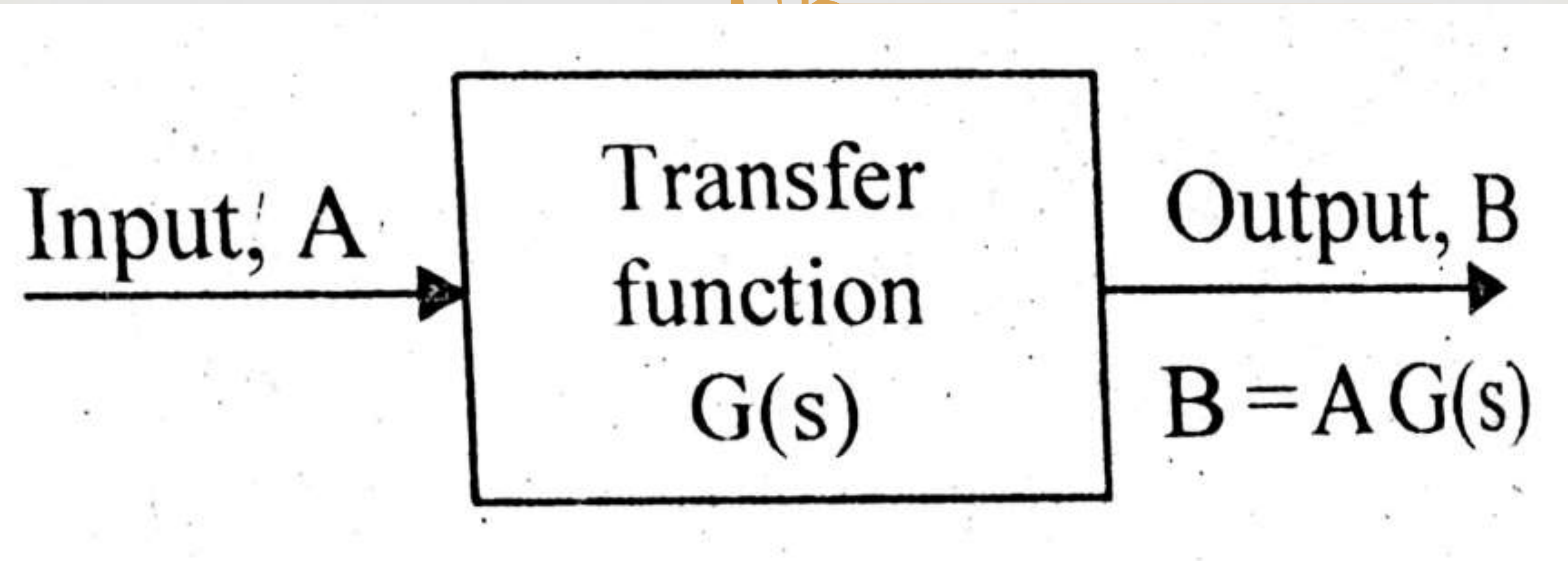
Block Diagrams and Signal Flow graphs

Block Diagram

- It is the pictorial representation of the functions performed by each component and of the flow of the signals.

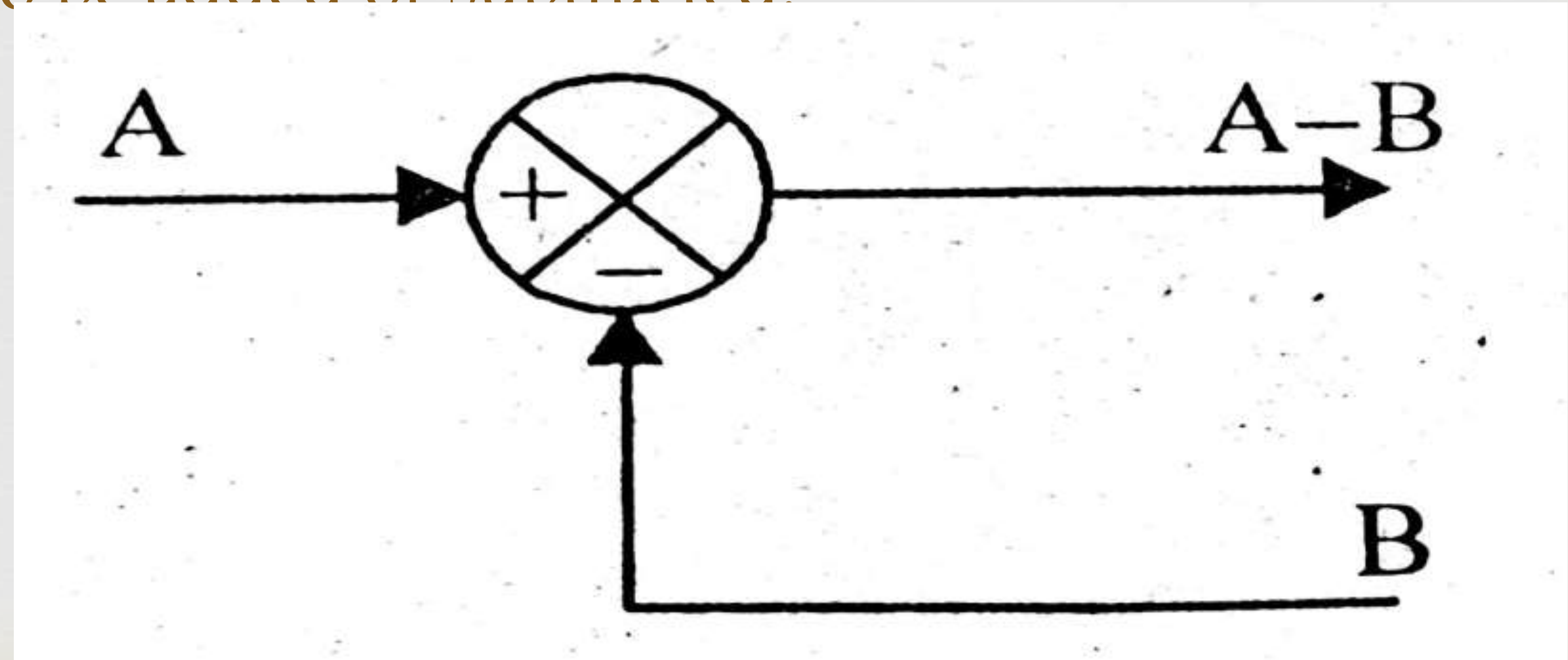
Block

- All system variables are linked to each other through functional blocks in block diagram.
- Block is a symbol for the mathematical operation on the input signal to the block that produces the output.
- Blocks are connected by arrows to indicate the direction of the flow of signals.
- Arrowhead pointing towards the block is input and away from the block is given by the product of input signal and transfer function in the block.


Input, A
Transfer
function
G(s)
Output, B
B = A G(s)

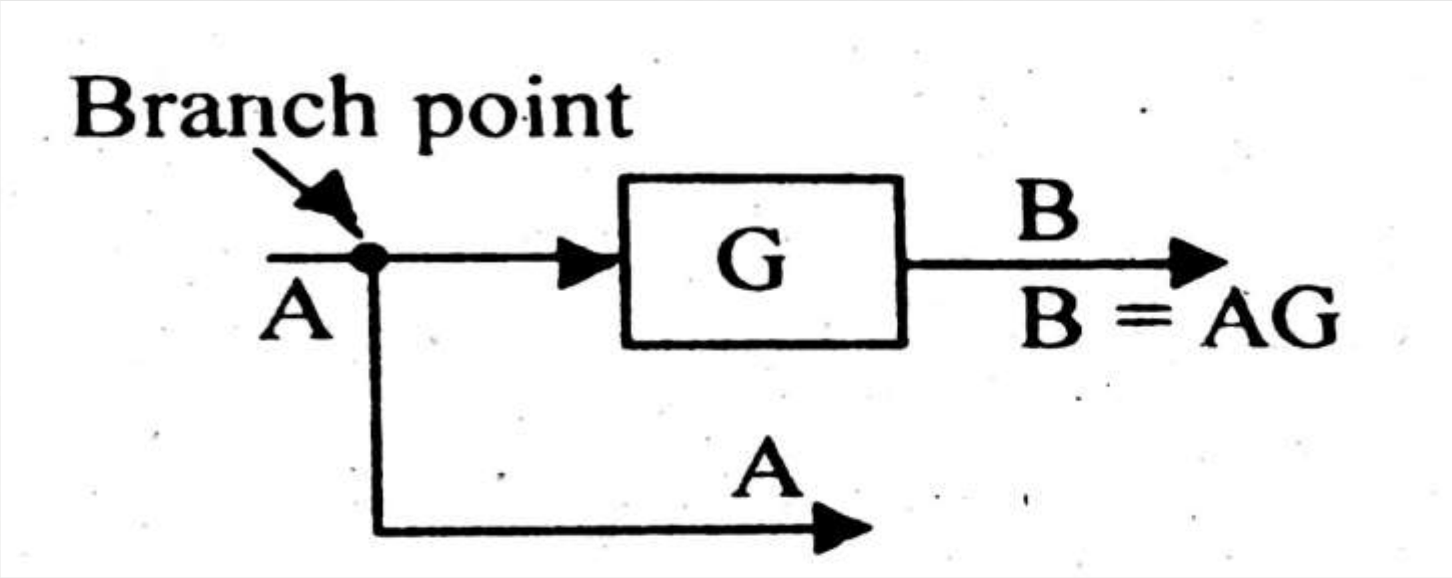
Summing point:

These are used to add 2 or more signals in the system.
A circle with a cross is the symbol.
Plus or minus sign indicates whether the signal is to be added or subtracted.



Branch Point/Take away

The point from which the signal from a block goes concurrently to other blocks.



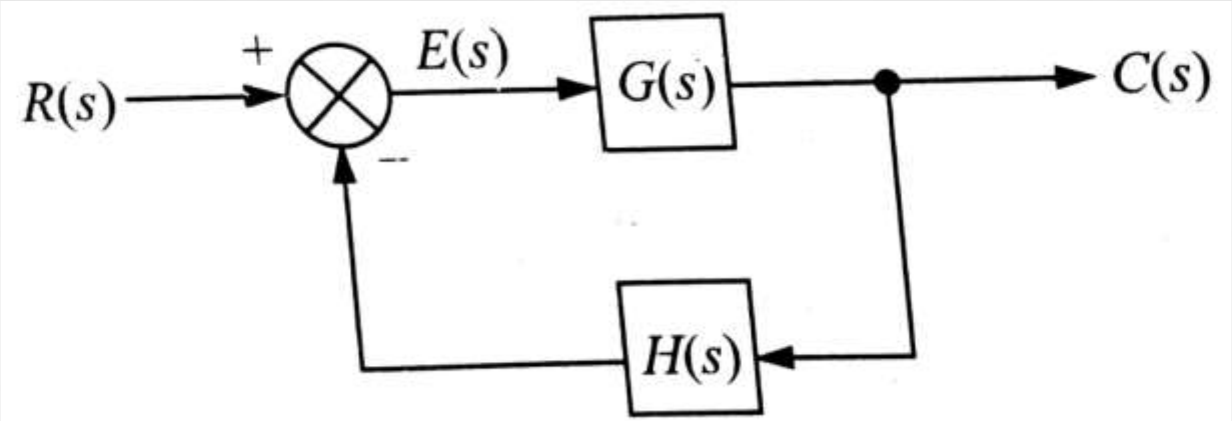
Closed loop transfer function

- A transfer function which encompasses an entire control system is called a closed loop transfer function
- There are 2 types of feedback loops:

Positive feedback and negative feedback

Negative Feedback system

- Summing point is used to make comparison between the controlled variable C(s) and the reference input R(s) so that an actuating signal E(s) is produced.
- If the feedback transfer function H(s) is unity, then it is called unity feedback system.
- For a unity feedback system, E(s) is error signal



$E(s) = R(s) – C(s).H(s)$

System output: $C(s) = E(s).G(s)$

Therefore, $C(s) = [R(s)-C(s).H(s)]G(s)$

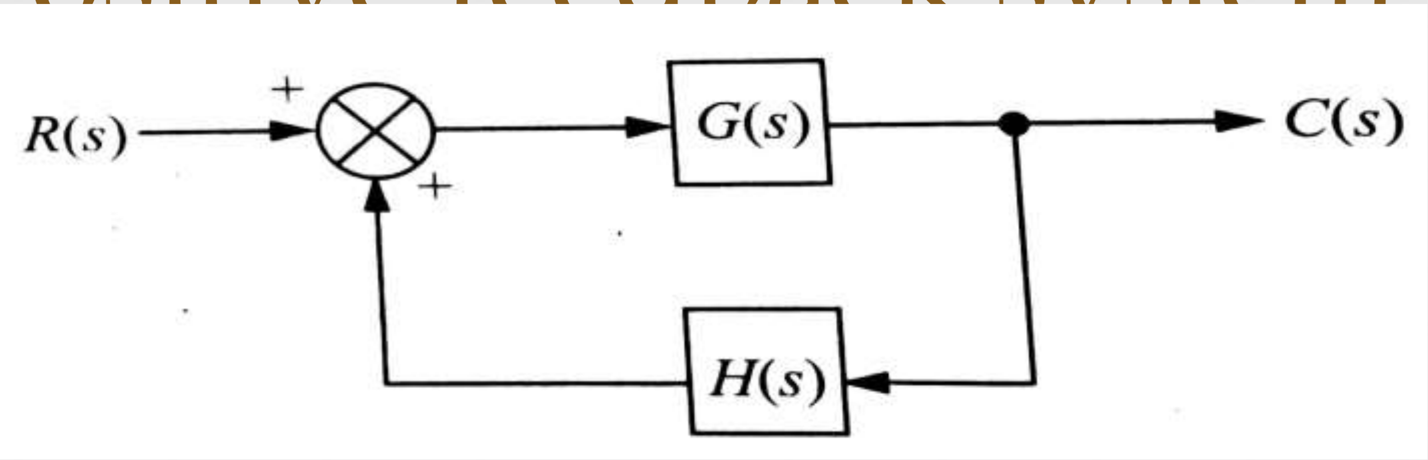
$= G(s).R(s) – C(s)H(s)G(S)$

$C(s) + C(s)H(s)G(S) = G(S).R(s)$

$C(S)[1+ H(s)G(s)] = G(S).R(s)$

Transfer function, $C(s)/R(s) = G(s)/[1 + G(s).H(s)]$

Positive feedback system



E(s) = R(s) + C(s).H(s)

System output: C(s) = E(s).G(s)

Therefore, C(s) = [R(s) +C(s).H(s)]G(s)

= G(s).R(s) + C(s)H(s)G(S)

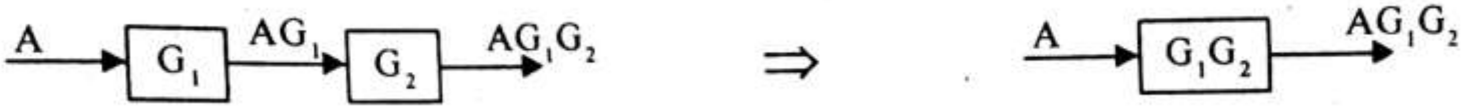
C(s) - C(s)H(s)G(S) = G(S).R(s)

C(S)[1- H(s)G(s)] = G(S).R(s)

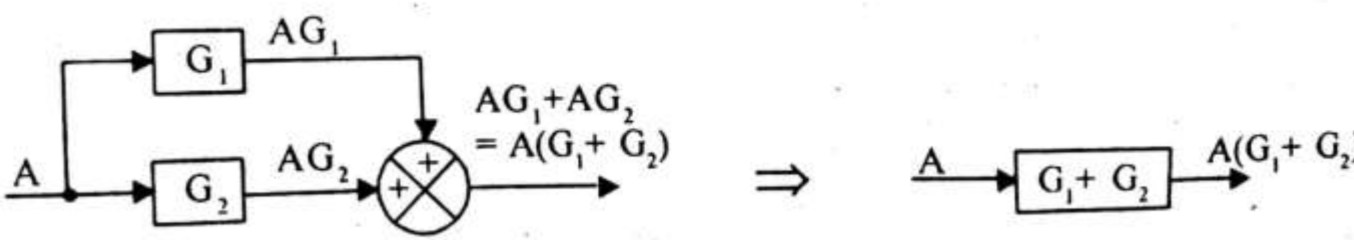
Transfer function, C(s)/R(s) = G(s)/[1 - G(s).H(s)]

Rules of Block Diagram

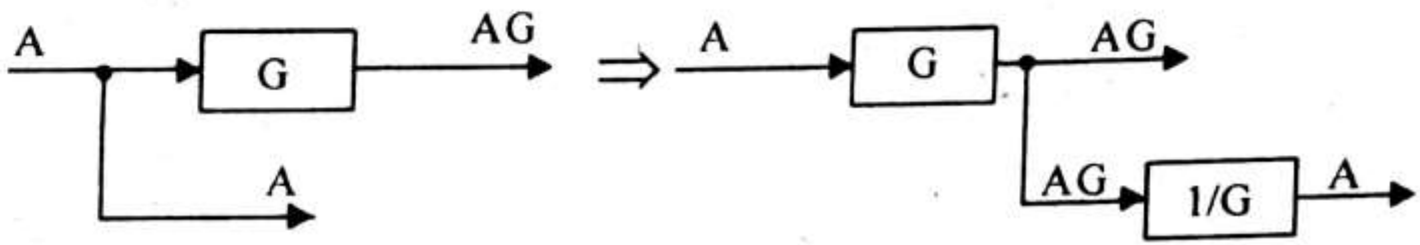
Rule-1 : ***Combining the blocks in cascade***



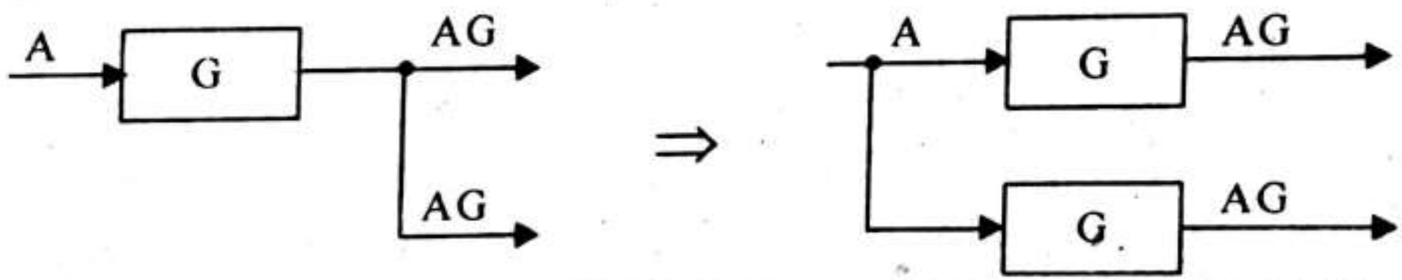
Rule-2 : ***Combining Parallel blocks (or combining feed forward paths)***



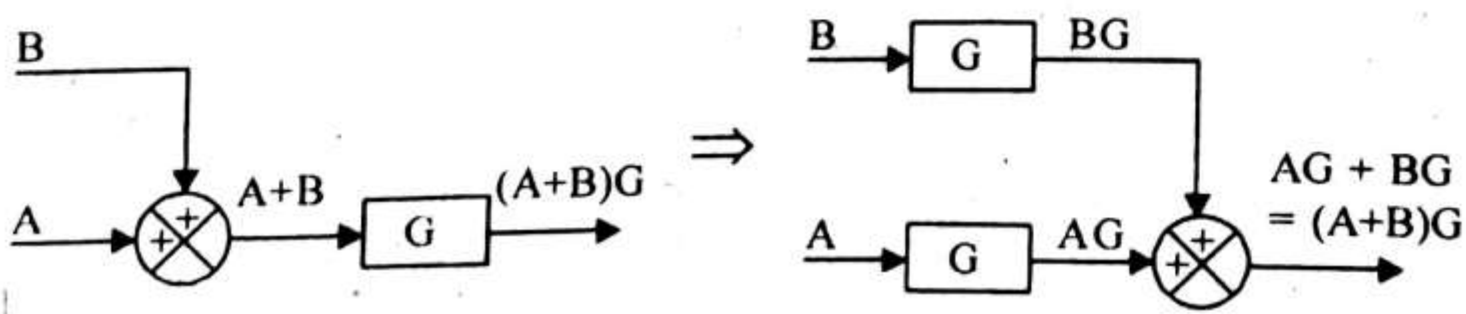
Rule-3 : ***Moving the branch point ahead of the block***



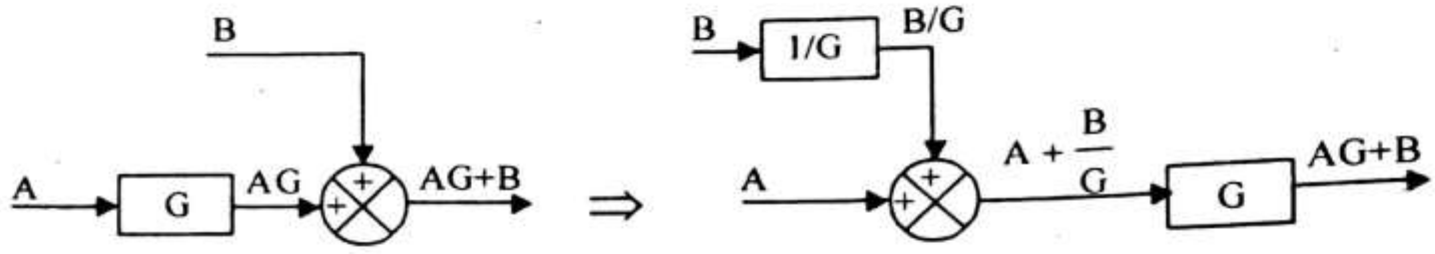
Rule-4 : ***Moving the branch point before the block***



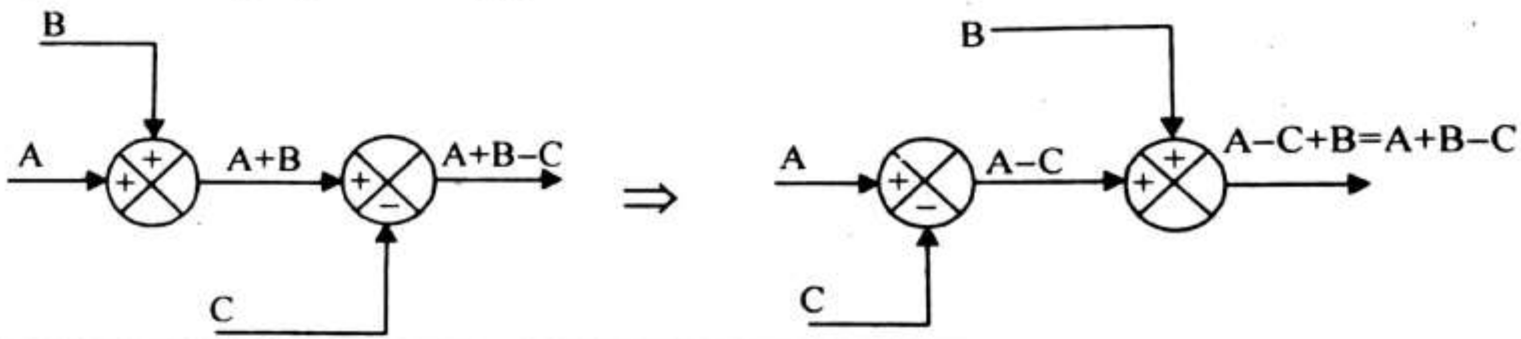
Rule-5 : ***Moving the summing point ahead of the block***



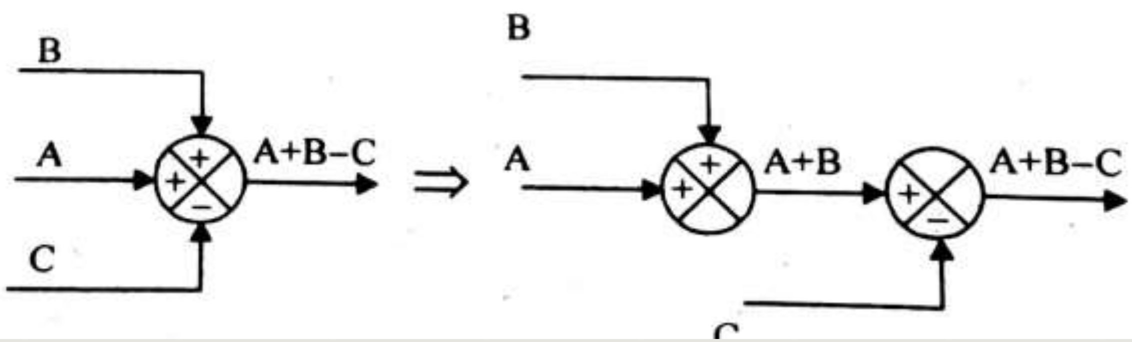
Rule-6 : ***Moving the summing point before the block***



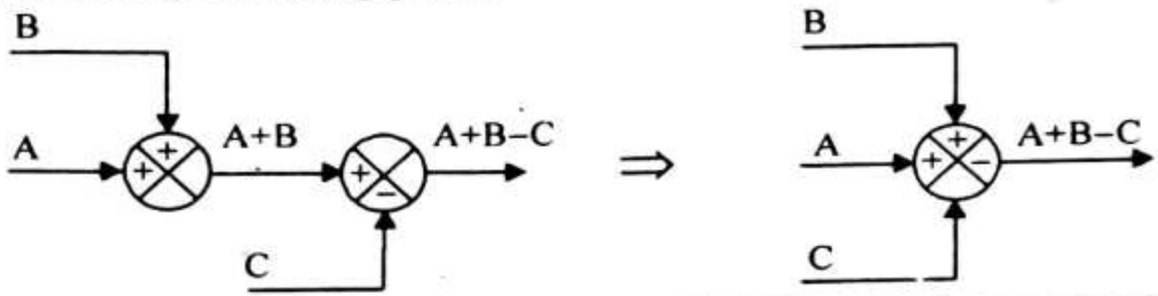
Rule-7 : ***Interchanging summing point***



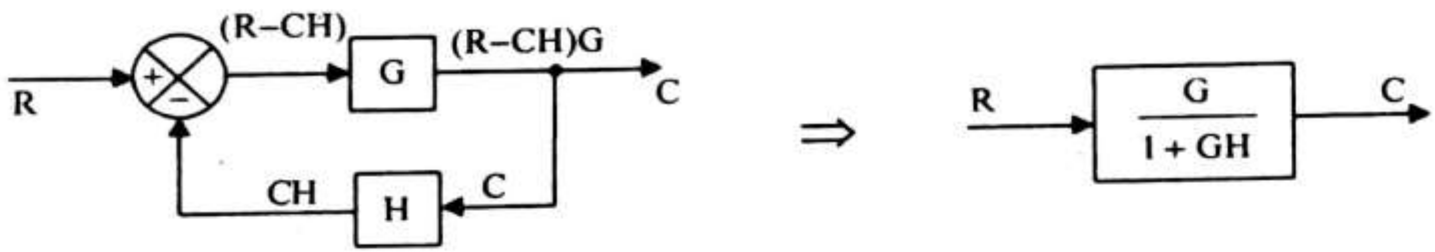
Rule-8 : ***Splitting summing points***



Rule-9 : *Combining summing points*



Rule-10 : *Elimination of (negative) feedback loop*



Proof :

$$C = (R - CH)\,G$$

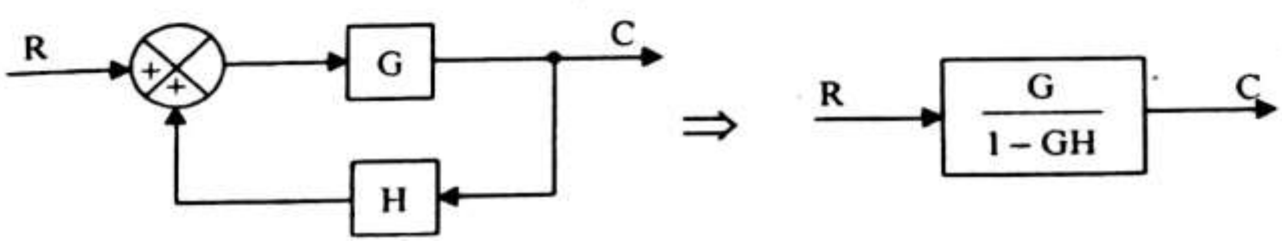
$$C = RG - CHG$$

$$C + CHG = RG$$

$$C(1+HG) = RG$$

$$\frac{C}{R} = \frac{G}{1+GH}$$

Rule-11 : *Elimination of (positive) feedback loop*



Signal Flow Graph

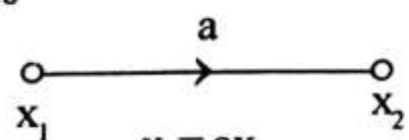
- SFG depicts the flow of signal from one point of a system to another and gives the relationships among the signals.
- It consists of a network in which nodes are connected by directed branches.
- Each node represents a system variable and each branch connected between 2 nodes acts as a signal multiplier.
- Each branch has gain and when the signal pass through a branch, it gets multiplied by the gain of the branch.

Rules to solve SFG

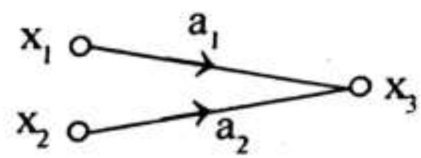
node is given by sum

Rule 1 : Incoming signal to a node through a branch is given by the product of a signal at previous node and the gain of the branch.

Examples



$x_2 = ax_1$



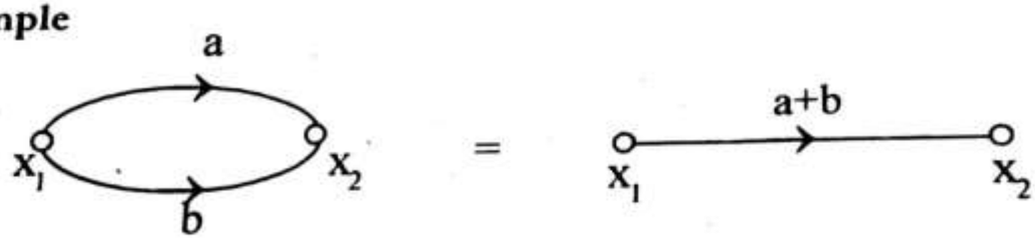
$x_3 = a_1x_1 + a_2x_2$

Rule 2 : Cascaded branches can be combined to give a single branch whose transmittance is equal to the product of individual branch transmittance.

Example

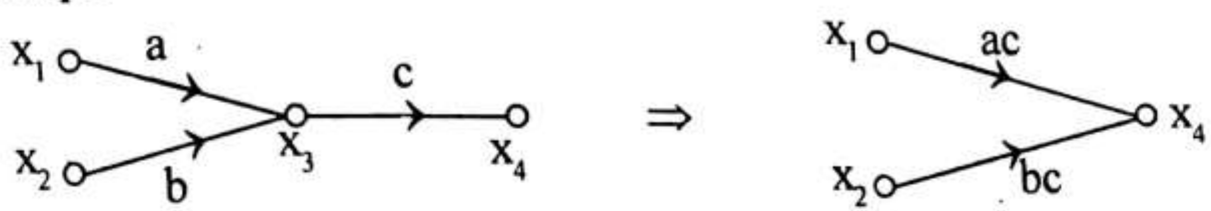
Rule 3 : Parallel branches may be represented by single branch whose transmittance is the sum of individual branch transmittances.

Example



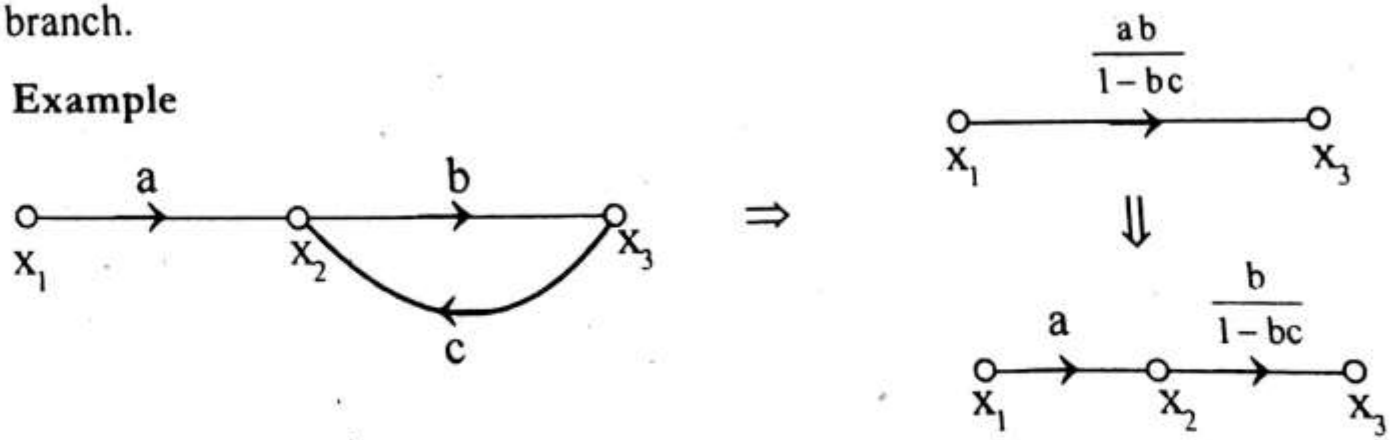
Rule 4 : A mixed node can be eliminated by multiplying the transmittance of outgoing branch (from the mixed node) to the transmittance of all incoming branches to the mixed node.

Example



Rule 5 : A loop may be eliminated by writing equations at the input and output node and rearranging the equations to find the ratio of output to input. This ratio gives the gain of resultant branch.

Example



Proof : $x_2 = ax_1 + cx_3$; $x_3 = bx_2$

Put, $x_2 = ax_1 + cx_3$ in the equation for x_3.

$\therefore \; x_3 = b(ax_1 + cx_3) \;\Rightarrow\; x_3 = abx_1 + bcx_3 \;\Rightarrow\; x_3 - bc\,x_3 = ab\,x_1 \;\Rightarrow\; x_3(1-bc) = ab\,x_1$

$$\therefore \; \frac{x_3}{x_1} = \frac{ab}{1-bc}$$