CONTROL SYSTEM

VTH SEMESTER

ETEL-307

Department of Electronics and Communication Engineering, BVCOE, New Delhi
Subject: Control System , Instructor: Avinash

UNIT-I

CONTROL SYSTEM: BASICS & COMPONENTS

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Topics to be covered :-

- Introduction To Basic Terms
- Classifications & Types Of Control Systems
- Block Diagrams & Signal Flow Graphs
- Transfer Function
- Determination Of Transfer Function Using Block Diagram Reduction Techniques
- Mason's Gain Formula

- Control System Components:
- A.C./D.C. Servo Motors, Stepper Motors, Tacho Generators, Synchronous, Magnetic Amplifiers, Servo Amplifiers

Introduction To Control System:

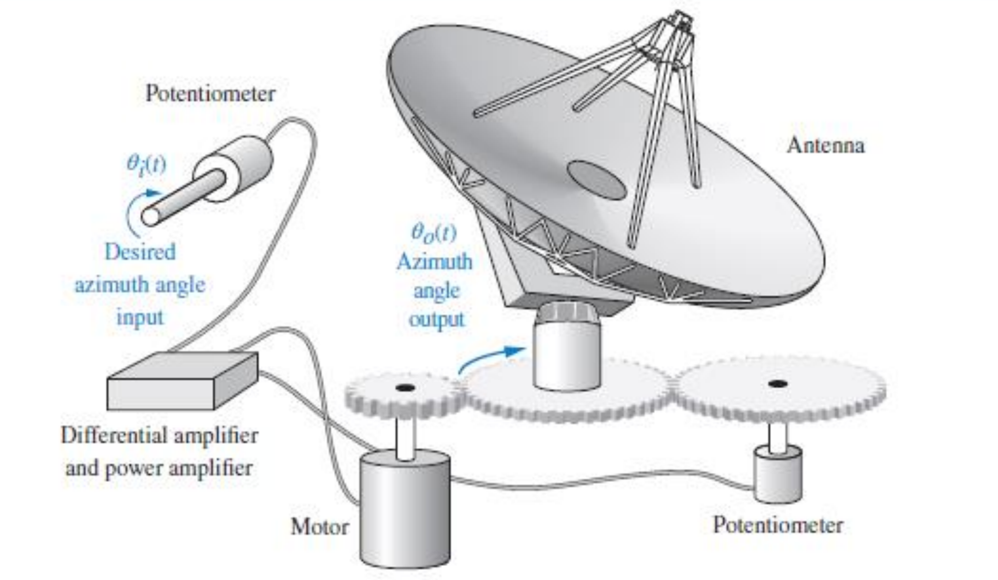
A control system consists of *subsystems* and *processes* (or *plants)* assembled for the purpose of obtaining a desired *output* with desired *performance*, given a specified *input*.

Application of Control System:

- Robotics (Black Line Follower)
- Space Application
- Power Plants, Steel Plants, Chemical Plants
- Your Bike (speed increases with pressure on accelerator)
- Water Tank Alarm
- Human Body

Introduction To Control System:

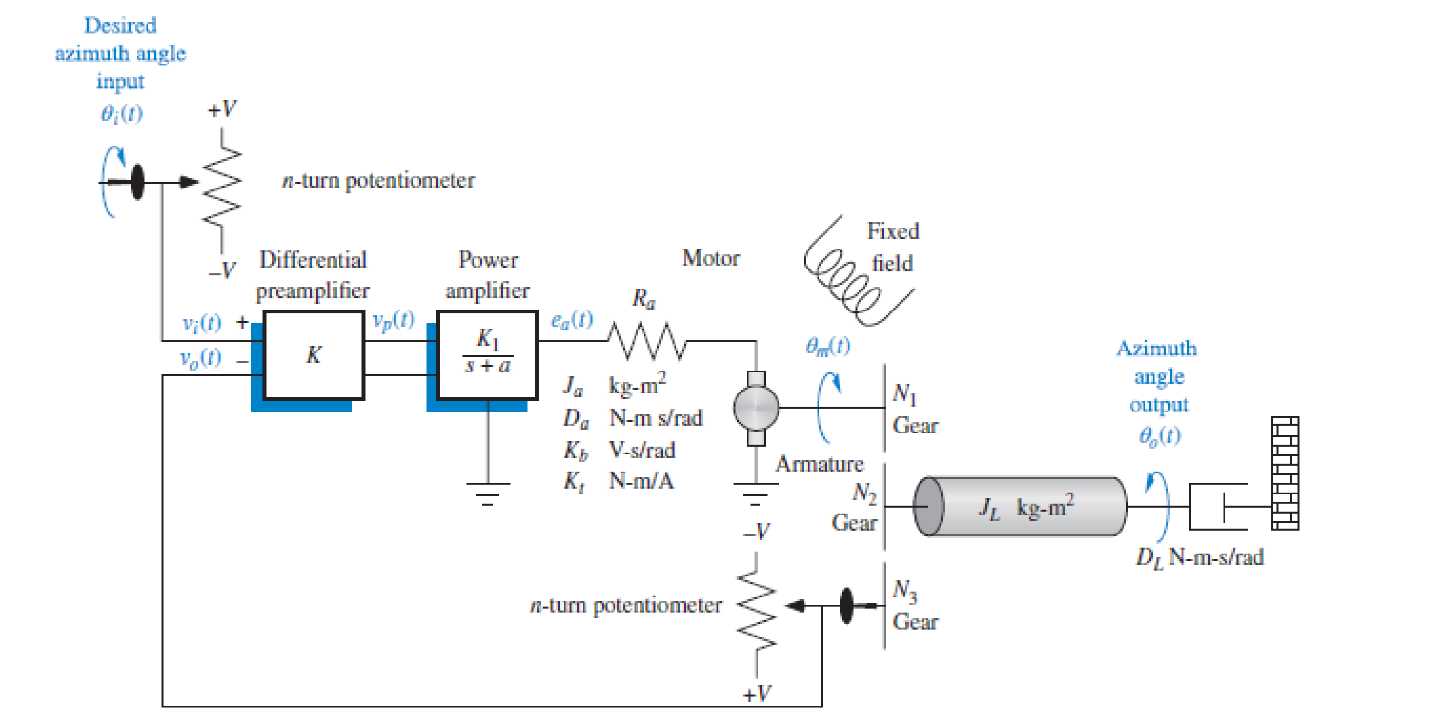
Antenna Azimuth Position Control System



Layout

Introduction To Control System:

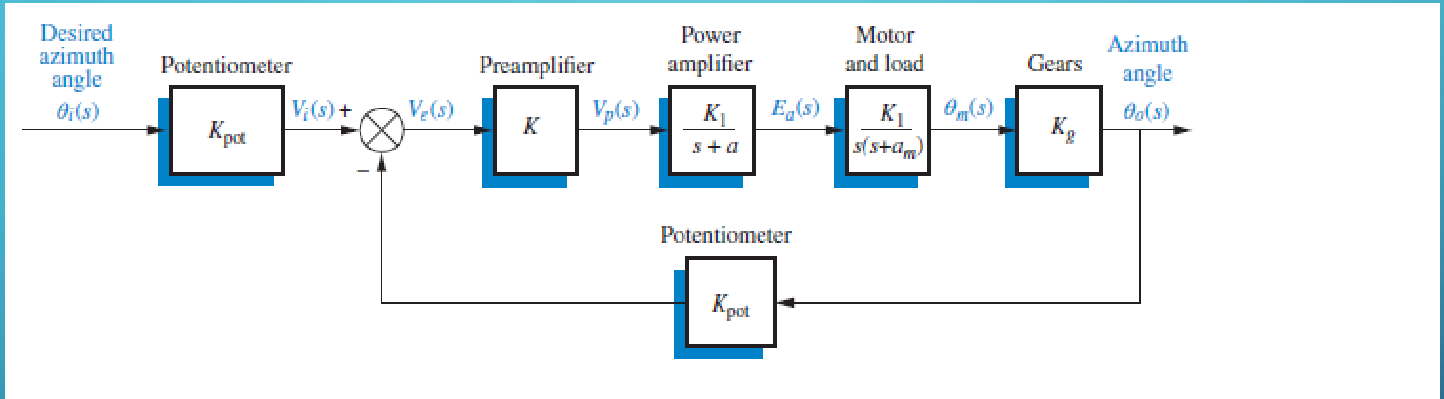
Antenna Azimuth Position Control System



Schematic

Introduction To Control System:

Antenna Azimuth Position Control System



Block Diagram

Basic Terms:-

Few basic terminologies must be defined:

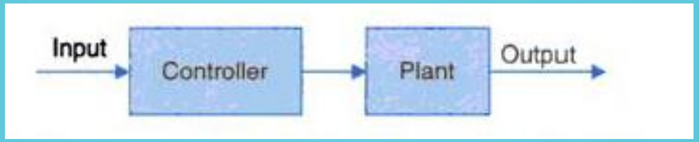
- *Controlled variable* The *controlled* variable is the quantity or condition that is measured and controlled.
- *Manipulated variable:* The *manipulated* variable is the quantity or condition that is varied by the controller so as to affect the value of the controlled variable
- *Plants:* A plant may be a piece of equipment, perhaps just a set of machine parts Functioning together, the purpose of which is to perform a particular operation
- *Processes:* A process to be a natural, progressively continuing operation or development marked by a series of gradual changes that succeed one another in a relatively fixed way and lead toward a particular result or end; or an artificial or voluntary, progressively continuing operation that consists of a series of controlled actions or movements systematically directed toward a particular result or end
- *Systems:* A system is a combination of components that act together and perform a certain objective
- *Disturbances:* A disturbance is a signal that tends to adversely affect the value of the output of a system
- *Feedback control:* Feedback control refers to an operation that, in the presence Of disturbances, tends to reduce the difference between the output of a system and some reference input and does so on the basis of this difference

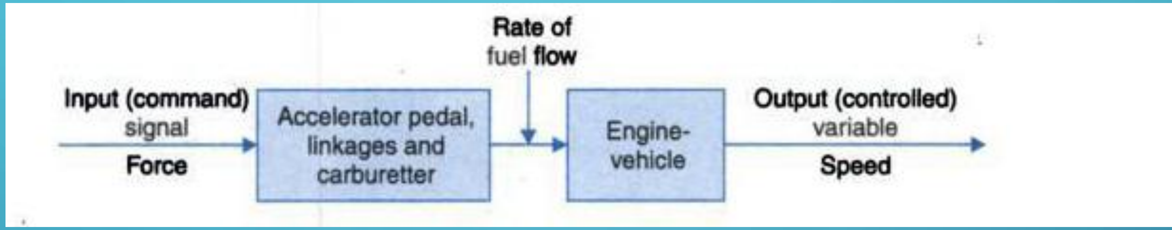
Classifications & Types Of Control Systems :-

- Based On Mathematical Equation:
  - Differential Equation
  - Difference Equation

- Based On Feedback Present:
  - Open Loop (Without Feedback)
  - Close Loop (With Feedback)

Open Loop Control System:





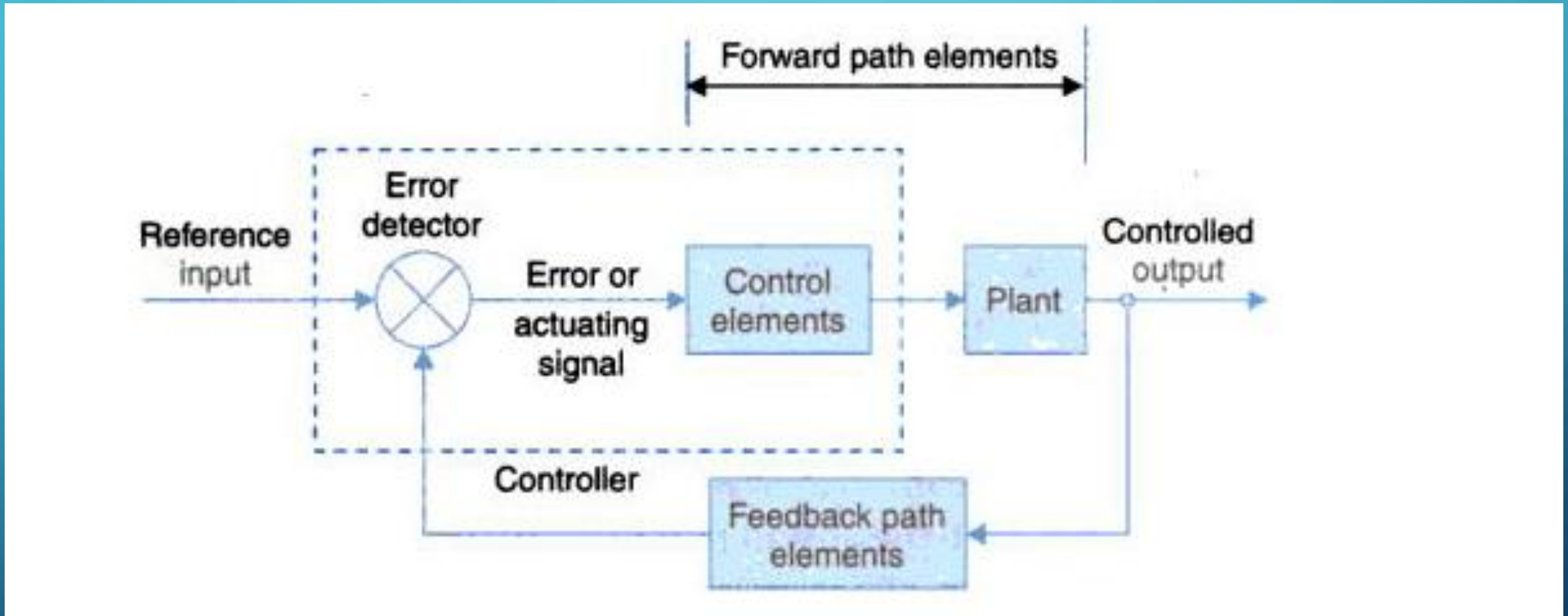
Open Loop Control System:

- Those systems in which the output has no effect on the control action are called *open-loop control systems*
- Open Loop control system the output is neither measured nor fed back for comparison with the Input
- In the presence of disturbances, an Open-loop control system will not perform the desired task
- Open-loop control can be Used, in practice, only if the relationship between the input and output is known and if there are neither internal nor external disturbances.

Close Loop Control System :

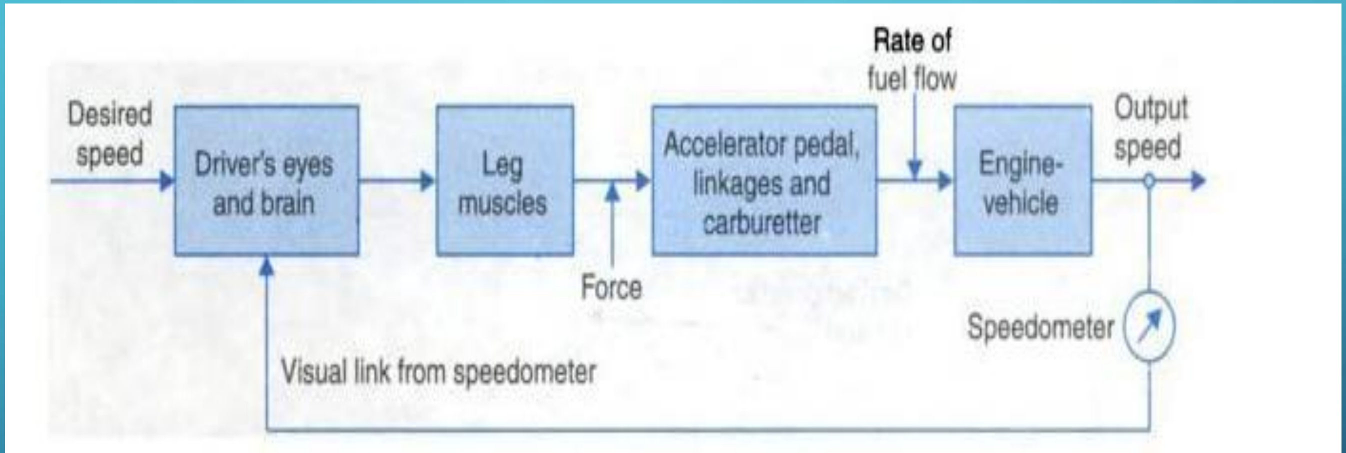
Feedback Control Systems / Closed Loop Control System:

A system that maintains a prescribed relationship between the output and the reference input by comparing them and using the difference as a means of control is called a *feedback control system*.



Close Loop Control System :

Feedback Control Systems / Closed Loop Control System:



Closed-loop Versus Open-loop Control Systems :

Open Loop Control System

- From the point of view of stability, the open-loop control system is easier to build because System stability is not a major problem
- It should be emphasized that for systems in which the inputs are known ahead of time and in which there are no disturbances it is advisable to use open-loop control
- Less no of components used
- Low power consumption
- Low Cost

Close Loop Control System

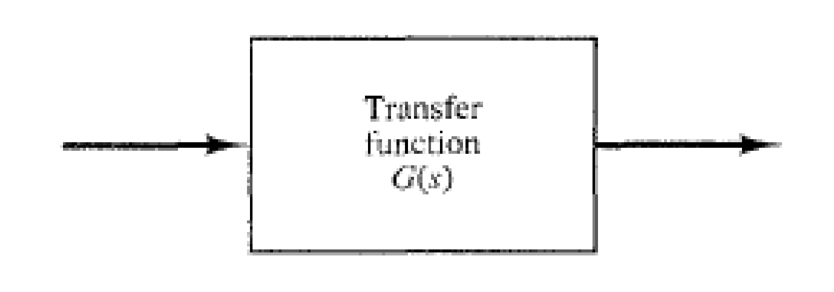
- System response relatively Insensitive to external disturbances and internal variations in system parameters
- Closed loop Control systems have advantages only when unpredictable disturbances and/or unpredictable Variations in system components are present
- Number of Components used in a closed-loop control system is more
- High Power consumption
- Higher in Cost

Block Diagrams:

A block diagram of a system is a pictorial representation of the functions performed by each component and of the flow of signals.

Interrelationships that exist among the various components.

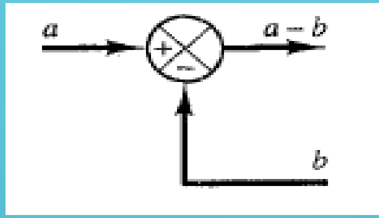
Block is a symbol for the mathematical operation on the input signal to the block that produces the output.



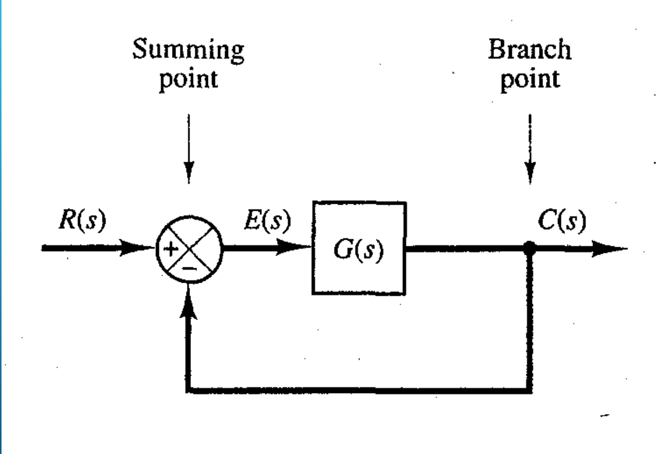
Elements of a block diagram

Block Diagram:

Summing Point: A circle with a cross is the symbol that indicates a summing operation. The plus or minus sign at each arrowhead indicates whether that signal is to be added or subtracted. It is important that the quantities being added or subtracted have the same dimensions and the same units.



Branch Point: A branch point is a point from which the signal from a block goes concurrently to other blocks or summing points



Transfer Function:

The *transfer function* of a linear, time-invariant, differential equation system is defined as the ratio of the Laplace transform of the output (response function) to the Laplace transform of the input (driving function) under the assumption that all initial conditions are zero.

$$Transfer\ Function = G(s) = \frac{\mathcal{L}\{Output\}}{\mathcal{L}\{Input\}} = \frac{C(s)}{R(s)}, at\ Zero\ Initial\ Conditions$$

Features And Advantages Of Transfer Function Representation:

- Using transfer functions, mathematical models can be obtained and analyzed.
- Output response can be obtained for any kind of inputs
- stability analysis can be performed.
- The usage of Laplace transform converts complex time domain equations to simple algebraic equations, expressed with complex variable *s*
- Analysis of a system is simplified due to the use of *s*-domain variable in the equations, rather than using time-domain variable.

Transfer Function:

Disadvantages Of Transfer Function Representation:

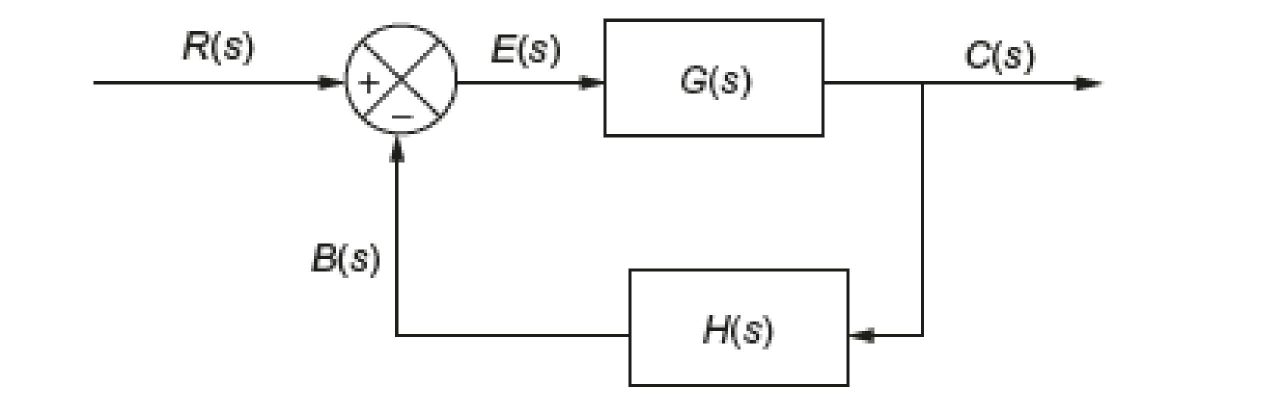
- It is not applicable to non-linear systems or time-varying system
- Initial conditions are neglected
- Physical nature of a system cannot be found (i.e., Whether it is mechanical or electrical or thermal system)

Transfer Function Of An Open-loop System:

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

Transfer Function:

Transfer Function Of a Close-loop System:



R(s)- Reference Input

E(s) – Error Signal

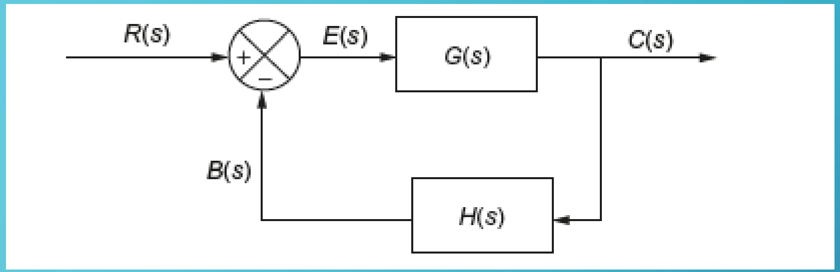
G(s) – Overall Gain in Forward Path

H(s) – Overall Gain in Feedback path

B(s) – Feedback Signal

Transfer Function:

Transfer Function Of a Close-loop System:



Open-loop transfer function: The ratio of the Feedback signal *B(s)* to the Actuating Error signal *E(s)* is called the *open-loop transfer function.*

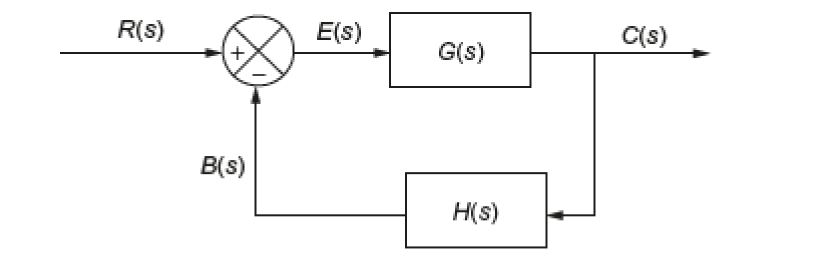
$$i.e.\ \ Open\ Loop\ Transfer\ Function\ = \frac{B(s)}{E(s)} = G(s)H(s)$$

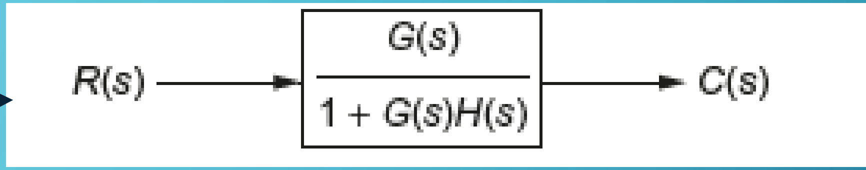
Feedforward transfer function: The ratio of the output *c(s)* to the actuating error signal *e(s)* is called the *feedforward transfer function.*

$$i.e.\ \ Feedforward\ Transfer\ Function\ = \frac{C(s)}{E(s)} = G(s)$$

Transfer Function:

Transfer Function Of a Close-loop System:





$$C(s) = G(s)E(s)$$

$$E(s) = R(s) - B(s)$$

$$B(s) = H(s)C(s)$$

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

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

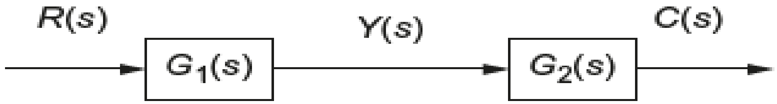
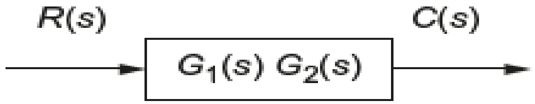
$$C(s)\{1 + G(s)H(s)\} = G(s)R(s)$$

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

Determination Of Transfer Function Using Block Diagram Reduction Techniques:

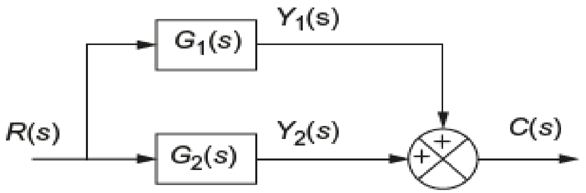
Rules For Block Reduction Technique:

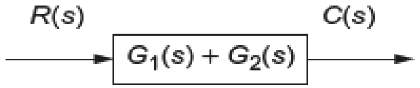
1. Cascading of blocks in series:

	
Proof: The intermediate output $Y(s)$ is given by $Y(s) = G_1(s)R(s)$ The total output $C(s)$ is given by $C(s) = G_2(s)Y(s)$ Using the above two equations, we obtain $C(s) = G_2(s)G_1(s)R(s)$	The output $C(s)$ is given by $C(s) = G_2(s)G_1(s)R(s)$

Rules For Block Reduction Technique:

2. Cascading of Blocks in Parallel:





Proof:

The intermediate outputs $Y_1(s)$ and $Y_2(s)$ are given by

$Y_1(s) = G_1(s)R(s)$

$Y_2(s) = G_2(s)R(s)$

The total output $C(s)$ is given by

$C(s) = Y_1(s) + Y_2(s)$

Using the above equations, we obtain

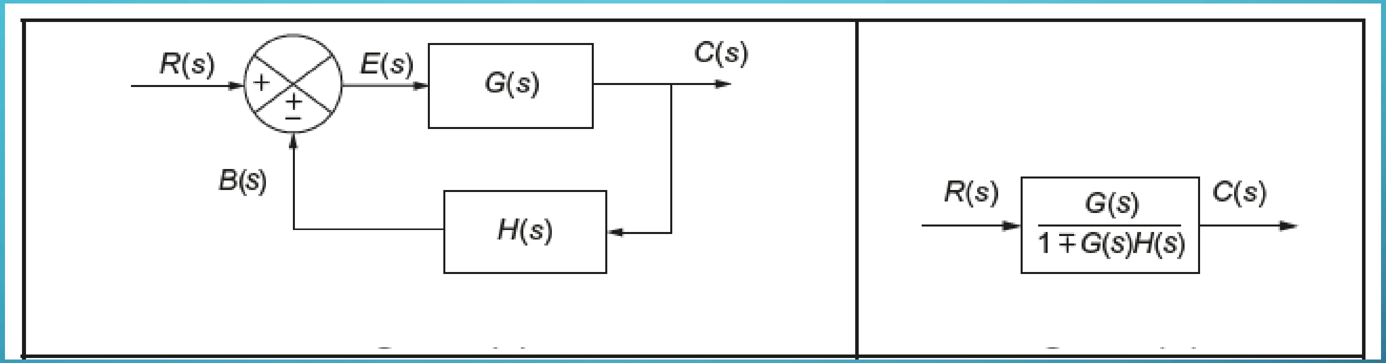
$C(s) = G_2(s)\ R(s) + G_1(s)R(s)$

$C(s) = (G_2(s) + G_1(s))R(s)$

The output $C(s)$ is given by
$C(s) = (G_2(s) + G_1(s))\ R(s)$

Rules For Block Reduction Technique:

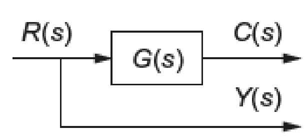
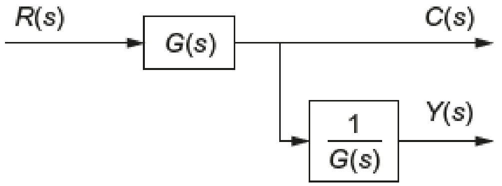
3. Reduction of Feedback Loop:



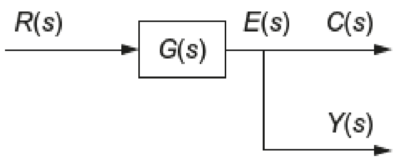
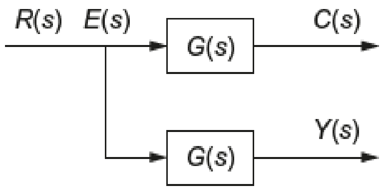
Rules For Block Reduction Technique:

4. Moving The Take Off Point After / Before A Block :

After

	
Proof: The first output $C(s) = R(s)G(s)$ The second output $Y(s) = R(s)$ (3.7)	The first output $C(s) = R(s)G(s)$ The second output $Y(s) = (G(s)R(s))\dfrac{1}{G(s)} = R(s)$ (3.8)

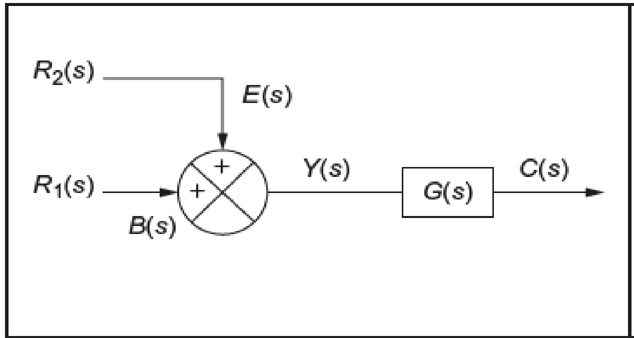
Before

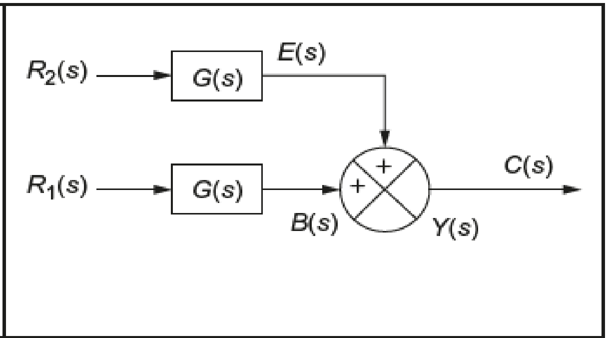
	
Proof: The output at node $E(s) = G(s)R(s)$ The first output $C(s) = E(s) = G(s)\, R(s)$ The second output $Y(s) = E(s) = G(s)\, R(s)$	The output at node $E(s) = R(s)$ The first output $C(s) = G(s)E(s) = G(s)\, R(s)$ The second output $Y(s) = G(s)E(s) = G(s)\, R(s)$

Rules For Block Reduction Technique:

5. Moving The Summing Point After / Before A Block :

After





Proof:

Inputs to summing point are:

$E(s) = R_2(s)$

$B(s) = R_1(s)$

The output of the summing point

$Y(s) = E(s) + B(s)$

$\quad = R_2(s) + R_1(s)$

The output $C(s) = G(s)\ Y(s)$

$\quad = G(s)(R_1(s) + R_2(s))$

Inputs to summing point are:

$E(s) = R_2(s)\ G(s)$

$B(s) = R_1(s)\ G(s)$

The output of the summing point

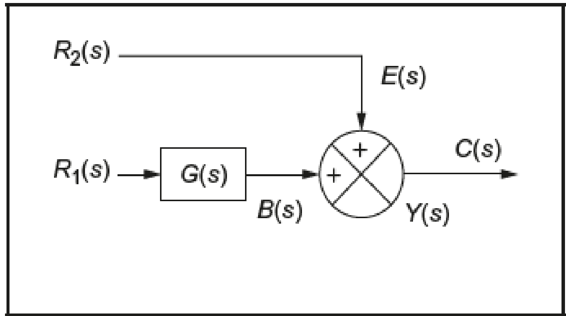
$Y(s) = E(s) + B(s)$

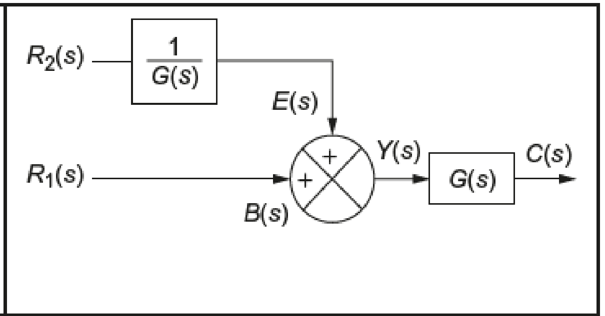
$\quad = (R_2(s) + R_1(s))\ G(s)$

The output $C(s) = Y(s)$

$\quad = G(s)(R_1(s) + R_2(s))$

Before





Proof:

Inputs to summing point are:

$E(s) = R_2(s)$

$B(s) = R_1(s)\ G(s)$

The output of the summing point

$Y(s) = E(s) + B(s)$

$\quad = R_2(s) + R_1(s)\ G(s)$

The output $C(s) = Y(s)$

$\quad = G(s) R_1(s) + R_2(s)$

Inputs to summing point are:

$E(s) = \dfrac{R_2(s)}{G(s)}$

$B(s) = R_1(s)$

The output of the summing point

$Y(s) = E(s) + B(s)$

$\quad = \dfrac{R_2(s)}{G(s)} + R_1(s)$

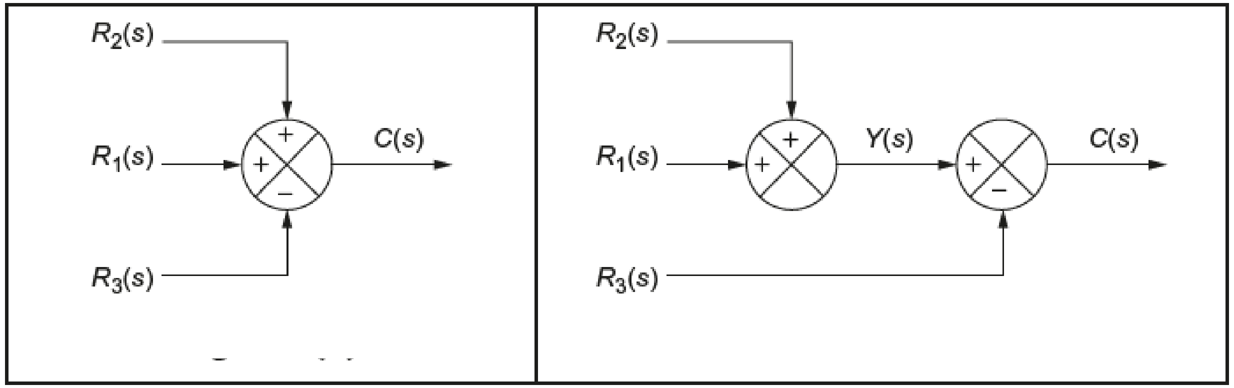
The output $C(s) = Y(s)\ G(s)$

$\quad = G(s)\ R_1(s) + R_2(s)$

Rules For Block Reduction Technique:

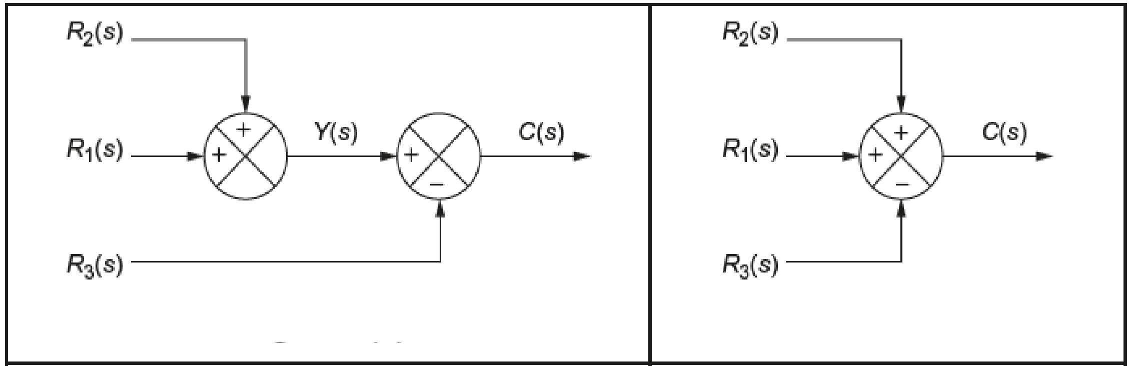
6. Splitting / Joining of Summing Points :

Splitting



Proof: The output of the summing point: $C(s) = R_1(s) + R_2(s) - R_3(s)$ (3.13)	The intermediate output $Y(s) = R_1(s) + R_2(s)$ The output of the summing point: $C(s) = Y(s) - R_3(s) = R_1(s) + R_2(s) - R_3(s)$ (3.14)

Joining

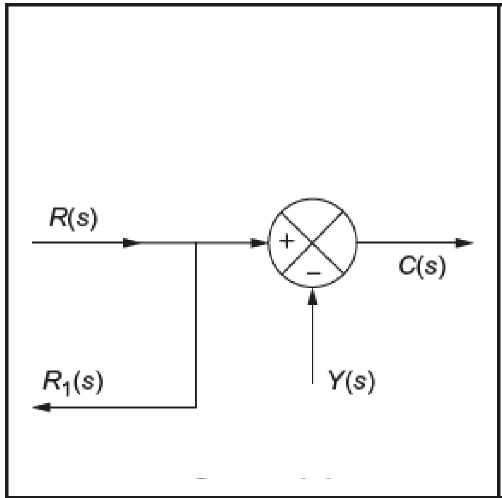


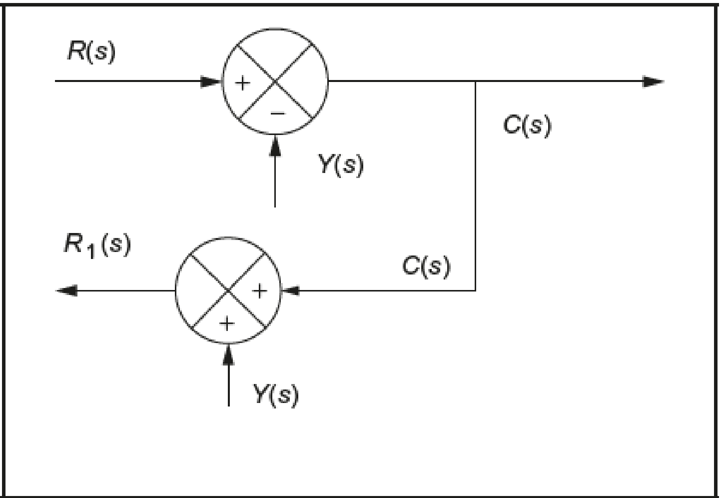
Proof: The intermediate output $Y(s) = R_1(s) + R_2(s)$ The output of the summing point $C(s) = Y(s) - R_3(s)$ $= R_1(s) + R_2(s) - R_3(s)$ (3.14)	The output of the summing point $C(s) = R_1(s) + R_2(s) - R_3(s)$ (3.15)

Rules For Block Reduction Technique:

7. Moving a Take-off Point After / Before a Summing Points :

After





Proof:

The output $C(s) = R(s) - Y(s)$

The output of the take-off point

$$R_1(s) = R(s) \tag{3.16}$$

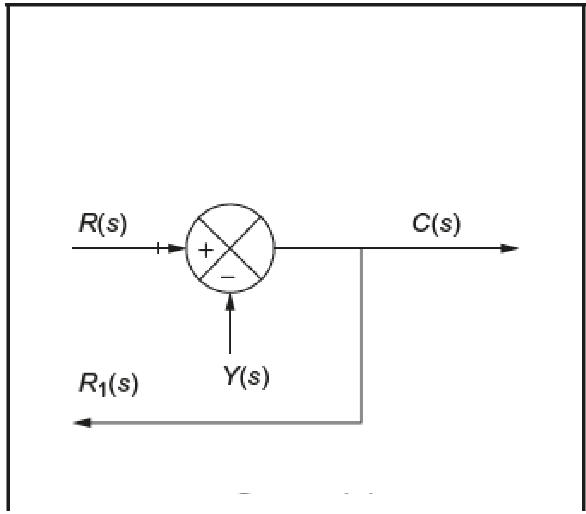
The output $C(s) = R(s) - Y(s)$

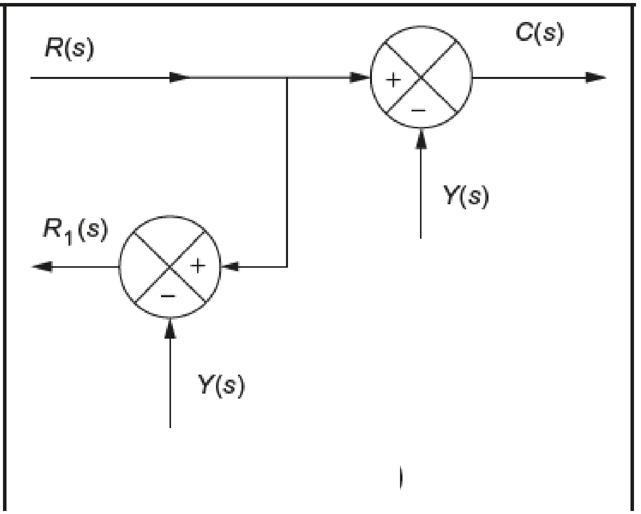
The output of the take-off point

$$R_1(s) = C(s) + Y(s)$$

$$= R(s) - Y(s) + Y(s) = R(s) \tag{3.17}$$

Before





Proof:

The output $C(s) = R(s) - Y(s)$

The output of the take-off point

$$R_1(s) = C(s)$$

$$= R(s) - Y(s) \tag{3.18}$$

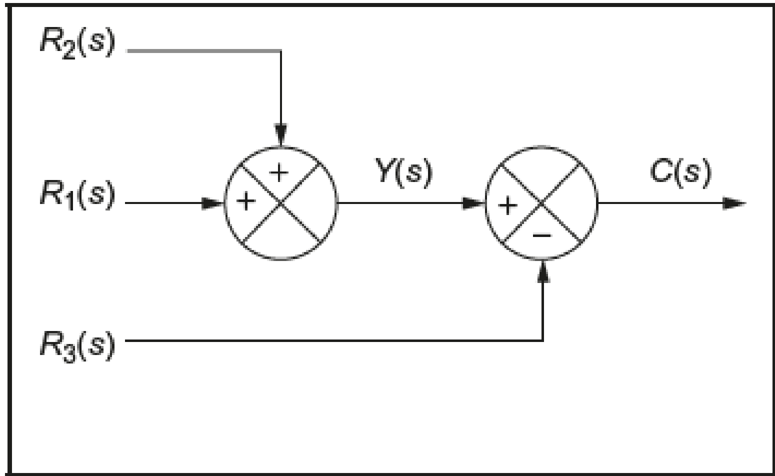
The output $C(s) = R(s) - Y(s)$

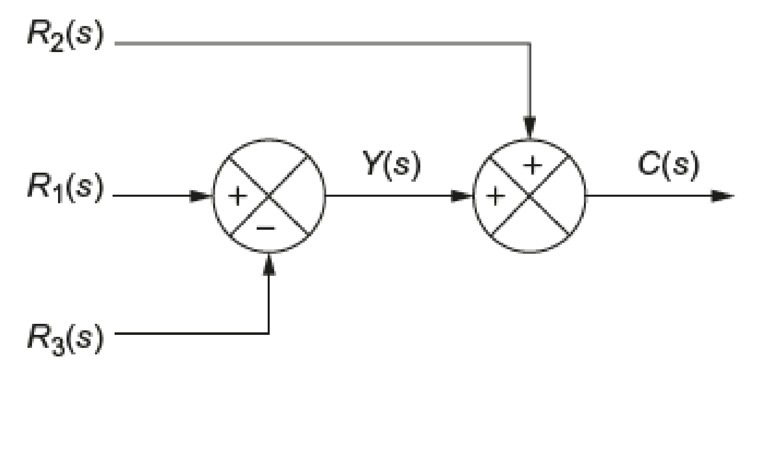
The output of the take-off point

$$R_1(s) = R(s) - Y(s) \tag{3.19}$$

Rules For Block Reduction Technique:

8. Exchanging of Two Summing Points:





Proof:

The intermediate output

$Y(s) = R_1(s) + R_2(s)$

The output of the summing point

$C(s) = Y(s) - R_3(s)$

$= R_1(s) + R_2(s) - R_3(s)$

The intermediate output

$Y(s) = R_1(s) - R_3(s)$

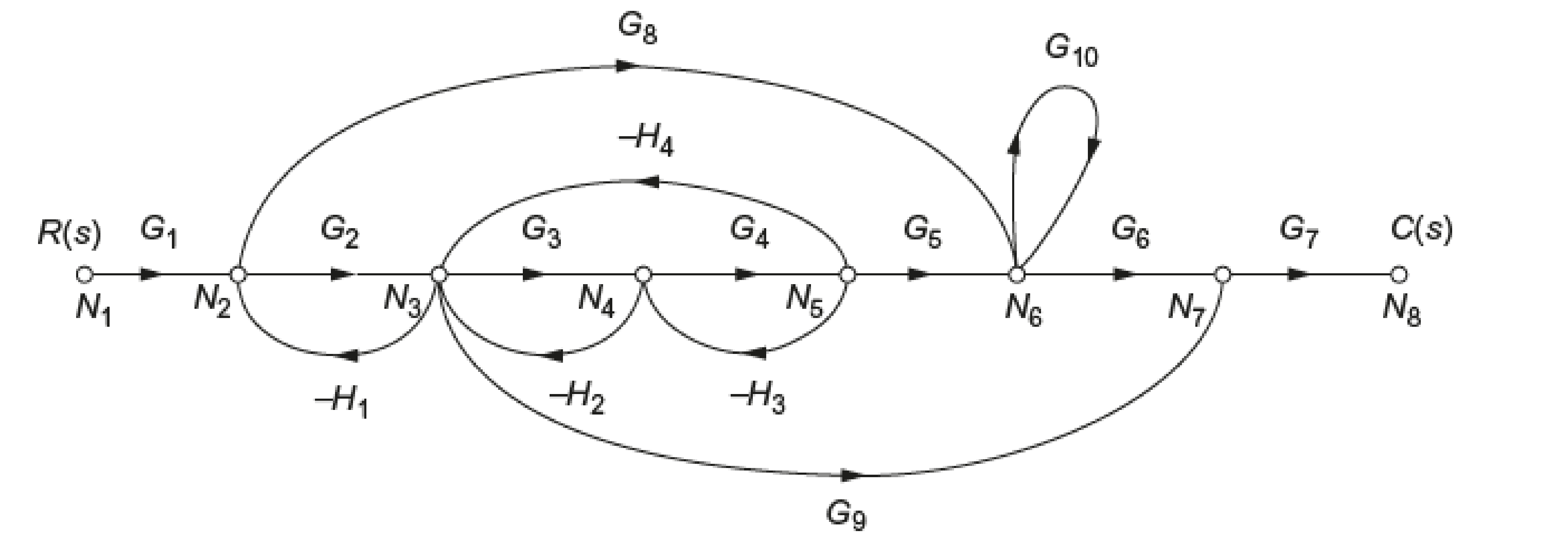
The output of the summing point

$C(s) = Y(s) + R_2(s)$

$= R_1(s) + R_2(s) - R_3(s)$

Signal Flow Graph:

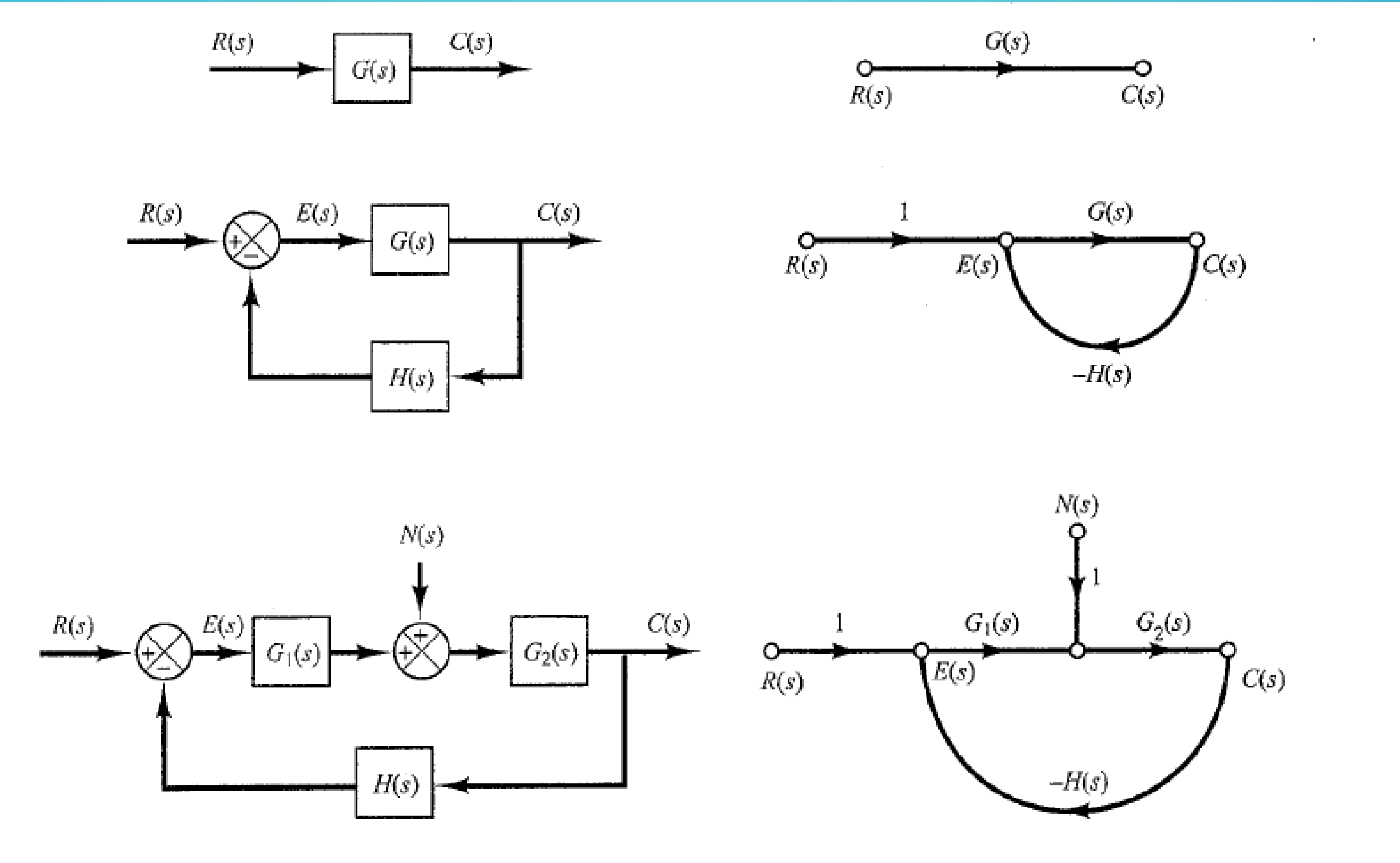
A signal flow graph is a diagram that represents a set of simultaneous linear algebraic equations. When applying the signal flow graph method to analyses of control systems.



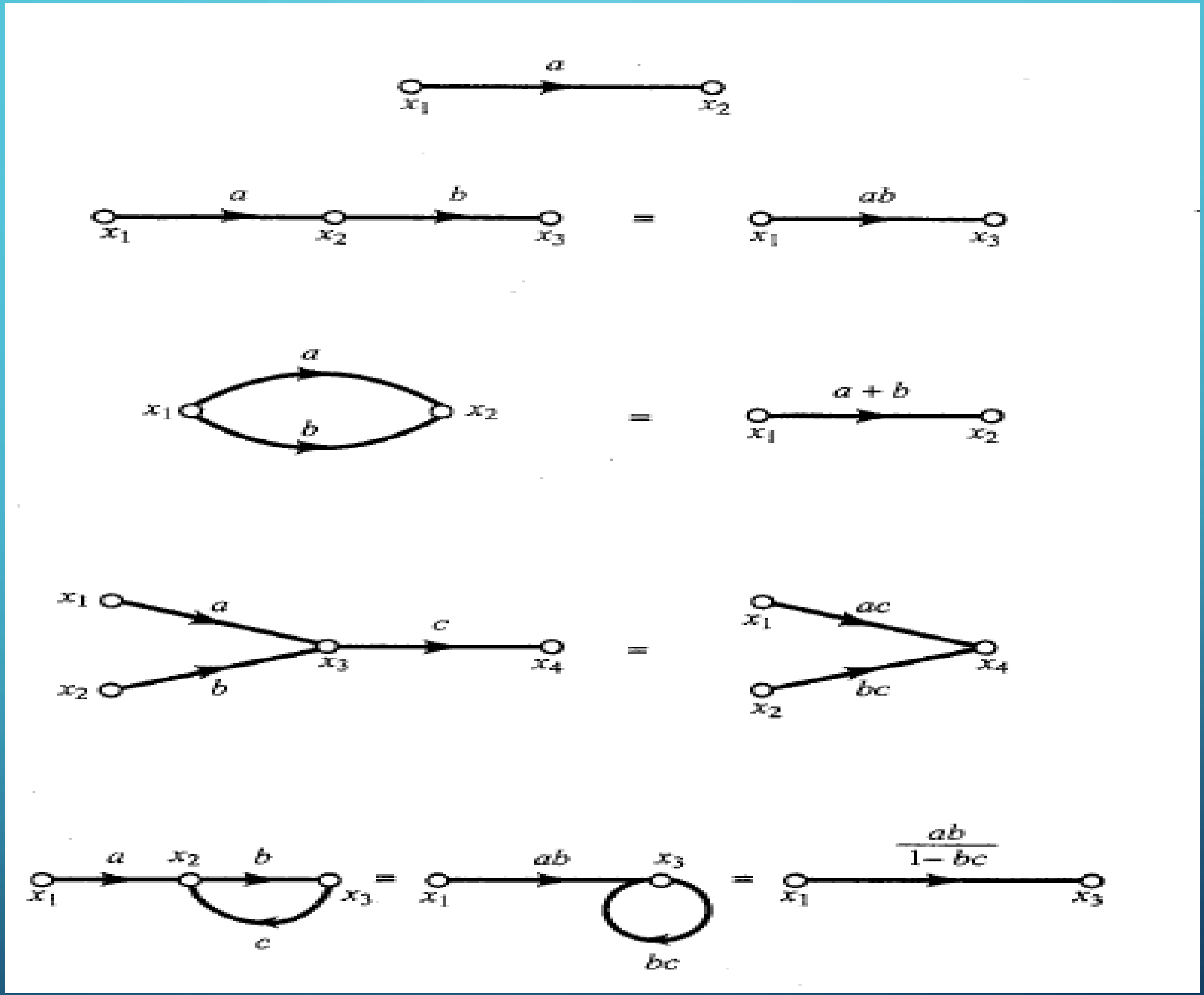
Signal Flow Graph:

- Terminologies used in Signal Flow Graph:
- *Node*- Source / Sink, Input / Output/ Mixed
- *Transmittance*- Real gain or complex gain between two nodes
- *Branch*- line segment joining the two nodes with a specific direction
- *Path* – Forward Path / Closed Path or Feedback Path
- *Loop - A* loop is a closed path
- *Loop gain* - the loop gain is the product of the branch transmittances of a loop
- *Non Touching Loops* - Loops are non touching if they do not possess any common nodes
- *Forward path - A* forward path is a path from an input node (source) to an output node (sink) that does not cross any nodes more than once
- *Forward Path Gain - A* forward path gain is the product of the branch transmittances Of a forward path

Signal Flow Graph:



Signal Flow Graph:



Mason's Gain Formula:

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

P_k= Path gain or transmittance of kth forward path

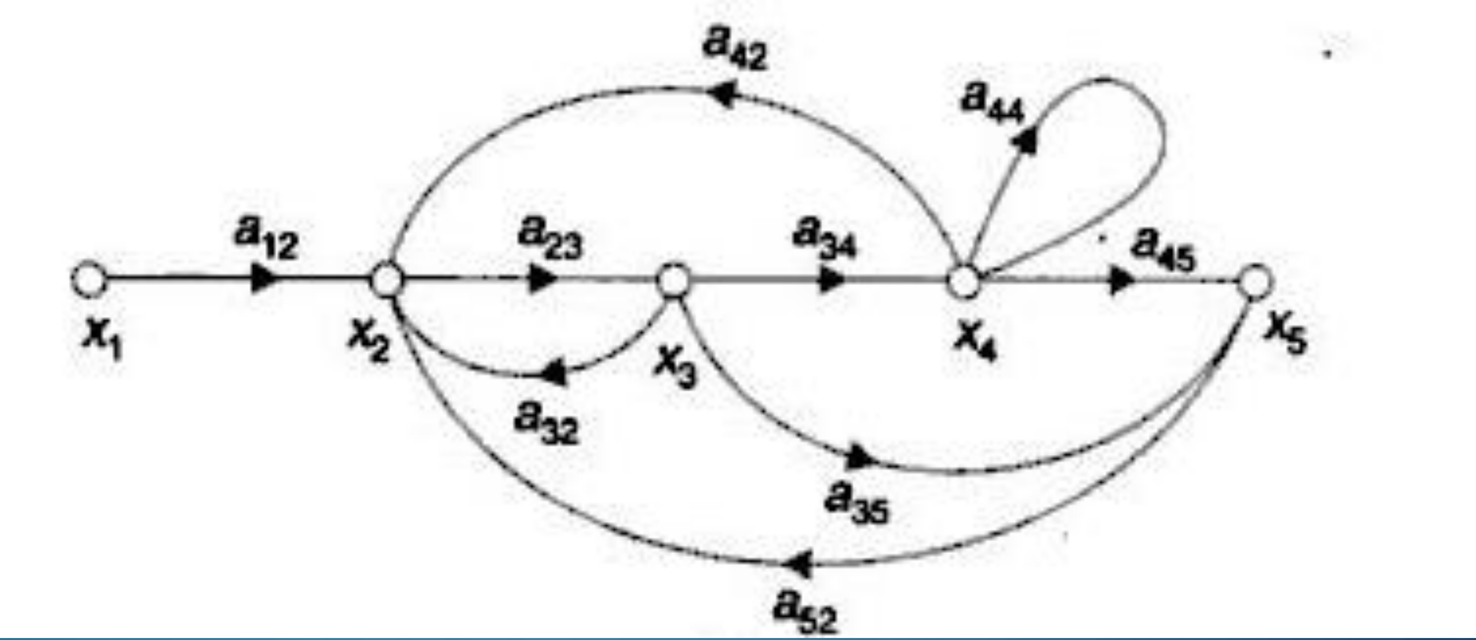
Δ = Determinant of graph

= 1 - (sum of all individual loop gains) + (sum of gain products of all possible combinations of two non touching loops) - (sum of gain products of all possible combinations of three non touching Loops) + . . .

Δ_k= Cofactor of the kth forward path determinant of the graph with the Loops touching the kth forward path removed, that is, the cofactor Δ_k is obtained from Δ by removing the loops that touch path P_k

Signal Flow Graph / Mason's Gain Formula:

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



Control System Components:

Devices which are used to convert the process variable in one form to another form (Transducer)

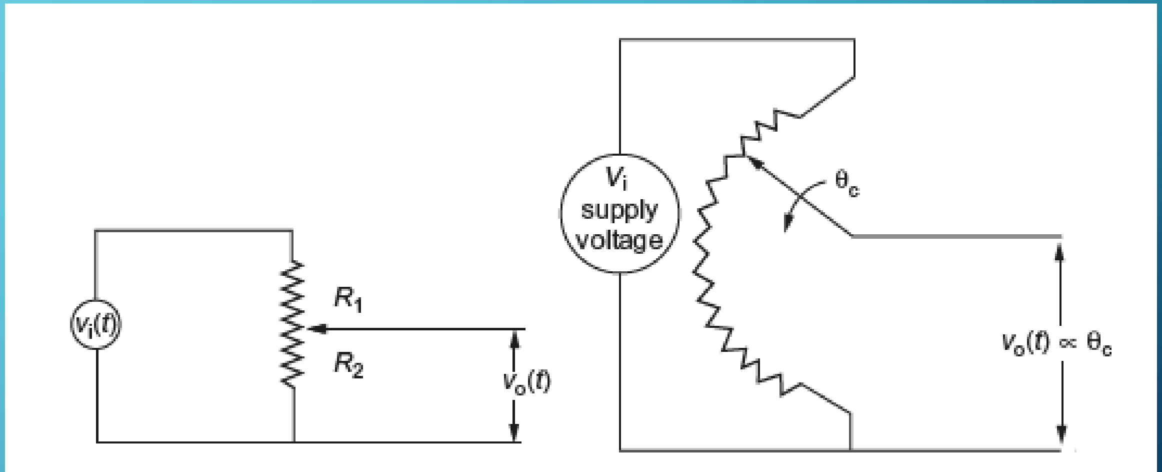
In control System following devices are used to serve this purpose:-

- Potentiometers
- Servomotors
- Synchros
- Stepper Motors
- Magnetic Amplifiers
- Tachogenerators
- Gyroscope
- Differential Amplifiers

Potentiometers:

A potentiometer is a variable resistor that is used to convert a linear or angular displacement into voltage.

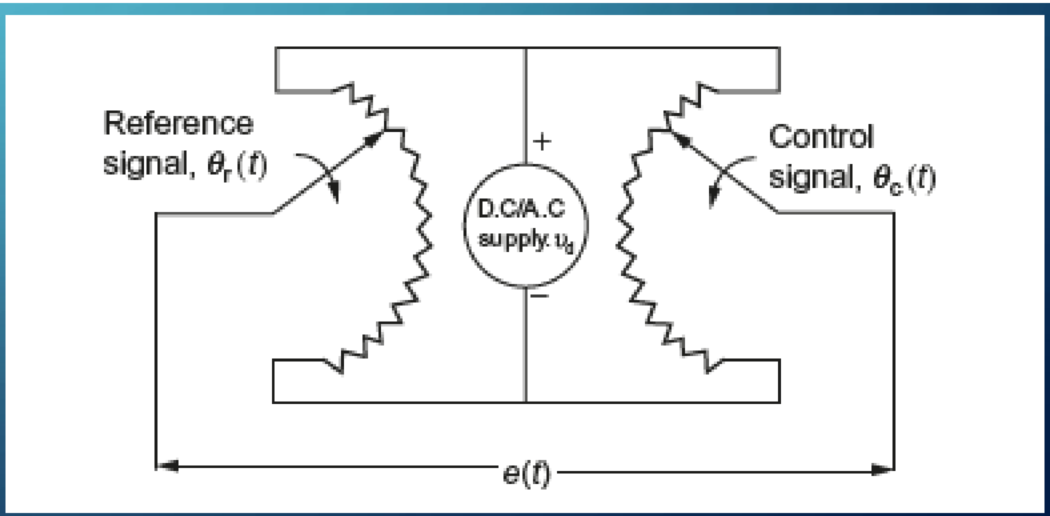
Used to measure the mechanical displacement



$$v_o(t) = \frac{R_2}{R_1 + R_2} v_i(t)$$

$$e(t) = K\left[\theta_r(t) - \theta_c(t)\right]$$

$$K = \frac{v_i}{n \times 2\pi} \text{ volts/radian}$$



Synchros:

A synchro is an electromagnetic rotary transducer that converts an angular shaft position into an electric signal (AC voltage) or vice versa

Synchros are widely used as error detectors and encoders

The elements in the synchros are synchro transmitter and synchro control transformer. Interconnection of synchro transmitter and synchro control transformer forms the synchro pair.

Synchros:

Synchro Control Transformer:

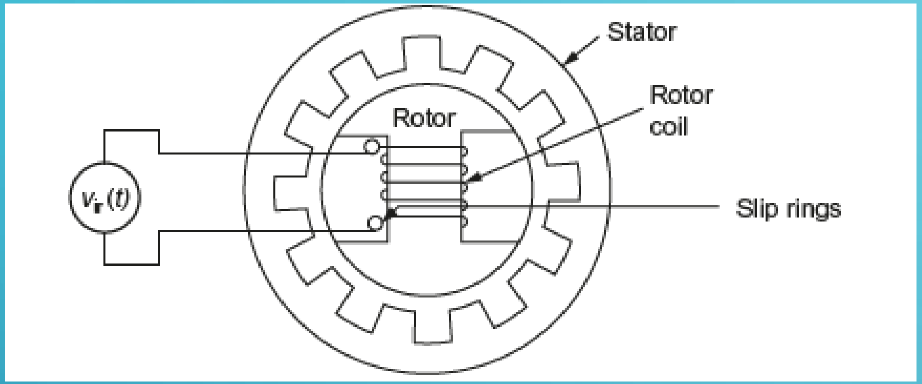
The synchro control transformer is similar to the synchro transmitter with the exception in the shape of the rotor. The shape of the rotor in the synchro control transformer is made cylindrical to have uniform air gap. The generated EMF of the synchro transmitter is applied as an input to the stator coils of the synchro control transformer. The load whose position is to be maintained at a desired value is connected with the rotor shaft.

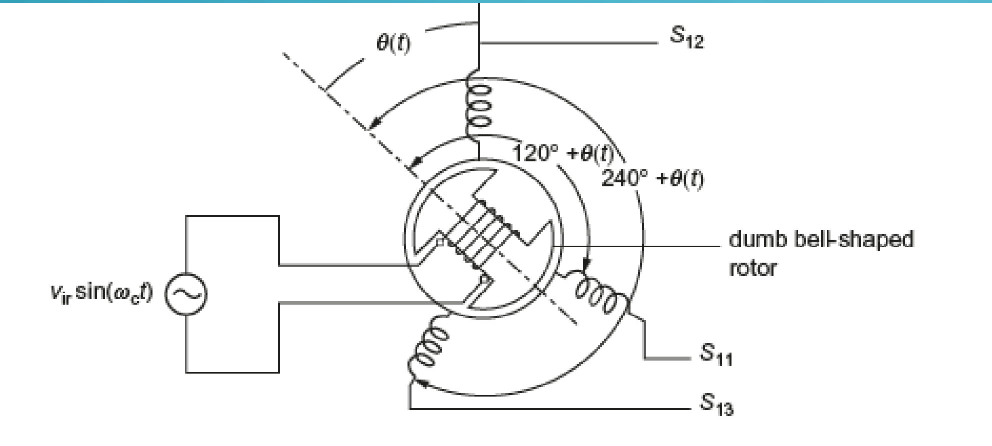
Synchro Transmitter:

Synchro transmitter is the basic element of the synchro system or synchro pair. The construction of the synchro transmitter and three phase alternator are very similar. It has a stationary Stator and rotor. The stationary stator is made up of laminated silicon steel and is slotted on The inner periphery to accommodate a balanced, concentric, identical three-phase star connected Winding with their axis 120o apart. The rotor is made up of dumbbell construction Wound with a concentric coil. An AC voltage is applied to the rotor winding through slip Rings. The synchro transmitter resembles a single-phase transformer in which the rotor coil Acts as the primary and the stator coils form the three secondary coils.

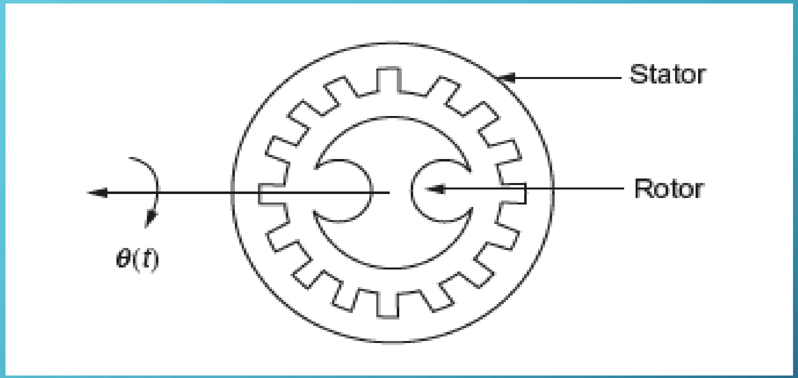
Synchro:

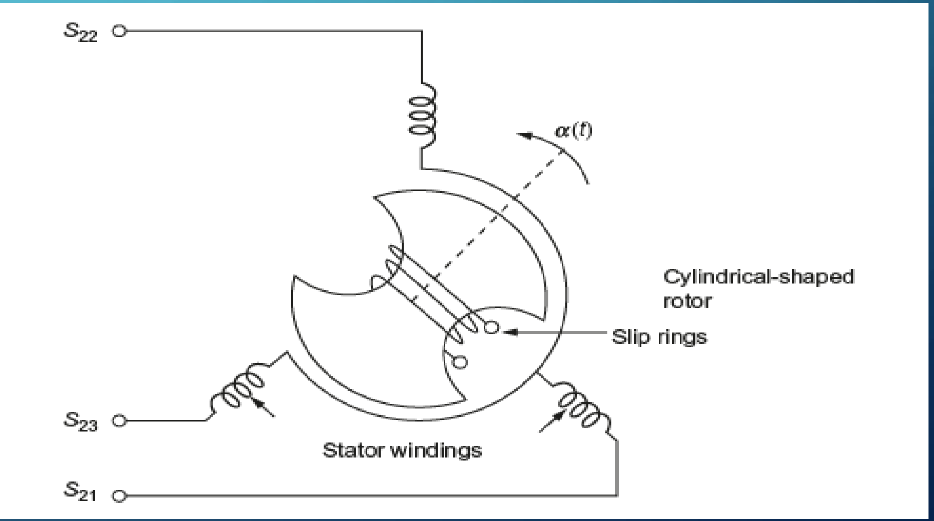
Synchro Transmitter





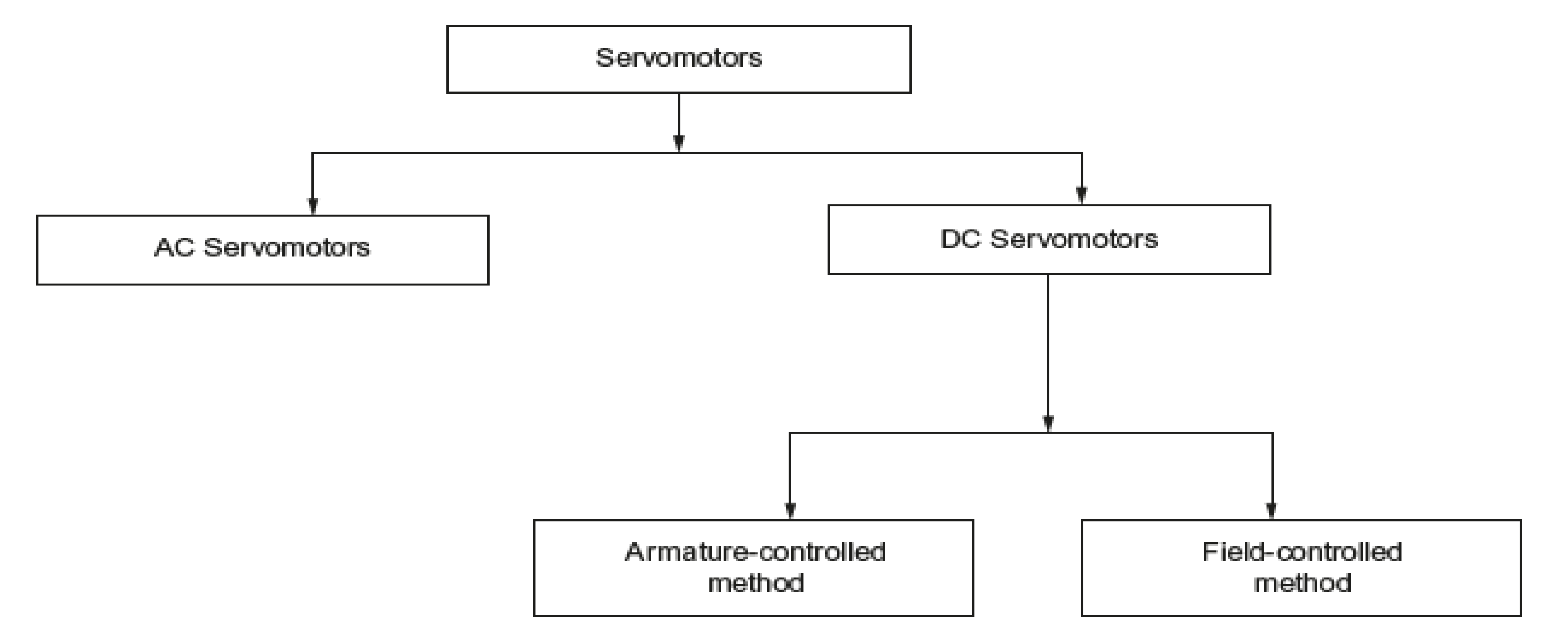
Synchro Control Transformer





Servo Motors:

The servomotors are used to convert an electrical signal (control voltage) applied to them into an angular displacement of the shaft. They are normally coupled to the controlled device by a gear train or some mechanical linkage. The main objective of the servomotor system is to control the position of an object and hence the system is known as servomechanism.



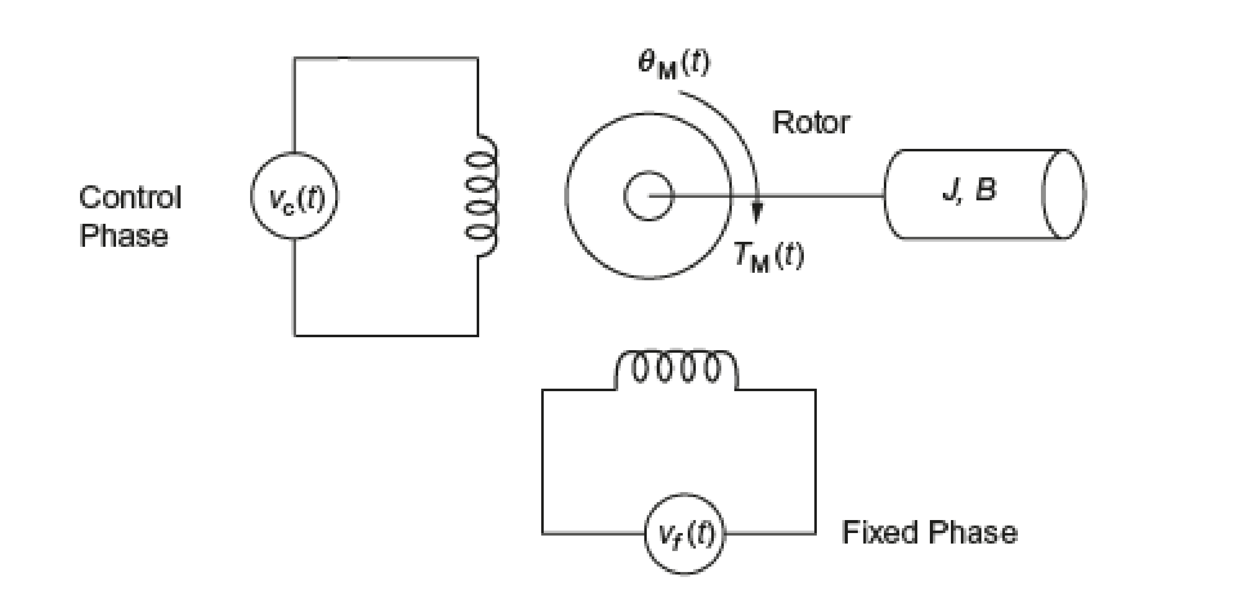
Servo Motors:

AC Servomotor:

The AC servomotor is a two-phase induction motor with some special design features. It comprises of a stator winding and a rotor.

Rotor have several forms:

- Squirrel cage
- Drag cup
- Solid iron



Servo Motors:

AC Servomotor:

The stator consists of two pole-pairs mounted on the inner periphery of the stator, such that their axes are at an angle of 90° in space. The rotor bars are placed on the slots and short circuited at both ends by end rings. The diameter of the rotor is kept small in order to reduce inertia and to obtain good accelerating characteristics. Each pole-pair carries a winding. The exciting current in the windings should have a phase displacement of 90° . the voltages applied to these windings are not balanced.

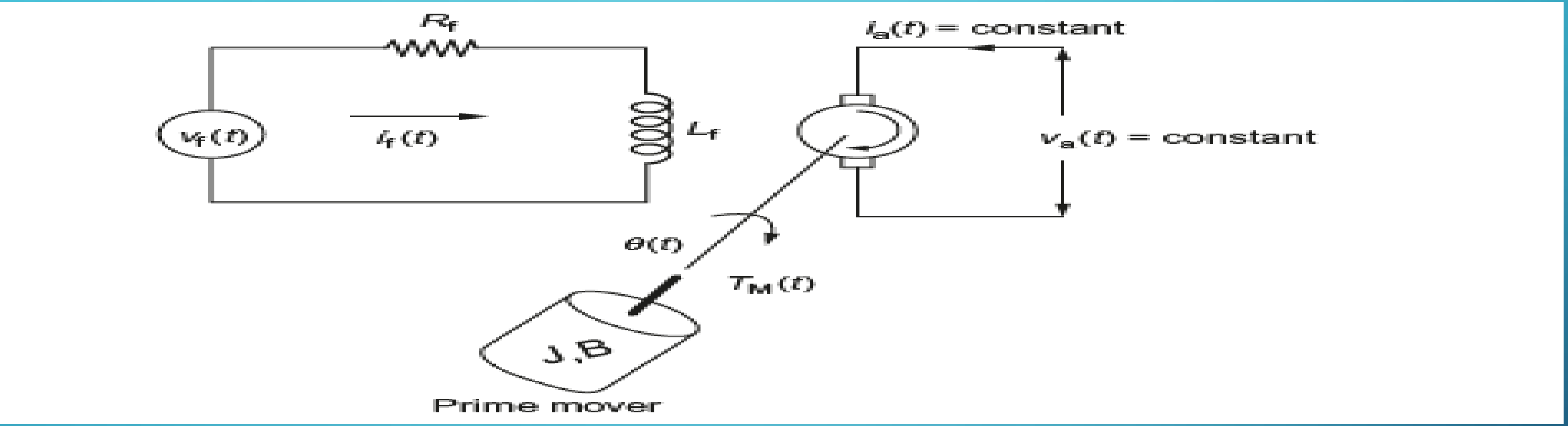
Under normal operating conditions, a fixed voltage form a constant voltage source is applied to one phase, which is called the reference phase. The other phase called the control phase is energized by a voltage of variable magnitude and polarity, which is at 90° out of phase with respect to the fixed phase. The control phase is usually applied from a servo amplifier. The direction of rotation reverses if the phase sequence is reversed.

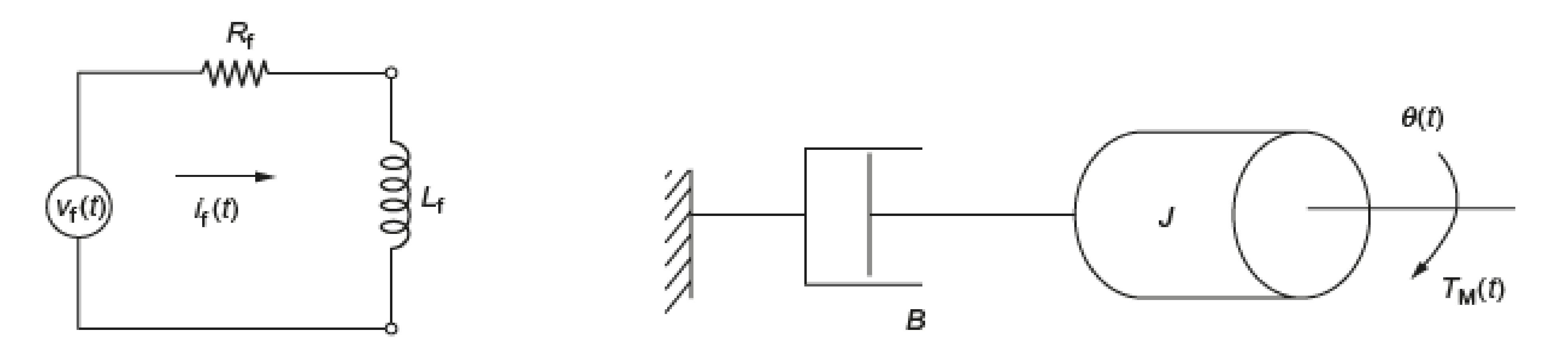
DC Servo Motors:

DC servomotor is used in applications such as machine tools and robotics, where there is an appreciable amount of shaft power is required.

Field-controlled DC Motor: In the case of field-controlled DC motor, the armature voltage and current are kept constant. The torque developed and hence the speed of the motor will be directly proportional to the field flux, generated by the field current flowing in the field winding. When the error signal is zero, there will be no field current and hence no torque is developed. The direction of rotation of the motor depends on the polarity of the field and hence on the nature of the error signal. If the field polarity is reserved, the motor will develop torque in the opposite direction

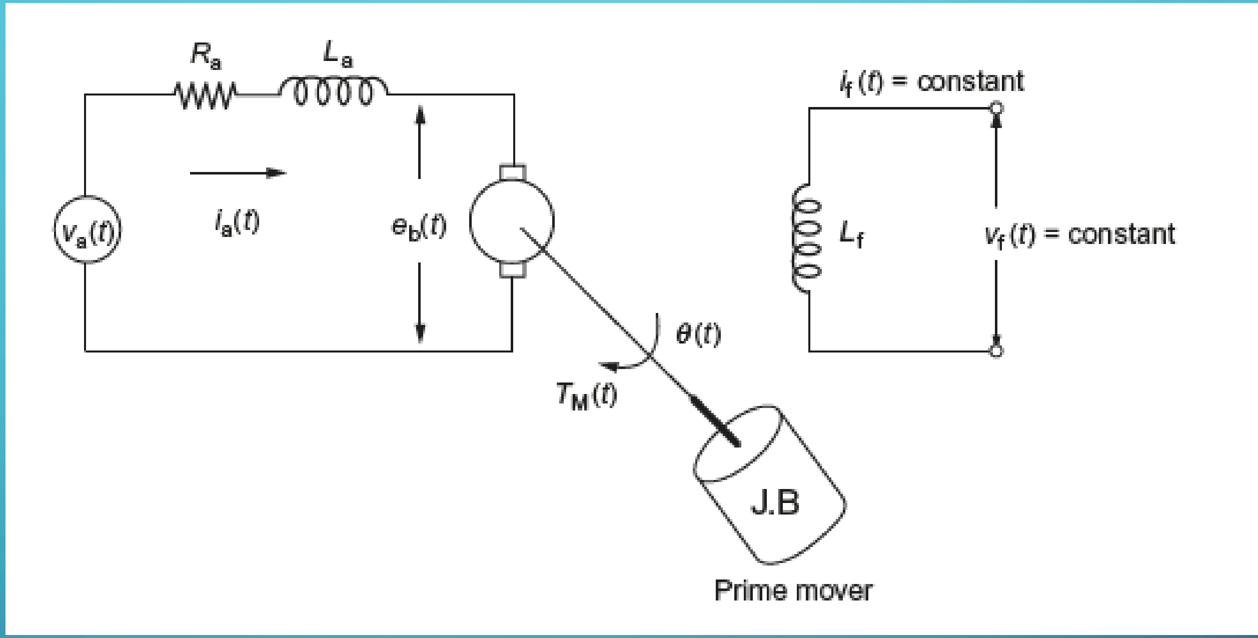
DC Servo Motors:

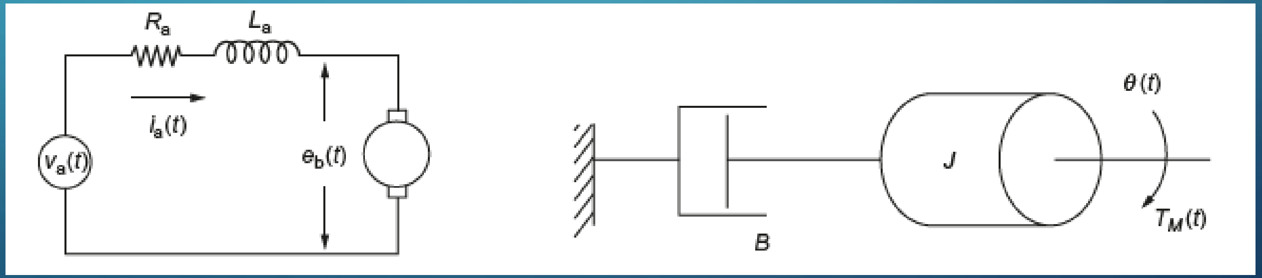




DC Servo Motors:

Armature Controlled DC Servomotor:





DC Servo Motors:

Advantages of DC servomotor

- It has a higher power output than a 50hz motor of the same size and weight
- Linear characteristics can easily be achieved.
- Speed control can be easily achieved (from zero speed to full speed).
- Quick acceleration of loads is possible due to high torque to inertia ratio.
- Time constants in the transfer function have low values.
- It involves less acoustic noise.
- Encoder sets resolution and accuracy.
- It has higher efficiency since it can reach up to 90% of light loads.
- It is free from vibration and resonance.

Disadvantages of dc servomotor

- It involves higher cost due to its complex architecture (encoders, servo drives).
- It requires larger motor or gear box.
- There is necessity of safety circuits.
- It needs to be tuned so as to get steady feedback loop.
- Motor generates peak power only at higher speeds and requires frequent gearing.
- Inefficient cooling mechanism. If motors are ventilated, they get easily contaminated

Tacho Generators: Mechanical Energy To Electrical Energy

Tacho generator is an electromechanical device that converts mechanical energy (shaft speed) to a proportional electrical energy (voltage). It is an ordinary generator that generates a voltage proportional to the magnitude of the angular velocity of the shaft.

It is used as speed indicator, velocity feedback device and signal integrator.

Tacho generators are classified as AC tacho generator and DC tacho generator.

TachoGenerators: Mechanical Energy To Electrical Energy

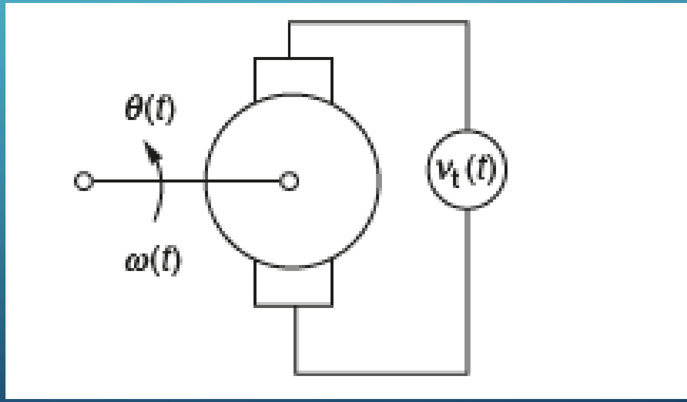
DC Tacho Generator:

A DC tachogenerator is an ordinary DC generator with linear characteristics.

The parts of the DC tachogenerator are stator with a permanent magnet to produce necessary magnetic field, rotating armature circuit connected To the commutator and brush assembly.

The output voltage is measured across the Pair of brushes that are connected with commutators. If required, modulated output of DC Tachogenerator can be used in controlling the AC system components.

The output voltage of the tachogenerator is proportional to the angular velocity of the Shaft. The polarity of the output voltage depends on the direction of rotation of the shaft.



Tachogeneratos:

Advantages of DC Tachogenerators

- It is used along with high pass output filters to reduce the servo velocity lags.
- It generates very high-voltage gradients in small sizes.
- There is no presence of residual voltage at zero speed.

Disadvantages of DC Tachogenerators

- Inherent ripples in the output waveform
- Poor commutation
- Requirement of additional filter to avoid the interference

TachoGenerators: Mechanical Energy To Electrical Energy

AC Tacho Generator:

The AC tachogenerator and a two-phase induction motor resemble each other.

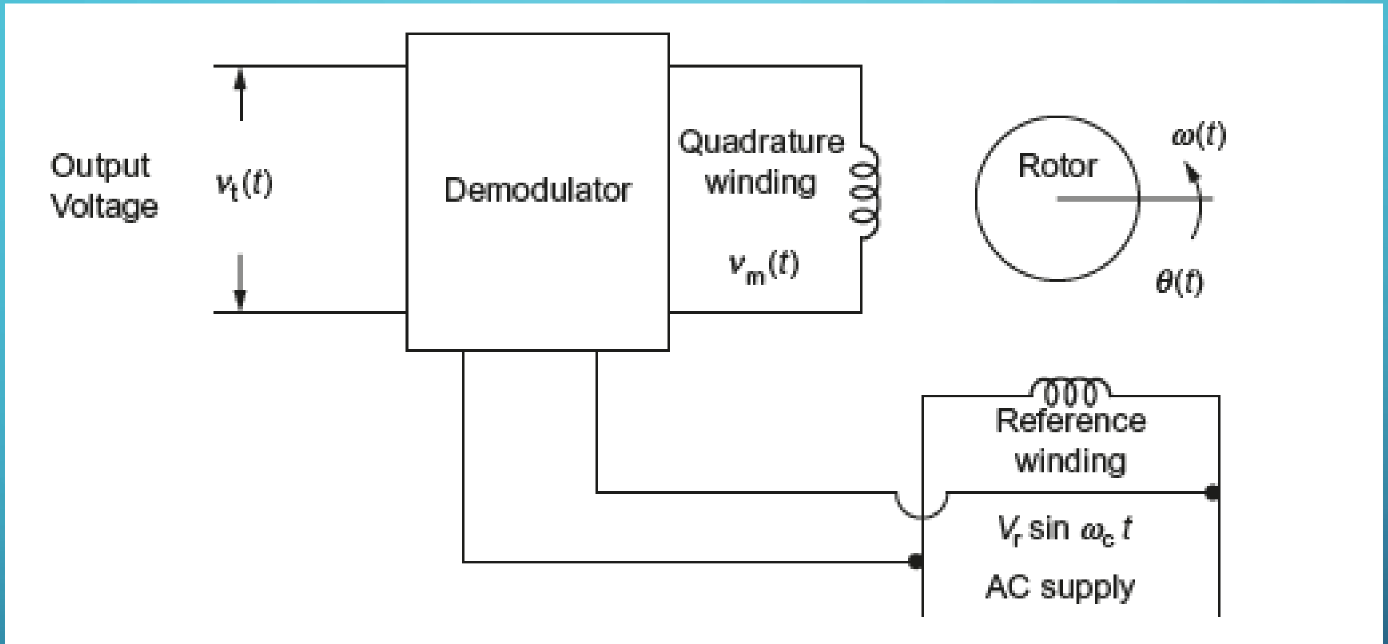
The parts of the AC tachogenerator are two-stator windings (reference and quadrature windings) with the angle between their axes as 90° are fixed on the inner periphery of stator arranged in space quadrature and the squirrel cage rotor.

Stator windings are referred to as reference winding and output winding. The reference winding is excited by a sinusoidal voltage with frequency, When the rotor rotates, a voltage will be induced in the quadrature winding.

An AC tachogenerator Along with a phase-sensitive demodulator circuit can be used in control system to convert an AC output to a DC output.

TachoGenerators: Mechanical Energy To Electrical Energy

AC Tacho Generator:



Stepper Motor:

A Special type of synchronous motor designed to rotate through a specific angle for each electrical pulse applied is known as stepper motor.

The specific angle through which the stepper motor rotates is called step.

Stepper motor is used along with electronic switching devices whose function is to switch the control windings of stepper motor according to the command received.

The stepper motor has gained importance in recent years because of the ease with which it can be interfaced with digital circuits.

The stepper motor completes a full rotation by sequencing through a series of discrete rotational steps (stepwise rotation).

Thus, continuous rotation is achieved by a train of input pulses, each of which causes an advance of one step.

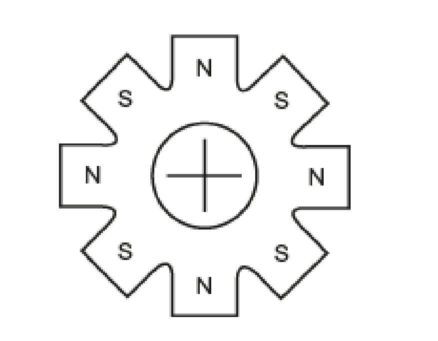
The stepper motor can be variable reluctance, permanent magnet or hybrid stepper motor depending on the type of rotor.

The stepper motor can also be classified into two-phase, three-phase or four-phase stepper motor depending on the number of windings on the stator.

Stepper Motor:

Permanent Magnet Stepper Motor:

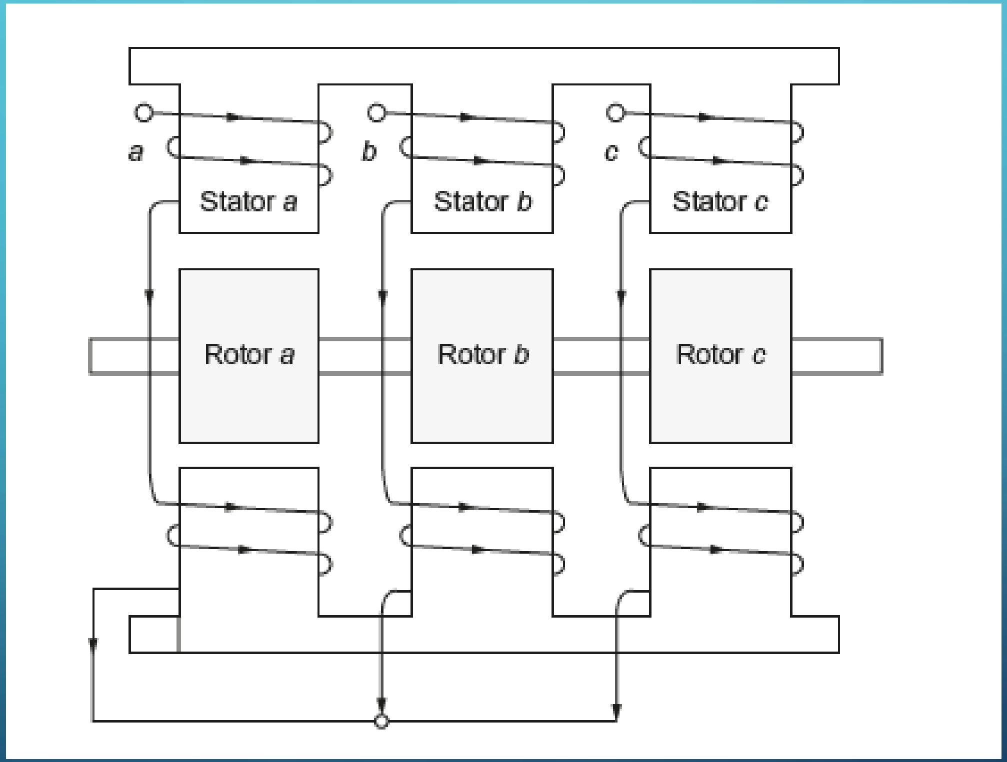
In this type of stepper motor, the stator has salient poles that carry control windings. A phase Is created when the two control windings are connected in series. The rotor of this type of stepper motor is made in the form of a spider cast integral permanent magnet or assembled Permanent magnets.



Stepper Motor:

Reluctance Type Stepper Motor:

In this type of stepper motor, it has a single or several stacks of stator and rotor. The stator has a common frame, whereas the rotor has a common shaft. The stator and rotor of this type of stepper motor has toothed structure. The longitudinal cross sectional view of three-stack Variable reluctance stepper motor is



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