Introduction to Digital Control

- Control systems are an integral part of modern society. Control systems exist in many systems of engineering, sciences, and in human body.

- *Control* means to regulate, direct, command, or govern and A *system* is a collection, set, or arrangement of elements (subsystems).

- A *control system* is an arrangement of physical components connected or related in such a manner as to command, regulate, direct, or govern itself or another system.

- Examples of control systems:
  - The rocket fires, and the space shuttle lifts off to earth orbit.
  - Our eyes follow a moving object to keep it in view; our hands grasp the object and place it properly at a fixed location.
  - Models showing automatic control of student performance (input =study time and output = grade).

Control System Definition

- 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*.

- Control systems can have more than one input or output.

- An electric switch is a man-made control system controlling the electricity-flow (*Man-made control systems*).

- Pointing at an object with a finger requires a biological control system (eyes, the arm, hand, finger and the brain of a person). (*Natural, including biological-control systems*)

- The control system consisting of a person driving an automobile (both *man-made and biological.)*

Examples of Control Systems

- ***Examples 1***

a) Residential heating and air-conditioning systems controlled by a thermostat (temperature sensor).
b) The cruise (speed) control of an automobile.
c) Automatic hot water heater.
d) Control system which automatically turns on a room lamp at dusk, and turns it off in daylight.

- ***Example 2***

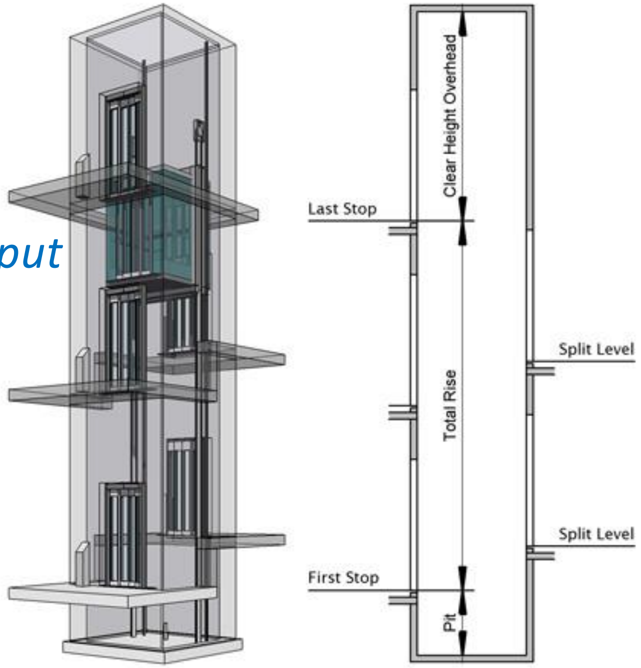
When the fourth-floor button is pressed on the first floor, the elevator rises to the fourth floor with a speed and floor-leveling accuracy designed for passenger comfort.
Input : The push of the fourth-floor button.
Output : the elevator rises to the fourth floor.

If the *transient response* is too fast, passenger comfort is sacrificed; if too slow, passenger patience is sacrificed.

The *steady-state error* is an important performance since passenger safety and convenience would be sacrificed if the elevator did not properly level.

Input

output



Advantages of Control Systems

We build control systems for four primary reasons:

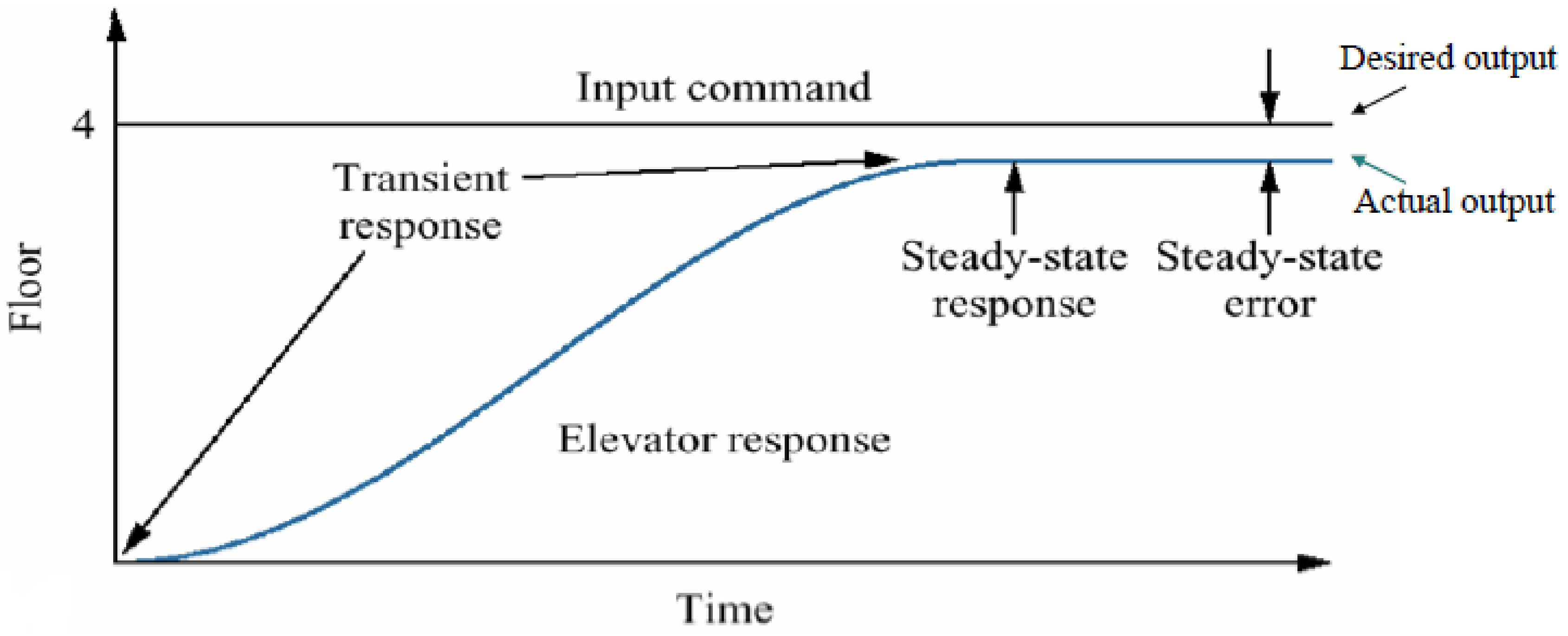
1. Power amplification → Low power input; high power output (move the antenna)
2. Remote control → Remote controlled robots (dangerous locations)
3. Convenience of input form → Temperature control system (desired thermal output)
4. Compensation for disturbances → Antenna system interrupted by wind forces or noise

Response Characteristics

- Two major measures of performance are apparent:
  - The transient response — The short period of time immediately after the system is turned on
  - The steady-state error — the difference between the actual output and the desired output as time tends to infinity

- ***Example***

Elevator Input-Output:



Control System Configurations

- There are two control system configurations: *open-loop control system* and *closed-loop control system*.

1.Block: set of elements that can be grouped together, with overall characteristics described by an input/output relationship.

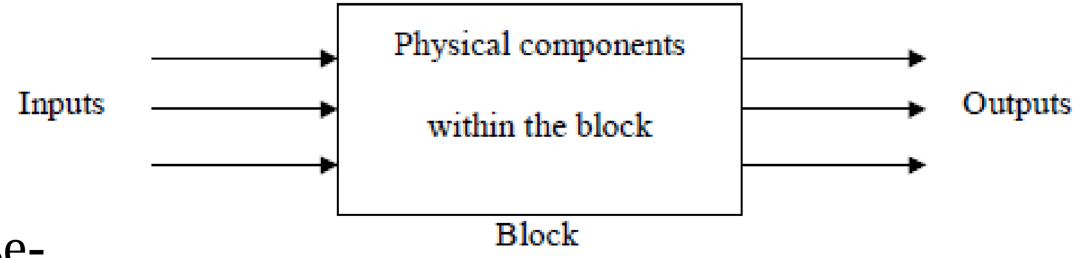


Fig.1 Block diagram

2. Block diagram: a simplified pictorial representation of the cause-and-effect relationship between the input(s) and output(s) of a physical system. The input and output characteristics of entire groups of elements within the block can be described by an appropriate mathematical expressions (Fig.2)

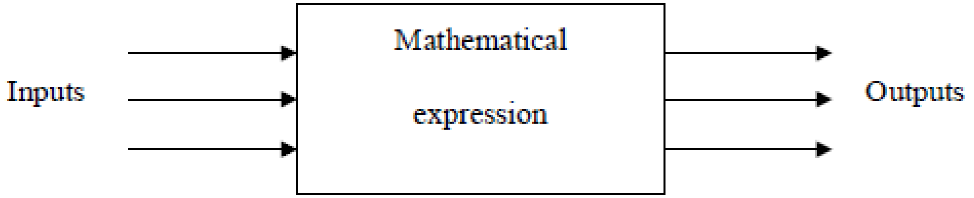


Fig.2 Block representation

3. Transfer function: property of the system elements only and is not dependent on the excitation and initial conditions. It is used to represent a mathematical model of each block in the block diagram representation. The transfer function of a system (or a block) is defined as the ratio of output to input.

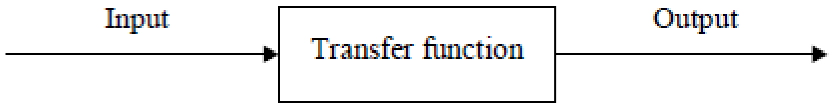


Fig.3 Transfer function

$$\text{Transfer function} = \frac{\text{Output}}{\text{Input}}$$

System Configurations: Open Loop Systems

- Open-loop control systems represent the simplest form of controlling devices.

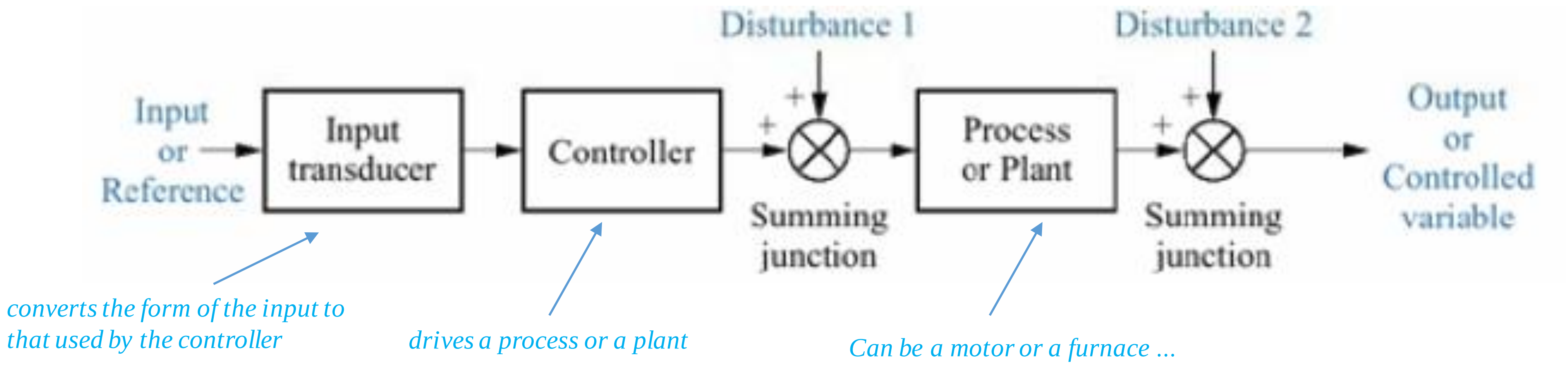


Fig General block diagram of open-loop control system

- ***Example***

plant → a furnace or air conditioning system

Controller → a heating system (with fuel valves) and the electrical system (operates the valves).

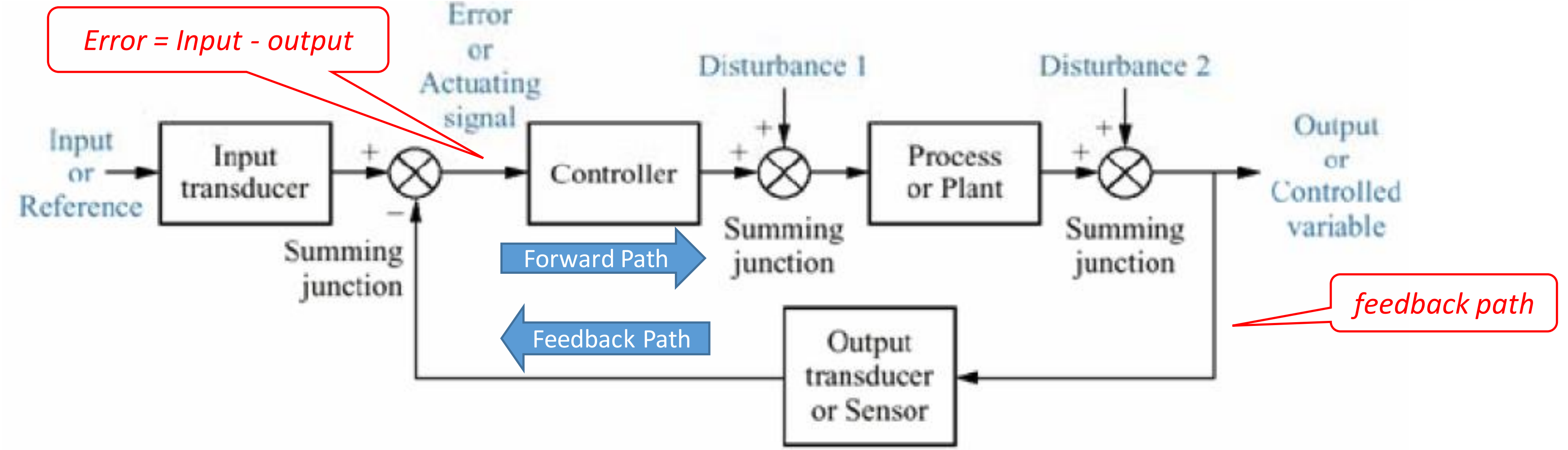
Open loop systems cannot compensate for any disturbances that add to:

a) The controller's driving signal (disturbance 1 in Figure);
b) The output (disturbance 2 in Figure).

Example: Toasters are open-loop systems,

System Configurations: Closed Loop Systems (Feedback Control)

- Closed-loop control systems derive their valuable accurate reproduction of the input from feedback comparison.



- *Output transducer (Sensor)* measures the output response and converts it into the form used by the controller.
- *Example:* if the controller uses electrical signals to operate the valves of a temperature control system, we need to convert the input position (*by a potentiometer*) and the output temperature (*by thermistor*) to electrical signals.
- *Characteristics*:

  1. Can compensate disturbances, noise and changes in the environment (greater accuracy than open-loop).
  2. Transient response and steady-state error can be controlled more conveniently and with greater flexibility.
  3. More complex and expensive than open-loop systems (A closed-loop toaster oven has to measure both color (through light reflectivity) and humidity.

Analysis and Design Objectives

Analysis ➡ The process by which a system's performance is determined.

we evaluate its transient response and steady-state error to determine if they meet the desired specifications

Design ➡ The process by which a system's performance is created or changed.

we change parameters or add additional components to meet the system's transient response and steady-state error specifications

Three major objectives:

1. Producing the desired transient response.
2. Reducing steady-state error.
3. Achieving stability.

other important considerations must be taken into account: hardware (motor size, sensor), Finances, *robust* design (system's parameters changes over time)

Examples: Elevator: A slow transient response makes passengers impatient;
an excessively rapid response makes them uncomfortable.
Must be level enough with the desired floor for passengers to exit.

Natural force must be zero or oscillate; otherwise elevator may crash through the floor or exit through the ceiling.

Total response of a system = *Natural response* + *Forced response*

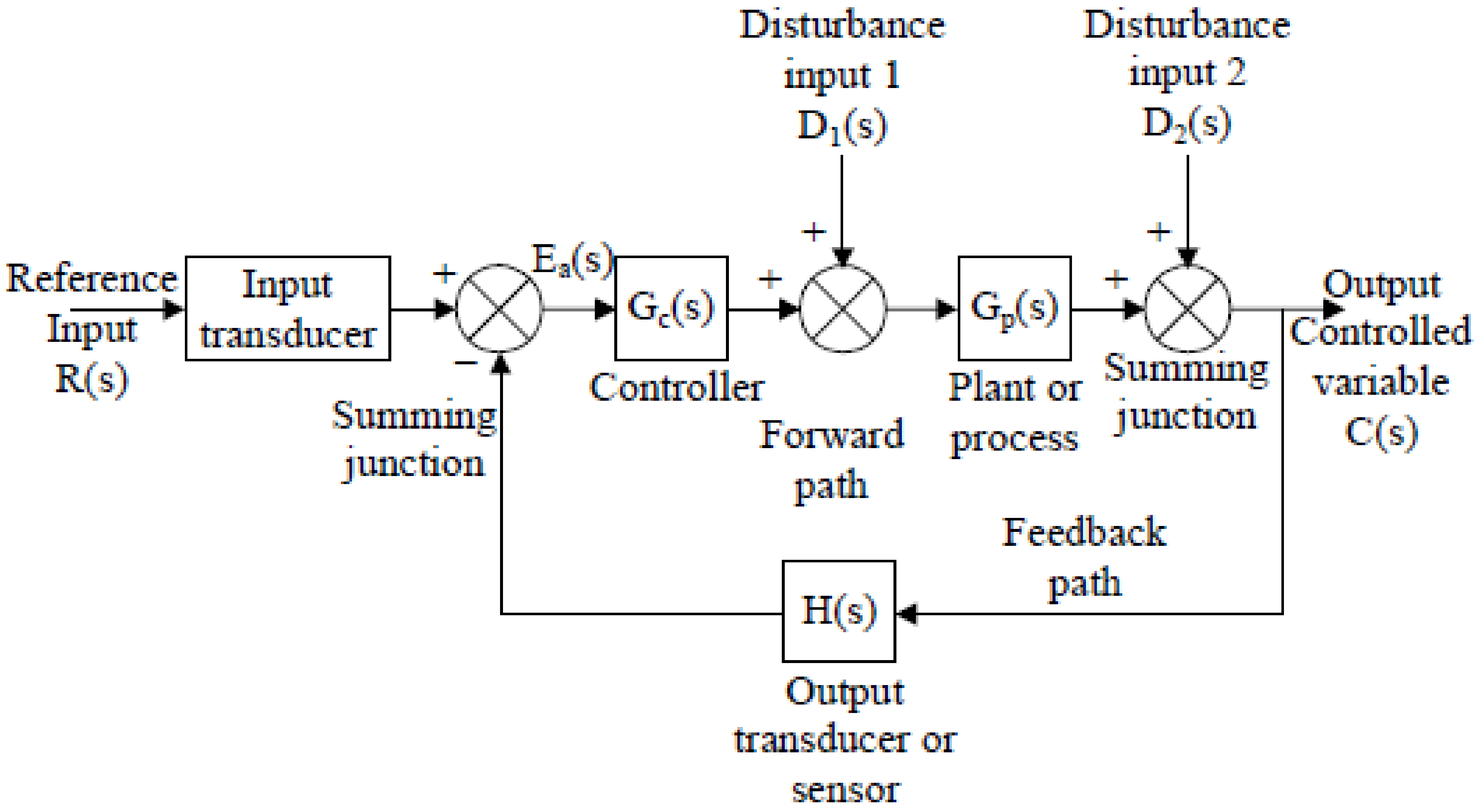
Natural response: depends only on the system, describes the way the system dissipates or acquires energy.

Forced response: depends on the input.

Control System Terminology

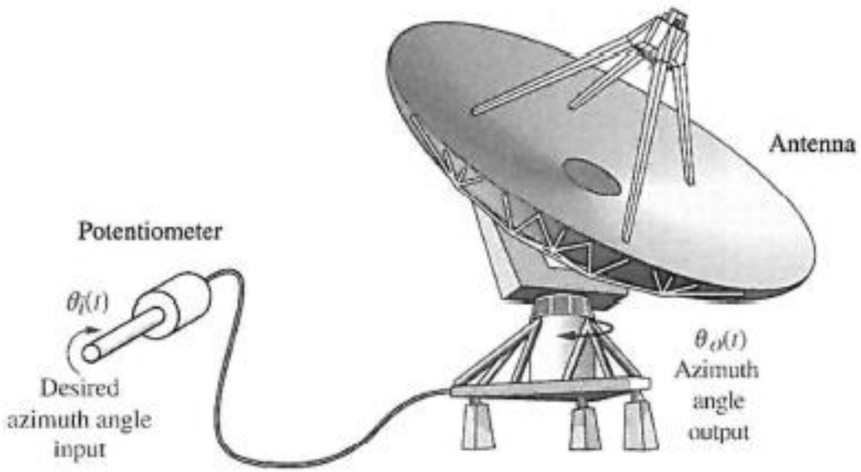
- *Controlled Output C(s):* the output variable of the plant under the control of the control system.
- *Controller:* drives a process or plant.
- *Disturbance or Noise Input*: is an undesired stimulus or input signal affecting the value of the controlled output.
- *Feedback Path.* The feedback path is the transmission path from the controlled output back to the summing point.
- *Forward Path*. The forward path is the transmission path from the summing point to the controlled output.
- *Transducer:* A transducer is a device that converts one energy form into another.
- *Input Transducer*. Input transducer converts the form of input to that used by the controller.
- *Plant, Process or Controlled System G(s):* Is the system, subsystem, process, or object controlled by the control system.
- *Reference Input R(s):* Is an external signal applied to the control system generally at the first summing input, so as to command a specified action of the process or plant. It typically represents ideal or desired process or plant output response.
- *Summing Point:* is a small circle called a summing point with the appropriate sign associated with the arrows entering the circle. The output is the algebraic sum of the inputs.
- *Takeoff Point*: allows the same signal or variable as input to more than one block or summing point, thus permitting the signal to proceed unaltered along several different paths to several destinations.

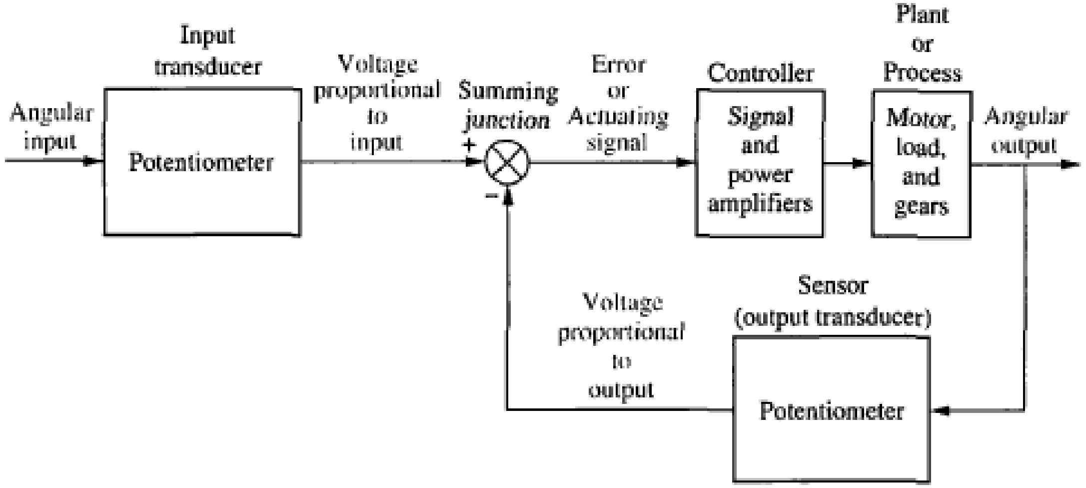
Control System Terminology

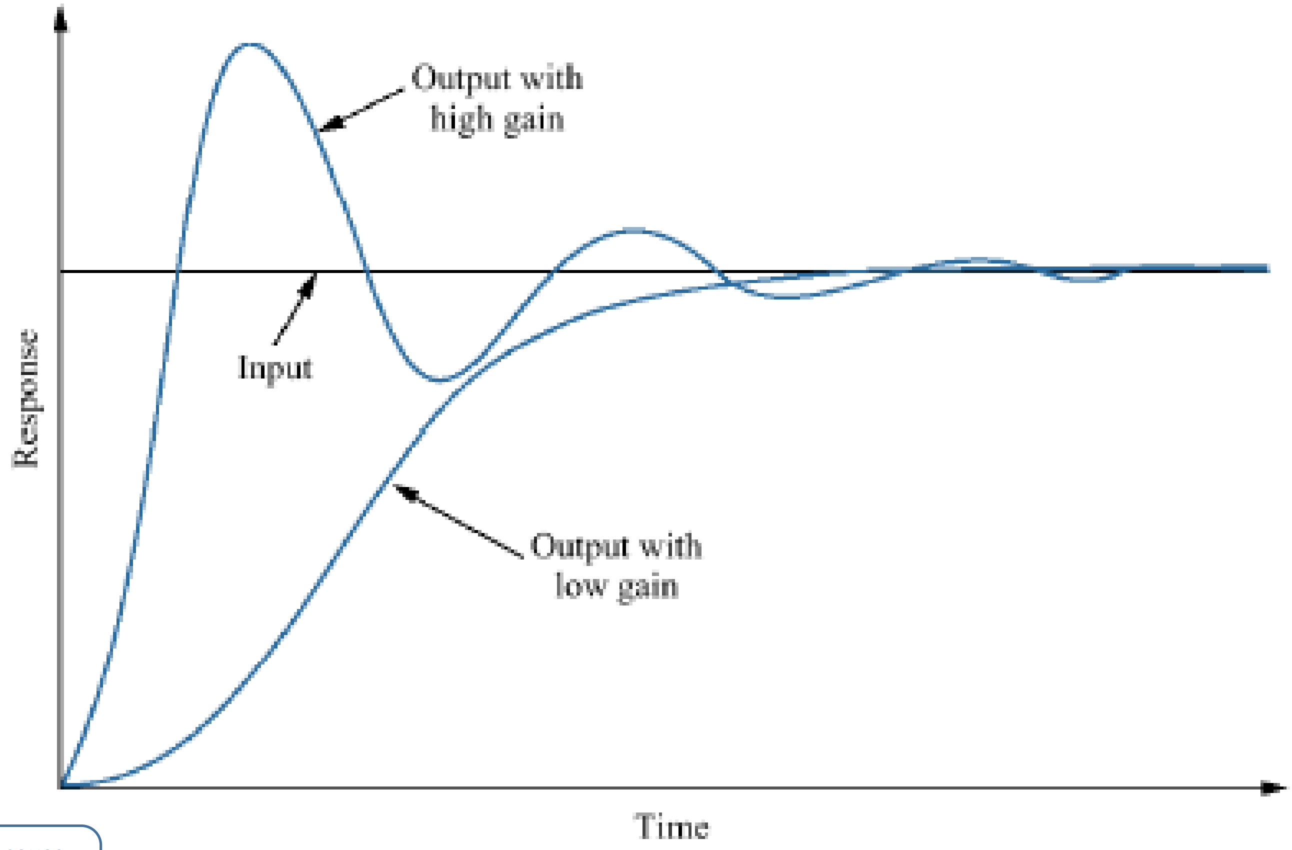


General block diagram of closed-loop control system

Response of Position Control System







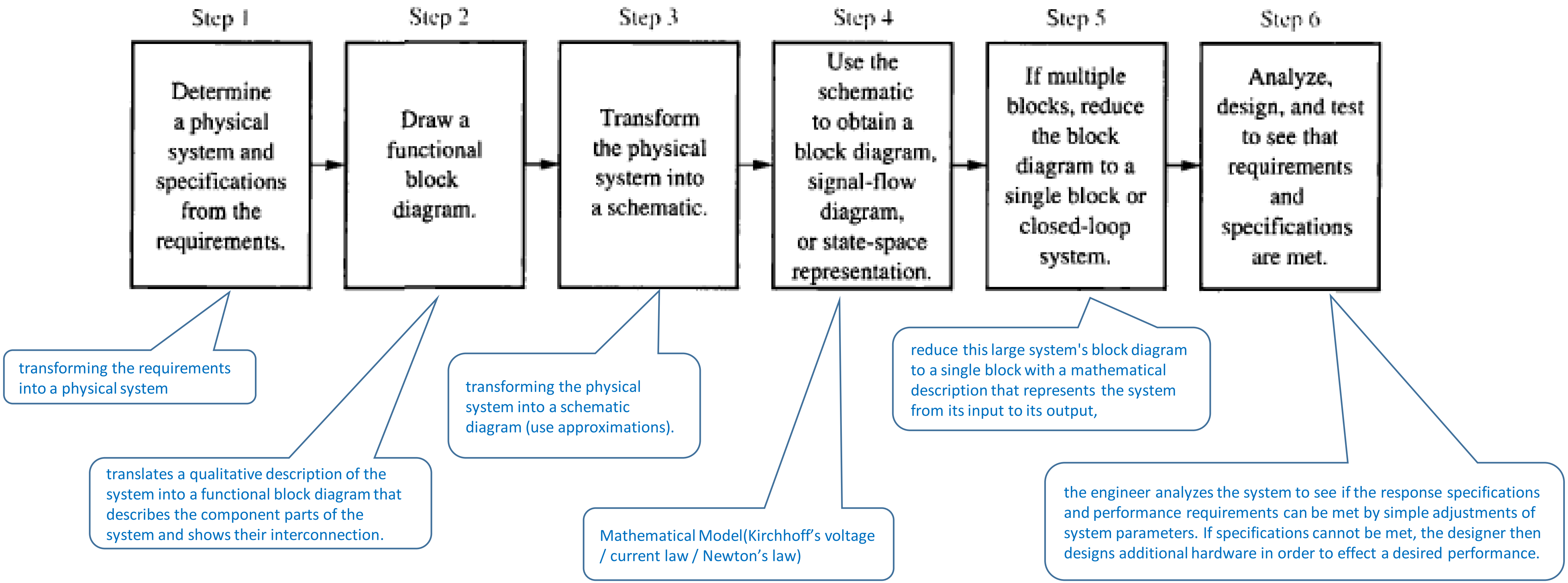
Response of a position control system, showing effect of high and low controller gain on the output response

- High gain causes oscillation.

the increased speed, increased momentum could cause the motor to overshoot the final value and be forced by the system to return to the commanded position.

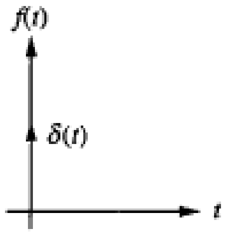
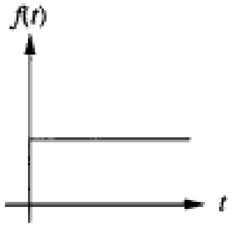
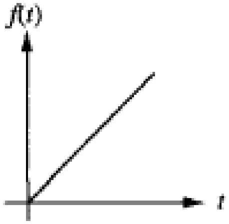
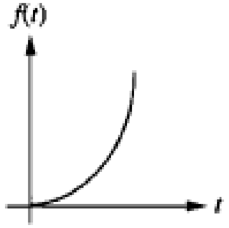
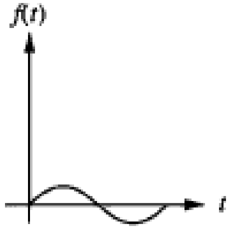
- Zero error at steady state.
- If not zero error, a controller is needed for gain adjustment to regulate transient response

The Design Process



Test Waveforms
Used in Control Systems

- *Test input signals* (standard test inputs) are used, both analytically and during testing, to verify the design.
- If t < 0, function value = 0
- An *impulse waveform* (infinite at t = 0 and zero elsewhere) is used to place initial energy into a system so that the response due to that initial energy is only the transient response of a system. From this response the designer can derive a mathematical model of the system.
- A *step waveform* (constant command) represents the desired position, desired velocity, desired acceleration or desired temperature.

Input	Function	Description	Sketch	Use
Impulse	$\delta(t)$	$\delta(t) = \infty$ for $0- < t < 0+$ $= 0$ elsewhere $\int_{0-}^{0+} \delta(t)dt = 1$		Transient response Modeling
Step	$u(t)$	$u(t) = 1$ for $t > 0$ $= 0$ for $t < 0$		Transient response Steady-state error
Ramp	$tu(t)$	$tu(t) = t$ for $t \geq 0$ $= 0$ elsewhere		Steady-state error
Parabola	$\frac{1}{2}t^2u(t)$	$\frac{1}{2}t^2u(t) = \frac{1}{2}t^2$ for $t \geq 0$ $= 0$ elsewhere		Steady-state error
Sinusoid	$\sin \omega t$			Transient response Modeling Steady-state error