# 09365060
# Principles of Automatic Control (1)
# 自动控制原理1

## Topic 1
## Introduction to Control Systems
(Chapter 1 in text book)

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# Before the Class

- What do you understand by the terms
  - Control, System?
  - Automatic Control?

- Give one/ two examples, may be a block diagram, some characteristics.

(2 - 3 minutes)

# Learning Outcomes for Topic 1

After completing this topic, you will be able to:

- Define a control system and describe some applications;
- Describe historical developments leading to modern day control theory;
- Describe the basic features and configurations of control systems;
- Describe control systems analysis and design objectives;
- Describe a control system’s design process;
- Describe the benfit from studying control systems.

# Outline for Topic 1

- Brief Introduction
- A History of Control Systems
- System Configurations
- Analysis and Design Objectives
- The Design Process
- Computer-Aided Design
- Summary

# New terminologies in this topic

- Control 控制
- System 系统
- Automatic Control 自动控制
- Input 输入
- Output 输出
- Disturbance 干扰
- Proportional 比例
- Integral 积分
- Differential 微分
- Open-Loop Systems 开环系统
- Closed-Loop Systems 闭环系统
- Feedback 反馈

- Transient Response 瞬态响应
- Steady-state Response 稳态响应
- Natural Response 自然响应
- Forced Response 强制响应
- Stability 稳定性
- Block Diagram 方框图
- Schematic 原理图
- Transfer function 传递函数
- Laplace transform 拉普拉斯变换
- Time-invariant 时不变
- Differential Equation 微分方程

# Brief Introduction

- Control system is an integral part of the society and are all around us.

- Examples:
  - Human body (control of pressure, sugar etc.)
  - Heating/Air-Con. System
  - Industrial processes (rolling, paper making etc))
  - Chemical/Industrial processes (Beer making)
  - Dam level control
  - Vehicle Steering system
  - Antenna position control (Inside cover of textbook)
  - Robotic Devices
  - Let's watch a video of robotic (floor clearner)

# Brief Introduction: Control System Definition

- A control system consists of processes (combination of sub processes and/or plant) assembled for the purpose of obtaining a desired output with a desired performance, given a specific input or disturbances.

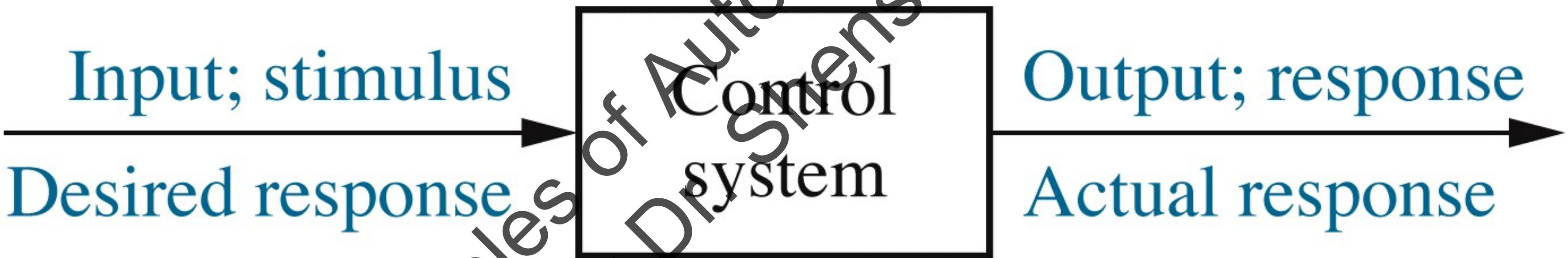


Figure 1.1

# An Example of Elevator: Discussion

- Discuss the input and output of an elevator.
- Discuss several aspects we should focus on when designing an elevator.



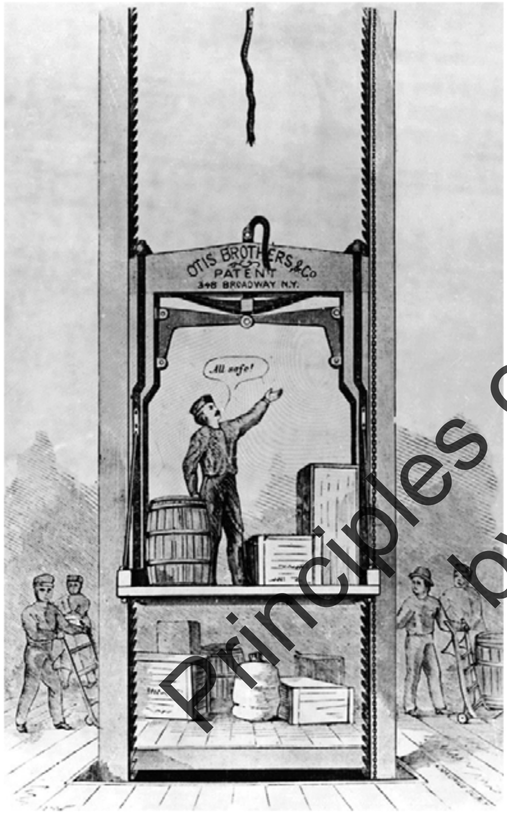


Figure 1.3a
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Figure 1.3b

# An Example of Elevator: Elevator Response

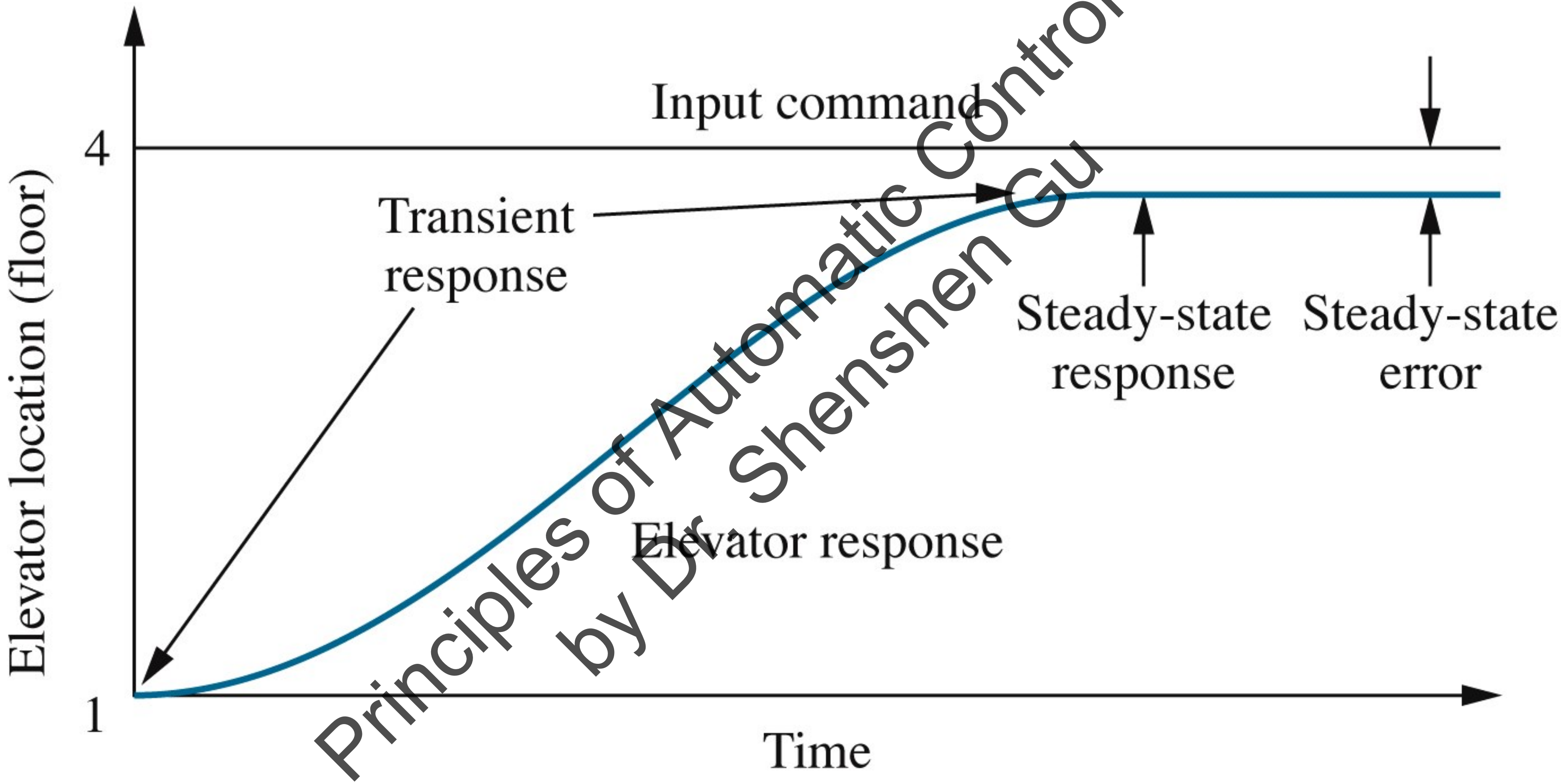



Figure 1.2

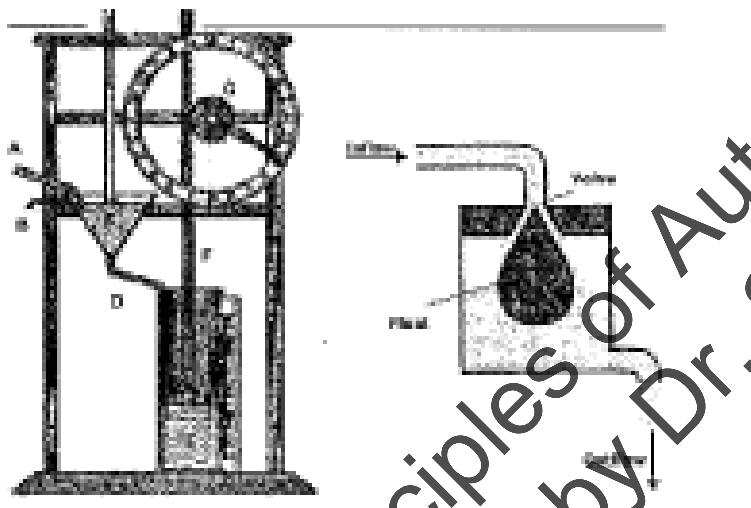
# Brief Introduction: Advantages of Control Systems

- What is the purpose?
  - Amplify Power (Antenna system, Industrial control)
  - Remote Control (Robot, rescue vehicle, satellite)
  - Convenience of input form (Heating system)
  - Compensation for disturbances (steering & all of the above)

These are not independent.

# A History of Control Systems

- Liquid level control (300 BC Greeks, water clock: constant flow of water from a tank)
  - Self filling oil lamp by Philon.



e 1.1: 250 BC water clock by Ctesibius of Alexandria, and his level
lled floating valve

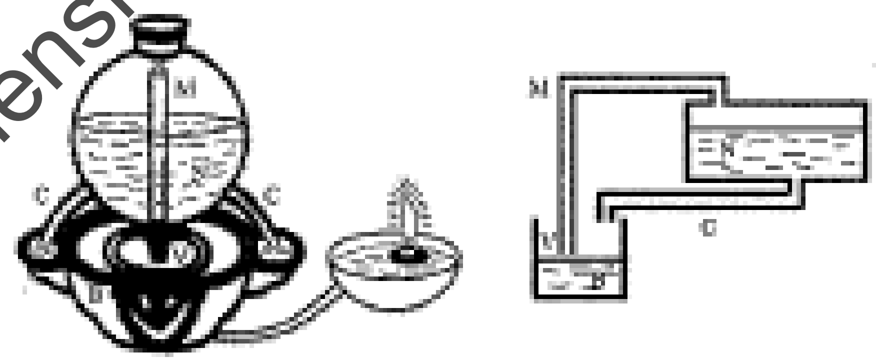


Figure 1.2: 300 BC Self re-filling oil lamp by Philon of Byzantium

# A History of Control Systems (Contd.)

- Steam Pressure & Temperature Controls (17th century)
  - Use of safety valve

1624
Incubator for eggs

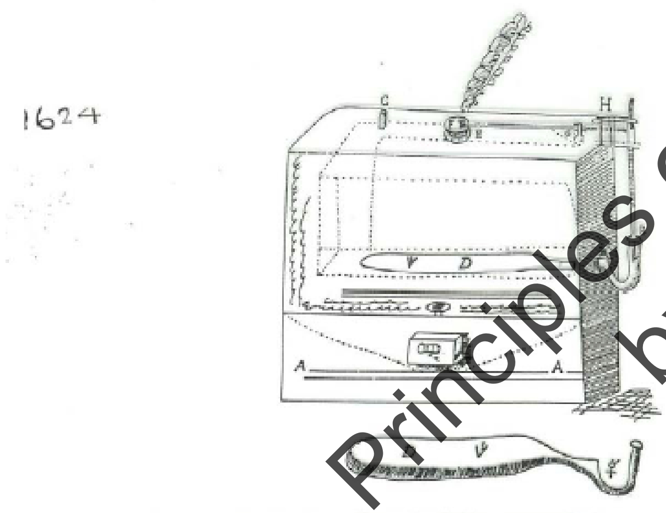
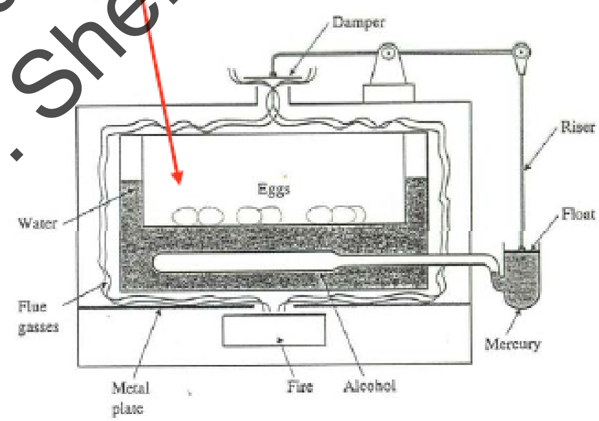



Figure 38 Drebbel's incubator (from Cambridge manuscript).

Desired performance:
Keep temperature inside incubator constant

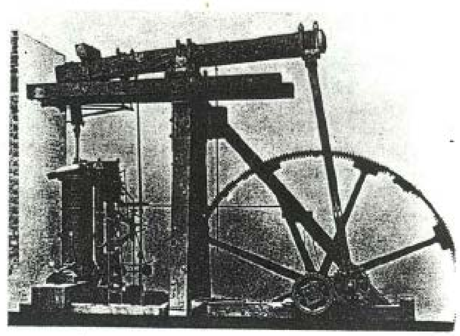


# A History of Control Systems (Contd.)

- Speed Control (18th century)
  - Wind-Mill speed control by adjusting the pitch of the blades. Watt's fly wheel governor.

James Watt's fly-ball governor for Steam Engine (1789-1800)

FIGURE 1.9 A steam engine from the shop of James Watt. (British Crown Copyright, Science Museum, London)



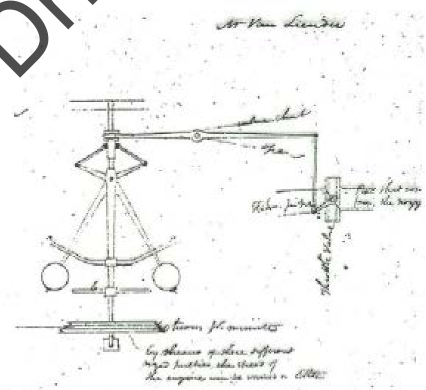
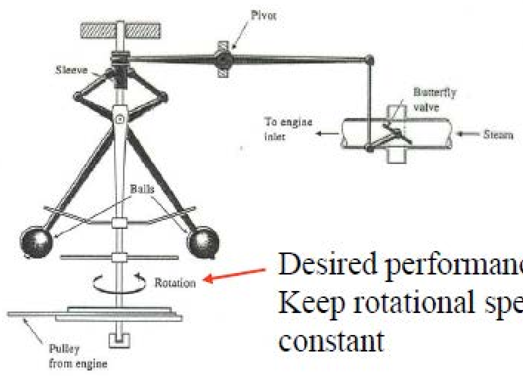


Figure 2 Centrifugal governor, design sketch, Boulton & Watt, 1798.




Desired performance: Keep rotational speed constant

# A History of Control Systems (Contd.)

- Stability (19th century)
  - Formalization of control theory by JC Maxwell, Routh (Routh- Hurwitz), Alexander Lyapunov, Bessemer (stabilization of ships)

# A History of Control Systems (Contd.)

- Current Control Theory (20th century)
  - During World war 2, problem of ship stabilization & gun turret positioning was solved by using control theory. It was referred to as Theory of Servomechanism.
  - Modern day control design is attributed to Nicholoas Minorsky who introduced PID (Proportional, Integral & Differential) control.
  - In the 20's & 30's Bode & Nyquist develop the analysis & design techniques.
  - In the late 40's Evans developed the technique of Root Locus method of analysis & design.
  - The control requirements of space vehicles gave birth to the State-Space techniques.

# A History of Control Systems (Contd.)

- 1940 – 1960 saw the development of classical control theory working in the frequency domain
  - Theory of servomechanisms
  - Nyquist Stability Criterion
  - Bode Plot
  - Root Locus Plots

- 75 – 80% of the industrial control problems can be solved by using the classical control theory

- (Focus of this unit)

# System Configurations

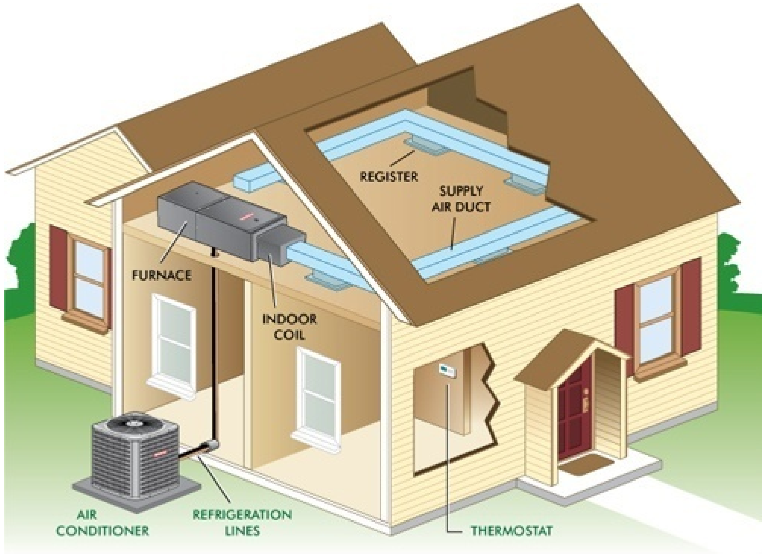
- Open-loop systems
- Closed-loop (feedback control) systems

What is open-loop system and closed-loop system?

Let us look at a simple example. Please compare the difference between:

- Closed room with a fan-forced electric heater.
- Central air-conditioning system with thermostat control





# System Configurations: Open-Loop Systems

- Definition:
  - The open loop control system is a non-feedback system in which the control input to the system is determined using only the current state of the system and a model of the system. There is no feedback to determine if the system is achieving the desired output based on the reference input or set point. The system does not observe itself to correct itself and, as such, is more prone to errors and cannot compensate for disturbances to the system.

# System Configurations: Closed-Loop Systems

- Definition:
  - The closed loop control system is a system where the actual behavior of the system is sensed and then fed back to the controller and mixed with the *reference* or desired state of the system to adjust the system to its desired state.

# System Configurations: Block Diagrams for Open-Loop and Closed Loop Systems

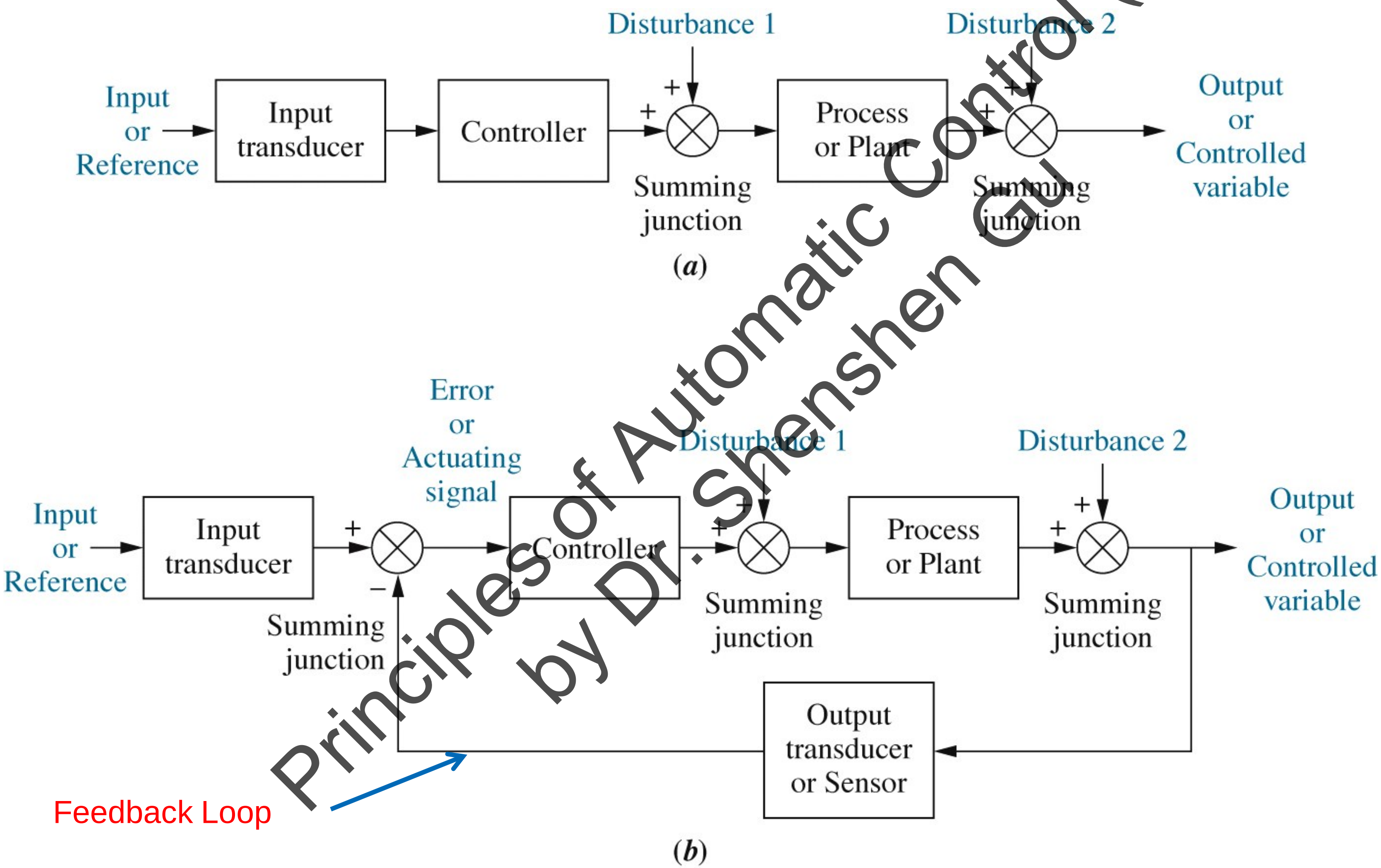



Figure 1.6

# System Configurations: Advantages and Disadvantages

| | Closed-Loop Systems | Open-Loop Systems |
|---|---|---|
| **Advantages** | • Can compensate for disturbances<br>• High accuracy | • Simple structure<br>• Cheap |
| **Dis-advantages** | • Complex structure<br>• Expensive | • Sensitive to disturbances<br>• Less accuracy |

# Analysis and Design Objectives

- *Analysis* is the process by which a system's performance is determined.
- *Design* is the process by which a system's performance is created or changed.
- A control system is *dynamic*: It responds to an input by undergoing a transient response before reaching a steady-state response that generally resembles the input.
  - Producing the desired transient response
  - Reducing steady-state error
  - Achieving stability

# Analysis and Design Objectives: Transient Response

- *Good Transient Response:* Get to the desired response quickly and smoothly.
- Disc drive's read/write head jumps from one track to another quickly.



Figure 1.7

## Analysis and Design Objectives: Steady-State Response

- *Low Steady State Error:* Get to the desired response.
- Disc drive finally stopped at the correct track.



Figure 1.7

# Analysis and Design Objectives: Stability

- Discussion of transient response and steady-state error is moot if the system does not have *stability*.
- Total response = Natural response + Forced response
- Natural response described the way the system dissipates or acquires energy. It is dependent only on the system, not the input.
- Forced response is dependent on the input.

- For a control system to be stable, the natural response must
  - Eventually approach zero, thus leaving only the forced response;
  - Or oscillate;

# Analysis and Design Objectives: Other Considerations

- Factors affecting hardware selection
- Finances
- Robust design

……

# The Design Process

- Step 1: Transform Requirements into a Physical System
- Step 2: Draw a Functional Block Diagram
- Step 3: Create a schematic

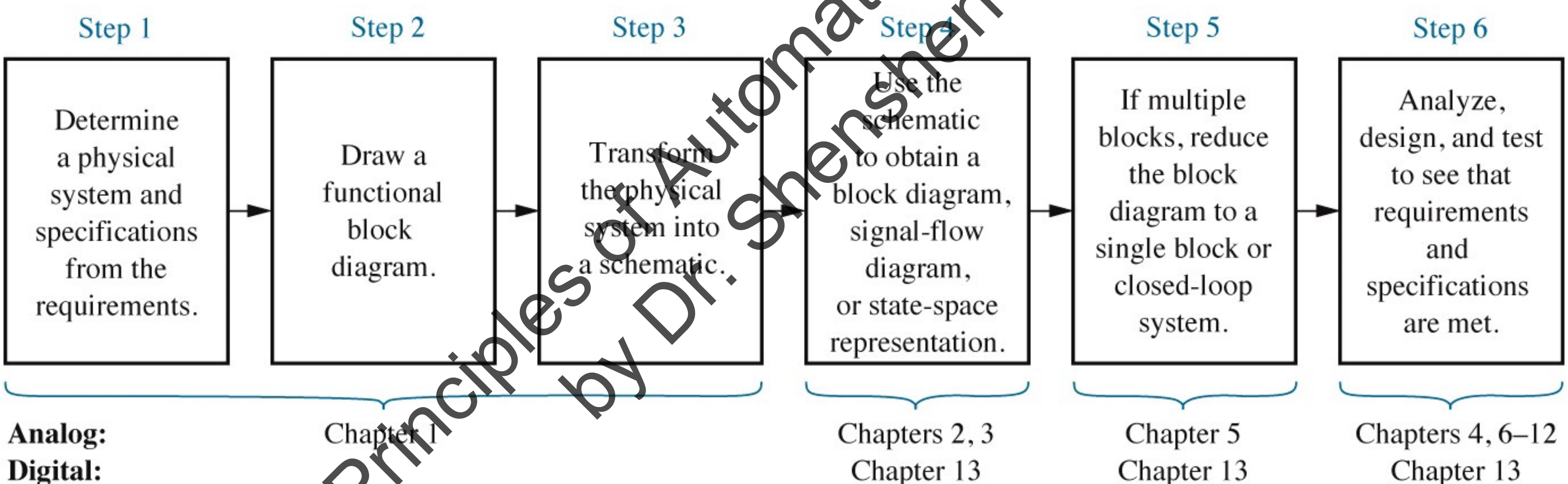



**Figure 1.11**
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# The Design Process: Step 4 Develop a Mathematical Model (Block Diagram)

- Linear, time-invariant differential equation

$$\frac{d^n c(t)}{dt^n} + d_{n-1}\frac{d^{n-1}c(t)}{dt^{n-1}} + \cdots + d_0 c(t) = b_m \frac{d^m r(t)}{dt^m} + b_{m-1}\frac{d^{m-1}r(t)}{dt^{m-1}} + \cdots + b_0 r(t)$$

- Transfer function (Apply Laplace transform to the differential equation)

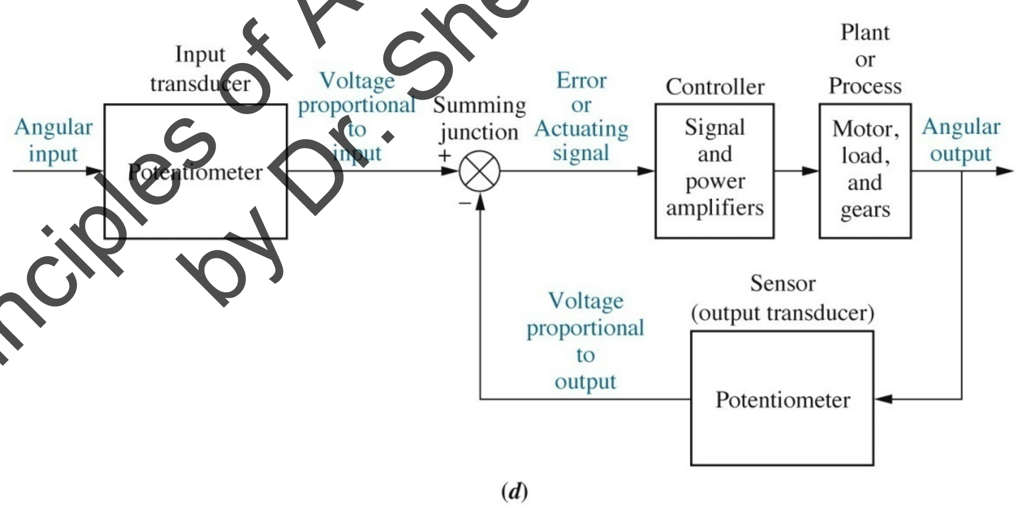



Figure 1.9d

# The Design Process: Step 5 Reduce the Block Diagram

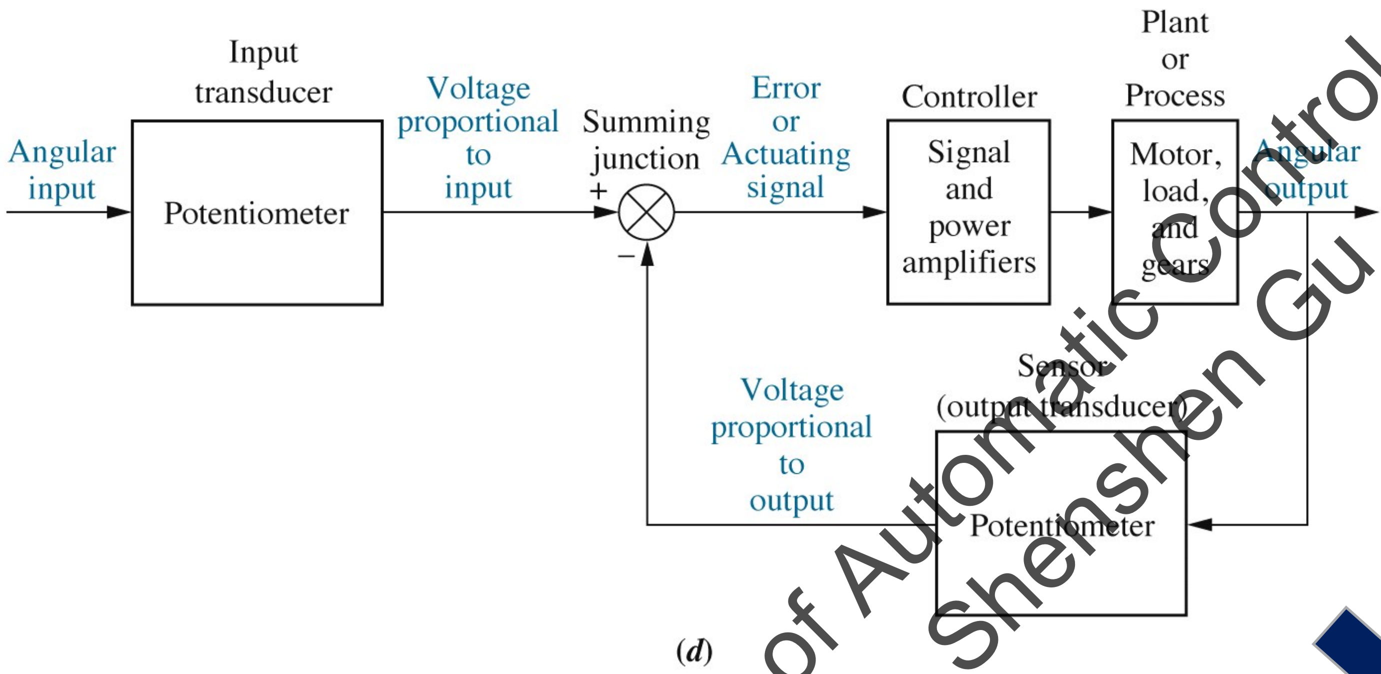



Figure 1.9d


Reduce

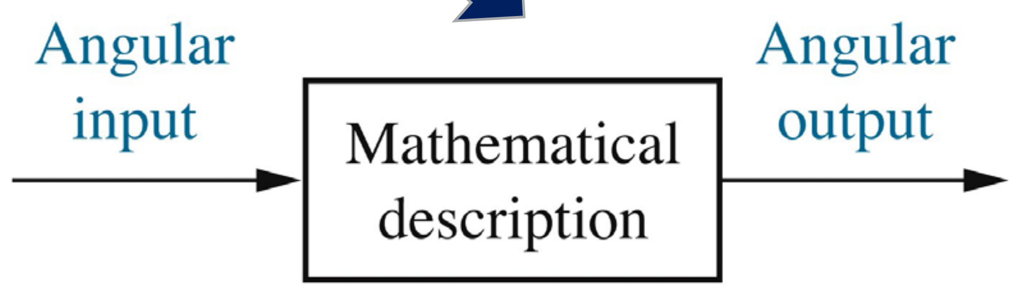



Figure 1.12

# The Design Process: Step 6 Analyze and Design

- Test input signals

**TABLE 1.1** Test waveforms used in control systems

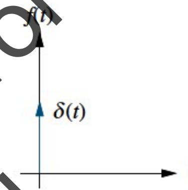
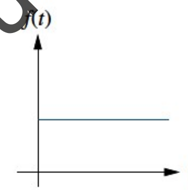
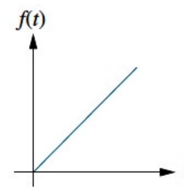
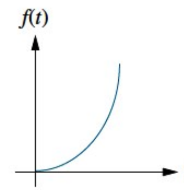
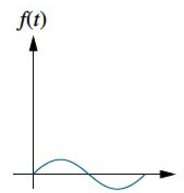
| Input | Function | Description | Sketch | Use |
|---|---|---|---|---|
| Impulse | $\delta(t)$ | $\delta(t) = \infty$ for $0- < t < 0+$<br>$= 0$ elsewhere<br>$\int_{0-}^{0+} \delta(t)dt = 1$ |  | Transient response<br>Modeling |
| Step | $u(t)$ | $u(t) = 1$ for $t > 0$<br>$= 0$ for $t < 0$ |  | Transient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

**Table 1.1**

# Computer-Aided Design

- MATLAB
  - Control System Tool Box
  - Simulink

# Summary

- The importance of control systems;
- The definition of a control system;
- Open loop control system vs. closed loop control system;
- Three primary objectives in control systems analysis and design;
- The steps for designing a control system.