PME3207 Control Systems I

上課老師：葉廷仁教授
辦公室：　工一514
上課教室：工一216
上課時間：M5M6F3
演習課時間：周二 19:00~21:00

Outline of this course

This course provides the students with basic knowledge in modeling, analysis and design for linear feedback control systems. It begins with reviewing some mathematical fundamentals and introducing block diagrams and signal-flow graphs. Students will then learn how to model mechanical, electrical, and electromechanical systems as differential equations and transfer functions. The analysis in this course includes stability of open-loop and closed-loop systems, time responses and frequency responses of low order systems. The design methods are divided into root-locus techniques and frequency response techniques using Bode plots for designing PID and lead/lag controllers. Students will also learn how to apply the automatic control theory to real engineering problems via Matlab simulations and Lab assignments.

Pre-requisite:

College Physics (大學物理), Engineering Mathematics (工程數學)

Course Contents

1. Introduction
2. Mathematical Foundation
3. Block diagrams and Signal-Flow Graphs
4. Modeling of Dynamic Systems
5. Time-domain Analysis of Control Systems
6. Root Locus Analysis
7. Frequency-Domain Analysis
8. Design of Control Systems

Tentative Schedule

- **Week 1: (Chap. 1) Introduction, (Chap. 2) Review of Laplace Transform**
- **Week 2: Application of Laplace Transform to Dynamic Systems, Step/Impulse Responses, Stability, Ruth-Hurwitz Criterion, Frequency Response, Polar plot. PS1 out**
- **Week 3: Polar plot, Bode plot, Magnitude-Phase plot.**
- **Week 4: (Chap. 3) Block-diagram, Signal-Flow Graphs, Mason's Rule, (Chap. 4) Modeling of Translational Mechanical Systems. PS 2 out**
- **Week 5: Modeling of Rotational Mechanical Systems, Gear Trains, Electric Circuits, Operational Amplifier, and Sensors.**
- **Week 6: Modeling of DC motors, DC motors in control systems. PS 3 out**
- **Week 7: (Chap. 5) Time-domain specification of control systems, Steady-state error analysis, Unity feedback systems, Step responses of 1st order, 2nd order systems.**
- **Week 8: Speed and position control of DC motors, Effects of adding poles and zeros. PS 4 out**
- **Week 9: (Chap. 7) Root locus problem, Root locus properties.**
- **Week 10: Root locus properties, Effects of adding poles and zeros in root locus, Controller design using root locus(PD, PI, PID, Lead, Lag). PS5 out**
- **Week 11: Controller design using root locus (Lead-Lag, Notch filter), (Chap. 8) Frequency domain specs, Effects of Adding poles/zeros to the forward path transfer function.**
- **Week 12: Nyquist Criterion, Effects of adding poles and zeros to Nyquist plot, Relative stability (Gain margin, Phase margin, etc.), Stability analysis with the Bode plot. PS6 out**
- **Week 13: Constant M loci, Nichols Chart, (Chap. 9) Design specifications, Design with the PD controller.**
- **Week 14: Design with the PD controller, Design with the PI controller. PS7 out**
- **Week 15: PI, PID control design,**
- **Week 16: Lead, Lag control design PS8 out**
- **Week 17: Lead-lag control design, Course review.**

Text Book

Farid Golnaraghi, and Benjamin C. Kuo, "Automatic Control Systems", 9th edition, John Wiley & Sons, Inc., 2009.

References

1. **Gene F. Franklin, J. David Powell, and Abbas Emami-Naeini, Feedback Control of Dynamic Systems, 6th Edition, Prentice Hall, 2009.**
2. **Norman S. Nise, "Control Systems Engineering", 6th edition, John Wiley & Sons, Inc., 2010.**

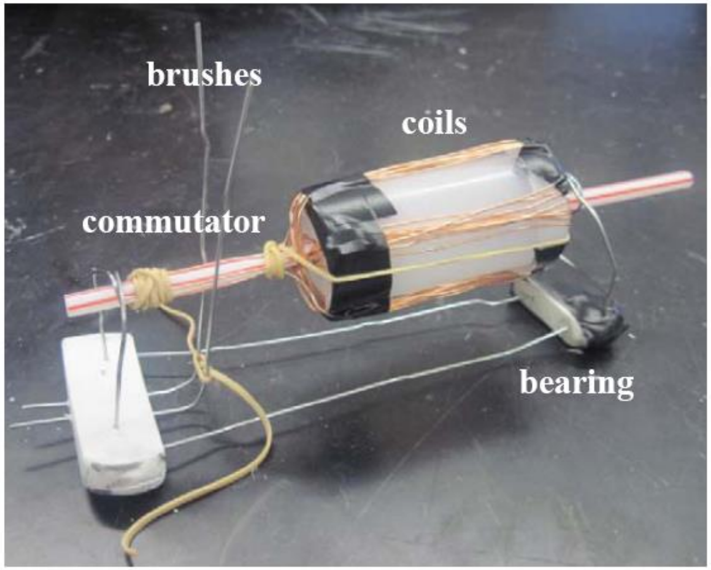
Grading Policy:

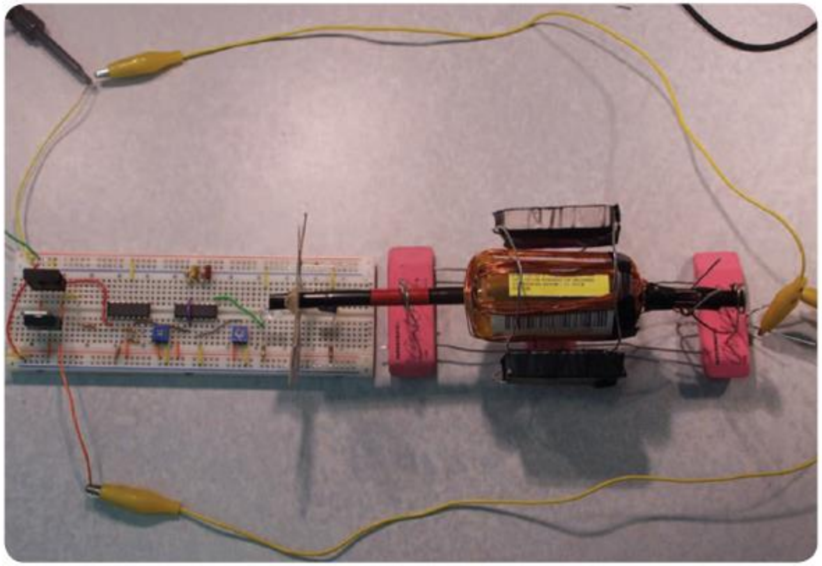
- **Homework assignments (25%), Midterms(40%), Final exam(30%), and Lab assignments (10%)**

Course website:

- **http://www.moodle.nthu.edu.tw**

Lab Assignments





References:
1. G. M. Clayton and R. A. Stein, “An inexpensive hands-on introduction to permanent magnet dc motors,” in *Proc. American Society Engineering Education Annu. Conf. Exposition*, Vancouver, BC, Canada, 2011, pp. 3649–3662.
2. G. M. Clayton , “Control Experiments on a Shoe String,” *IEEE Control Systems Magazine*, Dec. 2012, pp.106-110.

Lab Assignments

AC 2011-1082: AN INEXPENSIVE HANDS-ON INTRODUCTION TO PERMANENT MAGNET DIRECT CURRENT MOTORS

Garrett M. Clayton, Villanova University

Dr. Garrett M. Clayton received his BSME from Seattle University and his MSME and PhD in Mechanical Engineering from the University of Washington (Seattle). He is an Assistant Professor in Mechanical Engineering at Villanova University. His research interests focus on mechatronics, specifically modeling and control of scanning probe microscopes and unmanned vehicles.

Rebecca A Stein, University of Pennsylvania

Rebecca Stein is the Associate Director of Research and Educational Outreach in the School of Engineering and Applied Science at the University of Pennsylvania. She received her B.S. in Mechanical Engineering and Masters in Technology Management from Villanova University. Her background and work experience is in K-12 engineering education initiatives. Rebecca has spent the past 5 years involved in STEM high school programs at Villanova University and The School District of Philadelphia. Additionally, she has helped coordinate numerous robotics competitions such as BEST Robotics, FIRST LEGO League and MATE.

Control Experiments on a Shoe String

GARRETT M. CLAYTON

When teaching control systems, it is important for students to implement controllers experimentally. Oftentimes off-the-shelf experimental systems are used to achieve this goal. These systems can have a number of advantages, such as repeatability, durability, and safety, and can be interesting and exciting for students. However, they have two distinct disadvantages:

- » Cost: The high cost of an experimental system can prohibit the purchase of multiple experimental work stations. The use of only one or a small number of experimental work stations results in a) students having to work in large groups (reducing the time that each student interacts with the experiment), b) the course requiring multiple laboratory sections (which is costly in time for the instructor or teaching assistant), or c) the experiment being used only as a classroom demonstration.
- » The experiments are a black box: These experiments typically have computer interfaces with enclosed control boxes and sensors, etc. Students enter the control parameters, press a button on a user interface, and watch the system run. Although perhaps an advantage for some learning objectives, well-trained control engineers also need to acquire a working knowledge of sensors, actuators, and control systems implementation, which can not necessarily be gained from black-box experiments.

This article describes an approach that allows a control systems instructor to enable students to obtain some hands-on experimental experience even when there are not enough resources for expensive experimental equipment. A low-cost, hands-on motor speed control experiment is presented where students build all parts of the experimental apparatus, including the motor. In addition to being inexpensive, the experiment is fun and achieves the goal of giving students a hands-on introduction to actuators, sensors, and control system implementation.

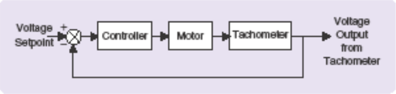


FIGURE 1 Block diagram showing the proposed motor control experiment.

EXPERIMENTAL APPARATUS

Motors are ubiquitous, being in everyday items such as children's toys, electric toothbrushes, and automobiles, as well as in manufacturing machinery [1], [2]. In many cases, the motor speed needs to be controlled [1], [3]. A typical motor speed control system is shown as a block diagram in Figure 1. In this article, each component of the closed-loop system is made from office/craft supplies and components available from any online electrical component store or your university's electrical engineering stores (see the parts lists in Tables 1 and 2). Standard electrical test equipment (dc power supply, oscilloscope, function generator, and multimeter) also must be available for troubleshooting and characterization. The remainder of this article provides an overview of the experimental setup and example results. Please visit the author's Web site [4] for more details concerning the experiment, such as electrical component value choice and assembly instructions, or to share your low-cost control systems/mechatronics experiments.

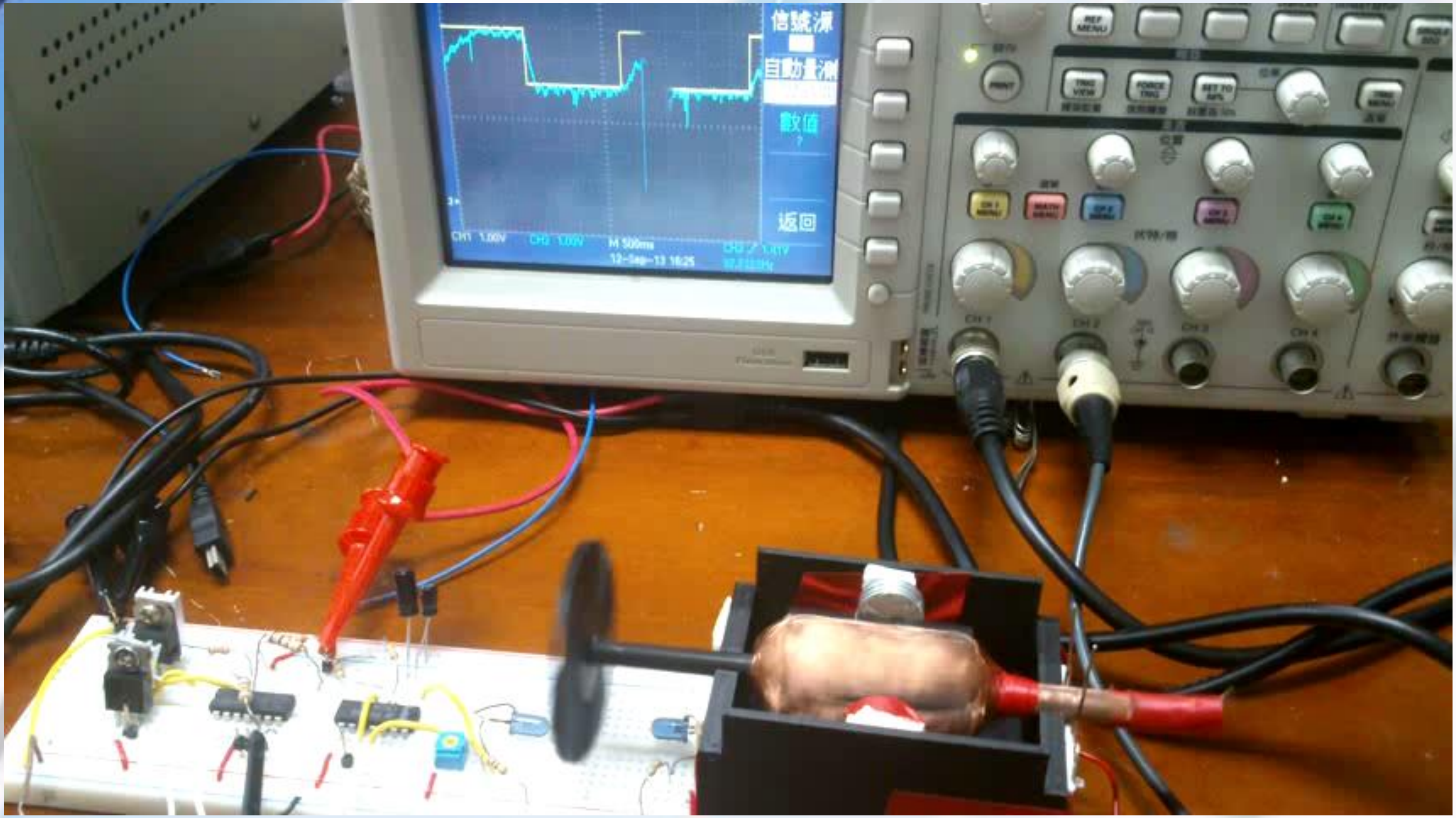
The Motor

There are many different commonly used motor configurations, including brushed or brushless dc permanent magnets or ac induction motors. For a breakdown of different motors, see [5, pp. 396], and for more detailed information see [6, Chapter 8]. In this article, the popular brushed permanent magnet dc motor (from here forward referred to as a dc motor) is used. DC motors consist of two main components: rotor and stator. The *rotor* (the spinning part of the motor) consists of coils and a commutator, and the *stator* (the stationary part of the motor) consists of brushes and magnets. When current in the coil flows through the magnetic field, a torque is generated on the rotor that causes the rotor to spin. An electrical connection is made between the spinning rotor and the stationary stator by passing current

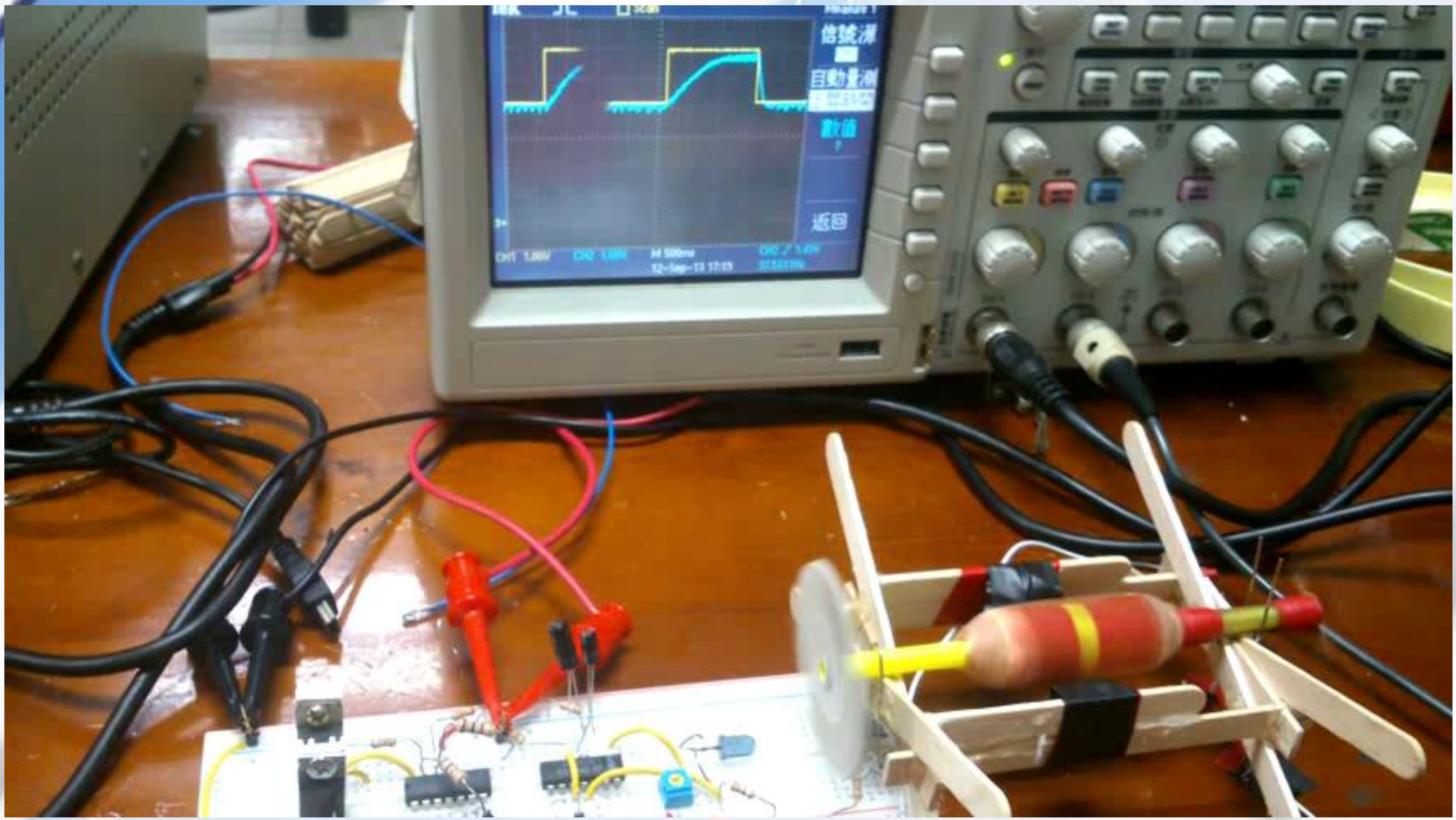
Digital Object Identifier 10.1109/MCS.2012.2214136
Date of publication: 12 November 2012

1066-033X/12/$31.00©2012IEEE

Lab Assignments



Lab Assignments



Important Dates:

- **Midterm I: 10/20/2014**
- **Midterm II: 12/1/2014**
- **Final exam: 1/12/2015**
- **Lab I (motor, 3%) due: 11/14/2014**
- **Lab II (encoder, 3%)due: 12/19/2014**
- **Lab III (system integration and controller implementation, 4%) due: 1/16/2015**

Chapter 1

Introduction

Automatic Control Systems, 9th Edition
F. Golnaraghi & B. C. Kuo

1-1 Introduction

Main objectives of this chapter:

1. To define a control system
2. To explain why control systems are important
3. To introduce the basic components of a control systems
4. To give some examples of control-system applications
5. To explain why feedback is incorporated into most control systems
6. To introduce types of control systems

Basic Components of a Control System

Figure 1-1 Basic components of a control system.

- **Objectives**: **inputs or actuating signals, *u***
- **Results**: **outputs or controlled variables, *y***

Examples of Control-System Applications

Idle-speed control of an automobile

- **Eliminate or minimize the speed droop when engine loading is applied**
- **Maintain the engine idle speed at a desired value**

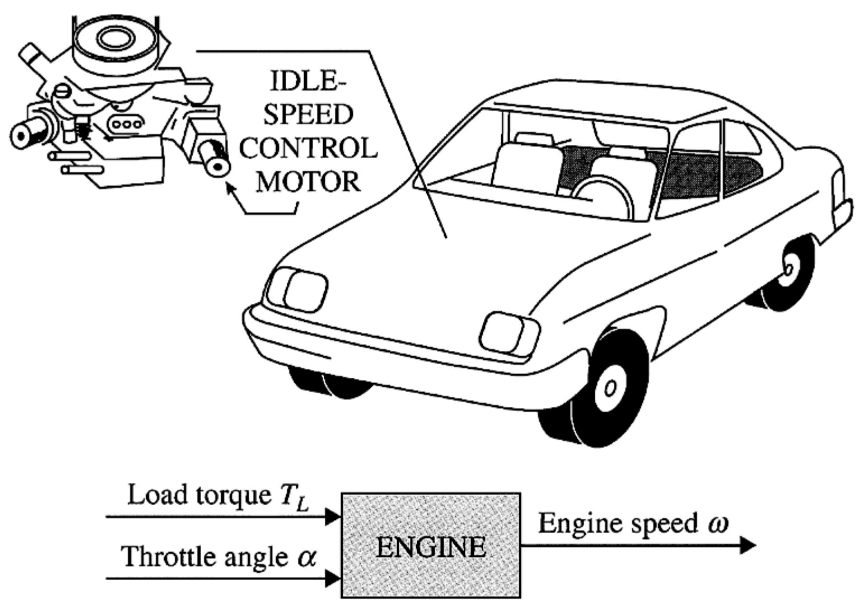


Figure 1-2 Idle-speed control system.

Examples of Control-System Applications

- **Sun-tracking control of solar collectors**

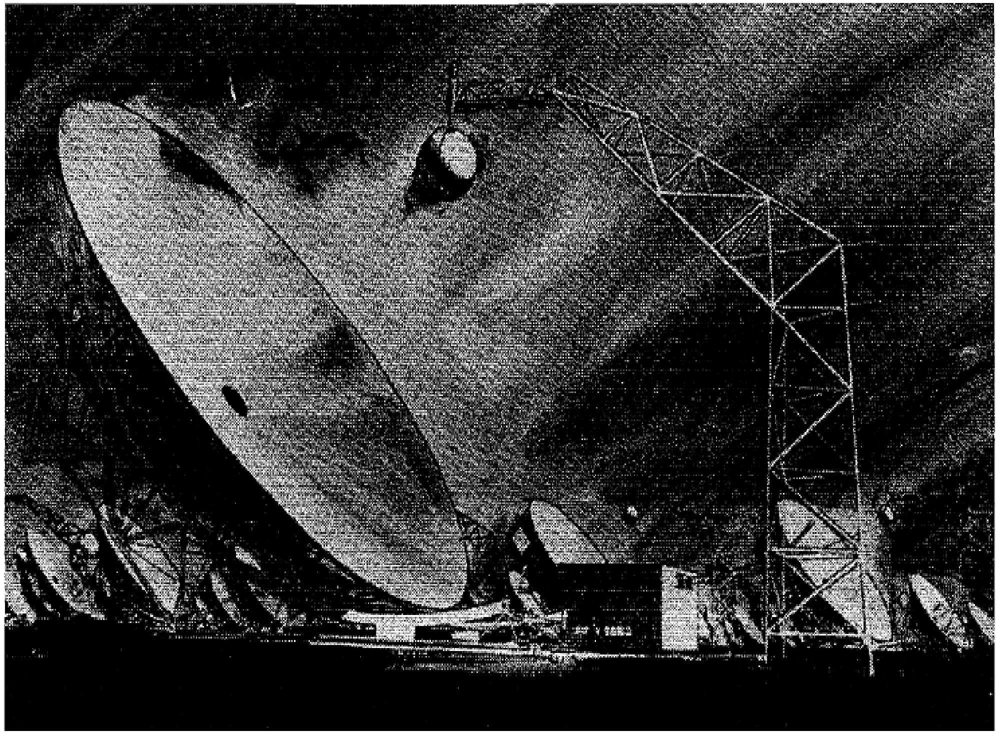


Figure 1-3 Solar collector field.

Sun-Tracking Control System

- Water extraction using solar power

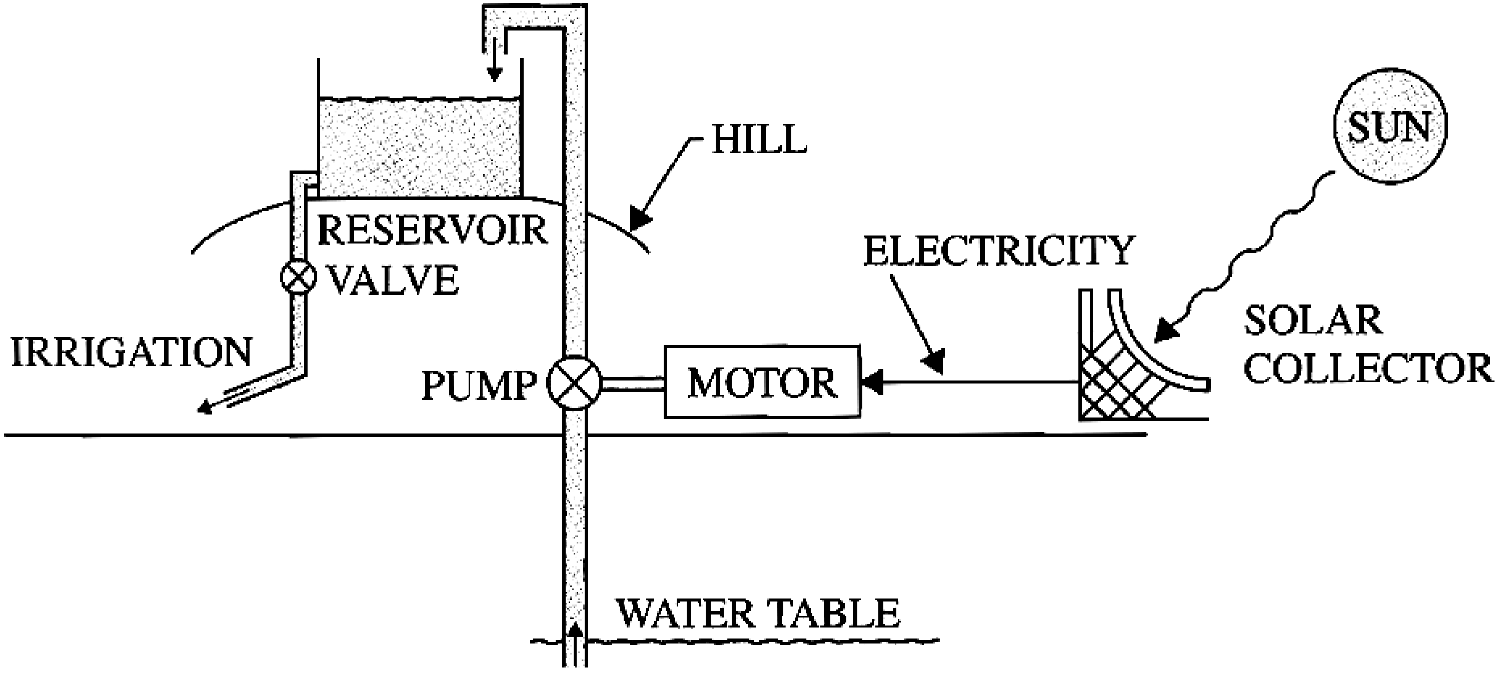


Figure 1-4 Conceptual method of efficient water extraction using solar power.

Sun-Tracking Control System

- **Important components**

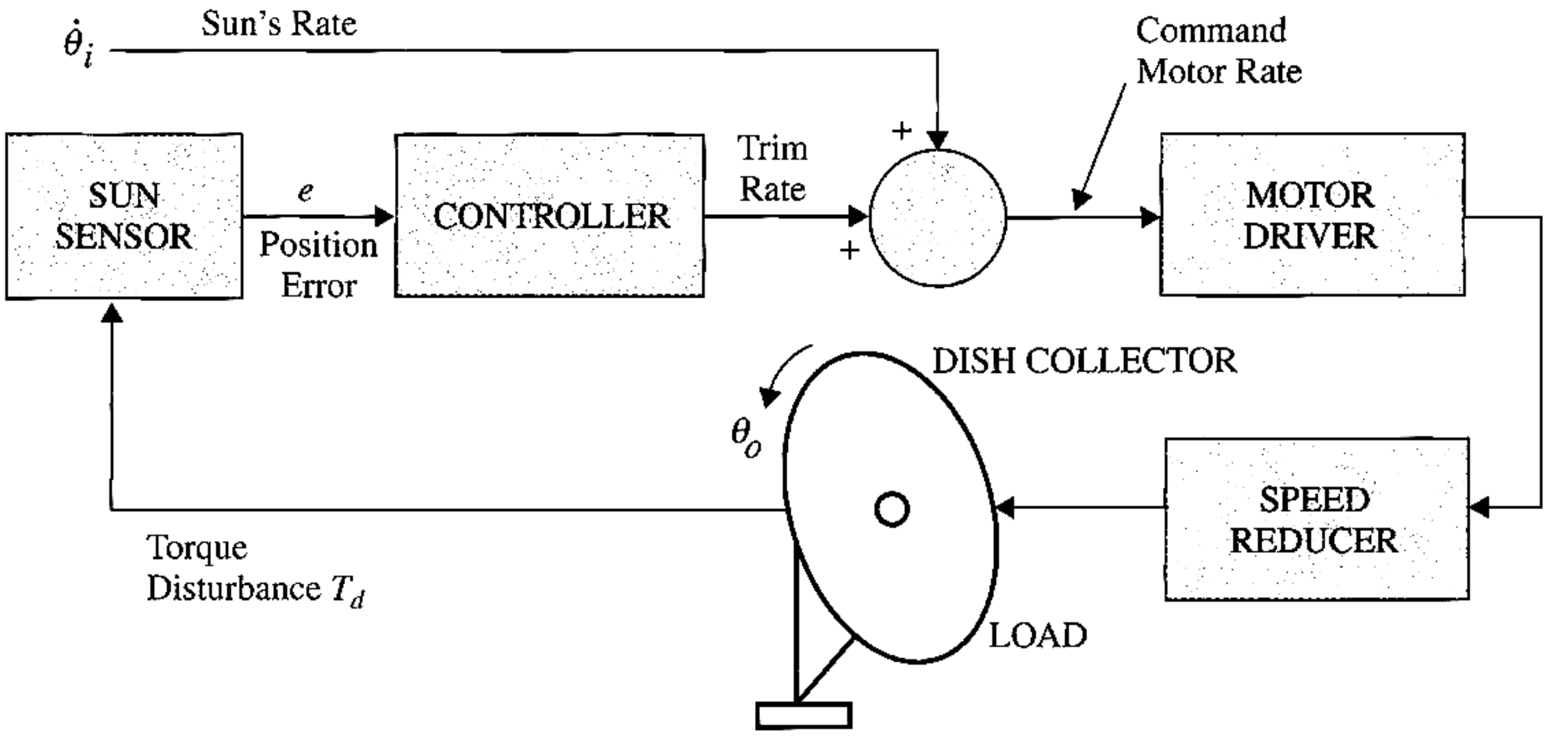


Figure 1-5 Important components of the sun-tracking control system.

Open-Loop Control Systems

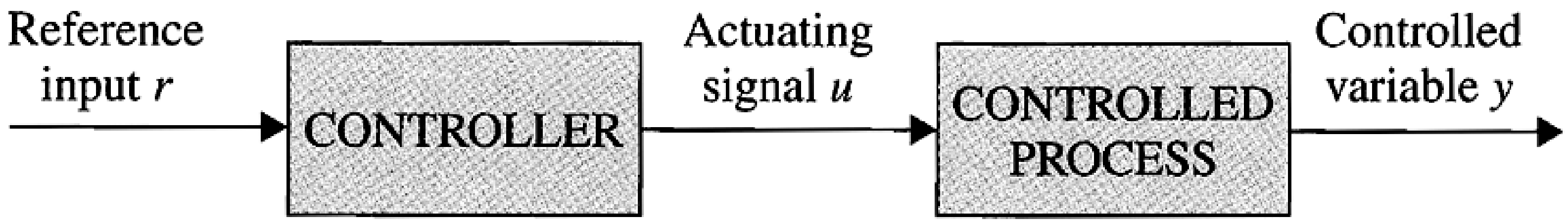
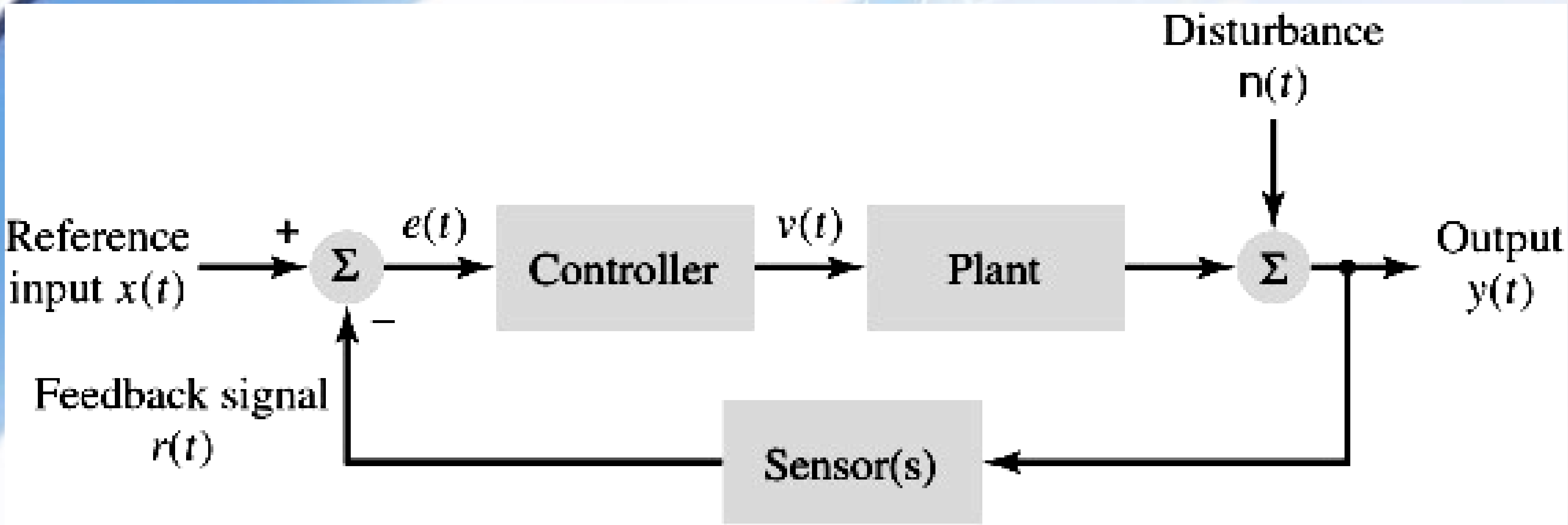


Figure 1-6 Elements of an open-loop control system.

- Open-loop systems ⇨ Nonfeedback systems
- The idle-speed control system shown in Fig. 1-2 is called an open-loop control systems.

Closed-Loop Control Systems



Block diagram of a feedback control system. The controller drives the plant, whose disturbed output drives the sensor(s). The resulting feedback signal is subtracted from the reference input to produce an error signal *e*(*t*), which, in turn, drives the controller. The feedback loop is thereby closed.

Closed-Loop Control Systems

- A system with one or more feedback paths is called a closed-loop system.

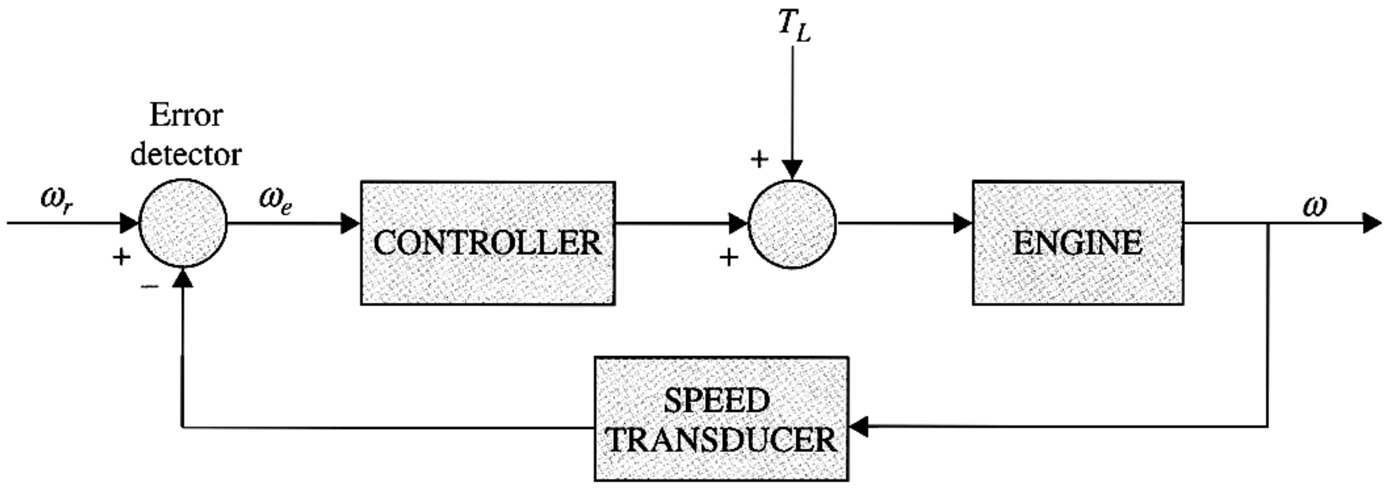


Figure 1-7 Block diagram of a closed-loop idle-speed control system.

- Closed-loop control systems ⇨ Feedback control systems
- Closed-loop systems have many advantages over open-loop systems.

Responses of Idle-Speed Control Syst.

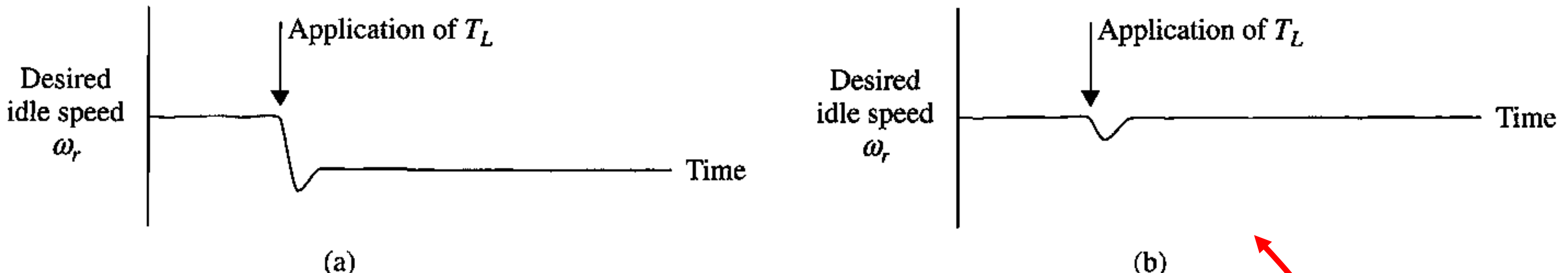
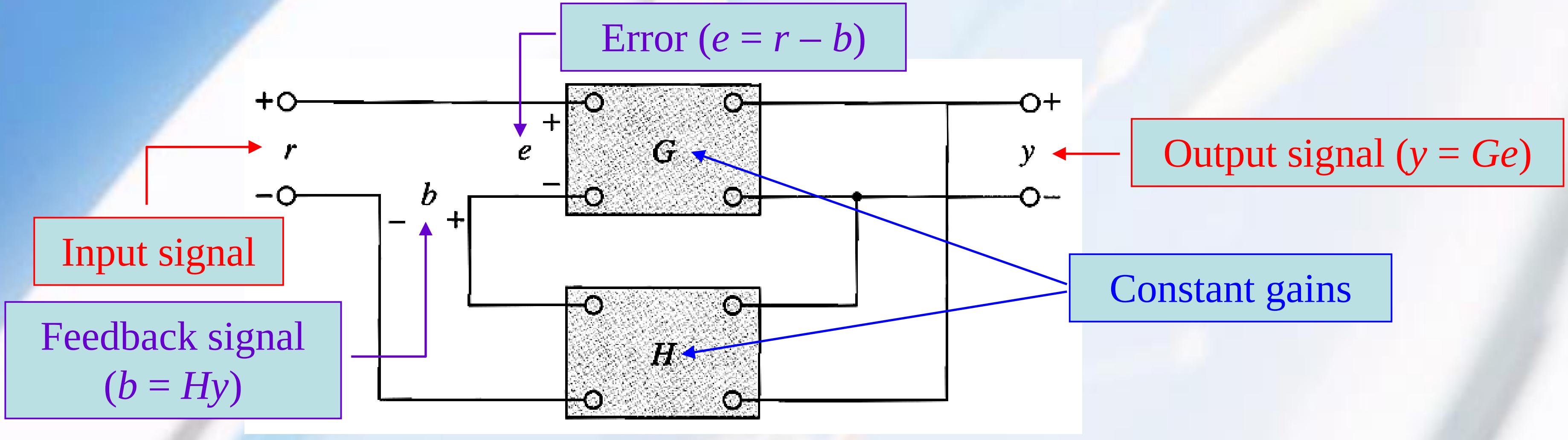


Figure 1-8 (a) Typical response of the open-loop idle-speed control system. (b) Typical response of the closed-loop idle-speed control system.

- **The objective of a regulator system is to maintain the system at a prescribed level.**

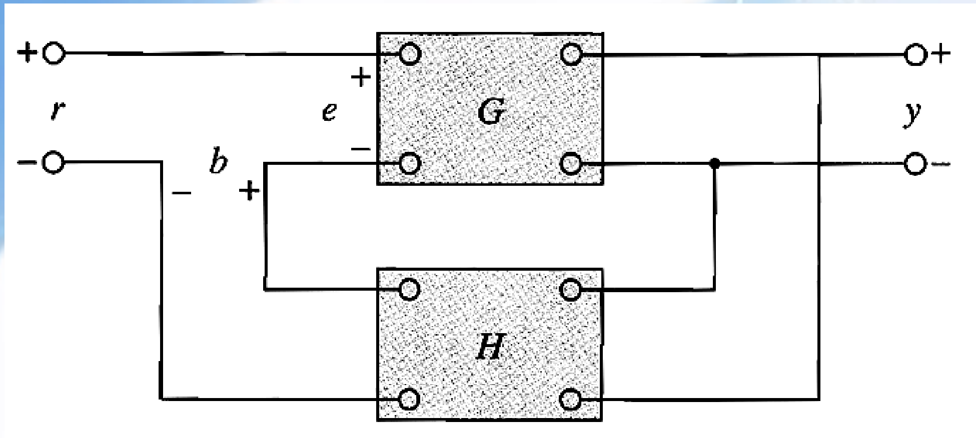
1-2 What Is Feedback, And What Are Its Effects?

Simple Feedback System Configuration



- **Feedback exists whenever there is a closed sequence of cause-and-effect relationships.**

Effect of Feedback on Overall Gain



- **Input-output relation:** $M = \frac{y}{r} = \frac{G}{1+GH}$ (1-1)

- ***Feedback may <u>increase</u> the gain of a system in one frequency range but <u>decrease</u> it in another.***

Two Feedback Loops

- **Input-output relation:** $M = \frac{y}{r} = \frac{G}{1+GH+GF}$ (1-2)

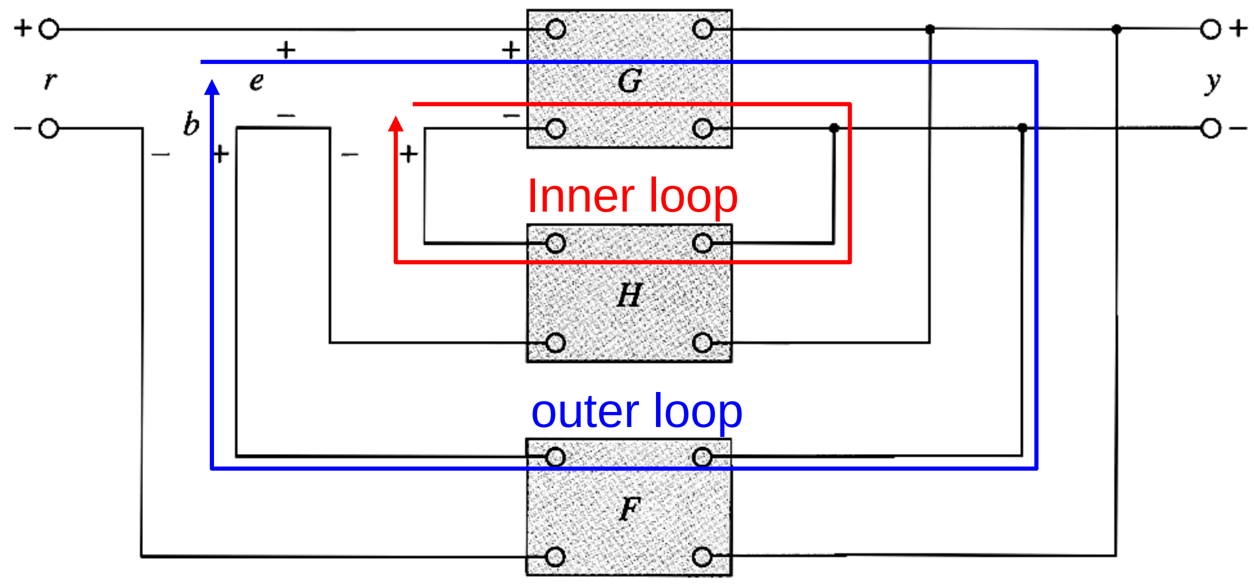


Figure 1-10 Feedback system with two feedback loops.

Effect of Feedback on Stability (1/2)

- **A system is *unstable* if its output is out of control.**
- ***Feedback can cause a system that is originally stable to become unstable.***
- *Example*: **If** $GH = -1$ **in (1-1), the output of the system is infinite for any finite input.**

$$M = \frac{y}{r} = \frac{G}{1+GH}$$

⇨ **The system is said to be unstable.**

Effect of Feedback on Stability (2/2)

- ***Feedback can stabilize an unstable system.***
- *Example*: **Assume that the inner-loop feedback system in Fig. 1-10 is unstable (i.e., $GH = -1$).**
  The overall system can be stable by properly selecting the outer-loop feedback gain F.

$$\Rightarrow \quad M = \frac{y}{r} = \frac{G}{1 + GH + GF} \qquad \begin{cases} 1 + GH = 0 \\ 1 + GH + GF \neq 0 \end{cases}$$

- ***Feedback can improve stability or be harmful to stability if it is not properly applied.***

Sensitivity

- **A good control system should be very *insensitive* to parameter variations but *sensitive* to the input commands.**
- *Definition*: **The sensitivity of the gain of the overall system** M **to the variation in** G:

$$S_G^M = \frac{\partial M / M}{\partial G / G} = \frac{\text{percentage change in } M}{\text{percentage change in } G} \qquad (1\text{-}3)$$

- **Let** $M = \frac{y}{r} = \frac{G}{1+GH}$. **Then** $S_G^M = \frac{\partial M}{\partial G}\frac{G}{M} = \frac{1}{1+GH} \qquad (1\text{-}4)$

- ***Feedback can increase or decrease the sensitivity of a system.***

Effect of Feedback on External Disturbance or Noise

- ***Feedback can reduce the effect of noise and disturbance on system performance.***

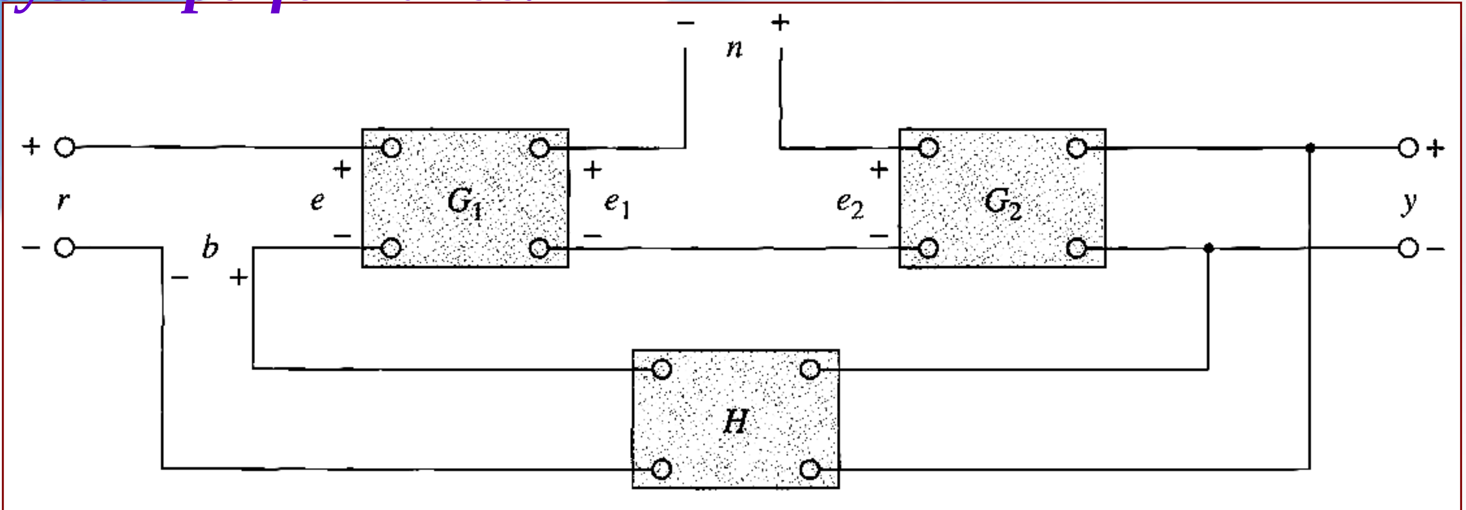


Figure 1-11 Feedback system with a noise signal.

- **The system output y due to the noise signal n acting alone**
  - **In the absence of feedback (H=0),** $y = G_2 n$ (1-5)
  - **With the presence of feedback,** $y = \frac{G_2}{1+G_1G_2H} n$ (1-6)

Effect of Feedback: Summary

- **Feedback may increase the gain of a system in one frequency range but decrease it in another.**
- **Feedback can improve stability or be harmful to stability if it is not properly applied.**
- **Feedback can increase or decrease the sensitivity of a system.**
- ***Feedback also can affect bandwidth, impedance, transient responses, and frequency responses.***

1-3 Types of Feedback Control Systems

- **According to the method of analysis and design**
  - ***linear or nonlinear***
  - ***time-varying or time-invariant***
- **According to the types of signal found in the system**
  - ***continuous-data or discrete-data***
    - **ac** or **dc** control system
    - **sampled-data** or **digital** control system
  - ***modulated or unmodulated***
- **According to the main purpose of the system**
  - ***position-control or velocity-control***

AC Control System

- **The signals in the system are *modulated* by some form of modulation scheme.**

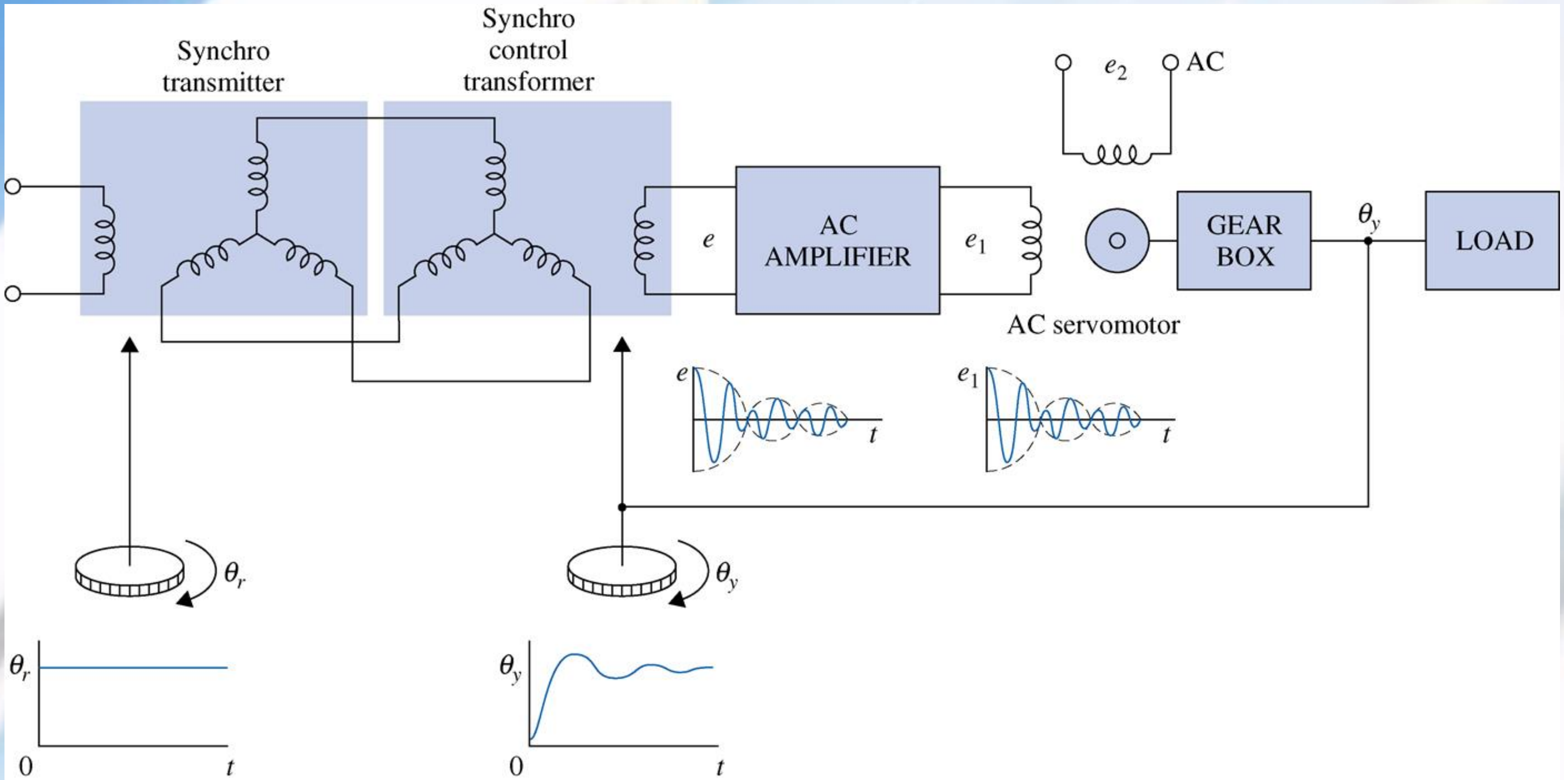


Figure 1-13: Schematic diagram of a typical ac closed-loop control system

DC Control System

- The signals in the system are *unmodulated*, but they are still ac signals according to the conventional definition.

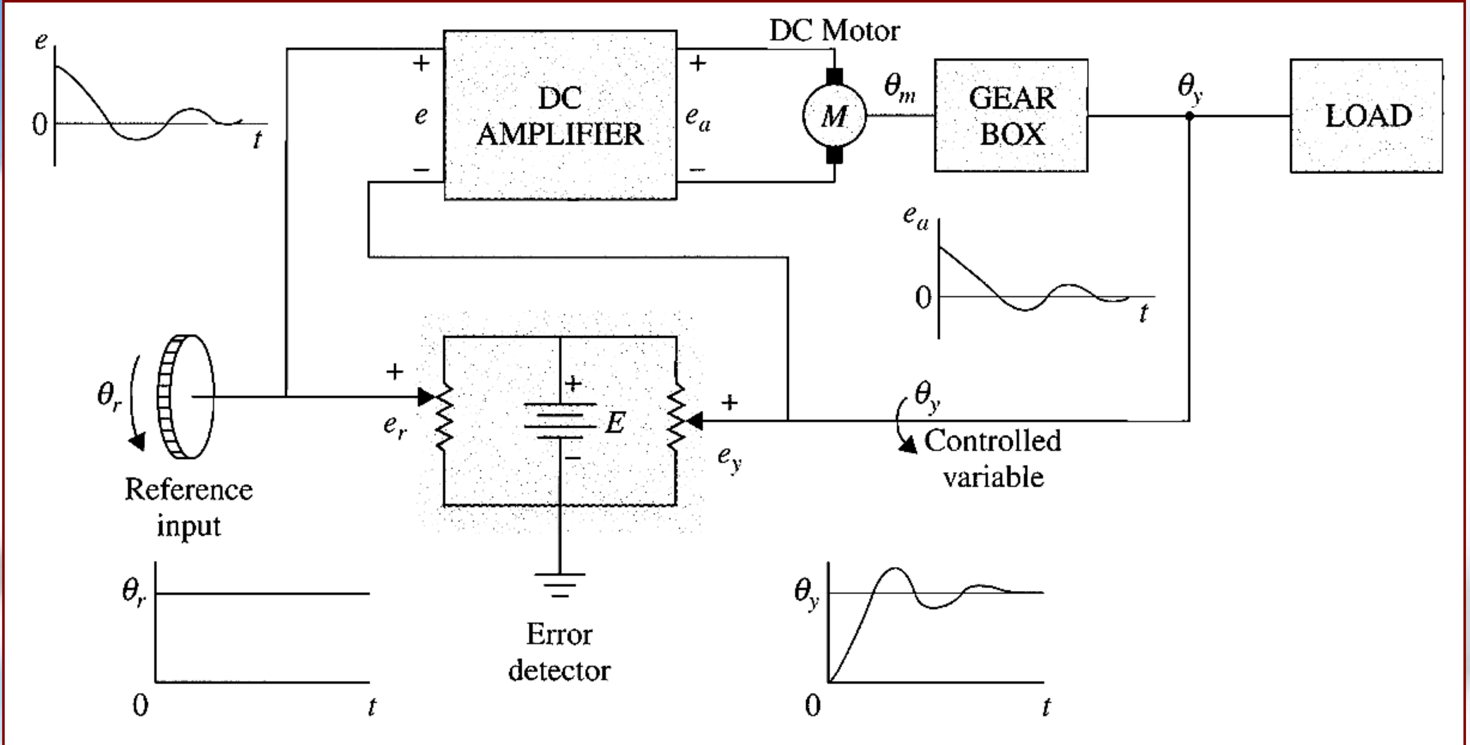


Figure 1-12 Schematic diagram of a typical dc closed-loop system.

Sample-Data & Digital Control Systems

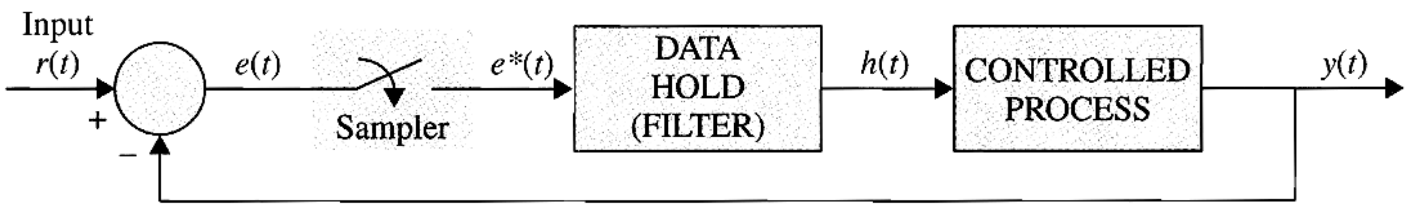


Figure 1-14 Block diagram of a sampled-data control system.

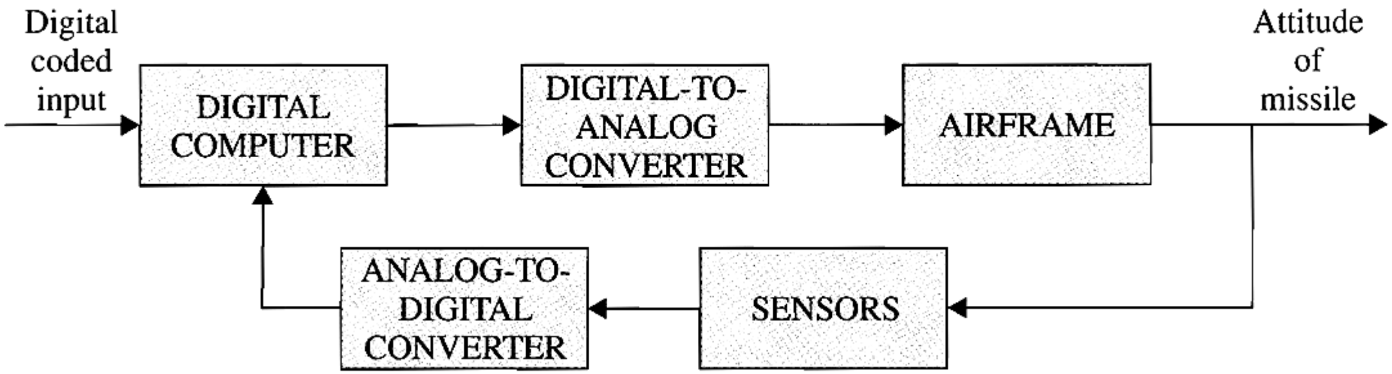


Figure 1-15 Digital autopilot system for a guided missile.