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# 电工学原理及应用

（英文精编版·第4版）

Electrical Engineering
Principles and Applications
Fourth Edition

（美）Allan R. Hambley 著

机械工业出版社
China Machine Press

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# Preface

As in the previous editions, my guiding philosophy in writing this book has three elements. The first element is my belief that in the long run students are best served by learning basic concepts in a general setting. Second, I believe that students need to be motivated by seeing how the principles apply to specific and interesting problems in their own fields. The third element of my philosophy is to take every opportunity to make learning free of frustration for the student.

This book covers circuit analysis and digital systems, at a level appropriate for either electrical-engineering students in an introductory course or nonmajors in a survey course. The only essential prerequisites are basic physics and single-variable calculus. Teaching a course using this book offers opportunities to develop theoretical and experimental skills and experiences in the following areas:

- Basic circuit analysis and measurement
- First-order transients
- Steady-state ac circuits
- Digital logic circuits
- Diode circuits
- Field-effect and bipolar junction transistors
- Operational amplifiers

While the emphasis of this book is on basic concepts, a key feature is the inclusion of short articles scattered throughout showing how electrical-engineering concepts are applied in other fields. The subjects of these articles include anti-knock signal processing for internal combustion engines, a cardiac pacemaker, active noise control, and the use of the Global Positioning System in surveying, among others.

I welcome comments from users of this book. Information on how the book could be improved is especially valuable and will be taken to heart in future revisions. My e-mail address is arhamble@mtu.edu.

## Prerequisites

The essential prerequisites for a course from this book are basic physics and single-variable calculus. A prior differential equations course would be helpful but is not essential. Differential equations are encountered in Chapter 4 on transient analysis, but the skills needed are developed from basic calculus.

## Pedagogical Features

The book includes various pedagogical features designed with the goal of stimulating student interest, eliminating frustration, and engendering an awareness of the relevance of the material to their chosen profession. These features are:

■ Statements of learning objectives open each chapter.

■ Comments in the margins emphasize and summarize important points or indicate common pitfalls that students need to avoid.

■ Short boxed articles demonstrate how electrical-engineering principles are applied in other fields of engineering. For example, see the articles on active noise cancellation and electronic pacemakers.

■ Step-by-step problem solving procedures.

■ Summaries of important points at the end of each chapter provide references for students.

## Meeting Abet-Directed Outcomes

Courses based on this book provide excellent opportunities to meet many of the directed outcomes for accreditation. The Criteria for Accrediting Engineering Programs require that graduates of accredited programs have "an ability to apply knowledge of mathematics, science, and engineering" and "an ability to identify, formulate, and solve engineering problems." This book, in its entirety, is aimed at developing these abilities.

Furthermore, the criteria require "an ability to function on multi-disciplinary teams" and "an ability to communicate effectively." Courses based on this book contribute to these abilities by giving nonmajors the knowledge and vocabulary to communicate effectively with electrical engineers. The book also helps to inform electrical engineers about applications in other fields of engineering. To aid in communication skills, end-of-chapter problems that ask students to explain electrical-engineering concepts in their own words are included.

## Solutions Manual and Website

Any corrections that may be needed for the book or solutions manual will be posted on the website as they are found. The home page for this book is located at www.myengineeringlab.com

Students will also find practice problems and online homework on this site if it is assigned by their instructor.

## Instructor Resources

The website also contains resources for instructors including:

- A new online homework system
- PowerPoint lecture slides
- Instructor's Solutions Manual

Furthermore, a complete solutions manual is available in hard copy from the publisher to instructors who have adopted the book.

## Acknowledgments

I wish to thank my colleagues, past and present, in the Electrical and Computer Engineering Department at Michigan Technological University, all of whom have given me help and encouragement at one time or another in writing this book and in my other projects.

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Over the years, many students and faculty using my books at Michigan Technological University and elsewhere have made many excellent suggestions for improving the books and correcting errors. I thank them very much.

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Allan R. Hambley

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# PART ONE
# Circuits

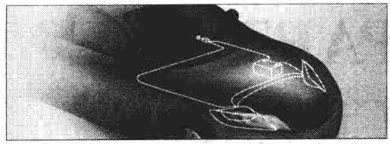
**Chapter 1** Introduction
**Chapter 2** Resistive Circuits
**Chapter 3** Inductance and Capacitance
**Chapter 4** Transients
**Chapter 5** Steady-State Sinusoidal Analysis
**Chapter 6** Frequency Response, Bode Plots, and Resonance

Electrical circuits are the subject of the first part of this book because they are the basis for all branches of electrical engineering, including digital logic, computers, instrumentation systems, electronics, electrical machines, power conversion, and power distribution.

In Chapter 1, we point out the reasons that the study of electrical engineering is important for all engineers and scientists, describe various branches of electrical engineering, and introduce electrical circuit quantities. In the second chapter, we analyze resistive circuits powered by dc sources. Capacitance and inductance are discussed in Chapter 3. Analysis of transients in electrical circuits is presented in Chapter 4. Chapter 5 analyzes circuits containing sinusoidal sources in steady-state conditions. Finally, Chapter 6 treats frequency response and resonance.

The study of electrical circuits has parallels in other areas of science and engineering. Dc analysis of resistive circuits corresponds to statics, transient analysis of circuits corresponds to dynamics, and many of the concepts of steady-state ac circuits, frequency response, and resonance have parallels in the study of sound and vibration. Learning circuit analysis will strengthen the mathematical and intuitive skills you will need in your engineering or scientific career.

# Chapter 1
# Introduction



**Study of this chapter will enable you to:**

1. Recognize interrelationships between electrical engineering and other fields of science and engineering.
2. List the major subfields of electrical engineering.
3. List several important reasons for studying electrical engineering.
4. Define current, voltage, and power, including their units.
5. Calculate power and energy and determine whether energy is supplied or absorbed by a circuit element.
6. State and apply Kirchhoff's current and voltage laws.
7. Recognize series and parallel connections.
8. Identify and describe the characteristics of voltage and current sources.
9. State and apply Ohm's law.
10 Solve for currents, voltages, and powers in simple circuits.

**Introduction to this chapter:**

In this chapter, we introduce electrical engineering, define circuit variables (current, voltage, power, and energy), study the laws that these circuit variables obey, and meet several circuit elements (current sources, voltage sources, and resistors).

## 1.1 Overview of Electrical Engineering

Electrical engineers design systems that have two main objectives:

1. To gather, store, process, transport, and present *information*.
2. To distribute, store, and convert *energy* between various forms.

In many electrical systems, the manipulation of energy and the manipulation of information are interdependent.

For example, numerous aspects of electrical engineering relating to information are applied in weather prediction. Data about cloud cover, precipitation, wind speed, and so on are gathered electronically by weather satellites, by land-based radar stations, and by sensors at numerous weather stations.

(Sensors are devices that convert physical measurements to electrical signals.) This information is transported by electronic communication systems and processed by computers to yield forecasts that are disseminated and displayed electronically.

In electrical power plants, energy is converted from various sources to electrical form. Electrical distribution systems transport the energy to virtually every factory, home, and business in the world, where it is converted to a multitude of useful forms, such as mechanical energy, heat, and light.

No doubt you can list scores of electrical engineering applications in your daily life. Increasingly, electrical and electronic features are integrated into new products. Automobiles and trucks provide just one example of this trend. The electronic content of the average automobile is growing rapidly in value. Auto designers realize that electronic technology is a good way to provide increased functionality at lower cost. Table 1.1 shows some of the applications of electrical engineering in automobiles.

As another example, we note that many common household appliances contain keypads for operator control, sensors, electronic displays, and computer chips, as well as more conventional switches, heating elements, and motors. Electronics have become so intimately integrated with mechanical systems that a new name, **mechatronics**[1], is beginning to be used for the combination.

Unfortunately, it would seem that too many engineers are not well equipped to design mechatronic products:

The world of engineering is like an archipelago whose inhabitants are familiar with their own islands but have only a distant view of the others and little communication with them. A comparable near-isolation impedes the productivity of engineers, whether their field is electrical and electronics, mechanical, chemical, civil, or industrial. Yet modern manufacturing systems, as well as the planes, cars, computers, and myriad other complex products of their making, depend on the harmonious blending of many different technologies. (Richard Comerford, "Mecha . . . what?" *IEEE Spectrum,* August 1994)

### 1.1.1 Subdivisions of Electrical Engineering

Next, we give you an overall picture of electrical engineering by listing and briefly discussing eight of its major areas.

**1. Communication systems** transport information in electrical form. Cellular phone, radio, satellite television, and the Internet are examples of commu-

[1] You may find it interesting to search the web for sites related to "mechatronics."

nication systems. It is possible for virtually any two people (or computers) on the globe to communicate almost instantaneously. A climber on a mountaintop in Nepal can call or send e-mail to friends whether they are hiking in Alaska or sitting in a New York City office. This kind of connectivity affects the way we live, the way we conduct business, and the design of everything we use. For example, communication systems will change the design of highways because traffic and road-condition information collected by roadside sensors can be transmitted to central locations and used to route traffic. When an accident occurs, an electrical signal can be emitted automatically when the airbags deploy, giving the exact location of the vehicle, summoning help, and notifying traffic-control computers.

**Table 1.1. Current and Emerging Electronic/Electrical Applications in Automobiles and Trucks**

| |
|---|
| Safety |
| Antiskid brakes |
| Inflatable restraints |
| Collision warning and avoidance |
| Blind-zone vehicle detection (especially for large trucks) |
| Infrared night vision systems |
| Heads-up displays |
| Automatic accident notification |
| Communications and entertainment |
| AM/FM radio |
| Digital audio broadcasting |
| CD/tape player |
| Cellular phone |
| Computer/e-mail |
| Satellite radio |
| Convenience |
| Electronic navigation |
| Personalized seat/mirror/radio settings |
| Electronic door locks |
| Emissions, performance, and fuel economy |
| Vehicle instrumentation |
| Electronic ignition |
| Tire inflation sensors |
| Computerized performance evaluation and maintenance scheduling |
| Adaptable suspension systems |
| Alternative propulsion systems |
| Electric vehicles |
| Advanced batteries |
| Hybrid vehicles |

**2. Computer systems**[1] process and store information in digital form. No doubt you have already encountered computer applications in your own field. Besides the computers of which you are aware, there are many in unobvious places, such as household appliances and automobiles. A typical modern automobile contains several dozen special-purpose computers. Chemical processes and railroad switching yards are routinely controlled through computers.

**3. Control systems** gather information with sensors and use electrical energy to control a physical process. A relatively simple control system is the heating/cooling system in a residence. A sensor (thermostat) compares the temperature with the desired value. Control circuits operate the furnace or air conditioner to achieve the desired temperature. In rolling sheet steel, an electrical control system is used to obtain the desired sheet thickness. If the sheet is too thick (or thin), more (or less) force is applied to the rollers. The temperatures and flow rates in chemical processes are controlled in a similar manner. Control systems have even been installed in tall buildings to reduce their movement due to wind.

**4. Electromagnetics** is the study and application of electric and magnetic fields. The device (known as a magnetron) used to produce microwave energy in an oven is one application. Similar devices, but with much higher power levels, are employed in manufacturing sheets of plywood. Electromagnetic fields heat the glue between layers of wood so that it will set quickly. Cellular phone and television antennas are also examples of electromagnetic devices.

**5. Electronics** is the study and application of materials, devices, and circuits used in amplifying and switching electrical signals. The most important electronic devices are transistors of various kinds. They are used in nearly all places where electrical information or energy is employed. For example, the cardiac pacemaker is an electronic circuit that senses heart beats, and if a beat does not occur when it should, applies a minute electrical stimulus to the heart, forcing a beat. Electronic instrumentation and electrical sensors are found in every field of science and engineering. Many of the aspects of electronic amplifiers studied later in this book have direct application to the instrumentation used in your field of engineering.

**6. Photonics** is an exciting new field of science and engineering that promises to replace conventional computing, signal-processing, sensing, and communication devices based on manipulating electrons with greatly improved products

---

[1] Computers that are part of products such as appliances and automobiles are called *embedded computers.*

based on manipulating photons. Photonics includes light generation by lasers and light-emitting diodes, transmission of light through optical components, as well as switching, modulation, amplification, detection, and steering light by electrical, acoustical, and photon-based devices. Current applications include readers for DVD disks, holograms, optical signal processors, and fiber-optic communication systems. Future applications include optical computers, holographic memories, and medical devices. Photonics offers tremendous opportunities for nearly all scientists and engineers.[1]

**7. Power systems** convert energy to and from electrical form and transmit energy over long distances. These systems are composed of generators, transformers, distribution lines, motors, and other elements. Mechanical engineers often utilize electrical motors to empower their designs. The selection of a motor having the proper torque-speed characteristic for a given mechanical application is another example of how you can apply the information in this book.

**8. Signal processing** is concerned with information-bearing electrical signals. Often, the objective is to extract useful information from electrical signals derived from sensors. An application is machine vision for robots in manufacturing. Another application of signal processing is in controlling ignition systems of internal combustion engines. The timing of the ignition spark is critical in achieving good performance and low levels of pollutants. The optimum ignition point relative to crankshaft rotation depends on fuel quality, air temperature, throttle setting, engine speed, and other factors.

If the ignition point is advanced slightly beyond the point of best performance, *engine knock* occurs. Knock can be heard as a sharp metallic noise that is caused by rapid pressure fluctuations during the spontaneous release of chemical energy in the combustion chamber. A combustion-chamber pressure pulse displaying knock is shown in Figure 1.1. At high levels, knock will destroy an engine in a very short time. Prior to the advent of practical signal-processing electronics for this application, engine timing needed to be adjusted for distinctly suboptimum performance to avoid knock under varying combinations of operating conditions.

By connecting a sensor through a tube to the combustion chamber, an electrical signal proportional to pressure is obtained. Electronic circuits process this signal to determine whether the rapid pressure fluctuations characteristic

[1] Electronic devices are based on controlling electrons. Photonic devices perform similar functions by controlling photons.