

ELECTRICAL ENGINEERING

PRINCIPLES & APPLICATIONS



ALLAN R. HAMBLEY

ELECTRICAL ENGINEERING

Principles and Applications

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*To
Judy and Tony*

Preface

This book surveys electrical engineering for nonmajors in their third or fourth year of study. The goals of the book are:

1. To give engineering students a solid foundation in the basics of circuits, electronics, and electromechanics.
2. To make the subject as interesting and as free of frustration as possible for the student.
3. To provide a self-contained treatment, including reviews of such topics as complex numbers and differential equations.
4. To discuss briefly some advanced applications of the basic principles, especially those closely related to other engineering fields, so students can see that electrical engineering is relevant to their chosen field.
5. To provide a generous amount of material so instructors can select the topics most appropriate for their students. (Depending on the time available, some chapters can be skipped altogether.)

The book proceeds through the basic concepts of electrical circuits, electronics (analog and digital), and electromechanics. Each chapter includes a statement of objectives at the outset, many worked examples, exercises with answers, an end-of-chapter summary, and numerous homework problems. (A solutions manual is available to instructors from the publisher.) The background required is provided by the usual physics, calculus, and differential equations courses taken by engineering students.

PHILOSOPHY OF THE BOOK

In the long run, students are best served by learning basic concepts in a general setting. However, students need the motivation provided by seeing how the principles apply to interesting and specific problems in their own fields. 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 antiknock signal-processing circuits for internal combustion engines, a cardiac pacemaker, the use of the global positioning system in surveying, and batteries for electric/hybrid vehicles, among others.

CONTENT

Part One covers basic circuit theory, including an introduction to computer-aided analysis using PSpice. Chapter 1 defines current, voltage, power, and energy.

Kirchhoff's laws are introduced. Voltage sources, current sources, and resistance are defined.

Chapter 2 treats resistive circuits. Analysis by network reduction, node voltages, and mesh currents is covered. Thévenin equivalents, superposition, and the Wheatstone bridge are treated. The last section of the chapter begins to introduce computer-aided analysis with PSpice.

Capacitance, inductance, and mutual inductance are treated in Chapter 3.

Transients in electrical circuits are discussed in Chapter 4. First-order RL and RC circuits and time constants are covered followed by a discussion of second-order circuits. The chapter ends with a section showing how transient analysis can be carried out with PSpice.

Chapter 5 considers sinusoidal steady-state circuit behavior. (A review of complex arithmetic is included in Appendix A.) Power calculations, ac Thévenin and Norton equivalents, and balanced three-phase circuits are treated. Finally, the chapter illustrates ac analysis with PSpice.

Chapter 6 covers frequency response, Bode plots, resonance, and filters. The basic concept of Fourier theory (that signals are composed of sinusoidal components having various amplitudes, phases, and frequencies) is discussed qualitatively. Frequency analysis using PSpice is illustrated.

Part Two treats analog and digital electronics. Chapter 7 presents the diode, its various models, load-line analysis, and diode circuits such as rectifiers, Zener-diode regulators, and wave-shapers.

In Chapter 8, the specifications and imperfections of amplifiers that need to be considered in applications are discussed from a user's perspective. These include gain, input impedance, output impedance, loading effects, frequency response, pulse response, nonlinear distortion, common-mode rejection, and dc offsets.

The bipolar junction transistor, its characteristic curves, load-line analysis, large- and small-signal models, bias circuits, the common-emitter amplifier, and the emitter follower are discussed in Chapter 9.

Chapter 10 gives a similar treatment for field-effect transistors. If desired, the order of Chapters 9 and 10 can be reversed. Another possibility is to skip most of both chapters so that more time can be devoted to op amps.

Chapter 11 treats the operational amplifier and many of its applications. Non-majors can learn enough from this chapter to design and use op-amp circuits for instrumentation applications in their own fields.

Chapter 12 introduces the CMOS logic inverter and gate circuits. It then proceeds to discuss combinatorial and sequential logic. Boolean algebra, De Morgan's laws, truth tables, Karnaugh maps, coders, decoders, flip-flops, and registers are discussed.

Chapter 13 treats digital systems, microprocessors, data acquisition, digital-to-analog and analog-to-digital converters, and data transmission.

Part Three is an introduction to electromechanics. In Chapter 14 we review basic magnetic field theory, analyze magnetic circuits, and present transformers.

Dc machines and ac machines are treated in Chapters 15 and 16, respectively. The emphasis is on motors rather than generators because the nonelectrical engineer applies motors much more often than generators.

In Chapter 15 an overall view of motors in general is presented before considering dc motors, their equivalent circuits, and performance calculations. The universal motor and its applications are discussed. If desired, Chapter 16 can be studied immediately after finishing Section 15.1.

Chapter 16 deals with ac motors, starting with the three-phase induction motor. Synchronous motors and their advantages with respect to power-factor correction are analyzed. Small motors, including single-phase induction motors, are also discussed.

E-MAIL

I look forward to receiving 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

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Any corrections that may be needed for the book will be posted on the internet as they are found. My home page is located at

<http://www.ee.mtu.edu/faculty/arhamble.html>

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Allan R. Hambley

ELECTRICAL ENGINEERING

Principles and Applications

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Chapter 1

Introduction

► **I**n 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).

Study of this chapter will enable you to:

- Recognize interrelationships of electrical engineering with other fields of engineering.
- List the major subfields of electrical engineering.
- List several important reasons for studying electrical engineering.
- Define current, voltage, and power, including their units.
- Calculate power and energy, as well as determine whether energy is supplied or absorbed by a circuit element.
- State and apply basic circuit laws.
- Solve for currents, voltages, and powers in simple circuits.

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 and convert *energy* between various forms

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

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 developed 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 was about \$1000 as of 1996 and is growing at about 12% annually. 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**, 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)

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

Communications and entertainment

- AM/FM radio
- Digital audio broadcasting
- CD/tape player
- Cellular phone

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
-

1.1.1 Subdivisions of Electrical Engineering

Next we give you an overall picture of the field by listing and briefly discussing seven of the major areas of electrical engineering.

1. Communication systems transport information in electrical form. Cellular phone, radio, satellite television, and the Internet are examples of communication systems. Shortly, it will be possible for any two people (or computers) on the globe to communicate almost instantaneously. A climber on a mountaintop in Nepal will be able to 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 is going to affect 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.

2. Computer systems 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 a dozen or more special-purpose computers. Chemical processes and railroad switching yards are now 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 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. A radio or television antenna is another example of an electromagnetic device.

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. 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.