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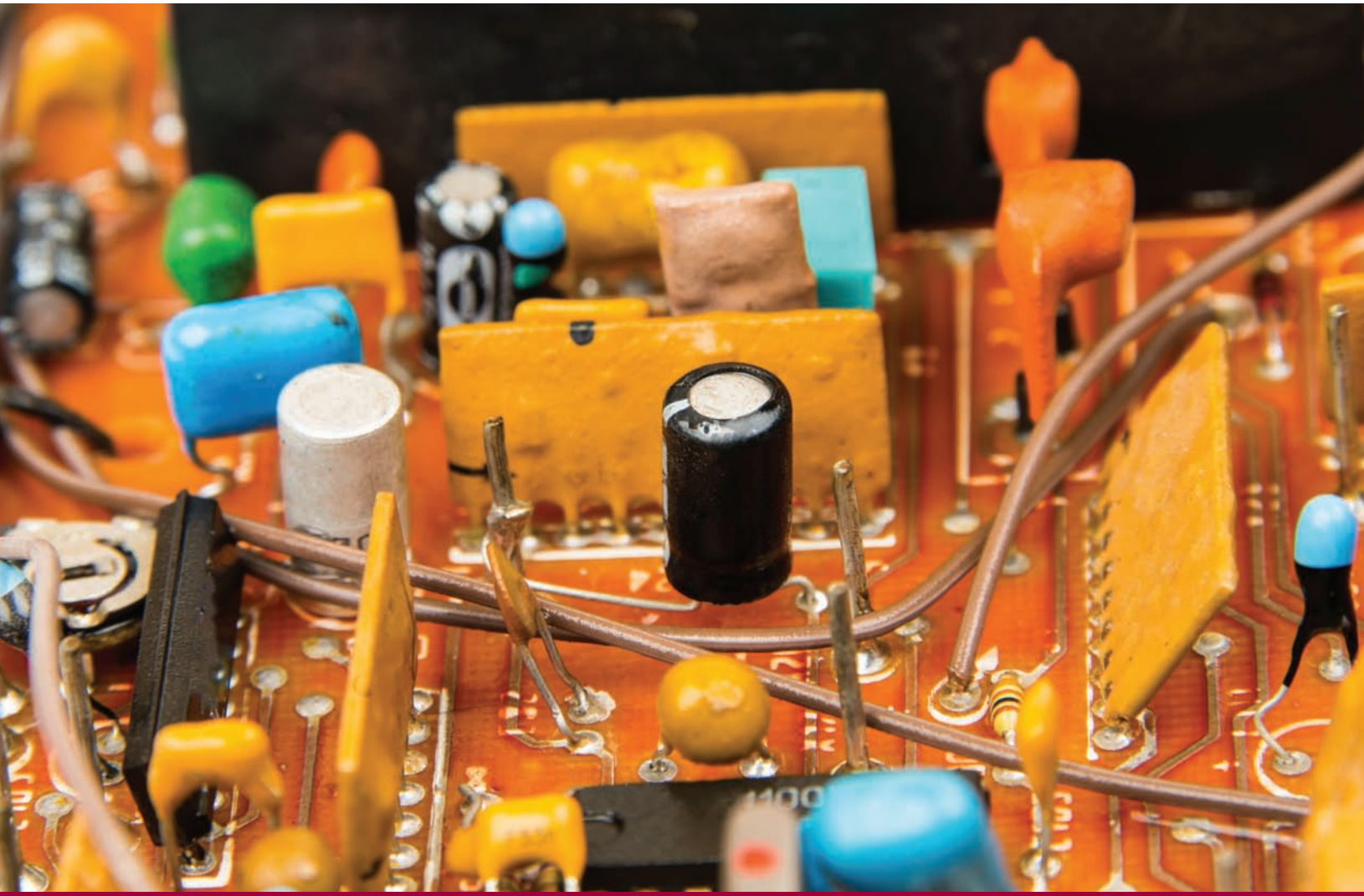
Electric Circuits

TENTH EDITION

James W. Nilsson • Susan A. Riedel



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To Anna

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Preface

The first edition of Electric Circuits, an introductory circuits text, was published in 1983. It included 100 worked examples and about 600 problems. It did not include a student workbook, supplements for PSpice or MultiSim, or any web support. Support for instructors was limited to a solution manual for the problems and enlarged copies of many text figures, suitable for making transparencies.

Much has changed in the 31 years since Electric Circuits first appeared, and during that time this text has evolved to better meet the needs of both students and their instructors. As an example, the text now includes about 150 worked examples, about 1850 problems, and extensive supplements and web content. The tenth edition is designed to revise and improve the material presented in the text, in its supplements, and on the web. Yet the fundamental goals of the text are unchanged. These goals are:

- To build an understanding of concepts and ideas explicitly in terms of previous learning. Students are constantly challenged by the need to layer new concepts on top of previous concepts they may still be struggling to master. This text provides an important focus on helping students understand how new concepts are related to and rely upon concepts previously presented.
- To emphasize the relationship between conceptual understanding and problem-solving approaches. Developing problem-solving skills continues to be the central challenge in a first-year circuits course. In this text we include numerous Examples that present problem-solving techniques followed by Assessment Problems that enable students to test their mastery of the material and techniques introduced. The problem-solving process we illustrate is based on concepts rather than the use of rote procedures. This encourages students to think about a problem before attempting to solve it.
- To provide students with a strong foundation of engineering practices. There are limited opportunities in a first-year circuit analysis course to introduce students to realistic engineering experiences. We continue to take advantage of the opportunities that do exist by including problems and examples that use realistic component values and represent realizable circuits. We include many problems related to the Practical Perspective problems that begin each chapter. We also include problems intended to stimulate the students' interest in engineering, where the problems require the type of insight typical of a practicing engineer.

WHY THIS EDITION?

The tenth edition revision of *Electric Circuits* began with a thorough review of the text. This review provided a clear picture of what matters most to instructors and their students and led to the following changes:

- Problem solving is fundamental to the study of circuit analysis. Having a wealth of new problems to assign and work is a key to success in any circuits course. Therefore, existing end-of-chapter problems were revised, and new end-of-chapter problems were added. As a result, more than 40% of the problems in the tenth edition have never appeared in any previous edition of the text.

- Both students and instructors want to know how the generalized techniques presented in a first-year circuit analysis course relate to problems faced by practicing engineers. The Practical Perspective problems provide this connection between circuit analysis and the real world. We have created new Practical Perspective problems for Chapters 2, 3, 6, 7, 8, and 10. Many of the new problems represent the world of the 21st century. Each Practical Perspective problem is solved, at least in part, at the end of the chapter, and additional end-of-chapter problems can be assigned to allow students to explore the Practical Perspective topic further.
- The PSpice and Multisim manuals have been revised to include screenshots from the most recent versions of these software simulation applications. Each manual presents the simulation material in the same order as the material is presented in the text. These manuals continue to include examples of circuits to be simulated that are drawn directly from the text. The text continues to indicate end-of-chapter problems that are good candidates for simulation using either PSpice or Multisim.
- Students who could benefit from additional examples and practice problems can use the Student Workbook, which has been revised to reflect changes to the tenth edition of the text. This workbook has examples and problems covering the following material: balancing power, simple resistive circuits, node voltage method, mesh current method, Thévenin and Norton equivalents, op amp circuits, first-order circuits, second-order circuits, AC steady-state analysis, and Laplace transform circuit analysis.
- The Student Workbook now includes access to Video Solutions, complete, step-by-step solution walkthroughs to representative homework problems.
- Learning Catalytics, a "bring your own device" student engagement, assessment, and classroom intelligence system is now available with the tenth edition. With Learning Catalytics you can:
  - Use open-ended questions to get into the minds of students to understand what they do or don't know and adjust lectures accordingly.
  - Use a wide variety of question types to sketch a graph, annotate a circuit diagram, compose numeric or algebraic answers, and more.
  - Access rich analytics to understand student performance.
  - Use pre-built questions or add your own to make Learning Catalytics fit your course exactly.
- MasteringEngineering is an online tutorial and assessment program that provides students with personalized feedback and hints and instructors with diagnostics to track students' progress. With the tenth edition, MasteringEngineering will offer new tutorial homework problems, Coaching Activities, and Adaptive Follow-Up assignments. Visit www.masteringengineering.com for more information.

HALLMARK FEATURES

Chapter Problems

Users of *Electric Circuits* have consistently rated the Chapter Problems as one of the book's most attractive features. In the tenth edition, there are over 1650 end-of-chapter problems with approximately 40% that have never appeared in a previous edition. Problems are organized at the end of each chapter by section.

Practical Perspectives

The tenth edition continues the use of Practical Perspectives introduced with the chapter openers. They offer examples of real-world circuits, taken from real-world devices. The Practical Perspectives for six of the chapters are brand new to this edition. Every chapter begins with a brief description of a practical application of the material that follows. Once the chapter material is presented, the chapter concludes with a quantitative analysis of the Practical Perspective application. A group of end-of-chapter problems directly relates to the Practical Perspective application. Solving some of these problems enables you to understand how to apply the chapter contents to the solution of a real-world problem.

Assessment Problems

Each chapter begins with a set of chapter objectives. At key points in the chapter, you are asked to stop and assess your mastery of a particular objective by solving one or more assessment problems. The answers to all of the assessment problems are given at the conclusion of each problem, so you can check your work. If you are able to solve the assessment problems for a given objective, you have mastered that objective. If you need more practice, several end-of-chapter problems that relate to the objective are suggested at the conclusion of the assessment problems.

Examples

Every chapter includes many examples that illustrate the concepts presented in the text in the form of a numeric example. There are nearly 150 examples in this text. The examples are intended to illustrate the application of a particular concept, and also to encourage good problem-solving skills.

Fundamental Equations and Concepts

Throughout the text, you will see fundamental equations and concepts set apart from the main text. This is done to help you focus on some of the key principles in electric circuits and to help you navigate through the important topics.

Integration of Computer Tools

Computer tools can assist students in the learning process by providing a visual representation of a circuit's behavior, validating a calculated solution, reducing the computational burden of more complex circuits, and iterating toward a desired solution using parameter variation. This computational support is often invaluable in the design process. The tenth edition includes the support of PSpice® and Multisim®, both popular computer tools for circuit simulation and analysis. Chapter problems suited for exploration with PSpice and Multisim are marked accordingly.

Design Emphasis

The tenth edition continues to support the emphasis on the design of circuits in many ways. First, many of the Practical Perspective discussions focus on the design aspects of the circuits. The accompanying Chapter Problems continue the discussion of the design issues in these practical examples. Second, design-oriented Chapter Problems have been labeled explicitly, enabling students and instructors to identify those problems with a design focus. Third, the identification of problems suited to exploration with PSpice or Multisim suggests design opportunities using these

software tools. Fourth, some problems in nearly every chapter focus on the use of realistic component values in achieving a desired circuit design. Once such a problem has been analyzed, the student can proceed to a laboratory to build and test the circuit, comparing the analysis with the measured performance of the actual circuit.

Accuracy

All text and problems in the tenth edition have undergone our strict hallmark accuracy checking process, to ensure the most error-free book possible.

RESOURCES FOR STUDENTS

MasteringEngineering. MasteringEngineering provides tutorial homework problems designed to emulate the instructor's office hour environment, guiding students through engineering concepts with self-paced individualized coaching. These in-depth tutorial homework problems provide students with feedback specific to their errors and optional hints that break problems down into simpler steps. Visit www.masteringengineering.com for more information.

Student Workbook. This resource teaches students techniques for solving problems presented in the text. Organized by concepts, this is a valuable problem-solving resource for all levels of students.

The Student Workbook now includes access to Video Solutions, complete, step-by-step solution walkthroughs to representative homework problems.

Introduction to Multisim and Introduction to PSpice Manuals—Updated for the tenth edition, these manuals are excellent resources for those wishing to integrate PSpice or Multisim into their classes.

RESOURCES FOR INSTRUCTORS

All instructor resources are available for download at www.pearsonglobaleditions.com. If you are in need of a login and password for this site, please contact your local Pearson representative.

Instructor Solutions Manual—Fully worked-out solutions to Assessment Problems and end-of-chapter problems.

PowerPoint lecture images—All figures from the text are available in PowerPoint for your lecture needs. An additional set of full lecture slides with embedded assessment questions are available upon request.

MasteringEngineering. This online tutorial and assessment program allows you to integrate dynamic homework with automated grading and personalized feedback. MasteringEngineering allows you to easily track the performance of your entire class on an assignment-by-assignment basis, or the detailed work of an individual student. For more information visit www.masteringengineering.com.

Learning Catalytics—This "bring your own device" student engagement, assessment and classroom intelligence system enables you to measure student learning during class, and adjust your lectures accordingly. A wide variety of question and answer types allows you to author your own questions, or you can use questions already authored into the system. For more information visit www.learningcatalytics.com.

PREREQUISITES

In writing the first 12 chapters of the text, we have assumed that the reader has taken a course in elementary differential and integral calculus. We have also assumed that the reader has had an introductory physics course, at either the high school or university level, that introduces the concepts of energy, power, electric charge, electric current, electric potential, and electromagnetic fields. In writing the final six chapters, we have assumed the student has had, or is enrolled in, an introductory course in differential equations.

COURSE OPTIONS

The text has been designed for use in a one-semester, two-semester, or a three-quarter sequence.

- *Single-semester course:* After covering Chapters 1–4 and Chapters 6–10 (omitting Sections 7.7 and 8.5) the instructor can choose from Chapter 5 (operational amplifiers), Chapter 11 (three-phase circuits), Chapters 13 and 14 (Laplace methods), and Chapter 18 (Two-Port Circuits) to develop the desired emphasis.
- *Two-semester sequence:* Assuming three lectures per week, the first nine chapters can be covered during the first semester, leaving Chapters 10–18 for the second semester.
- *Academic quarter schedule:* The book can be subdivided into three parts: Chapters 1–6, Chapters 7–12, and Chapters 13–18.

The introduction to operational amplifier circuits in Chapter 5 can be omitted without interfering with the reading of subsequent chapters. For example, if Chapter 5 is omitted, the instructor can simply skip Section 7.7, Section 8.5, Chapter 15, and those assessment problems and end-of-chapter problems in the chapters following Chapter 5 that pertain to operational amplifiers.

There are several appendixes at the end of the book to help readers make effective use of their mathematical background. Appendix A reviews Cramer's method of solving simultaneous linear equations and simple matrix algebra; complex numbers are reviewed in Appendix B; Appendix C contains additional material on magnetically coupled coils and ideal transformers; Appendix D contains a brief discussion of the decibel; Appendix E is dedicated to Bode diagrams; Appendix F is devoted to an abbreviated table of trigonometric identities that are useful in circuit analysis; and an abbreviated table of useful integrals is given in Appendix G. Appendix H provides tables of common standard component values for resistors, inductors, and capacitors, to be used in solving many end-of-chapter problems. Selected Answers provides answers to selected end-of-chapter problems.

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There were many hard-working people behind the scenes at our publisher who deserve our thanks and gratitude for their efforts on behalf of the tenth edition. At Pearson, we would like to thank Andrew Gilfillan, Rose Kernan, Gregory Dulles, Tim Galligan, and Scott Disanno for their continued support and encouragement, their professional demeanor, their willingness to lend an ear, and their months of long hours and no weekends. The authors would also like to acknowledge the staff at Integra Software Solutions for their dedication and hard work in typesetting this text. The authors would also like to thank Kurt Norlin for his help in accuracy checking the text and problems.

We are very grateful for the many instructors and students who have done formal reviews of the text or offered positive feedback and suggestions for improvement more informally. We are pleased to receive email from instructors and students who use the book, even when they are pointing out an error we failed to catch in the review process. We have been contacted by people who use our text from all over the world, and we thank all of you for taking the time to do so. We use as many of your suggestions as possible to continue to improve the content, the pedagogy, and the presentation in this text. We are privileged to have the opportunity to impact the educational experience of the many thousands of future engineers who will use this text.

James W. Nilsson
Susan A. Riedel

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ELECTRIC CIRCUITS

TENTH EDITION

CHAPTER

1

Circuit Variables

CHAPTER CONTENTS

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1.2 **The International System of Units** *p. 30*
1.3 **Circuit Analysis: An Overview** *p. 32*
1.4 **Voltage and Current** *p. 33*
1.5 **The Ideal Basic Circuit Element** *p. 34*
1.6 **Power and Energy** *p. 36*

✓CHAPTER OBJECTIVES

1. Understand and be able to use SI units and the standard prefixes for powers of 10.
2. Know and be able to use the definitions of *voltage* and *current*.
3. Know and be able to use the definitions of *power* and *energy*.
4. Be able to use the passive sign convention to calculate the power for an ideal basic circuit element given its voltage and current.

Electrical engineering is an exciting and challenging profession for anyone who has a genuine interest in, and aptitude for, applied science and mathematics. Over the past century and a half, electrical engineers have played a dominant role in the development of systems that have changed the way people live and work. Satellite communication links, telephones, digital computers, televisions, diagnostic and surgical medical equipment, assembly-line robots, and electrical power tools are representative components of systems that define a modern technological society. As an electrical engineer, you can participate in this ongoing technological revolution by improving and refining these existing systems and by discovering and developing new systems to meet the needs of our ever-changing society.

As you embark on the study of circuit analysis, you need to gain a feel for where this study fits into the hierarchy of topics that comprise an introduction to electrical engineering. Hence we begin by presenting an overview of electrical engineering, some ideas about an engineering point of view as it relates to circuit analysis, and a review of the international system of units.

We then describe generally what circuit analysis entails. Next, we introduce the concepts of voltage and current. We follow these concepts with discussion of an ideal basic element and the need for a polarity reference system. We conclude the chapter by describing how current and voltage relate to power and energy.

Practical Perspective

Balancing Power

One of the most important skills you will develop is the ability to check your answers for the circuits you design and analyze using the tools developed in this text. A common method used to check for valid answers is to balance the power in the circuit. The linear circuits we study have no net power, so the sum of the power associated with each circuit component must be zero. If the total power for the circuit is zero, we say that the power balances, but if the total power is not zero, we need to find the errors in our calculation.

As an example, we will consider a very simple model for the distribution of electricity to a typical home, as shown below. (Note that a more realistic model will be investigated in the Practical Perspective for Chapter 9.) The components labeled a and b represent the electrical source to the home. The components labeled c, d, and e represent the wires that carry the electrical current from the source to the devices in the home requiring electrical power. The components labeled f, g, and h represent lamps, televisions, hair dryers, refrigerators, and other devices that require power.

Once we have introduced the concepts of voltage, current, power, and energy, we will examine this circuit model in detail, and use a power balance to determine whether the results of analyzing this circuit are correct.

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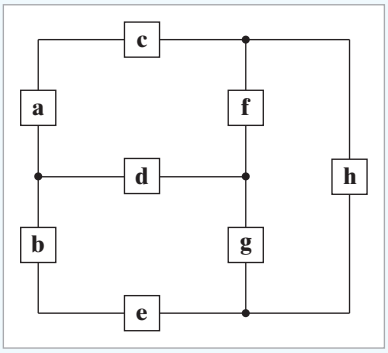

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1.1 Electrical Engineering: An Overview

Electrical engineering is the profession concerned with systems that produce, transmit, and measure electric signals. Electrical engineering combines the physicist's models of natural phenomena with the mathematician's tools for manipulating those models to produce systems that meet practical needs. Electrical systems pervade our lives; they are found in homes, schools, workplaces, and transportation vehicles everywhere. We begin by presenting a few examples from each of the five major classifications of electrical systems:

- communication systems
- computer systems
- control systems
- power systems
- signal-processing systems

Then we describe how electrical engineers analyze and design such systems.

Communication systems are electrical systems that generate, transmit, and distribute information. Well-known examples include television equipment, such as cameras, transmitters, receivers, and VCRs; radio telescopes, used to explore the universe; satellite systems, which return images of other planets and our own; radar systems, used to coordinate plane flights; and telephone systems.

Figure 1.1 depicts the major components of a modern telephone system. Starting at the left of the figure, inside a telephone, a microphone turns sound waves into electric signals. These signals are carried to a switching center where they are combined with the signals from tens, hundreds, or thousands of other telephones. The combined signals leave the switching center; their form depends on the distance they must travel. In our example, they are sent through wires in underground coaxial cables to a microwave transmission station. Here, the signals are transformed into microwave frequencies and broadcast from a transmission antenna through air and space, via a communications satellite, to a receiving antenna. The microwave receiving station translates the microwave signals into a form suitable for further transmission, perhaps as pulses of light to be sent through fiber-optic cable. On arrival at the second switching center, the combined signals are separated, and each is routed to the appropriate telephone, where an earphone acts as a speaker to convert the received electric signals back into sound waves. At each stage of the process, electric circuits operate on the signals. Imagine the challenge involved in designing, building, and operating each circuit in a way that guarantees that all of the hundreds of thousands of simultaneous calls have high-quality connections.

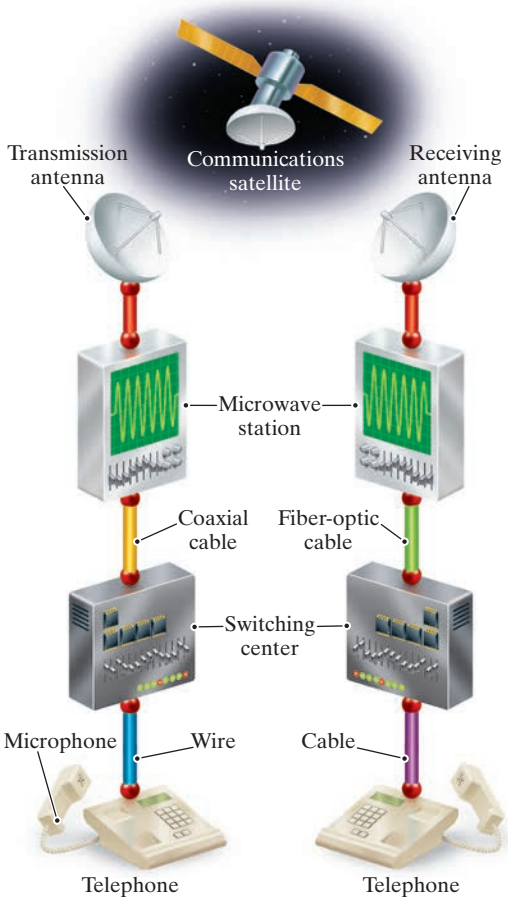

Figure 1.1 ▲ A telephone system.

Computer systems use electric signals to process information ranging from word processing to mathematical computations. Systems range in size and power from pocket calculators to personal computers to supercomputers that perform such complex tasks as processing weather data and modeling chemical interactions of complex organic molecules. These systems include networks of microcircuits, or integrated circuits—postage-stampsized assemblies of hundreds, thousands, or millions of electrical components that often operate at speeds and power levels close to fundamental physical limits, including the speed of light and the thermodynamic laws.

Control systems use electric signals to regulate processes. Examples include the control of temperatures, pressures, and flow rates in an oil refinery; the fuel-air mixture in a fuel-injected automobile engine; mechanisms such as the motors, doors, and lights in elevators; and the locks in the

Panama Canal. The autopilot and autolanding systems that help to fly and land airplanes are also familiar control systems.

Power systems generate and distribute electric power. Electric power, which is the foundation of our technology-based society, usually is generated in large quantities by nuclear, hydroelectric, and thermal (coal-, oil-, or gas-fired) generators. Power is distributed by a grid of conductors that crisscross the country. A major challenge in designing and operating such a system is to provide sufficient redundancy and control so that failure of any piece of equipment does not leave a city, state, or region completely without power.

Signal-processing systems act on electric signals that represent information. They transform the signals and the information contained in them into a more suitable form. There are many different ways to process the signals and their information. For example, image-processing systems gather massive quantities of data from orbiting weather satellites, reduce the amount of data to a manageable level, and transform the remaining data into a video image for the evening news broadcast. A computerized tomography (CT) scan is another example of an image-processing system. It takes signals generated by a special X-ray machine and transforms them into an image such as the one in Fig. 1.2. Although the original X-ray signals are of little use to a physician, once they are processed into a recognizable image the information they contain can be used in the diagnosis of disease and injury.

Considerable interaction takes place among the engineering disciplines involved in designing and operating these five classes of systems. Thus communications engineers use digital computers to control the flow of information. Computers contain control systems, and control systems contain computers. Power systems require extensive communications systems to coordinate safely and reliably the operation of components, which may be spread across a continent. A signal-processing system may involve a communications link, a computer, and a control system.

A good example of the interaction among systems is a commercial airplane, such as the one shown in Fig. 1.3. A sophisticated communications system enables the pilot and the air traffic controller to monitor the plane's location, permitting the air traffic controller to design a safe flight path for all of the nearby aircraft and enabling the pilot to keep the plane on its designated path. On the newest commercial airplanes, an onboard computer system is used for managing engine functions, implementing the navigation and flight control systems, and generating video information screens in the cockpit. A complex control system uses cockpit commands to adjust the position and speed of the airplane, producing the appropriate signals to the engines and the control surfaces (such as the wing flaps, ailerons, and rudder) to ensure the plane remains safely airborne and on the desired flight path. The plane must have its own power system to stay aloft and to provide and distribute the electric power needed to keep the cabin lights on, make the coffee, and show the movie. Signal-processing systems reduce the noise in air traffic communications and transform information about the plane's location into the more meaningful form of a video display in the cockpit. Engineering challenges abound in the design of each of these systems and their integration into a coherent whole. For example, these systems must operate in widely varying and unpredictable environmental conditions. Perhaps the most important engineering challenge is to guarantee that sufficient redundancy is incorporated in the designs to ensure that passengers arrive safely and on time at their desired destinations.

Although electrical engineers may be interested primarily in one area, they must also be knowledgeable in other areas that interact with this area of interest. This interaction is part of what makes electrical

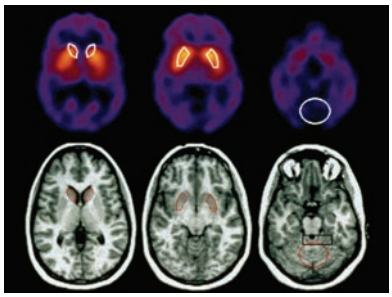

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Figure 1.2 ▲ A CT scan of an adult head.

Figure 1.3 ▲ An airplane.

engineering a challenging and exciting profession. The emphasis in engineering is on making things work, so an engineer is free to acquire and use any technique, from any field, that helps to get the job done.

Circuit Theory

In a field as diverse as electrical engineering, you might well ask whether all of its branches have anything in common. The answer is yes—electric circuits. An **electric circuit** is a mathematical model that approximates the behavior of an actual electrical system. As such, it provides an important foundation for learning—in your later courses and as a practicing engineer—the details of how to design and operate systems such as those just described. The models, the mathematical techniques, and the language of circuit theory will form the intellectual framework for your future engineering endeavors.

Note that the term *electric circuit* is commonly used to refer to an actual electrical system as well as to the model that represents it. In this text, when we talk about an electric circuit, we always mean a model, unless otherwise stated. It is the modeling aspect of circuit theory that has broad applications across engineering disciplines.

Circuit theory is a special case of electromagnetic field theory: the study of static and moving electric charges. Although generalized field theory might seem to be an appropriate starting point for investigating electric signals, its application is not only cumbersome but also requires the use of advanced mathematics. Consequently, a course in electromagnetic field theory is not a prerequisite to understanding the material in this book. We do, however, assume that you have had an introductory physics course in which electrical and magnetic phenomena were discussed.

Three basic assumptions permit us to use circuit theory, rather than electromagnetic field theory, to study a physical system represented by an electric circuit. These assumptions are as follows:

1. *Electrical effects happen instantaneously throughout a system.* We can make this assumption because we know that electric signals travel at or near the speed of light. Thus, if the system is physically small, electric signals move through it so quickly that we can consider them to affect every point in the system simultaneously. A system that is small enough so that we can make this assumption is called a **lumped-parameter system**.
2. *The net charge on every component in the system is always zero.* Thus no component can collect a net excess of charge, although some components, as you will learn later, can hold equal but opposite separated charges.
3. *There is no magnetic coupling between the components in a system.* As we demonstrate later, magnetic coupling can occur *within* a component.

That's it; there are no other assumptions. Using circuit theory provides simple solutions (of sufficient accuracy) to problems that would become hopelessly complicated if we were to use electromagnetic field theory. These benefits are so great that engineers sometimes specifically design electrical systems to ensure that these assumptions are met. The importance of assumptions 2 and 3 becomes apparent after we introduce the basic circuit elements and the rules for analyzing interconnected elements.

However, we need to take a closer look at assumption 1. The question is, "How small does a physical system have to be to qualify as a lumped-parameter system?" We can get a quantitative handle on the question by noting that electric signals propagate by wave phenomena. If the wavelength of the signal is large compared to the physical dimensions of the

system, we have a lumped-parameter system. The wavelength λ is the velocity divided by the repetition rate, or **frequency**, of the signal; that is, $\lambda = c/f$. The frequency f is measured in hertz (Hz). For example, power systems in the United States operate at 60 Hz. If we use the speed of light ($c = 3 \times 10^8$ m/s) as the velocity of propagation, the wavelength is 5×10^6 m. If the power system of interest is physically smaller than this wavelength, we can represent it as a lumped-parameter system and use circuit theory to analyze its behavior. How do we define *smaller*? A good rule is the *rule of 1/10th*: If the dimension of the system is 1/10th (or smaller) of the dimension of the wavelength, you have a lumped-parameter system. Thus, as long as the physical dimension of the power system is less than 5×10^5 m, we can treat it as a lumped-parameter system.

On the other hand, the propagation frequency of radio signals is on the order of 10^9 Hz. Thus the wavelength is 0.3 m. Using the rule of 1/10th, the relevant dimensions of a communication system that sends or receives radio signals must be less than 3 cm to qualify as a lumped-parameter system. Whenever any of the pertinent physical dimensions of a system under study approaches the wavelength of its signals, we must use electromagnetic field theory to analyze that system. Throughout this book we study circuits derived from lumped-parameter systems.

Problem Solving

As a practicing engineer, you will not be asked to solve problems that have already been solved. Whether you are trying to improve the performance of an existing system or creating a new system, you will be working on unsolved problems. As a student, however, you will devote much of your attention to the discussion of problems already solved. By reading about and discussing how these problems were solved in the past, and by solving related homework and exam problems on your own, you will begin to develop the skills to successfully attack the unsolved problems you'll face as a practicing engineer.

Some general problem-solving procedures are presented here. Many of them pertain to thinking about and organizing your solution strategy *before* proceeding with calculations.

1. *Identify what's given and what's to be found.* In problem solving, you need to know your destination before you can select a route for getting there. What is the problem asking you to solve or find? Sometimes the goal of the problem is obvious; other times you may need to paraphrase or make lists or tables of known and unknown information to see your objective.

   The problem statement may contain extraneous information that you need to weed out before proceeding. On the other hand, it may offer incomplete information or more complexities than can be handled given the solution methods at your disposal. In that case, you'll need to make assumptions to fill in the missing information or simplify the problem context. Be prepared to circle back and reconsider supposedly extraneous information and/or your assumptions if your calculations get bogged down or produce an answer that doesn't seem to make sense.

2. *Sketch a circuit diagram or other visual model.* Translating a verbal problem description into a visual model is often a useful step in the solution process. If a circuit diagram is already provided, you may need to add information to it, such as labels, values, or reference directions. You may also want to redraw the circuit in a simpler, but equivalent, form. Later in this text you will learn the methods for developing such simplified equivalent circuits.