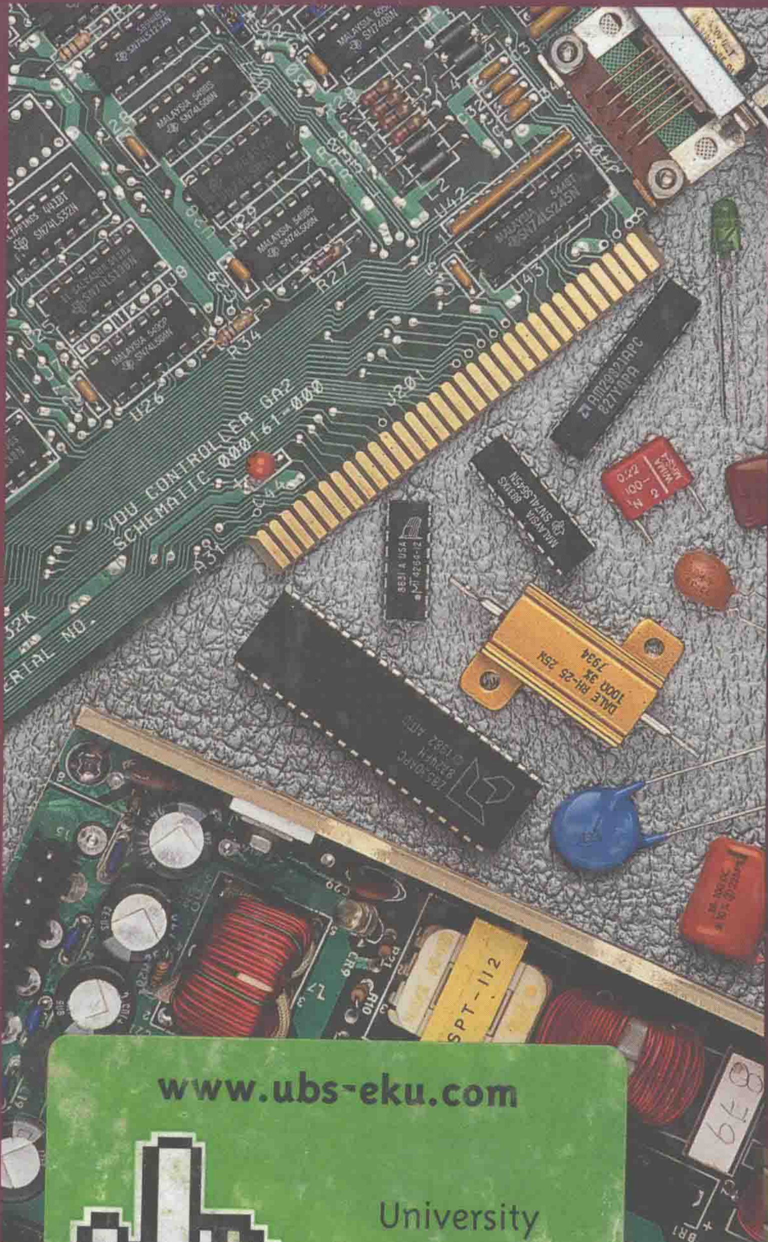

PRACTICAL ELECTRONICS

NIGEL P. COOK

Practical Electronics

Nigel P. Cook

PRENTICE HALL
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Preface

TO THE STUDENT

The early pioneers in electronics were intrigued by the mystery and wonder of a newly discovered science, whereas people today are attracted by its ability to lend its hand to any application and accomplish almost anything imaginable. If you analyze exactly how you feel at this stage, you will probably discover that you have mixed emotions about the journey ahead. On one hand, imagination, curiosity, and excitement are driving you on, while apprehension and reservations may be slowing you down. Your enthusiasm will overcome any indecision you have once you become actively involved in electronics and realize that it is as exciting as you ever expected it to be.

ORGANIZATION OF THE TEXTBOOK

This textbook has been divided into five basic parts. Chapters 1 and 2 introduce semiconductor electronics and review dc/ac electronics. Chapters 3 through 7 cover diodes and diode circuits. Chapters 8 through 12 cover transistors and transistor circuits, and Chapters 13 through 14 cover integrated circuits. Finally, in Part V, Chapter 15 covers thyristors and transducers.

PART I Introduction, Review, and Semiconductor Principles
- Chapter 1 Electricity and Electronics—Analog and Digital
- Chapter 2 Semiconductor Principles

PART II Diodes and Diode Circuits
- Chapter 3 Junction Diodes
- Chapter 4 Zener Diodes and Light-Emitting Diodes
- Chapter 5 Diode Power Supply Circuits
- Chapter 6 Diode Multiplier and Clipper Circuits
- Chapter 7 Special Application Diodes

PART III Transistors and Transistor Circuits
- Chapter 8 Bipolar Junction Transistors (BJTs)
- Chapter 9 Bipolar Transistor Amplifier Circuits

Chapter 10 Bipolar Transistor Oscillator Circuits
Chapter 11 Junction Field Effect Transistors (JFETs)
Chapter 12 Metal Oxide Semiconductor Field Effect Transistors (MOSFETs)

PART IV Integrated Circuits
Chapter 13 Operational Amplifiers
Chapter 14 Linear Circuits

PART V Thyristors and Transducers
Chapter 15 Thyristors and Transducers

The material covered in this book has been logically divided and sequenced to provide a gradual progression from the known to the unknown and from the simple to the complex. A great deal of effort has been made to ensure that the style, format, approach, and content of this book are compatible with you, the student.

TO THE INSTRUCTOR

Many people have asked me if there is one single factor involved with student retention. My answer is that whether a student enjoys electronics or hates it, and therefore stays in the program or leaves, is directly dependent on the instructor. I'm sure we have all seen the power we possess over a class of students. If this is used in a positive way, we can retain students despite any obstacles.

The responsibility of being the single most important factor in a student's education can be intimidating, unless we feel that we are fully supported. This support comes in the form of:

- a good textbook and set of teaching aids
- a good lab manual and set of test equipment
- a good course curriculum, and
- some teaching tricks of the trade

TEXTBOOK, LAB MANUAL, AND TEACHING AIDS

In all introductory texts, readability and relativity should be prime concerns to provide a complete understanding of the topics presented. However, in the pursuit of simplicity, boredom is often the price to be paid. Students are more involved in the learning process when they understand how the subject relates to their personal needs, career opportunities, and interests. Consequently, logical, current, and dynamic avenues of approach are needed to generate student enthusiasm, interest, and persistence.

This text has been specifically designed around the above philosophies, with a **complete picture introduction, real-life vignettes** at the beginning of each chapter, the use of **concept analogies** to take the student from the known to the unknown, and a constant reference to **actual applications.**

The objective of this textbook, and its associated lab manual, is to provide a student with all of the theoretical and practical knowledge needed in the area of semiconductor electronics to become an electronics technician. By definition, **an electronics technician must be able to diagnose, isolate, and repair electrical and electronic circuit and system malfunctions.** In order to achieve this goal, he or she must have a thorough knowledge of electronics, test equipment, and troubleshooting techniques. This text has been designed specifically with this objective in mind and therefore contains **all aspects of semiconductor electronics** along with a strong emphasis on **practical applications, test equipment,** and **testing and troubleshooting techniques.**

Throughout this text I have also tried to provide to the student the basis for gaining *intelligence* along with an education. All too often education is mistaken for intelligence. Education is simply the acquisition of information. For example, just because I have acquired a first-rate set of woodworking tools does not make me a good carpenter. To be a good carpenter, I must first develop carpentry skills. There are many elements in that nebulous, indefinable quality we call "intelligence"; however, generally it falls into our understanding of **analogies,** which measure our ability to see relationships, and **mathematics, reasoning,** and **logic,** which measure our ability to think logically and make use of the facts we know. Therefore, instead of simply stating a formula and requiring a student to memorize it, which would be simply supplying an education, I have introduced the student to the quantities involved, compared them to something they know, and then studied the relationships to build up a formula in the same way as the pioneers. These analogies will develop a student's ability to see relationships while the study of relationships will develop good reasoning and logic skills, and therefore instill "intelligence." Although this takes a little more time in the early stages, the rewards and ease of understanding in the later stages will compensate for the initial effort.

ELECTRONIC TECHNICIAN TRAINING: INDUSTRY FEEDBACK

To be competitive, "electronic manufacturing companies" and "electronic servicing companies" must make a choice: either they compete with foreign nations on their terms with *lower wages, increased hours,* and *demoralized workers,* or they restructure the work organization and upgrade worker skills for a *high-skill, high-performance organization.* The high school graduate and experienced worker are therefore faced with the same simple choice: *high skills or low wages*. Since "high skills" would be the most obvious choice, the next question is, what skills should the electronics technician have to be competitive in today's and tomorrow's workforce? Posing this question to advisory board members and electronic panels from more than 40 electronic companies, the following feedback was obtained.

1. *Training must provide a core of knowledge for an electronic technician.* Training must produce an electronic technician. By definition, an electronic technician is a person having a complete understanding of the oper-

TABLE 1 Areas of Training Most Useful for Job Performance

ELECTRONIC MANUFACTURERS	ELECTRONIC SERVICING
1. Troubleshooting Techniques	1. Customer Relations
2. Use of Test Equipment	2. Troubleshooting Techniques
3. Circuit Recognition and Analysis	3. Use of Test Equipment
4. Adaptability and Teamwork Skills	4. Adaptability and Teamwork Skills
5. Customer Relations	5. Circuit Recognition and Analysis

ation, application, and testing of electronic devices, circuits, and systems. Table 1 indicates in priority which training skills industry felt were most useful.

Table 1 lists test equipment and troubleshooting equipment rate as high priorities. Since test equipment is a technician's tool of the trade, Table 2 lists, in order, the test equipment that industry felt should have the most emphasis.

2. *Technician must be trained to adapt to new technologies.* Training should supply "intelligence along with an education." By definition, education is the acquisition of information and an indication of the ability to make such acquisitions, and intelligence is our ability to think logically and make use of facts we know. This is dependent on our mathematical, logic, and reasoning skills, and our ability to continually learn and see relationships. Concentrating on math skills, logic and reasoning skills, learning skills, and relationship skills develops intelligence, which in turn develops better adaptability and organizational and problem solving skills. Success in these areas will ensure career advancement. To address each of these skills in a little more detail:

a. *Math Skills:* As a tool, math should be integrated into appropriate position and, once taught, should be instantly applied so as to demonstrate need.

b. *Logic and Reasoning Skills:* To give only an education, a student would be told to "memorize a formula." To give an education along with intelligence, training should explain why certain quantities are included in a formula and why they are either proportional or inversely proportional. In short, work first on concept comprehension.

c. *Learning Skills:* The ability to adapt to new technology is directly dependent on an employee's ability to study and learn independently.

TABLE 2 Test Equipment Most Useful for Job Performance

1. Digital Multimeter	5. Power Supply
2. Oscilloscope	6. Logic Analyzer
3. Logic Probe and Pulser	7. Signal Generators
4. Automatic Test Equipment	

Reading comprehension is therefore a necessity. To encourage this skill, training must be conversational and interactive, not dry and cold.

   d. *Relationship Skills:* Use analogies to go from the known to the unknown. Learning, retention, and comprehension are enhanced when parallels are explored, and this will in turn develop organizational and relationship skills.

3. *Training must develop better communication, teamwork, and customer service skills.* Industry's drive for high quality and reduced cost has led to the integration of electronic system design, manufacture, and service. There is a need, therefore, for increased teamwork at all levels of personnel, and technicians must have good communication and interpersonal skills. From the standpoint of customer service skills, training should address how to work under pressure with customers on-site, dress professionally, and explain technical topics to nontechnical people. This can be achieved by having students constantly practice communicating their science (written and spoken).
4. *Training should educate students so that they have a better understanding of business practices, including manufacturing and production processes, and technical and business data.* Training should include tours of electronic companies and details on development procedures, job titles and responsibilities (technical and nontechnical), work ethics, environments, and so on.
5. *The electronic technician's role is evolving due to the complexity of electronic systems, the increase in computer-driven systems, and the economics of unit replacement versus component replacement.* To address these points:
   a. Since computer work stations are becoming an increasingly important tool, training must provide a complete understanding of computer applications in industry.
   b. As equipment becomes more complex, analytical and troubleshooting skills are critical for technicians. However, since yesterday's system is today's component, troubleshooting is moving away from a focus on discrete components to a subsystem and unit (functional) level of maintenance.
   c. Since nearly all design, manufacturing, and service equipment are programmable, the ratio of a technician's involvement in hardware versus software has changed:

      Late 1980s: 80 percent Hardware, 20 percent Software
      Present: 60 percent Hardware, 40 percent Software

   Training should therefore include an introduction to computers and their applications at an early stage in the program. Technicians must be "application software proficient," and, therefore, the following should be covered: DOS, Windows, UNIX, Word Processing, Databases, Spreadsheets, Circuit Simulation Software, Basic Programming (such as C), and Networks.

Most employers agreed that the electronic technician's role is continually evolving to keep pace with the ever-changing electronics industry. As educators, we are also having to continually adapt to the needs of industry so that our graduates have the skills for both career and advancement.

TEACHING TECHNIQUES

Over the past 15 years I have taught thousands of students all aspects of electronics. In this time I have acquired a considerable amount of feedback regarding students' needs and responses to their introduction to the science of electricity and electronics. In this section I would like to share some of my teaching techniques that have enabled me to obtain a high level of student retention.

1. Using concept analogies wherever possible to take the student from the known to the unknown.
2. Keeping the objective "to produce an electrical/electronics technician" in mind at all times, and therefore concentrating on delivering a complete knowledge of electricity, electronics, test equipment, and troubleshooting techniques.
3. Explaining all topics with analogies, reasoning, and logic first, and reinforcing the topic with mathematics second. This provides for giving the students intelligence along with an education.
4. Assuming no prior knowledge of electricity, electronics, or technical mathematics. Starting with the complete picture or world of electronics, and including mini-math reviews where they are needed.
5. Encouraging student enthusiasm, interest, and persistence by including real-life vignettes of entrepreneurs, actual applications, and a career opportunity tour.

In addition, there are a few other teaching methods that have yielded a very good response in my classes, and so I will mention them to you for your consideration.

6. Application Presentations: These 20-minute presentations, generally on the first day of each week, describe and demonstrate systems such as a Jacob's Ladder, laser, computer system, a variety of application software, robots, test equipment, and so on. These presentations seem to generate a lot of student enthusiasm since they demonstrate the exciting end objective of their studies.

I have also turned the tables and had students give presentations on any electrical or electronic equipment. Although the topics seem to be limited to video games, remote controlled toys, and car stereo systems, the presentations have helped develop necessary student communication skills.

7. Schematic Descriptions and Troubleshooting: Once a certain knowledge of electricity, electronics, and test equipment has been mastered, I begin to apply this knowledge to actual system schematics. To cover a circuit fully, we follow four steps.
   a. First we study the purpose of a circuit, its inputs and outputs, and its schematic diagram and circuit description.

   b. Second, we compare the schematic to the actual printed circuit board so that we can identify the components.
   c. Next we study the troubleshooting guides or charts and analyze the process of diagnosing and isolating a problem.
   d. The final step is for me to introduce a problem and then have a team of normally two students diagnose, isolate, and repair the problem.

8. First Approximations of a Subject: It was philosopher René Descartes who first stated that to solve any problem you should start with the simple and then proceed to the complex. For Descartes there were three approximations; the **first approximation** was the simplest, the **second approximation** contained more detail, and the **third approximation** was the complex. I have applied this method to my teaching of all topics of electricity and electronics and have noticed a dramatic improvement in student comprehension. To explain this in a little more detail, a first approximation is a general description of a subject in which the key points and purposes are outlined. Following this complete picture description, we step through the details of the chapter, which is a second approximation of the subject. In keeping with the main objective, only the first and second approximations of a subject are needed for a technician since they cover purpose, construction, symbol, operation, characteristics, applications, testing, and troubleshooting. The third approximation of a subject covers design and therefore is only covered by engineering students.

   These first approximations give the student a view of the complete picture, instead of having to wait until we finish all of the pieces in the chapter and then trying to connect them all together.

   Like me, you may wish to develop first approximation presentations for all topics, especially the more difficult to grasp subjects, such as series-parallel circuits, capacitance, inductance, transistors, and so on.

If you should have any other ideas that you have found in your experience would assist other instructors, please send them to me in care of Prentice Hall.

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Nigel P. Cook

Contents

CHAPTER 1

Electricity and Electronics—Analog and Digital

VIGNETTE

Communication Skills

Josiah Williard Gibbs was born in New Haven, Connecticut, in 1839. He graduated from Yale in 1858 and was appointed professor of mathematical physics at Yale in 1869, a position he held until his death in 1903. In his lifetime Gibbs wrote many important papers on the equilibrium of heterogeneous substances, the elements of vector analysis, and the electromagnetic theory of light.

Many historians rank Gibbs along with Newton and Einstein; however, he remains generally unknown to the public. This fact is due largely to his inability to communicate clearly and effectively. Strangely, for all of his technical genius, he just could not explain himself, a frustration that plagued him throughout his life. It took scientists years to comprehend what he was trying to explain, and as one scientist joked, "It was easier to rediscover Gibbs than to read him."

Note: This vignette carries a strong message. No matter how great a technical genius a person might become, if he or she cannot communicate this technical capability, they will never be understood or appreciated. In a recent survey of industry's needs for the technician of today and tomorrow, this point was addressed directly in the following way: "Training must develop better communication skills. Industry's drive for high quality and reduced cost has led to the *integration of design, manufacture, and service.* There is a need for increased teamwork at all levels of personnel." Technicians must have good communication and interpersonal skills. This can be achieved by constantly practicing communicating (in written and spoken form) your science.

INTRODUCTION

In this chapter, we will start by reviewing the complete picture of electricity and electronics, and then introduce what will be covered in the next phase of your course in electronics.

1-1 REVIEW OF ELECTRICITY AND ELECTRONICS

Electronics
Science related to the behavior of electrons in devices.

Electricity
Science that states that certain particles possess a force field, which with electrons is negative and with protons is positive.

By definition, **electronics** is the branch of technology or science that deals with the use of *components* to control the flow of **electricity** in a vacuum, gas, liquid, semiconductor, conductor, or superconductor. Both electrical and electronic components, circuits, and systems control electron flow; however, their applications are distinctly different.

To properly manage power, electrical devices must perform such functions as *generating, distributing,* and *converting* electrical power.

To properly manage information, electronic devices must perform such functions as *generating, sensing, storing, retrieving, amplifying, transmitting, receiving,* and *displaying* information.

Some systems are designed specifically to manage the flow of power and therefore are only electrical, while other systems are designed to manage both power and information. For example, a television contains both electrical components and circuits that manage the flow of electrical power from the wall outlet and also electronic components and circuits that manage the flow of information or TV signals from the antenna or cable. The electrical circuits are needed because they supply power to the electronic circuits which in turn manage the flow of audio (sound) and video (picture) information signals.

Analog
Relating to devices or circuits in which the output varies in direct proportion to the input.

Digital
Relating to devices or circuits that have outputs of only two distinct levels or steps, for example, on-off, 0-1, open-closed, and so on.

Analog Electronic Circuits
Electronic circuits that represent information in a continuously varying form.

Analog Electrical Circuits
A power circuit designed to control power in a continuously varying form.

1-1-1 The Tree of Electricity and Electronics

Figure 1-1(a) illustrates the tree of electricity and electronics. Working from the bottom up, you can see that everything rests on the four basic electrical roots: voltage, current, resistance, and power. Electrical and electronic components were developed to generate and control these four basic electrical phenomena. When a group of components are interconnected, they form a circuit. Just as components are the building blocks for circuits, circuits are in turn the building blocks for electronic equipment or systems.

Figure 1-1(b) breaks up your electronics course into four basic steps, which correlate to the basic blocks shown in the tree.

After completing Steps 1, 2 and 3, you will have obtained a good knowledge of electrical and electronic devices and circuits and be ready to apply this knowledge to communication, data processing, consumer, industrial, test and measurement equipment, and biomedical system applications. These six different branches or classifications of electrical and electronic equipment are shown at the top of the tree in Figure 1-1(a) and listed under Step 4 in Figure 1-1(b).

1-1-2 Analog and Digital

Analog and **digital** are two other terms that need to be further explained, since all of the electrical and electronic circuits listed in Step 3 of Figure 1-1(b) were classified in one of these two categories. To begin, let us examine **analog electronic circuits** and **analog electrical circuits.**

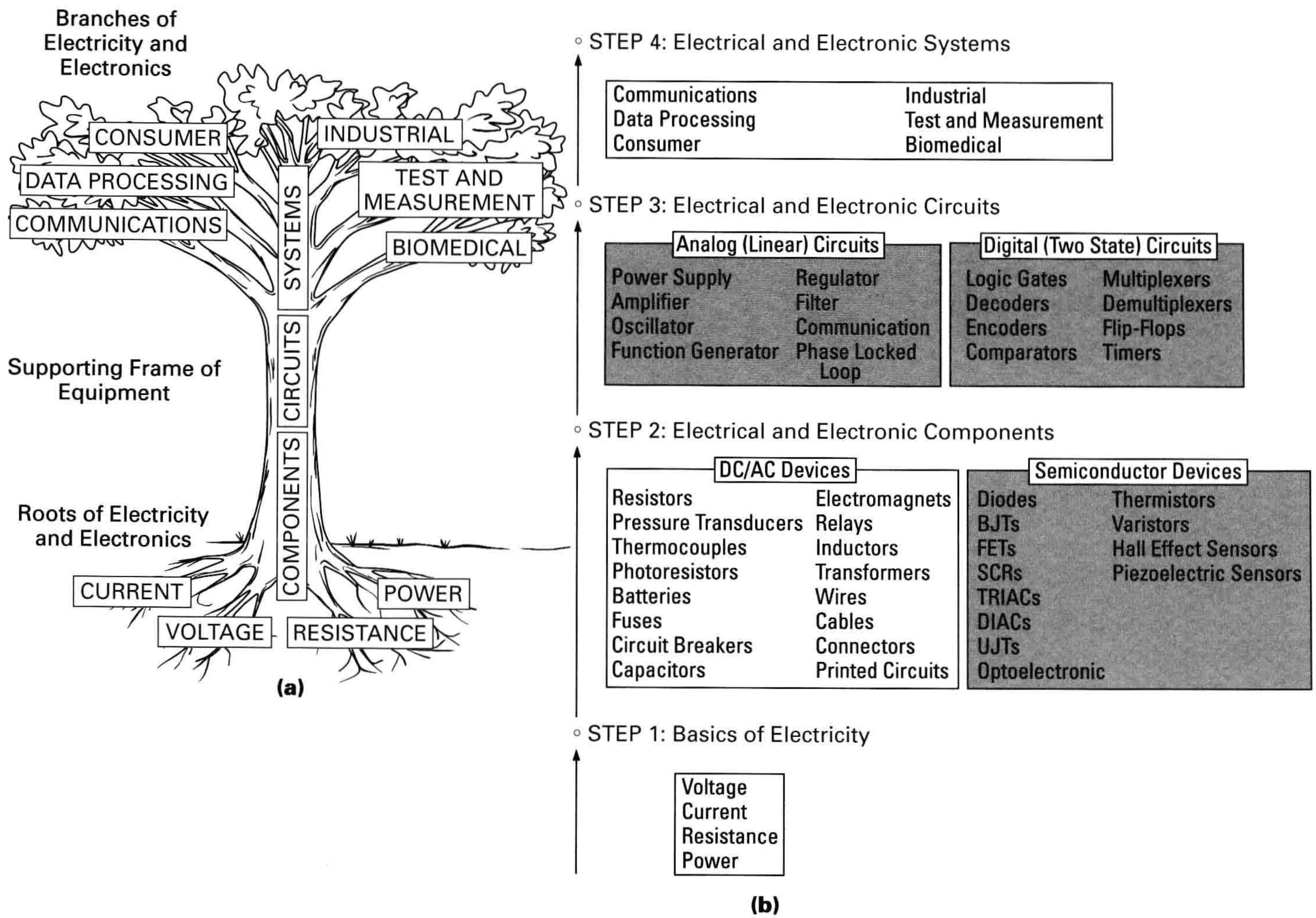

FIGURE 1-1 The Tree of Electricity and Electronics.

Analog Signals, Components, and Circuits

Figure 1-2(a) shows an electronic circuit designed to amplify speech information detected by a microphone. One of the best ways to represent information electrically is to have a voltage change in direct proportion to the information it is representing. In the example in Figure 1-2(a), the *pitch and loudness* of the sound waves applied to the microphone should control the *frequency and amplitude* of the voltage signal from the microphone. Therefore, this output voltage signal is said to be an analog of the input speech signal. The word "analog" means "similar to," and in Figure 1-2(a) the electronic signal produced by the microphone is an analog (or similar) to the speech signal since a change in speech loudness or pitch will cause a corresponding change in voltage amplitude or frequency.

In Figure 1-2(b), a light detector or solar cell converts light energy into an electronic signal. This electronic signal represents the amount of light present because changes in voltage amplitude result in a change in light level intensity. Once again, the output electronic signal is an analog (or similar) to the light signal.

Therefore, Figure 1-2 indicates two analog electronic (information) circuits. The microphone in Figure 1-2(a) generates an *AC analog signal* that is then amplified by an *AC amplifier circuit.* The microphone is considered an *analog device or component* and the amplifier is an *analog circuit.* The light detector would also be an analog component; however, in this example, it generates a *DC analog signal* that is then amplified by a *DC analog amplifier circuit.* Both of

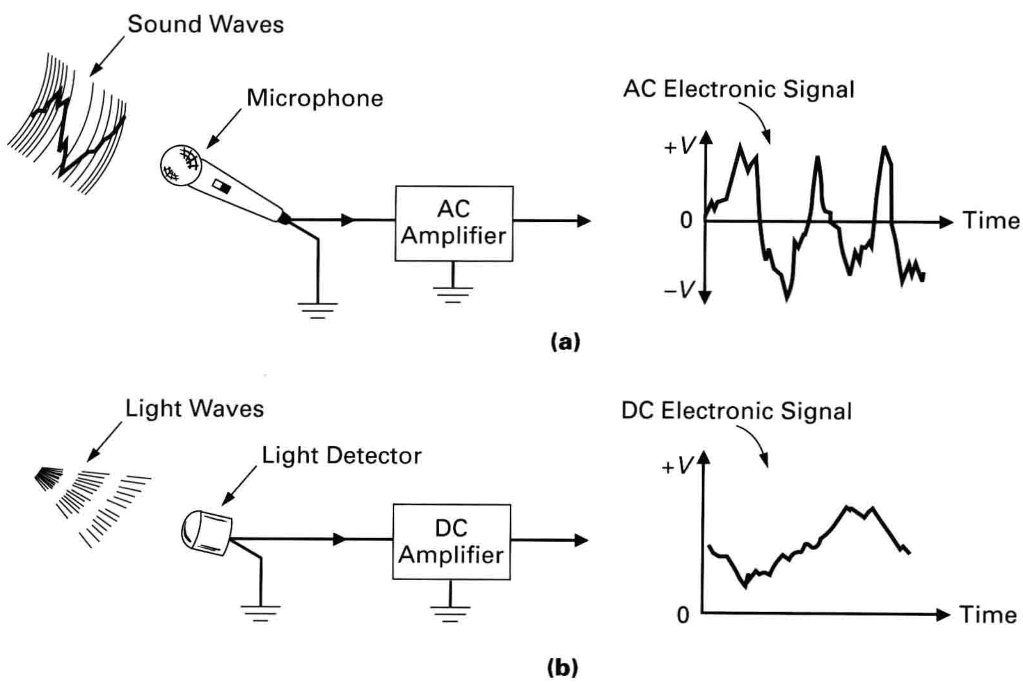

FIGURE 1-2 Analog Electronic Signals, Components, and Circuits. (a) AC Information Signal. (b) DC Information Signal.