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Introductory DC/AC Circuits

NIGEL P. COOK

R_s  Voltmeter

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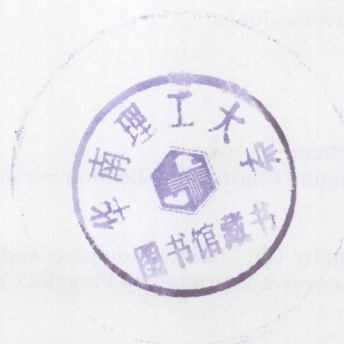
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Introductory DC/AC Circuits

Fifth Edition



Nigel P. Cook



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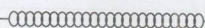
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Introductory DC/AC Circuits

To Dawn, Candy, and Jon

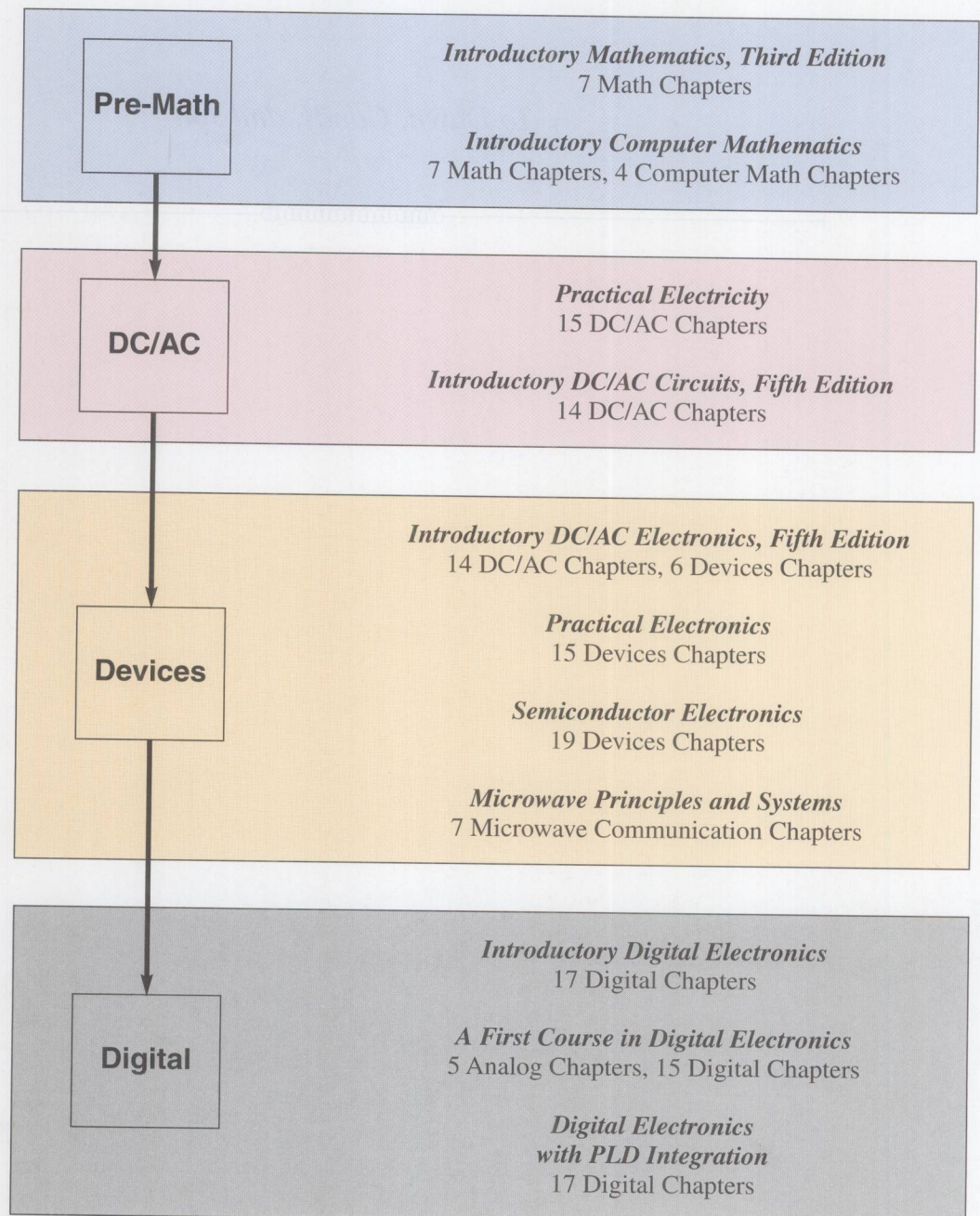


DC/AC

Devices

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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 three basic parts. Chapters 1 through 3 introduce you to the world of electronics and the fundamentals of electricity. Chapters 4 through 7 cover direct current, or dc, circuits; and Chapters 8 through 14 cover alternating current, or ac, circuits.

Introduction to Electronics

Part I The Fundamentals of Electricity

- Chapter 1 Voltage and Current
- Chapter 2 Resistance and Power
- Chapter 3 Resistors

Part II Direct-Current Electronics

- Chapter 4 Direct Current (DC)
- Chapter 5 Series DC Circuits
- Chapter 6 Parallel DC Circuits
- Chapter 7 Series-Parallel DC Circuits

Part III Alternating-Current Electronics

- Chapter 8 Alternating Current (AC)
- Chapter 9 Capacitance and Capacitors
- Chapter 10 Capacitive Circuits, Testing, and Applications
- Chapter 11 Electromagnetism and Electromagnetic Induction
- Chapter 12 Inductance and Inductors
- Chapter 13 Transformers
- Chapter 14 Resistive, Inductive, and Capacitive (*RLC*) Circuits

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.

ANCILLARIES ACCOMPANYING THIS TEXT

The following ancillaries accompanying this text provide extensive opportunity for further study and support:

- **Electronics Workbench/MultiSim CD-ROM.** Packaged with each copy of this text, the CD-ROM contains over 100 circuits from the text, created in both Electronics Workbench Version 5 and Electronics Workbench MultiSim Version 6. Forty (40) of these circuits can be simulated in the free demonstration version of MultiSim. The remaining circuits require that the user have the Electronics Workbench software, as this software is not included. Electronics Workbench software can be obtained by contacting your local bookstore, or by visiting <http://www.electronicsworkbench.com>.
- **Laboratory Manual.** Co-authored by Nigel Cook and Gary Lancaster, the lab manual offers numerous experiments designed to translate all of the textbook's theory into practical experimentation.
- **Practical Circuit Applications in DC/AC Electronics, with Study Wizard CD-ROM,** by Bradley Thompson. This important study guide lends additional support, including a math review and many practical circuit applications.
- **Companion Website,** located at <http://www.prenhall.com/cook>. Numerous interactive study questions are provided on this site to reinforce the concepts covered in the book.

To complete the ancillary package, the following supplements are essential elements for any instructor using this text for a course:

- **Instructor's Solutions Manual**
- **Solutions Manual to Accompany Laboratory Manual**
- **Instructor's Answer Key to Practical Circuit Applications in DC/AC Electronics**
- **PowerPoint™ Transparencies.** This CD-ROM includes a full set of **lecture presentations** as well as transparencies for all schematics appearing in the text.
- **Test Item File**
- **PH Custom Test Manager**



CIRCUIT SIMULATION CD-ROM USING EWB VERSION 5 AND EWB MULTISIM VERSION 6

In the back of this book is a CD-ROM containing the circuit simulation software *Electronics Workbench® (EWB)*. Using the demo on this CD, you can simulate forty circuits taken directly from this text. The EWB icon shown here in the margin indicates which circuits in this text have been prebuilt and stored on the CD, ready for simulation.

DEVELOPMENT, CLASS TESTING, AND REVIEWING

The first phase of development for this manuscript was conducted in the classroom with students and instructors as critics. Each topic was class-tested by videotaping each lesson, and the results were then evaluated and implemented. This invaluable feedback enabled

me to fine-tune my presentation of topics and instill understanding and confidence in the students.

The second phase of development was to forward a copy of the revised manuscript to several instructors at schools throughout the country. Their technical and topical critiques helped to mold the text into a more accurate form.

The third and final phase was to class-test the final revised manuscript and then commission the last technical review in the final stages of production.

ACKNOWLEDGMENTS

My appreciation and thanks are extended to the following instructors who have reviewed and contributed greatly to the development of this textbook: Venkata Anadu, Southwest Texas State University; Don Barrett, Jr., DeVry Institute of Technology; Lynnette Garetz, Heald College; Joe Gryniuk, Lake Washington Technical College; Jerry M. Manno, DeVry Institute of Technology; George Sweiss, ITT Technical Institute; and Bradley J. Thompson, State University of New York College of Technology at Alfred.

Nigel P. Cook

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Photos in Introduction to Electronics, pp. xxv–xxx, courtesy of Hewlett-Packard Company.

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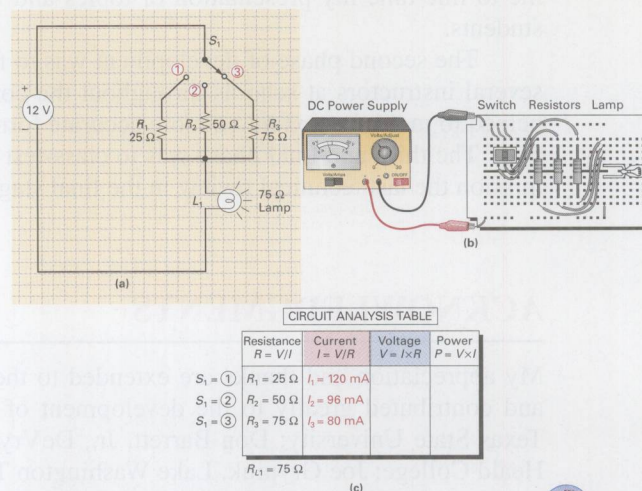


FIGURE 5-8 Three-Position Switch Controlling Lamp Brightness. (a) Schematic. (b) Protoboard Circuit. (c) Circuit Analysis Table.

$$\text{Position 3: } R_T = R_3 + R_{\text{lamp}} = 75 \Omega + 75 \Omega = 150 \Omega$$

$$I_T = \frac{V_T}{R_T} = \frac{12 \text{ V}}{150 \Omega} = 80 \text{ mA}$$

The details of this circuit are summarized in the analysis table shown in Figure 5-8(c).

SELF-TEST EVALUATION POINT FOR SECTION 5-3

Now that you have completed this section, you should be able to:

- **Objective 5.** Explain how to calculate total resistance in a series circuit.
- **Objective 6.** Explain how Ohm's law can be applied, and, resistance.

Use the following questions to test your understanding of Section 5-3.

1. State the total resistance formula for a series circuit.
2. Calculate R_T if $R_1 = 2 \text{ k}\Omega$, $R_2 = 3 \text{ k}\Omega$, and $R_3 = 4700 \Omega$.

CALCULATOR KEYS

Name: Exponent entry key EXP or EE

Function: Prepares calculator to accept next digits entered as a power-of-ten exponent. The sign of the exponent can be changed by using the change-sign key (+/-).

Example: 76×10^4

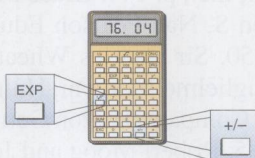
Press keys: 7 6 EXP 4

Display shows: 76.04

Example: 85×10^{-5}

Press keys: 8 5 EXP 5 +/-

Display shows: $85. -05$



Scientific Notation

A widely used floating-point system in which numbers are expressed as products consisting of a number between 1 and 10 multiplied by an appropriate power of 10.

Engineering Notation

A widely used floating-point system in which numbers are expressed as products consisting of a number that is greater than 1 multiplied by a power of 10 that is some multiple of 3.



TIME LINE

As a small boy, James C. Maxwell (1831-1879) was persistently inquisitive. He built many scientific toys before he was 8. At the age of 14 he wrote a paper on how to construct oval curves, and at 18 two of his papers were published. The supreme achievement of this Scottish physicist, however, was to translate Michael Faraday's experiments into scientific notation. This set of mathematical equations, known as Maxwell's equations, shows the relationship between electricity and magnetism.

Scientific and Engineering Notation

As mentioned previously, powers of ten are used in science and technology as a shorthand due to the large number of zeros in many values. There are basically two systems or notations used, involving values that have exponents that are a power of ten. They are called **scientific notation** and **engineering notation**.

A number in *scientific notation* is expressed as a base number between 1 and 10 multiplied by a power of ten. In the following examples, the values on the left have been converted to scientific notation.

EXAMPLE A:

$$32,000 = 3.20000 \times 10^4 \quad \text{Scientific notation}$$

Decimal point is moved to a position that results in a base number between 1 and 10. If decimal point is moved left, exponent is positive. If decimal point is moved right, exponent is negative.

EXAMPLE B:

$$0.0019 = 1.9 \times 10^{-3} \quad \text{Scientific notation}$$

EXAMPLE C:

$$114,300,000 = 1.14300000 \times 10^8 \quad \text{Scientific notation}$$

NEW! Extensive **First-Section Mini-Math Reviews** are included in their appropriate positions to overview and test the students on the math concepts needed for electronics concepts that follow.

Introduction to Electronics

From World War II onward, no branch of science has contributed more to the development of the modern world than electronics. It has stimulated dramatic advances in the fields of communication, computing, consumer products, industrial automation, test and measurement, and health care. It has now become the largest single industry in the world, exceeding the automobile and oil industries, with annual sales of electronic systems exceeding \$2 trillion.

Your Course in Electronics

Your future in the electronics industry begins with this text. To give you an idea of where you are going and what we will be covering, Figure I-1 acts as a sort of road map, breaking up your study of electronics into four basic steps.

- Step 1: Basics of Electricity
- Step 2: Electronic Components
- Step 3: Electronic Circuits
- Step 4: Electronic Systems

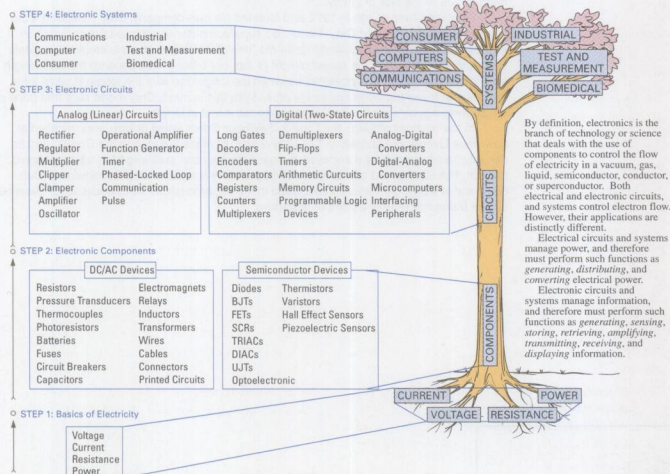


FIGURE I-1 The Steps Involved in Studying Electronics.

NEW! An Introduction to Electronics section before Chapter 1 overviews the electronics industry. In addition, it details the Product Development Process and the responsibilities and requirements of different technician job types.

JOB INTERVIEW TEST

After you have read this section, you will challenge your knowledge of the practice you need to be realistic, the test will

comprise both technical and personal questions. In order to take full advantage of this exercise, you may want to set up a simulation of the interview environment, have a friend read the questions to you, and record your responses for later analysis.

Company Name: Power Service, Inc.
Industry Branch: Test and Measurement.
Function: Maintain and Service Kilowatt-Hour Meters.
Job Title: Field Service Technician.

1. What do you know about us?

Answers

1. Visit the company's web site before the interview to get an overall understanding of the company's ownership, production line, service, and support.
2. Section 2-5.
3. Discuss how you have worked alone on project assignments and other related work history.
4. Section 2-5.
5. Say that you would report the problem to your supervisor and ask for help.

2. Could you tell me what a kilowatt-hour meter does?
3. How would you feel about working on your own in the field?
4. What is the difference between energy and power?
5. If you couldn't determine the answer to a problem, what would you do?
6. What is the difference between resistance and power?
7. What would you say is the job function of a field service technician?
8. Without supervision in the field, could you discipline yourself to get through a heavy schedule of stops?
9. Tell me what you know about Ohm's law.
10. What makes you think you are the right person for this job?

6. Sections 2-3 and 2-5.
7. See introduction, Field Service Technician.
8. Discuss how you have juggled school, studying, and a job to get to the position you currently hold, and other related work experience.
9. Section 2-3.
10. Describe why you were first attracted to the company's advertisement, why it felt compatible with your career goals, and how the company's positive attributes listed in its web site matched your expectations.

NEW! To hone a student's interview skills, the end-of-chapter **Job Interview Tests** are designed to challenge a student's technical knowledge along with testing their character traits with personal questions.

NEW! Over 35 **Margin Timeline Photographs** highlight key historical milestones by industry entrepreneurs, connecting their discoveries to appropriate text topics.

Resistance and Power

Genius of Chippewa Falls



In 1960, Seymour R. Cray, a young vice-president of engineering for Control Data Corporation, informed president William Norris that in order to build the world's most powerful computer he would need a small research lab built near his home. Norris would have shown any other employee the door, but Cray was his greatest asset, so in 1962 Cray moved into his lab, staffed by 34 people and nestled in the woods near his home overlooking the Chippewa River in Wisconsin. Eighteen months later the press was invited to view the 14- by 6-foot 6600 supercomputer that could execute 3 million instructions per second and contained 80 miles of circuitry and 350,000 transistors, which were so densely packed that a refrigeration cooling unit was needed due to the lack of airflow.

Cray left Control Data in 1972 and founded his own company, Cray Research. Four years later the \$8.8 million Cray-1 scientific supercomputer outstripped the competition. It included some revolutionary design features, one of which is that since electronic signals cannot travel faster than the speed of light (1 foot per billionth of a second) the wire length should be kept as short as possible, because the longer the wire the longer it takes for a message to travel from one end to the other. With this in mind, Cray made sure that none of the supercomputer's conducting wires exceeded 4 feet in length.

In the summer of 1985, the Cray-2, Seymour Cray's latest design, was installed at Lawrence Livermore Laboratory. The Cray-2 was 12 times faster than the Cray-1, and its densely packed circuits are encased in clear Plexiglas and submerged in a bath of liquid coolant. The 60-year-old genius has moved on from his latest triumph, nicknamed "Bubbles," and is working on another revolution in the supercomputer field, because for Seymour Cray a triumph is merely a point of departure.

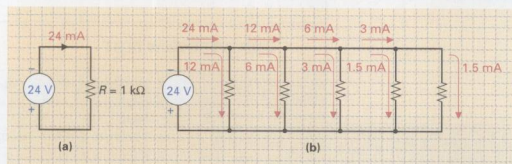


FIGURE 7-39 R - $2R$ Circuit with Data Inserted.

SELF-TEST EVALUATION POINT FOR SECTION 7-7

Now that you have completed this section, you should be able to:

- **Objective 4.** Explain what loading effect a piece of equipment will have when connected to a voltage divider.
- **Objective 5.** Identify and describe the Wheatstone bridge circuit in both the balanced and unbalanced condition.
- **Objective 6.** Describe the R - $2R$ ladder circuit used for digital-to-analog conversion.

Use the following questions to test your understanding of Section 7-7.

1. What is meant by loading of a voltage-divider circuit?
2. Sketch a Wheatstone bridge circuit and list an application of this circuit.
3. What value will the total resistance of an R - $2R$ ladder circuit always equal?
4. For what application could the R - $2R$ ladder be used?

7-8 TROUBLESHOOTING SERIES-PARALLEL CIRCUITS

Troubleshooting is defined as the process of locating and diagnosing malfunctions or breakdowns in equipment by means of systematic checking or analysis. As discussed in previous resistive-circuit troubleshooting procedures, there are basically only three problems that can occur:

1. A component will open. This usually occurs if a resistor burns out or a wire or switch contact breaks.
2. A component will short. This usually occurs if a conductor, such as solder, wire, or some other conducting material, is dropped or left in the equipment, making or connecting two points that should not be connected.
3. There is a variation in a component's value. This occurs with age in resistors over a long period of time and can eventually cause a malfunction of the equipment.

Using the example circuit in Figure 7-40, we will step through a few problems, beginning with an open component. Throughout the troubleshooting, we will use the voltmeter whenever possible, as it can measure voltage by just connecting the leads across the component, rather than the ammeter, which has to be placed in the circuit, in which case the circuit path has to be opened. In some situations, using an ammeter can be difficult.

To begin, let's calculate the voltage drops and branch current obtained when the circuit is operating normally.

NEW! The section review breaks are now **Self-Test Evaluation Points**, with a list of objectives that should have been met up to that point, and a set of questions designed to test the student's level of comprehension.



FIGURE 8-65 The Hand-Held Scopemeter. (Courtesy of Fluke Corporation. Reproduced with permission.)

Measure menu: The measurement menu button gives you direct access to a quick pop-up menu of more than 30 measurements including: V_{rms} , V_{mean} (arithmetic average), $V_{peak-to-peak}$, frequency, time delay, rise time, phase, current, and so on. Once the measurement is selected, the scopemeter automatically sets itself up and takes the measurement, as seen in the example in Figure 8-66(a).

Auto set: As you move from test point to test point, the scopemeter will handle the changing inputs automatically in this continuous autoset mode. Each time the signal input changes, the scopemeter will automatically search for the best trigger level, timebase (sweep time), and range scale to speed up measurements and reduce errors, as seen in Figure 8-66(b).

Min max trendplot: This function is used to display and record up to 40 days of signal trend which is sometimes needed in order to pinpoint intermittent problems that occur randomly. Figure 8-66(c) shows an example of how the display shows minimum, maximum, and average readings.

Save: Most scopemeters have large internal memories for saving screen images, setups, and waveforms from the field. These stored measurements can be recalled at any time, downloaded or sent to a personal computer for reports, or sent directly to a printer. Figure 8-66(d) shows how these waveforms and setups would appear on a computer screen.

SELF-TEST EVALUATION POINT FOR SECTION 8-5-4

Use the following questions to test your understanding of Section 8-5-4.

2. What advantages does the scopemeter have over the previously discussed instruments?

1. What is a scopemeter?

Circuit Simulation icons in the margin indicate which of the text's circuits can be simulated using Electronics Workbench.

New Technology Topics have been added, such as how to solder and desolder surface mount components (SMCs), how to use the handheld scopemeter, and so on.

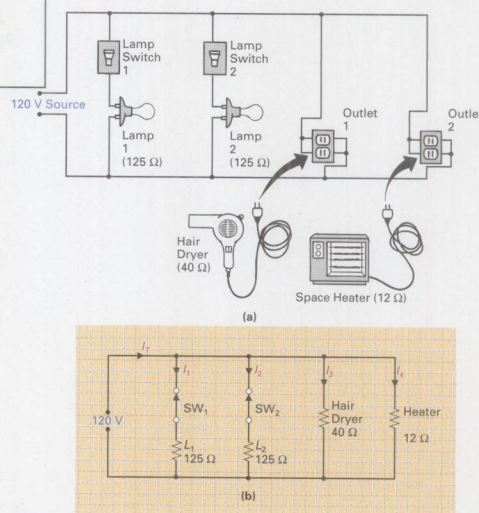


FIGURE 6-15 Parallel Home Electrical System.

the space heater and hair dryer, what will the individual branch currents be, and what will be the total current drawn from the source?

Solution:

Figure 6-15(b) shows the schematic of the pictorial in Figure 6-15(a). Since all resistances are connected in parallel across a 120 V source, the voltage across all devices will be 120 V. Using Ohm's law we can calculate the four branch currents:

$$I_1 = \frac{V_{\text{lamp1}}}{R_{\text{lamp1}}} = \frac{120 \text{ V}}{125 \Omega} = 960 \text{ mA}$$

$$I_2 = \frac{V_{\text{lamp2}}}{R_{\text{lamp2}}} = \frac{120 \text{ V}}{125 \Omega} = 960 \text{ mA}$$

$$I_3 = \frac{V_{\text{hairdryer}}}{R_{\text{hairdryer}}} = \frac{120 \text{ V}}{40 \Omega} = 3 \text{ A}$$

$$I_4 = \frac{V_{\text{heater}}}{R_{\text{heater}}} = \frac{120 \text{ V}}{12 \Omega} = 10 \text{ A}$$

Circuit Analysis Tables train the student to collect circuit facts in an easy-to-read table that enables the student to clearly see the total and individual current, voltage, resistance, and power values and relationships.

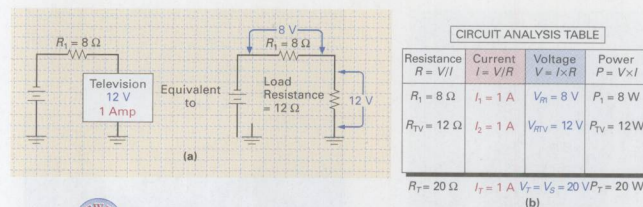


FIGURE 5-31 Series Circuit Example with Values Inserted. (a) Schematic, (b) Circuit Analysis Table.

The nearest commercially available device would be a 10 W resistor. If size is not a consideration, it is ideal to double the wattage needed and use a 16 W resistor.

- b. You may recall that any piece of equipment is equivalent to a load resistance. The TV set has 12 V across it and is pulling 1 A of current. Its load resistance can be calculated simply by using Ohm's law and deriving an equivalent circuit, as shown in Figure 5-31(a).

$$\begin{aligned}
 R_L \text{ (load resistance)} &= \frac{V}{I} \\
 &= \frac{12 \text{ V}}{1 \text{ A}} \\
 &= 12 \Omega
 \end{aligned}$$

- c. The amount of power being consumed by the TV set is

$$P = V \times I = 12 \text{ V} \times 1 \text{ A} = 12 \text{ W}$$

- d. Figure 5-31(b) shows the circuit analysis table for this example.

EXAMPLE:

Calculate the total amount of power dissipated in the series circuit in Figure 5-32, and insert any calculated values in a circuit analysis table.

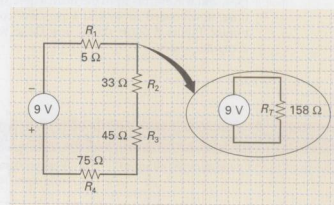
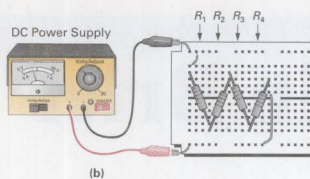
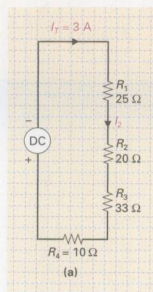


FIGURE 5-32 Series Circuit Example.



CIRCUIT ANALYSIS TABLE

Resistance $R = V/I$	Current $I = V/R$	Voltage $V = I \times R$	Power $P = V \times I$
$R_1 = 25 \Omega$	$I_1 = 3 \text{ A}$		
$R_2 = 20 \Omega$	$I_2 = 3 \text{ A}$		
$R_3 = 33 \Omega$	$I_3 = 3 \text{ A}$		
$R_4 = 10 \Omega$	$I_4 = 3 \text{ A}$		
$R_T = 88 \Omega$	$I_T = 3 \text{ A}$		

(c)



FIGURE 5-7 Total Resistance Example. (a) Schematic. (b) Protoboard Circuit. (c) Circuit Analysis Table.

The details of this circuit are summarized in the analysis table shown in Figure 5-7(c).

EXAMPLE:

Figure 5-8(a) and (b) shows how a single-pole three-position switch is being used to provide three different lamp brightness levels. In position ① R_1 is placed in series with the lamp, in position ② R_2 is placed in series with the lamp, and in position ③ R_3 is placed in series with the lamp. If the lamp has a resistance of 75Ω , calculate the three values of current for each switch position.

Solution:

$$\begin{aligned} \text{Position 1: } R_T &= R_1 + R_{\text{lamp}} \\ &= 25 \Omega + 75 \Omega = 100 \Omega \\ I_T &= \frac{V_T}{R_T} = \frac{12 \text{ V}}{100 \Omega} = 120 \text{ mA} \end{aligned}$$

$$\begin{aligned} \text{Position 2: } R_T &= R_2 + R_{\text{lamp}} = 50 \Omega + 75 \Omega = 125 \Omega \\ I_T &= \frac{V_T}{R_T} = \frac{12 \text{ V}}{125 \Omega} = 96 \text{ mA} \end{aligned}$$

Protoboard Pictorials help the beginning student make the transition from the circuit schematic on paper to the constructed circuit on a protoboard.

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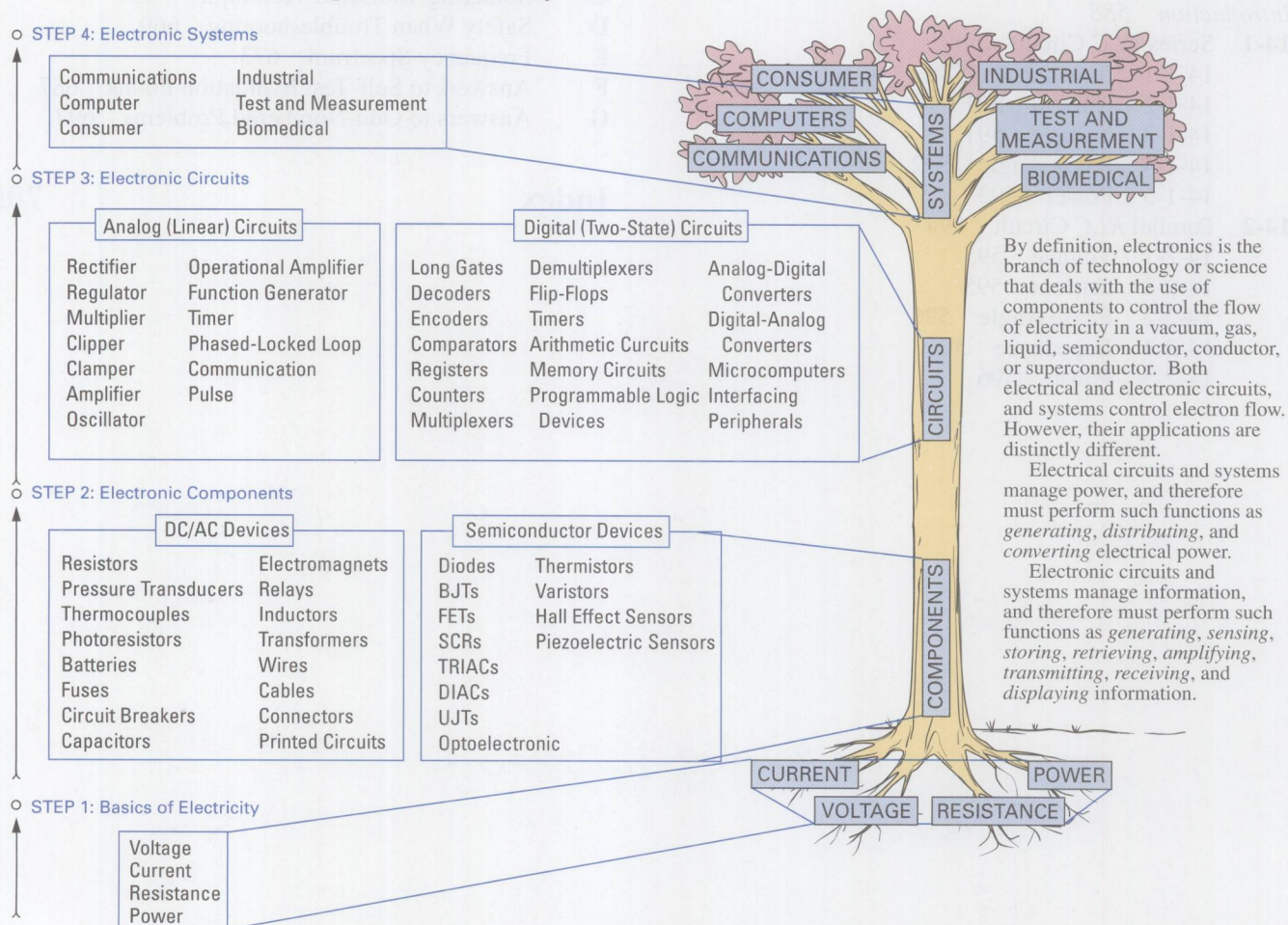




FIGURE I-1 The Steps Involved in Studying Electronics.


The main purpose of this introduction is not only to introduce you to the terms of the industry, but also to show you why the first two chapters in this text begin at the very beginning with “voltage and current,” and then “resistance and power.” **Components**, which are the basic electronic building blocks, were developed to control these four roots or properties, and when these devices are combined they form **circuits**. Moving up the tree to the six different branches of electronics, you will notice that just as components are the building blocks for circuits, circuits are in turn the building blocks for **systems**. Take a glance at the following pages, which will list many of the different types of components, circuits, and systems in the electronics industry.

Resistors 


Fixed (chip, composition, deposited carbon, metal film, wirewound)
Resistive Networks (thick film, thin film)
Thermistors
Variable (rheostats, potentiometers, trimmers)

Capacitors 


Fixed (ceramic, chips, electrolytic, film and paper, glass, mica)
Variable

Magnetic 


Transformer (AF, RF, and power)
Inductors (coils and chokes)
Yokes
Flybacks
Relays (crystal can, general, reed, solid state, telephone type, time delay)

Transducers 

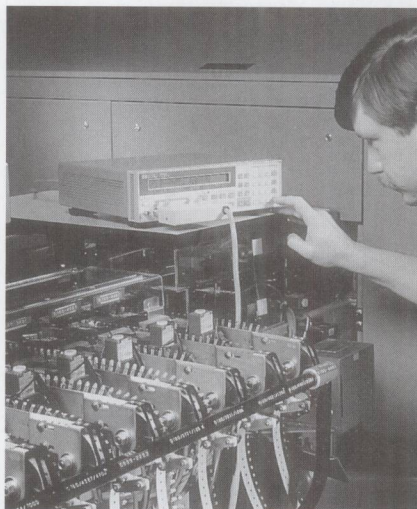
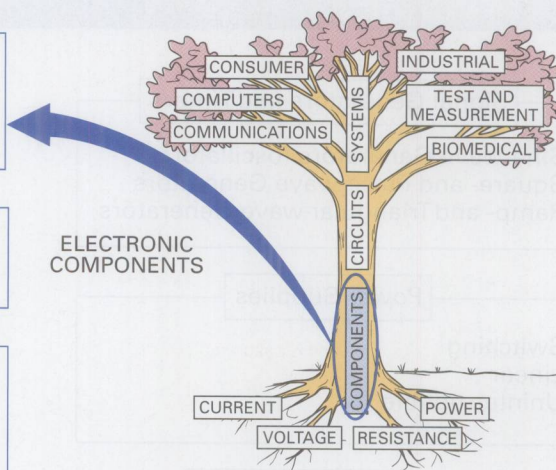
Flow
Fluid Level
Motion (linear and angular)
Pressure (air, liquid, mechanical)
Temperature (thermocouples, thermistors)
Vibration


Switches and Keyboard 

Dual-in-line
Keyboards (keypads and matrixes)
Lighted
Push Button
Rotary
Slide
Snap-action
Thumbwheel
Toggle

Electron Tubes 

Cathode Ray
Power and Special Purpose (gas and vapor, klystrons, light and image sensing, magnetrons, TWTs)
TV Picture (color, monochrome)
Computer Monitors (text, graphics)



Semiconductors 

Discrete Semiconductors
Diodes (arrays, rectifiers, signal, varactor, zeners, microwave)
Protection Devices
Thyristors
Transistors (bipolar, field effect, gallium arsenide)

Integrated Circuits
Custom and Semicustom (custom, gate arrays, PALs)
Linear (amplifiers, switches, communications, consumer, data conversion, interface, voltage reference)
Memories (RAM-dynamic and static, ROM-bipolar, CMOS, EEROMs, EPROMs)
Microprocessors (bipolar, NMOS, CMOS)
Logic Families (bipolar, MOS)

Optoelectronic Devices
Imaging Arrays (CCD, MOS)
Laser Diodes
Light-emitting Diodes (infrared, visible)
Optically Coupled Isolators
Photoconductive Cells
Photodiodes
Phototransistors
Photovoltaic Cells