

Introduction to Electronics



5th Edition

Gates



INTRODUCTION TO ELECTRONICS

FIFTH EDITION

Earl D. Gates



Australia • Brazil • Japan • Korea • Mexico • Singapore • Spain • United Kingdom • United States

**Introduction to Electronics,
Fifth Edition****Earl D. Gates**Vice President, Technology
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PREFACE

INTENDED AUDIENCE

Introduction to Electronics is intended to meet the needs of a one-year program in electronics for high schools, vocational schools, career colleges, and community colleges. The book may also be used in a survey course in electronics for electronics technology, computer technology, and telecommunications. The fifth edition continues to give students the basic background that more closely relates to the needs of industry. It provides the hands-on instruction required by industry along with the required theory.

BACKGROUND OF THIS BOOK

This fifth edition has the same objectives as the four previous editions, namely, to provide a text and reference book that summarizes in understandable terms those principles and techniques that are the basic tools of electronics. In keeping with current trends, increased emphasis is placed on the general techniques of electronics. During my teaching in public school I completed a study on what industry wanted from students graduating with a background in electronics. I found that industry valued students' ability to *do* more than their ability to *know*. I found that industry wanted less time spent on teaching theory and more time spent on instructing hands-on applications.

After I had rewritten my curriculum, I found I had to use several textbooks to teach it. I originally wrote the first edition of *Introduction to Electronics* to provide the students with all the information required by the curriculum in one easy-to-use textbook. The fifth edition continues to refine the

needs of the students through input from teachers and changes from the electronics field.

TEXTBOOK ORGANIZATION

Due to the rapid growth of electronics, it becomes impossible to cover all of the important topics in a one-year course. *Introduction to Electronics* provides the instructor with an opportunity to select those topics that he/she wishes to emphasize and, at the same time, provides the student with a reference book of basic electronics coverage and continuing value.

Teachers can guide students to concentrate on the material related to a particular course syllabus, leaving the remaining subject matter as enrichment should students wish to extend their knowledge at a future date. Alternatively, instructors can choose to cover a series of selected topics, such as DC and AC circuits. Another possibility is to concentrate on the material related primarily to linear electronics circuits or another topic of choice. Many other combinations are possible.

The emphasis still continues to be coverage of electronics combined with a presentation that allows the student to study a particular topic without having to read the entire text. The level of the presentation remains unchanged.

The textbook is divided into six separate sections.

Section 1—DC Circuits discusses fundamentals of electricity, current, voltage, resistance, ohm's law, electrical measurements—meters, power, DC circuits, magnetism, inductance, and capacitance.

Section 2—AC Circuits discusses alternating current, AC measurement, resistive AC circuits, capacitive AC circuits, inductive AC circuits, resonance circuits, and transformers.

Section 3—Semiconductor Devices discusses semiconductor fundamentals, PN junction diodes, zener diodes, bipolar transistors, field effect transistors (FET), thyristors, integrated circuits, and optoelectric devices.

Section 4—Linear Electronic Circuits discusses power supplies, amplifier basics, amplifier applications, oscillators, and waveshaping circuits.

Section 5—Digital Electronic Circuits discusses binary number systems, basic logic gates, simplifying logic circuit, sequential logic circuits, combinational logic circuits, and microcomputer basics.

Section 6—Practical Applications discusses fabricating a printed circuit board, printed circuit board assembly and repair, and basic troubleshooting.

A **Glossary** contains key terms and definitions.

Self-Test Answers are included for students.

Appendices include Appendix 1—Electronics Abbreviations, Appendix 2—Periodic Table of Elements, Appendix 3—The Greek Alphabet, Appendix 4—Metric Prefixes Used in Electronics, Appendix 5—Resistor Color Code, Appendix 6—Capacitor Color Code, Appendix 7—Electronics Symbols, Appendix 8—Semiconductor Schematic Symbols, Appendix 9—Digital Logic Symbols, and Appendix 10—DC and AC Circuit Formulas.

FEATURES

The following list provides some of the significant features of the textbook.

- Chapters are brief and focused.
- Objectives are clearly stated with the learning goals at the beginning of each chapter.
- Colorful illustrations are generously used throughout the text to strengthen concepts learned.
- Cautions and notes are color coded for easy identification throughout the text.
- Review questions appear at the end of every chapter subdivision to allow a comprehension check.
- All formulas are written using fundamental formulas only.
- Many examples show math and formulas in use throughout the text.
- Summaries are included at the end of each chapter for reviewing important concepts.
- Self-tests are included at the end of each chapter as a learning tool.
- Four-color photographs are used to show the learner exactly what is addressed in the text.
- Four-color layouts focus attention to important features in the text.
- Numerous examples incorporate the chapters' material with real life applications.
- Section activities provide an opportunity to reinforce concepts with hands-on projects.

NEW FEATURES IN THIS EDITION

- New photographs are used throughout the book and detailed, step-by-step examples are included to show how math and formulas are used.
- Many examples have been developed into MultiSIM® version 9 on a companion disk

for students to learn first hand what is happening in the circuit.

- New career profiles are located at the beginning of each section to stimulate the student's interest in further study and/or potential employment in the electronics fields.
- New chapters and chapter sections include:

33–7 Buffer

Section 6—Practical Applications

Chapter 38 Fabricating a Printed Circuit Board

38–1 Fundamentals

38–2 Schematic Diagram

38–3 Breadboarding

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38–5 Transferring Designs

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Chapter 40 Basic Troubleshooting

40–1 Tools for Troubleshooting

40–2 Isolation Techniques for Effective Troubleshooting

40–3 Common Types of Defects

40–4 Troubleshooting Tips

40–5 Documentation

USING THE CD-ROM

The accompanying CD includes MultiSIM™ circuit files. Students can use these precreated files for troubleshooting and simulation. Textbook figures created as MultiSIM files are identified by a CD icon throughout the text.

In addition, the CD includes *Electronics into the Future*, which offers interactive tutorials and presentations on fundamental electronics concepts, such as Ohm's Law, series circuits, parallel circuits, series-parallel circuits, network theorems and magnetism.

THE LEARNING PACKAGE

The complete ancillary package was developed to achieve two goals:

- 1 To assist students in learning the essential information needed to prepare for the exciting field of electronics.
- 2 To assist instructors in planning and implementing their instructional programs for the most efficient use of time and other resources.

LAB MANUAL. Labs provide students with the opportunity to transfer theory provided in class to hands-on practical applications. Projects serve to reinforce the student's learning, providing them the opportunities to see theory become practice. (ISBN: 1-4018-8901-8)

INSTRUCTOR'S GUIDE. The Instructor's Guide contains solutions to end-of-chapter textbook questions and to the lab manual experiments. To assist the instructor/teacher in preparing the program, a curriculum guide is provided in the Instructor's Guide. It helps instructors to provide a program that will develop a student's interest in the field of electronics. (ISBN: 1-4018-8902-6)

E.RESOURCE. The *e.resource* is an educational resource that creates a truly electronic classroom. It is a CD-ROM containing tools and instructional resources that enrich your classroom and make your preparation time shorter. The elements of *e.resource* link directly to the text and tie together to provide a unified instructional system. With the *e.resource*, you can spend your time teaching, not preparing to teach. (ISBN: 1-4018-8903-4)

Features contained in the *e.resource* include:

POWERPOINT PRESENTATION. These slides provide the basis for a lecture outline that helps you to present concepts and material. Key points and concepts can be graphically highlighted for student retention. There are 480 slides, covering every chapter in the text.

COMPUTERIZED TESTBANK. Includes over 900 questions in multiple-choice format so you can assess student comprehension.

IMAGE LIBRARY. Includes over 200 images from the textbook to create your own transparency masters or to customize your own PowerPoint slides. The Image Library comes with the ability to browse and search images with key words and allows quick and easy use.

ONLINE COMPANION

The text has a companion website at www.electronictech.delmar.cengage.com, which will have high appeal to both educators and students. The Online Companion provides access to text updates.

ABOUT THE AUTHOR

- Associate Professor, Emeritus at the State University of New York at Oswego where he taught Electronics Technology.

- Has 23 years experience in public education as a teacher and administrator.
- Retired from the US Navy as an Electronics Technician Senior Chief.
- Member of the International Technology Education Association, New York State Technology Education Association and the International Graphic Arts Education Association.
- President of TEK Prep, a small business that does education consulting.
- As an education consultant, he teaches courses in South Carolina and Florida.

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Earl D. Gates
Oswego, New York
2006

CAREERS IN ELECTRONICS

Many exciting career opportunities exist in the electrical/electronics field. A sample of these available opportunities are provided in the following information. Check for other career opportunities at the career information center in your school or community.

AUTOMATION MECHANIC

An automation mechanic maintains controllers, assembly equipment, copying machines, robots, and other automated or computerized devices. A person with this job installs, repairs, and services machinery with electrical, mechanical, hydraulic, or pneumatic components. Precision measuring instruments, test equipment, and handtools are used. A knowledge of electronics and the ability to read wiring diagrams and schematics are required.

Becoming an automation mechanic requires formal training, which is offered by the military, junior/community colleges, vocational-technical schools, and in-house apprenticeship programs. Although most training is provided through formal classroom instruction, some of the training may only be obtained through on-the-job training.

Automation mechanic is one of the fastest growing vocations in the industry. This rapid growth is expected to continue annually.

AUTOMOTIVE MECHANIC

There are currently more computers aboard today's automobile than aboard our first spaceship. A typical automobile contains approximately ten to fifteen computers that operate everything from the engine and radio to the driver's seat. As

a result, automotive mechanics now need a greater knowledge of electronics.

To be able to distinguish an electronic malfunction from a mechanical malfunction, automotive mechanics must be familiar with the minimum of the basic principles of electronics. In addition, they must be able to test and replace electronic components.

Becoming an automotive mechanic requires formal training, which is offered by the military, junior/community colleges, vocational-technical schools, and in-house apprenticeship programs. Although most training is provided through formal classroom instruction, some of the training may be obtained only through on-the-job training. To reduce the amount of time invested in training a prospective mechanic, more employers are now looking for people who have completed a formal automotive training program.

Employment opportunities are good for automotive mechanics who have completed an automotive training program. People whose training includes basic electronics skills will have the best opportunities. Employment growth is expected to increase at a normal rate annually with a concentration in automobile dealerships, independent automotive repair shops, and specialty car-care chains. Employment in gasoline service stations will continue to decline as fewer stations will offer repair services.

COMPUTER TECHNICIAN

A computer technician installs, maintains, and repairs computer equipment and systems. Initially, the computer technician is responsible for laying cables and making equipment con-

nections. This person must thoroughly test the new system(s), resolving all problems before the customer uses the equipment. At regular intervals, the computer technician maintains the equipment to ensure that everything is operating efficiently. A knowledge of basic and specialized test equipment and handtools is necessary.

Computer technicians spend much of their time working with people—listening to complaints, answering questions, and sometimes offering advice on both equipment system purchases and ways to keep equipment operating efficiently. Experienced computer technicians often train new technicians and sometimes have limited supervisory roles before moving into a supervisory or service managerial position.

A computer technician is required to have one or two years of training in basic electronics or electrical engineering from a junior college, college or vocational training center, or military institution. The computer technician must be able to keep up with all the new hardware and software.

Projections indicate that employment for computer technicians will be high. The nation's economy is expanding, so the need for computer equipment will increase; therefore, more computer technicians will be required to install and maintain equipment. Many job openings for computer technicians may develop from the need to replace technicians who leave the labor force, transfer to other occupations or fields, or move into management.

COMPUTER ENGINEERS

The rapid growth in computers has generated a demand for people trained in designing new hardware and software systems and incorporating new technologies into existing and new systems. These trained professionals are known as computer engineers and system analysts.

Computer engineers can be further broken down into hardware and software engineers. Computer hardware engineers design, develop, test, and supervise the manufacturing of computer hardware. Computer software engineers design and develop software systems for control and automation of manufacturing, business, and management processes. They also may design and develop software applications for consumer use at home or create custom software applications for clients.

There is no universally accepted preparation for a computer professional because the job often depends on the work that needs to be done. Most employers require that employees have at least a bachelor's degree. However, a passion for computers and proficiency in advanced computer skills will at times win out over a bachelor's degree.

This field is one of the fastest-growing fields. Technological advances are occurring so rapidly in the computer field that employers are struggling to keep up with trained professionals. As the technology becomes more sophisticated and complex, more expertise and a higher level of skills will be required. A continual learning process must be undertaken to keep up. College graduates with a bachelor's degree in computer science, computer engineering, information science, or information systems will enjoy favorable employment opportunities.

ELECTRICAL ENGINEER

Electrical engineers make up the largest branch of engineering. An electrical engineer designs new products, writes performance specifications, and develops maintenance requirements. Electrical engineers also test equipment and solve operating problems within a system, and predict how much time a project will require. Then, based on the time estimate, the electrical engineer determines how much the project will cost.

The electrical engineering field is divided into two specialty groups: electrical engineering and electronic engineering. An electrical engineer

works in one or more areas of power-generating equipment, power-transmitting equipment, electric motors, machinery control, and lighting and wiring installation. An electronics engineer works with electronic equipment associated with radar, computers, communications, and consumer goods.

The number of engineers in demand is expected to increase annually. This projected growth is attributed to an increase in demand for computers, communication equipment, and military equipment. Additional jobs are being created through research and development of new types of industrial robot control systems and aviation electronics. Despite this rapid growth, a majority of openings will result from a need to replace electrical and electronics engineers who leave the labor force, transfer to other occupations or fields, or move into management.

ELECTRICIAN

An electrician may specialize in construction, maintenance, or both. Electricians assemble, install, and maintain heating, lighting, power, air-conditioning, and refrigeration components. The work of an electrician is active and sometimes strenuous. An electrician risks injury from electrical shock, falls, and cuts from sharp objects. To decrease the risk of these job-related hazards, an electrician is taught to use protective equipment and clothing to prevent shocks and other injuries. An electrician must adhere to the *National Electrical Code (NEC)*^{®*} specifications and procedures, as well as to the requirements of state, county, and municipal electric codes.

A large proportion of electricians are trained through apprenticeship programs. These programs are comprehensive, and people who com-

plete them are qualified for both maintenance and construction work. Most localities require that an electrician be licensed. To obtain the license, electricians must pass an examination that tests their knowledge of electrical theory, the *National Electrical Code*[®], and local electrical and building codes. After electricians are licensed, it is their responsibility to keep abreast of changes in the *National Electrical Code*[®], with new materials, and with methods of installation.

Employment for an electrician is expected to increase annually. As population increases and the economy grows, more electricians will be needed to maintain the electrical systems used in industry and in homes. Additionally, as both new and old homes are prepared for new technologies to make them smarter, the demand will require more electricians who are trained in the new technologies.

ELECTRONICS TECHNICIAN

Electronics technicians develop, manufacture, and service electronic equipment and they use sophisticated measuring and diagnostic equipment to test, adjust, and repair electronic equipment. This equipment includes radio, radar, sonar, television, and computers, as well as industrial and medical measuring and controlling devices.

One of the largest areas of employment for electronics technicians is in research and development. Technicians work with engineers to set up experiments and equipment and calculate the results. They also assist engineers by making prototypes of newly developed equipment, as well as by performing routine design work. Some electronics technicians work as sales or field representatives to give advice on installation and maintenance of complex equipment. Most electronics technicians work in laboratories, electronics shops, or industrial plants. Ninety percent of electronics technicians work in private industry.

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Becoming an electronics technician requires formal training, which is offered by the military, junior/community colleges, vocational-technical schools, or in-house apprenticeship programs.

Employment of electronics technicians is expected to increase annually due to an increased de-

mand for computers, communication equipment, military electronics, and electronic consumer goods. Increased product demand will provide job opportunities, but the need to replace technicians who leave the labor force, transfer to other occupations or fields, or move into management may also increase.

USING A CALCULATOR

Due to a decrease in cost, the handheld electronic calculator are very popular. Many students have rejoiced that all of their mathematical work is now mastered. In just a few keystrokes, a calculator will give the correct answer. However, students fail to realize that a calculator is just a tool to perform calculations very quickly, but with no guarantees for a correct answer. A calculator gives the correct answer only when the correct numbers are entered, in the correct order, and with the correct function keys used at the appropriate time.

If operators do not understand principles of the mathematical process, they will not be able to properly enter data into a calculator, nor will they be able to correctly interpret the results. Mathematical skills still count. Even when all data is entered correctly, the answer may be incorrect due to battery failure or other conditions.

Selecting a calculator appropriate for electronics is an important decision. The marketplace is flooded with many makes and models. Which is the right one? What are the functions that will prove to be the most useful? For this course, choose one that has the following functions: $+$, $-$, \times , \div , $1/x$, x^2 , and $\sqrt{\quad}$. A memory function is optional. Scientific and programmable calculators have become popular. Although they are not needed for this textbook, they typically include formulas and functions used in trigonometry and statistics. If you decide to purchase one, study the manual carefully so you may use the calculator to its fullest extent. All calculators generally come with a manual, which should be kept handy.

The following examples show how a calculator is used to solve various types of problems in electronics. Turn on your calculator. Examine the keyboard. Let's do some calculating.

ADDITION

EXAMPLE 1 Add: $39,857 + 19,733$

Solution:

Enter	Display
39857	39857
+	39857
19733	19733
=	59590

SUBTRACTION

EXAMPLE 2 Subtract: $30,102 - 15,249$

Solution:

Enter	Display
30102	30102
-	30102
15249	15249
=	14853

MULTIPLICATION

EXAMPLE 3 Multiply: $33,545 \times 981$

Solution

Enter	Display
33545	33545
\times	33545
981	981
=	32907645

DIVISION

EXAMPLE 4 Divide: 36,980 by 43 or $36,980$
or $43 \div 36,980$ 43

Solution

Enter	Display
36980	36980
\div	36980
43	43
=	860

SQUARE ROOT

EXAMPLE 5 Find the square root of 35,721

Solution

Enter	Display
35721	35721
$\sqrt{}$	189

TOTAL RESISTANCE (PARALLEL CIRCUIT)

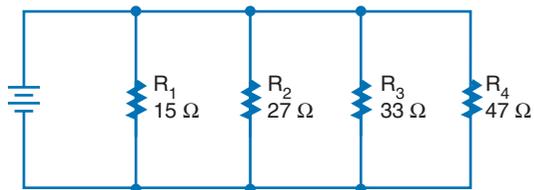
The total resistance of a parallel circuit may be calculated by first computing the reciprocal of each branch and then taking the reciprocal of the branch total.

Parallel circuits are made up of resistors that are sold in resistance values of ohms. Calculating parallel circuit total resistance involves the use of reciprocals ($1/R$) as shown in the parallel circuit formula:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \cdots + \frac{1}{R_n}$$

A calculator gives the reciprocal of a number by simply pressing the $1/X$ key. If the calculator does not have a $1/X$ key, then each reciprocal value will be found separately by dividing 1 by the resistance value.

EXAMPLE 6 Calculate the total equivalent resistance of the parallel circuit shown



Solution

	Enter	Display
Reciprocal of R_1	15	15
	$1/X$	0.0666667

Reciprocal of R_2	27	27
	$1/X$	0.037037
Reciprocal of R_3	33	33
	$1/X$	0.030303
Reciprocal of R_4	47	47
	$1/X$	0.0212766
	Enter	Display
Totals of reciprocals	0.0666667	0.0666667
	+	
	0.037037	0.1037037
	+	
	0.030303	0.1340067
	+	
	0.0212766	0.1552833
	Enter	Display
Reciprocal of totals	0.1552833	0.1552833
	$1/X$ 6.4398425	Round answer to 6.44 Ω

EXAMPLE 7 Using a calculator with memory function

Solution

	Enter	Display
Reciprocal of R_1	15	15
	$1/X$	0.0666667
	M+	0.0666667 M
	C	0
Reciprocal of R_2	27	27
	$1/X$	0.037037
	M+	0.037037 M
	C 0	
Reciprocal of R_3	33	33
	$1/X$	0.030303
	M+	0.030303 M
	C	0
Reciprocal of R_4	47	47
	$1/X$	0.0212766
	M+	0.0212766 M
	C	0
Totals of reciprocals	RM	0.0.155283329
Reciprocal of totals	$1/X$	6.439841299
	Round answer to 6.44 Ω	

ROUNDING

Note: Rounding is not a calculator function and must be done mentally. The number of significant digits can be reduced by *rounding off*. This means dropping the least significant digits until the desired number of digits remain. The new least significant digit may be changed using the following rules:

If the highest significant digit dropped is

- less than 5, the new significant digit is not changed.
- greater than 5, the new significant digit is increased by one.

- 5, the new significant digit is not changed if it is even.
- 5, the new significant digit is increased by one if it is odd.

EXAMPLE Round 352.580

Round to the nearest tenth	352.6
Round to the nearest whole number	352
Round to the nearest hundred	400

These rules result in a rounding off technique that on the average gives the most consistent reliability.

SAFETY PRECAUTIONS

The following safety precautions are not intended as a replacement for information given in class or lab manuals. If at any time you question what steps or procedures to follow, consult your teacher.

GENERAL SAFETY PRECAUTIONS

Because of the possibility of personal injury, danger of fire, and possible damage to equipment and materials, all work on electrical and electronic circuits should be conducted following these basic safety procedures.

1. *Remove power from the circuit or equipment prior to working on it.* Never override interlock safety devices. Never assume the circuit is off; check it with a voltmeter.
2. *Remove and replace fuses only after the power to the circuit has been deenergized.*
3. *Make sure all equipment is properly grounded.*
4. *Use extreme caution when removing or installing batteries containing acid.*
5. *Use cleaning fluids only in well-ventilated spaces.*
6. *Dispose of cleaning rags and other flammable materials in tightly closed metal containers.*
7. *In case of an electrical fire, deenergize the circuit and report it immediately to the appropriate authority.*

HIGH VOLTAGE SAFETY PRECAUTIONS

As people become familiar with working on circuits, it is human nature to become careless with routine procedures. Many pieces of electrical equipment use voltages that are dangerous and can be fatal if contacted. The following precau-

tions should be followed at all times when working on or near high-voltage circuits:

1. *Consider the result of each act.* There is absolutely no reason for individuals to take chances that will endanger their life or the lives of others.
2. *Keep away from live circuits.* Do not work on or make adjustments with high voltage on.
3. *Do not work alone.* Always work in the presence of another person capable of providing assistance and first aid in case of an emergency. People who are considering a career working in the electricity and electronics field should become CPR certified.
4. *Do not tamper with interlocks.*
5. *Do not ground yourself.* Make sure you are not grounded when making adjustments or using measuring instruments. Use only one hand when connecting equipment to a circuit. Make it a practice to put one hand in your rear pocket.
6. *Use an isolation transformer when working on AC-powered circuits/equipment.* An isolation transformer isolates the circuit/equipment from the power source, adding an additional safety factor.
7. *Never energize equipment in the presence of water leakage.*

PERSONAL SAFETY PRECAUTIONS

Take time to be safe when working on electrical and electronic circuits. Do not work on any circuits or equipment unless the power is secured.

1. *Work only in clean, dry areas.* Avoid working in damp or wet locations because the resistance