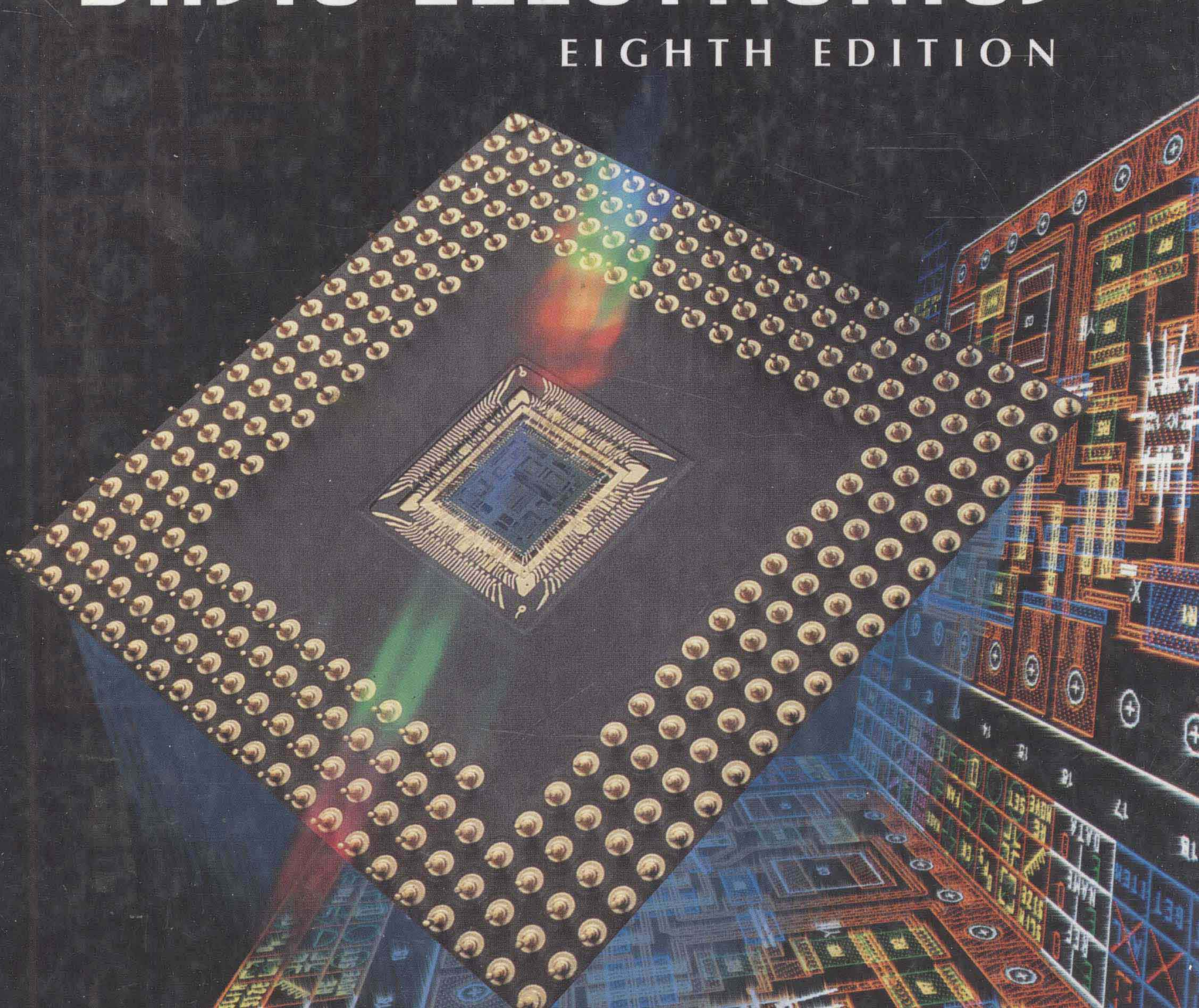
BOOK 2 Chapters 16-32

GROB

BASIC ELECTRONICS

EIGHTH EDITION



BOOK 2 Chapters 16-32

GROB

BASIC ELECTRONICS

EIGHTH EDITION

Bernard Grob

Glencoe
McGraw-Hill

New York, New York Columbus, Ohio Woodland Hills, California Peoria, Illinois

IN MEMORY OF RUTH

TO THE STUDENT

Basic Electronics, Eighth Edition, has been split into two convenient books. This set divides the original text into two logical parts. Book 1 contains the Survey chapter and Chapters 1 through 15, which cover all the material on direct current. Book 2 contains the remainder of the book—Chapters 16 to 32, which cover alternating current and an introduction to electronics.

For the convenience of the student, the glossary and appendixes are included in both Book 1 and Book 2. To facilitate reference to the supplemental materials and to maintain continuity between the volumes, the page numbering system has been kept as it appears in the single-volume textbook. For instance, the text of Book 1 is numbered through page 412, with the appendixes beginning on the next page, numbered 955. The text of Book 2 is numbered from page 414 through 954, and the appendixes continue on page 955.

Photo credits appear on page 1010, which is hereby made part of this copyright page.

The Library of Congress has cataloged *Basic Electronics,* Eighth Edition, as follows:
Grob, Bernard.
Basic electronics / Bernard Grob.—8th ed.
p. cm.
Includes bibliographical references and index.
ISBN 0-02-802253-X
1. Electronics. I. Title.
TK7816.G75 1997
621.3—dc21 96-39669
CIP

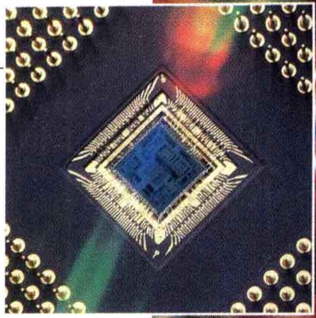
Glencoe/McGraw-Hill
A Division of The McGraw-Hill Companies

Basic Electronics, Eighth Edition, Book 2, Chapters 16 to 32

Send all inquiries to:
Glencoe/McGraw-Hill
936 Eastwind Drive
Westerville, Ohio 43081

ISBN 0-02-802265-3

2 3 4 5 6 7 8 9 027 02 01 00 99 98 97



PREFACE

Basic Electronics, now in its eighth edition, is intended for students taking their first course in the fundamentals of electricity and electronics. The book is written for the beginning student, who is assumed to have no prior knowledge of the technical aspects of the subject. The prerequisites for using this book include an understanding of basic algebra and some trigonometry. In many schools, it will be possible to take a basic algebra-trigonometry course concurrently with the use of this book in a course covering the fundamental concepts of dc and ac theory.

The primary focus of this revision was a very careful review of its content and layout. Many additions, deletions, and reordering of topics have occurred as a direct result of an extensive survey sent to electronics instructors all across the country. For current users of the book, the additions and changes will be easy to identify throughout the book.

ORGANIZATION The book begins with a chapter entitled "Survey of Electronics." This chapter provides a brief overview of the history of the development of electronics, describes a variety of career opportunities available in electronics, explains the most common components used in electronics, and identifies some of the most common types of equipment used by professionals in the electronics field. Following the "Survey of Electronics" chapter, the book provides complete and comprehensive coverage of the subjects which form the real fundamentals of basic electronics. Beginning with the atomic nature of electricity in Chapter 1, the topics progress through a study of resistors, Ohm's law, series and parallel circuits, series-parallel circuits, voltage and current dividers, dc meters, Kirchhoff's laws and network theorems, conductors and insulators, batteries, magnetism, magnetic units, electromagnetic induction, alternating voltage and current, capacitance, capacitive reactance, capacitive circuits, inductance, inductive reactance, inductive circuits, *RC* and *L/R* time constants, ac circuits, complex numbers, resonance, and filters.

Current users of the book will notice that the chapters on capacitance, capacitive reactance, and capacitive circuits now precede the chapters on inductance, inductive reactance, and inductive circuits. This change has been made as a result of the previously mentioned survey that was sent to electronics instructors. If they wish, instructors may choose to cover the chapters on inductance prior to those on capacitance.

In this edition, several changes have been made in Chapter 2, "Resistors." There is expanded coverage of both carbon and metal film resistors and the five-band resistor color code. Also new to this chapter is coverage of surface-mount resistors and zero-ohm resistors. These additions reflect the most state-of-the-art coverage available on resistors in any basic textbook covering dc and ac theory.

In Chapter 11, "Conductors and Insulators," more information on switches has been added. In Chapter 15, "Electromagnetic Induction," a new section on electromechanical relays has been added.

In Chapter 17, "Capacitance," new and updated material regarding the coding system used with a wide variety of types of capacitors has been added. Also new to this chapter is the coverage of surface-mount capacitors and the coding systems used with them. In Chapter 20, "Inductance," new material covers impedance matching and the many ratings associated with transformers. In Chapter 23, "*RC* and *L*/*R* Time Constants," new information on differentiation and integration is included. In Chapter 27, "Filters," a wealth of new information, on phase angles, calculating cutoff frequency and output voltage, decibels, and frequency response curves, now appears.

The last five chapters of the book provide a basic introduction to semiconductor theory, diodes, transistors, amplifiers, oscillators, modulation, rectifier circuits, circuit configurations, class of operation, troubleshooting, number systems, basic logic gates, Boolean algebra, flip-flops, counters, op amp characteristics, and op amp circuits. The coverage of op amp circuits has been expanded in response to the survey.

Following the text chapters are four appendixes: Appendix A, "Electrical Symbols and Abbreviations," Appendix B, "Solder and the Soldering Process," Appendix C, "Schematic Symbols," and Appendix D, "Using the Oscilloscope." The appendixes are followed by a glossary, answers to self-tests, answers to odd-numbered chapter problems and critical thinking problems, and an index.

CHAPTER LAYOUT Each chapter begins with a brief introduction of the topic, a list of important terms, chapter objectives (new to this edition), and a list of the sections appearing within the chapter. Within each chapter, test-point questions are given at the end of each section. This provides the student with a quick means of checking his or her understanding of the material in that section. At the end of each chapter are the following items: summary, self-test, questions, problems, and critical thinking questions. Like the chapter objectives, the critical thinking questions are new to the eighth edition. It should be noted that new problems have been added to each chapter. The answers to the test-point questions appear at the end of each chapter.

Step-by-step solutions of typical problems dealing with a particular concept are generously provided in every chapter of the book. Where appropriate, typical calculator keystroke routines are provided as an additional aid to the student. The illustrative examples are highlighted so that students can access them more readily.

ANCILLARY PACKAGE The following supplements are available to adopters of Grob *Basic Electronics*:

- *Problems in Grob Basic Electronics:* This book, written by Mitchel E. Schultz, provides students and instructors with a source of hundreds of practical problems for self-study, homework assignments, tests, and review. Each chapter contains a number of solved illustrative problems demonstrating, step-by-step, how representative problems on a particular topic are solved. Following the solved problems are sets of problems for the students to solve.
- *Experiments in Grob Basic Electronics:* This book, written by Frank Pugh and Wes Ponick, provides students and instructors with 67 easy-to-follow laboratory experiments. The experiments range from an introduction to laboratory equipment to an experiment on operational amplifiers. All experiments have been student-tested to ensure their effectiveness.
- *Mathematics for Grob Basic Electronics:* This book, written by Bernard Grob, provides students with the basic math skills needed to solve problems in the text, *Grob Basic Electronics.* Included are chapters on algebra, trigonometry, the basics of computer mathematics, and a new chapter on complex numbers for ac circuits.
- *Instructor's Productivity Center for Grob Basic Electronics, Eighth Edition:* This package includes a Windows-based test generator, a math tutorial, and a Power Point presentation for every chapter of the text. It also includes a graphics file of the circuits in the text. These files can be used for tests or presentations. The optional Group Instruction software, developed by HyperGraphics, can be accessed directly from the IPC. An optional Electronics Workbench file of the circuits in *Basic Electronics* is also available.
- *Instructor's Annotated Edition for Grob Basic Electronics, Eighth Edition:* This book includes teaching hints and scheduling suggestions for the instructor and career information for students. Much of this material has been given in the margin of this text for the instructor's ease of reference while teaching a class. Answers to test-point questions, which appear in the student's text, are also included in the margin of this version, produced especially for the instructor.
- *Instructor's Manual for Grob Basic Electronics, Eighth Edition:* This book provides the instructor with answers to all the questions and problems in the text and in its supplements, *Problems in Grob Basic Electronics, Experiments in Grob Basic Electronics,* and *Mathematics for Grob Basic Electronics.*

Bernard Grob

CREDITS AND ACKNOWLEDGMENTS

The author would like to thank those individuals who responded to the survey which was sent out long before this book was revised. Their comments and suggestions provided the information needed to make this the most up-to-date book available on electricity and electronics. The author would also like to thank the reviewers listed below who painstakingly examined every sentence, example, and problem for accuracy prior to the publication of the eighth edition.

In addition, the author would like to thank the highly professional staff at Glencoe in Columbus, Ohio—especially Brian Mackin for his patience, hard work, and understanding during the long period of the manuscript preparation. My thanks also go to Mitchel Schultz for his help on this project. Finally, it is a pleasure to thank my wife, Sylvia, for her help in preparing the manuscript.

Tim Beecher
Wisconsin Indianhead Technical College
Superior, WI

Jack Berger
ITT Technical Institute
Murray, UT

B. J. Tobias Boydell
Seva Electronics
Burford, Ontario, Canada

Patrick J. Chalmers
ITT Technical Institute
Matteson, IL

Michael Fairbanks
ITT Technical Institute
Nashville, TN

Richard L. Green
ITT Technical Institute
Maitland, FL

Rich Hassler
ITT Technical Institute
Youngstown, OH

William M. Hessmiller
QRS Corporation
Dunmore, PA

Barry Hoy
ITT Technical Institute
Norfolk, VA

Arnold Kroeger
Hillsborough Community College
Tampa, FL

James A. McQuoid
ITT Technical Institute
San Antonio, TX

Jim Myers
Wallace Community College
Selma, AL

Tony Richardson
ITT Technical Institute
Strongsville, OH

T. Randall Riggs
ITT Technical Institute
Tampa, FL

Gregg Richley
ITT Technical Institute
Youngstown, OH

Victor Rozeboom
Burlington, NC

John Ryan
ITT Technical Institute
Knoxville, TN

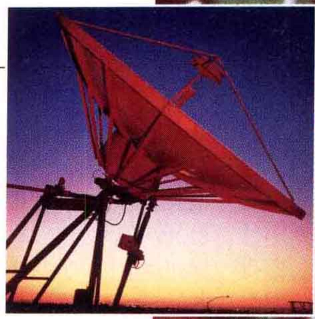
Dan Siddall
ITT Technical Institute
Boise, ID

Mike Siemion
Madison Area Technical College
Madison, WI

William H. Sims III
ITT Technical Institute
Jacksonville, FL

Pat Thomason
Patterson State Technical
College
Montgomery, AL

Bryon K. Van Beek
Courtesy Communications
Spokane, WA



CONTENTS

CHAPTER 20 INDUCTANCE 540

CHAPTER 21 INDUCTIVE REACTANCE 584

CHAPTER 22 INDUCTIVE CIRCUITS 604

CHAPTER 23 *RC* AND *L/R* TIME CONSTANTS 630

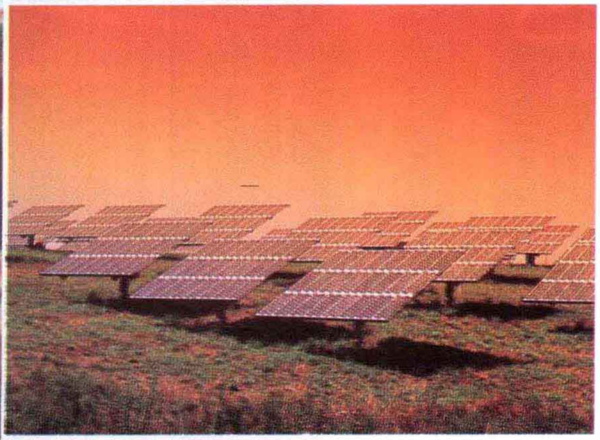
CHAPTER 24 ALTERNATING CURRENT CIRCUITS 664

CHAPTER 25 COMPLEX NUMBERS FOR AC CIRCUITS 690

CHAPTER 16

ALTERNATING VOLTAGE AND CURRENT

This chapter begins the analysis of alternating voltage, as used for the 120-Vac power line, and the alternating current that the voltage produces in an ac circuit. Alternating voltage reverses in polarity and amplitude periodically with time. One cycle includes two alternations in polarity. The number of cycles per second is the frequency whose unit is the hertz (Hz). One hertz is equal to one cycle per second (1 Hz = 1 cps). The ac power line frequency is standardized at 60 Hz in the United States.



For an ac voltage:

1. The *V* reverses polarity at a specific rate. Consider one terminal of the ac source positive at a given time, with respect to the other terminal. A little later in time, the positive terminal will become negative to reverse the polarity of the ac output voltage. The polarity reversals are continuously repeated at a regular rate.
2. For either polarity, the ac voltage varies in amplitude. In fact, the voltage must vary from a maximum value to zero in order to be ready for the next polarity reversal.

The alternating current that results has the following features:

1. The *I* reverses in direction with the polarity reversal in *V*.
2. The amplitude of *I* varies with the changing values of voltage.

The ac waveform with its polarity reversals and amplitude variations is very important in electronics because the many audio, radio, and video signals are examples of ac voltages.

CHAPTER OBJECTIVES

Upon completion of this chapter, you should be able to:

- *Understand* how a sine wave of alternating voltage is generated.
- *Calculate* the instantaneous value of a sine wave.
- *Define* the following values for a sine wave: peak, peak-to-peak, root-mean-square, and average.
- *Calculate* the rms, average, and peak-to-peak values of a sine wave when the peak value is known.
- *Define* the terms *frequency* and *period* and list the units of each.
- *Calculate* the wavelength when the frequency is known.
- *Understand* the concept of phase angles.
- *Understand* the makeup of a nonsinusoidal waveform.
- Define the term *harmonics.*
- *Understand* the 60-Hz ac power line and the basics of residential house wiring.

IMPORTANT TERMS IN THIS CHAPTER

alternation
alternator
armature
average value
brushes
commutator
cycle
delta connections
effective value
field winding
frequency
harmonic
hertz
octave
peak value
phase angle
phasor
rms value
sawtooth wave
sine wave
sinusoid
slip rings
square wave
three-phase power
wavelength
wye connections

TOPICS COVERED IN THIS CHAPTER

16-1 Alternating Current Applications
16-2 Alternating-Voltage Generator
16-3 The Sine Wave
16-4 Alternating Current
16-5 Voltage and Current Values for a Sine Wave
16-6 Frequency
16-7 Period
16-8 Wavelength
16-9 Phase Angle
16-10 The Time Factor in Frequency and Phase
16-11 Alternating Current Circuits with Resistance
16-12 Nonsinusoidal AC Waveforms
16-13 Harmonic Frequencies
16-14 The 60-Hz AC Power Line
16-15 Motors and Generators
16-16 Three-Phase AC Power

16-1 ALTERNATING CURRENT APPLICATIONS

Figure 16-1 shows the output from an ac voltage generator, with the reversals between positive and negative polarities and the variations in amplitude. In Fig. 16-1*a*, the waveform shown simulates an ac voltage as it would appear on the screen of an oscilloscope, which is an important test instrument for ac voltages. The oscilloscope shows a picture of any ac voltage connected to its input terminals, while indicating the amplitude. The details of how to use the oscilloscope for ac voltage measurements are explained in App. D, "Using the Oscilloscope."

In Fig. 16-1*b*, the graph of the ac waveform shows how the output from the generator in Fig. 16-1*c* varies with respect to time. Assume that this graph shows *V* at terminal 2 with respect to terminal 1. Then the voltage at terminal 1 corresponds to the zero axis in the graph as the reference level. At terminal 2, the output voltage has positive amplitude variations from zero up to the peak value and down to zero. All these voltage values are with respect to terminal 1. After a half-cycle, the voltage at terminal 2 becomes negative, still with respect to the other terminal. Then the same voltage variations are repeated at terminal 2, but they have negative polarity compared to the reference level. It should be noted that if we take the voltage at terminal 1 with terminal 2 as the reference, the waveform in Fig. 16-1*b* would have the same shape but be inverted in polarity. The negative half-cycle would come first, but it does not matter which is first or second.

The characteristic of varying values is the reason why ac circuits have so many uses. For instance, a transformer can operate only with alternating current, to step up or step down an ac voltage. The reason is that the changing current produces changes in its associated magnetic field. This application is just an example of inductance *L* in ac circuits, where the changing magnetic flux of a varying current can produce induced voltage. The details of inductance are explained in Chaps. 20, 21, and 22.

A similar but opposite effect in ac circuits is capacitance *C*. The capacitance is important with the changing electric field of a varying voltage. Just as *L* has

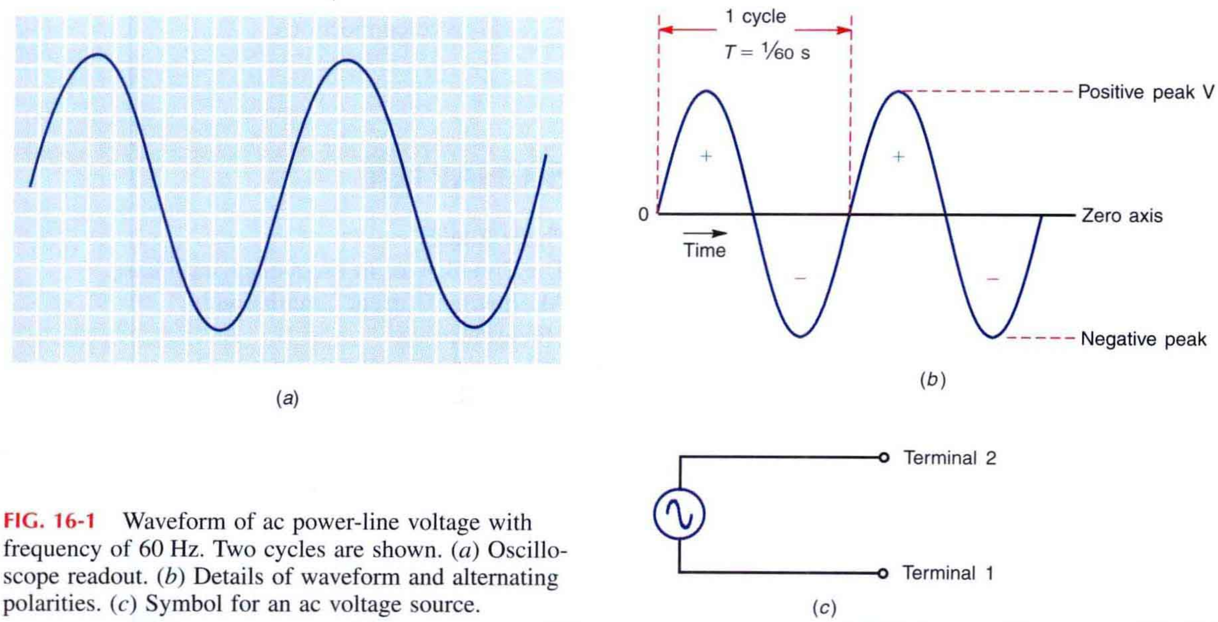


FIG. 16-1 Waveform of ac power-line voltage with frequency of 60 Hz. Two cycles are shown. (*a*) Oscilloscope readout. (*b*) Details of waveform and alternating polarities. (*c*) Symbol for an ac voltage source.

an effect with alternating current, C has an effect which depends on alternating voltage. The details of capacitance are explained in Chaps. 17, 18, and 19.

The L and C are additional factors, besides resistance R, in the operation of ac circuits. It should be noted that R is the same for either a dc or an ac circuit. However, the effects of L and C depend on having an ac source. The rate at which the ac variations occur, which determines the frequency, allows a greater or lesser reaction by L and C. Therefore, the effect is different for different frequencies. One important application is a resonant circuit with L and C which is tuned to a particular frequency. Tuning in radio and television stations are applications of resonance in an LC circuit.

In general, electronic circuits are combinations of R, L, and C, with both direct current and alternating current. The audio, video, and radio signals are ac voltages and currents. However, the amplifiers that use transistors need dc voltages in order to conduct any current at all. The resulting output of an amplifier circuit, therefore, consists of direct current with a superimposed ac signal. More details of amplifiers are explained in Chap. 29, "Electronic Circuits."

TEST-POINT QUESTION 16-1

Answers at end of chapter.

Answer True or False.

a. An ac voltage varies in magnitude and reverses in polarity.
b. A transformer can operate with either ac or steady dc input.
c. Inductance L and capacitance C are important factors in ac circuits.

16-2 ALTERNATING-VOLTAGE GENERATOR

We can define an ac voltage as one that continuously varies in magnitude and periodically reverses in polarity. In Fig. 16-1, the variations up and down on the waveform show the changes in magnitude. The zero axis is a horizontal line across the center. Then voltages above the center have positive polarity, while the values below center are negative.

Figure 16-2 illustrates how such a voltage waveform is produced by a rotary generator. The conductor loop rotates through the magnetic field to generate the induced ac voltage across its open terminals. The magnetic flux shown here is vertical, with lines of force down in the plane of the paper.

In Fig. 16-2a the loop is in its horizontal starting position in a plane perpendicular to the paper. When the loop rotates counterclockwise, the two longer conductors move around a circle. Note that in the flat position shown, the two long conductors of the loop move vertically up or down but parallel to the vertical flux lines. In this position, motion of the loop does not induce a voltage because the conductors are not cutting across the flux.

When the loop rotates through the upright position in Fig. 16-2b, however, the conductors cut across the flux, producing maximum induced voltage. The shorter connecting wires in the loop do not have any appreciable voltage induced in them.

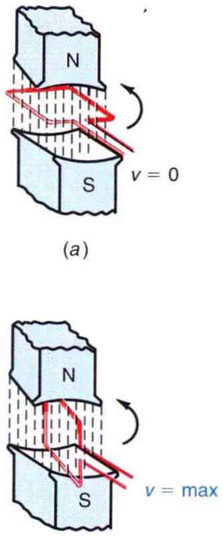


FIG. 16-2 Loop rotating in magnetic field to produce induced voltage v with alternating polarities. (a) Loop conductors moving parallel to magnetic field results in zero voltage. (b) Loop conductors cutting across magnetic field produce maximum induced voltage.

Each of the longer conductors has opposite polarity of induced voltage because the conductor at the top is moving to the left while the bottom conductor is moving to the right. The amount of voltage varies from zero to maximum as the loop moves from a flat position to upright, where it can cut across the flux. Also, the polarity at the terminals of the loop reverses as the motion of each conductor reverses during each half-revolution.

With one revolution of the loop in a complete circle back to the starting position, therefore, the induced voltage provides a potential difference v across the loop, varying in the same way as the wave of voltage shown in Fig. 16-1. If the loop rotates at the speed of 60 revolutions per second, the ac voltage will have the frequency of 60 Hz.

THE CYCLE One complete revolution of the loop around the circle is a *cycle.* In Fig. 16-3, the generator loop is shown in its position at each quarter-turn during one complete cycle. The corresponding wave of induced voltage also goes through one cycle. Although not shown, the magnetic field is from top to bottom of the page as in Fig. 16-2.

At position A in Fig. 16-3, the loop is flat and moves parallel to the magnetic field, so that the induced voltage is zero. Counterclockwise rotation of the loop moves the dark conductor to the top at position B, where it cuts across the field to produce maximum induced voltage. The polarity of the induced voltage here makes the open end of the dark conductor positive. This conductor at the top is cutting across the flux from right to left. At the same time, the opposite conductor below is moving from left to right, causing its induced voltage to have opposite polarity. Therefore, maximum induced voltage is produced at this time across the two open ends of the loop. Now the top conductor is positive with respect to the bottom conductor.

In the graph of induced voltage values below the loop in Fig. 16-3, the polarity of the dark conductor is shown with respect to the other conductor. Positive voltage is shown above the zero axis in the graph. As the dark conductor

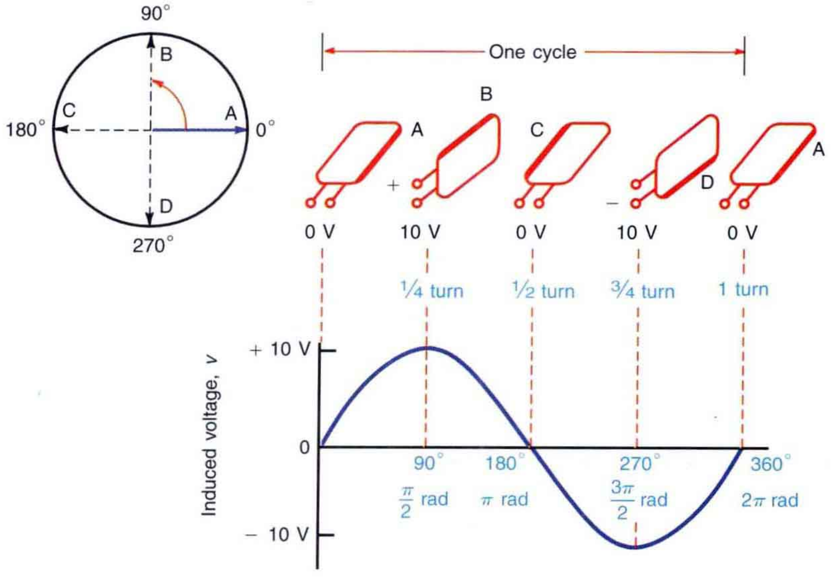


FIG. 16-3 One cycle of alternating voltage generated by rotating loop. Magnetic field, not shown here, is directed from top to bottom, as in Fig. 16-2.