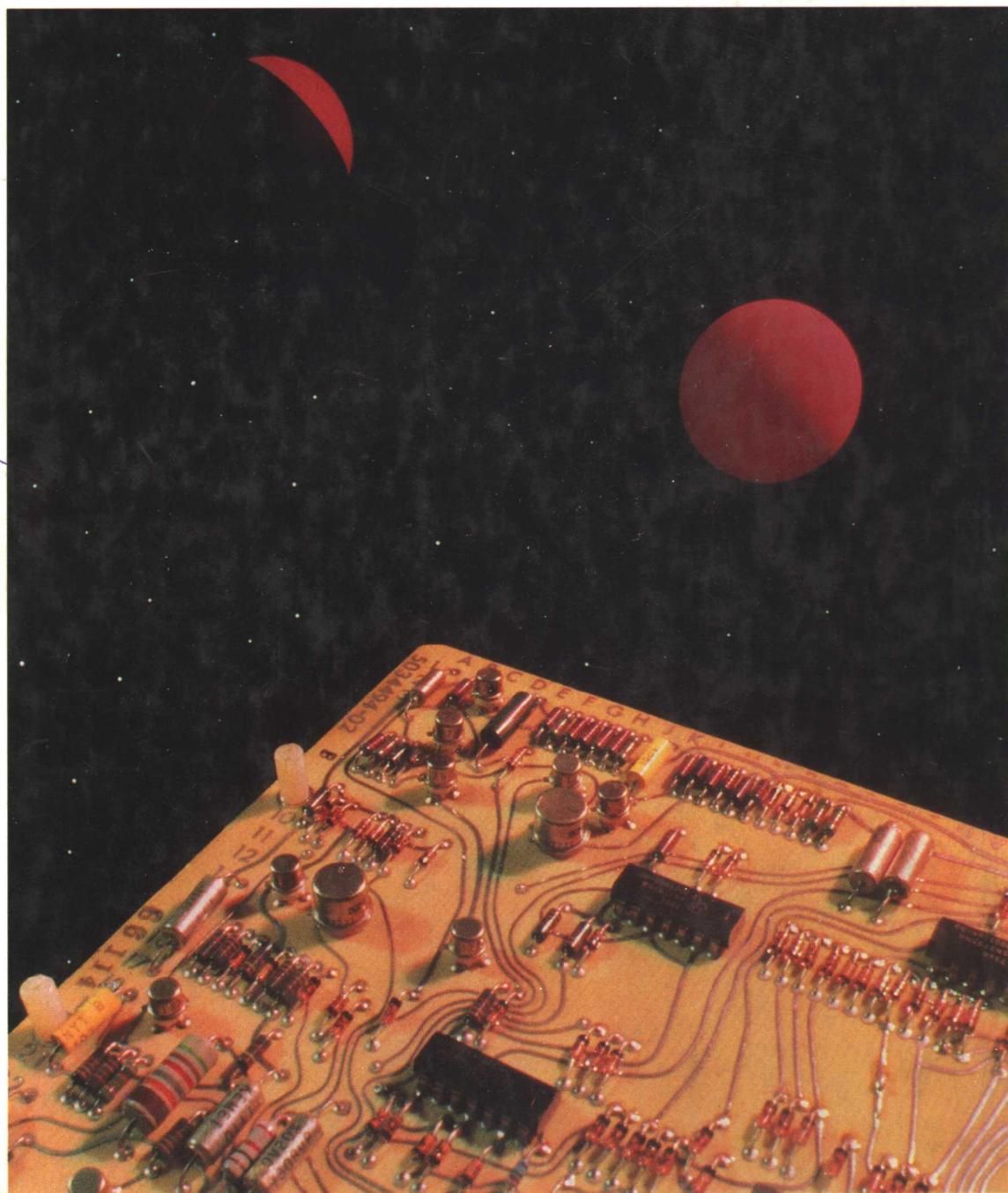


ELECTRONICS FUNDAMENTALS: CIRCUITS, DEVICES AND APPLICATIONS



F L O Y D

Thomas L. Floyd

**ELECTRONICS FUNDAMENTALS:
CIRCUITS, DEVICES
AND APPLICATIONS**

**Merrill Publishing Company
A Bell & Howell Information Company
Columbus Toronto London Melbourne**

***To the electronics instructor, in the hope that this book will make
your job a little easier***

Published by
Merrill Publishing Company
A Bell & Howell Information Company
Columbus, Ohio 43216

This book was set in Century Schoolbook.

Administrative Editor: Tim McEwen
Developmental Editor: Don Thompson
Production Coordinator: Constantina Geldis
Cover Designer: Cathy Watterson
Text Designer: Cynthia Brunk
Cover Photo: Merrill Publishing/Larry Hamill

Credits: Part 1 opening photo by Merrill Publishing/Bruce Johnson; Part 2 opening and Chapter 1, 8, 9, 11, and 18 opening photos courtesy of Tektronix, Inc.; Part 3 opening and Chapter 5 opening photos courtesy of Motorola Semiconductor Products, Inc. Chapter 2 opening photo courtesy of University of Akron; Chapter 3 and 16 opening photos courtesy of Texas Instruments, Inc.; Chapter 4 and 6 opening photos courtesy of Hawaii Visitors Bureau; Chapter 7 opening photo courtesy of ADT Security Systems; Chapter 10, 15, 19, and 20 opening photos by Jo Hall; Chapter 12 opening photo courtesy of The Coliseum, Richfield, Ohio; Chapter 13 opening photo courtesy of Tandy Corp.; Chapter 14 opening photo courtesy of the Bureau of Sport Fisheries and Wildlife, Washington, D.C.; Chapter 17 opening photo courtesy of Hewlett-Packard; Chapter 21 opening photo courtesy of Grumman Corp.; Chapter 22 opening photo courtesy of E. I. duPont de Nemours and Co.; and four-color insert photos by Merrill Publishing/Bruce Johnson.

Copyright © 1987 by Merrill Publishing Company. All rights reserved. No part of this book may be reproduced in any form, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the publisher. "Merrill Publishing Company" and "Merrill" are registered trademarks of Merrill Publishing Company.

Library of Congress Catalog Card Number: 86-61567
International Standard Book Number: 0-675-20714-2
Printed in the United States of America
5 6 7 8 9—91 90

MERRILL'S INTERNATIONAL SERIES IN ELECTRICAL AND ELECTRONICS TECHNOLOGY

BATESON	<i>Introduction to Control System Technology, Second Edition,</i> 8255-2
BEACH/JUSTICE	<i>DC/AC Circuit Essentials,</i> 20193-4
BERLIN	<i>Experiments in Electronic Devices,</i> 20234-5 <i>The Illustrated Electronics Dictionary,</i> 20451-8
BOGART	<i>Electronic Devices and Circuits,</i> 20317-1
BOGART/BROWN	<i>Experiments in Electronic Devices and Circuits,</i> 20488-7
BOYLESTAD	<i>Introductory Circuit Analysis, Fifth Edition,</i> 20631-6
BOYLESTAD/KOUSOUROU	<i>Experiments in Circuit Analysis, Fifth Edition,</i> 20743-6
BREY	<i>Advanced Microprocessors (16-Bit),</i> 20443-7 <i>Microprocessor/Hardware Interfacing and Applications,</i> 20158-6
BUCHLA	<i>Experiments in Electric Circuits Fundamentals,</i> 20736-3 <i>Digital Experiments: Emphasizing Systems and Design,</i> 20562-X
COX	<i>Digital Experiments: Emphasizing Troubleshooting,</i> 20518-2
FLOYD	<i>Electric Circuits Fundamentals,</i> 20756-8 <i>Electronics Fundamentals: Circuits, Devices, and</i> <i>Applications,</i> 20714-2 <i>Digital Fundamentals, Third Edition,</i> 20517-4 <i>Electronic Devices,</i> 20157-8 <i>Essentials of Electronic Devices,</i> 20062-8 <i>Principles of Electric Circuits, Second Edition,</i> 20402-X <i>Electric Circuits, Electron Flow Version,</i> 20037-7 <i>Microprocessor Architecture, Programming, and Applications</i> <i>with the 8085/8080A,</i> 20159-4
GAONKAR	<i>Drafting for Electronics,</i> 20200-0
LAMIT/LLOYD	<i>Workbook in Drafting for Electronics,</i> 20417-8
LAMIT/WAHLER/HIGGINS	<i>Technical Graphics: Electronics Worktext,</i> 20311-2
MARUGGI	<i>BASIC Applied to Circuit Analysis,</i> 20161-6
NASHELSKY/BOYLESTAD	<i>Direct and Alternating Current Machinery, Second Edition,</i> 20160-8
ROSENBLATT/FRIEDMAN	<i>Survey of Electronics, Third Edition,</i> 20162-4 <i>Electronics: Devices, Discrete and Integrated Circuits,</i> 8494-6 <i>Experiments in Electric Circuits, Second Edition,</i> 20403-8 <i>Operational Amplifiers with Linear Integrated Circuits,</i> 20090-3
SCHWARTZ	<i>Fundamentals of Electronic Devices, Third Edition,</i> 9887-4
SEIDMAN/WAINTRAUB	<i>Electronic Devices, Third Edition, Conventional Flow Version,</i> 20063-6
STANLEY, B. H.	<i>Fundamentals of Pulse and Digital Circuits, Third Edition,</i> 20033-4
STANLEY, W. D.	<i>Introduction to Electric Circuit Analysis, Second Edition,</i> 20002-4
TOCCI	<i>Applied Digital Electronics,</i> 9925-0 <i>Electronic Communication Techniques,</i> 20202-7
WARD	
YOUNG	

Preface

Electronics Fundamentals: Circuits, Devices and Applications covers the essential topics in dc and ac circuits and electronic devices with emphasis on applications and troubleshooting. The coverage provides a thorough foundation on which to develop skills in electronics and related fields.

This book is designed particularly for those students in technician-level programs in technical institutes, community colleges, and vocational/technical schools. Emphasis is on the understanding and application of basic concepts. Mathematics is held to a minimum and is used only in a supportive role where it is essential for the development of a complete and meaningful coverage of a topic or for providing a means of analyzing basic circuit operation.

Some of the specific features are:

- Chapter objectives
- Application assignments
- Application notes
- Calculator sequences
- Section reviews with answers at the end of each chapter
- Two-color format throughout; use of color in the art program is *functional*, emphasizing concepts
- Full-color section keyed to figures, problems, section reviews, and examples
- Many photographs
- Over 1,200 illustrations
- Over 250 numbered examples
- Emphasis on applications and troubleshooting
- End-of-chapter summaries
- Self-tests at the end of each chapter with solutions at the end of the book
- Two end-of-chapter problem sets (one easier, the other more difficult); answers to odd-numbered problems at the end of the book
- Glossary at the end of the book
- Availability of a coordinated lab manual and a set of transparencies

Chapter Organization

At the beginning of each chapter, the introduction provides an overview of the material to be covered, and the *objectives* list itemizes the specific things that the student will learn.

The *Application Assignment* at the beginning of each chapter places the students in a practical on-the-job situation as technicians and requires them to complete the assignment based on knowledge gained during the study of the chapter. These Application Assignments are intended to be not only educational, but also motivational. They put the students in a situation to which they can relate but which they are generally unable to handle before studying the chapter. After completing the material in the chapter, however, they can successfully carry out the assignment and thus derive a sense of accomplishment. The *Application Note* at the end of the chapter provides a suggested approach or solution to the assignment.

Calculator Sequences are provided for selected examples to show the student how to use a typical calculator (TI55-II; sequences may vary for other calculators) to arrive at the solution. Generally, these appear where an unfamiliar mathematical procedure is first introduced.

The *Section Reviews* consist of questions and problems which focus on key concepts presented in that section in order to provide students with frequent feedback on their comprehension of the material. Answers are given at the end of the chapter.

The *Summary* at the end of the chapter provides a concise listing of facts, definitions, new symbols, and a formula list.

The *Self-test* at the end of the chapter allows the students to check their mastery of the general concepts covered in the chapter. The self-test consists of essay-type questions, definitions, and multiple-choice questions as well as basic problems requiring some calculation. Solutions to all self-tests appear at the end of the book.

In each of the first 16 chapters, there are two problem sets. Problem Set A is a sectionalized series of relatively straightforward exercises, and Problem Set B contains exercises that are more demanding and thought provoking. Answers to the odd-numbered problems appear at the end of the book.

In the first six chapters, a number of figures, problems, section reviews, and examples relate to a unique full-color section positioned between pages 128 and 129. In these exercises, the students are required to identify simple component relationships in actual breadboard assemblies or on printed circuit boards, to determine resistance values directly from the color bands, and to read instruments connected to operating circuits in order to analyze or troubleshoot the circuit.

Overall Organization of the Text

The text is divided into three parts: DC Circuits, consisting of Chapters 1 through 8; AC Circuits, consisting of Chapters 9 through 16; and Electronic Devices consisting of Chapters 17 through 22.

For those wishing to introduce capacitance and inductance in the dc portion of the course, all of Chapter 10 except Sections 10-6 and 10-7 and all of Chapter 11 except Sections 11-6 and 11-7 can be added to the dc coverage.

Then, Sections 10-6, 10-7, 11-6, and 11-7 can be covered as part of the ac course.

The organization and content of this book are suited particularly to those programs which cover dc, ac, and devices during the first year in a two-term or three-term sequence.

Acknowledgments

This book is the result of the efforts of many people. In particular, I want to express my appreciation to Don Thompson, Connie Geldis, Tim McEwen, Cindy Brunk, Bruce Johnson, Jim Hubbard, Terry Tietz, and Cathy Watterson at Merrill Publishing Company for their work in making this book a reality. As always, the people at Merrill are progressive, creative, and dedicated to quality. My thanks also go to the following instructors who reviewed the manuscript and provided many valuable suggestions: Roman R. Braun, Terrence D. Nelson, and Kenneth J. Dreistadt, Lincoln Technical Institute; Robert A. Ciuffetti, Sylvania Technical Institute; John Colyer, ITT Technical Institute—Austin; Kenneth Edwards, International Brotherhood of Electrical Workers; William Greer, Albuquerque Technical Vocational Institute; Jill Harlamert, DeVry Institute of Technology—Columbus; Steve Kalina, DeVry, Inc.; Arnold Kroeger, Hillsborough Community College; Floyd Martin, Santa Ana College; W. A. McIntyre, DeVry Institute of Technology—Chicago; and Tim Staley, DeVry Institute of Technology—Dallas. In addition, I thank Morris McCarthy, DeVry—Atlanta for suggesting the four-color insert and Dean Gay Farmer, DeVry—Columbus, for his help in implementing this suggestion. Art Vildavs, Joyce Mielke, and Sam McCord, all students at DeVry Institute of Technology—Columbus, helped to build and to set up the circuits for the full-color photographs. I am grateful to the following industrial organizations that contributed photographs and other technical material for use in this book: Tektronix, Texas Instruments, Hewlett-Packard, Bell Laboratories, B&K Precision/Dynascan Corporation, Grumman Corporation, Burroughs Corporation, Motorola Semiconductor Products, E. I. duPont de Nemours and Company, Triplett, Bussman, Eaton, Grayhill, Bourns Trimpot, Dale Electronics, Radio Shack, Ford, Murata Erie, Delevan, and Sprague Electric. Finally, my wife, Sheila, deserves a great deal of credit for her help and support during the development of this book.

Thomas L. Floyd

Contents

PART ONE DC CIRCUITS

INTRODUCTION 2

1	1-1	History of Electricity and Electronics	4
	1-2	Careers in Electronics	8
	1-3	Applications of Electricity and Electronics	10
	1-4	Circuit Components and Measuring Instruments	13
	1-5	Electrical Units	16
	1-6	Scientific Notation	17
	1-7	Metric Prefixes	20

THE BASIC ELECTRICAL QUANTITIES 24

2	2-1	Atoms	26
	2-2	Electrical Charge	28
	2-3	Voltage	30
	2-4	Current	33
	2-5	Resistance	35
	2-6	The Electric Circuit	42
	2-7	Basic Circuit Measurements	46

OHM'S LAW AND POWER 56

3	3-1	Demonstration of Ohm's Law	58
	3-2	Application of Ohm's Law	62
	3-3	Power and Energy	67
	3-4	Power in an Electric Circuit	68
	3-5	The Power Rating of Resistors	71

SERIES CIRCUITS**84****4**

4-1	Resistors in Series	86
4-2	Current in a Series Circuit	88
4-3	Total Series Resistance	90
4-4	Ohm's Law in Series Circuits	93
4-5	Voltage Sources in Series	97
4-6	Kirchhoff's Voltage Law	99
4-7	Voltage Dividers	103
4-8	Power in a Series Circuit	109
4-9	Troubles in Series Circuits	110

PARALLEL CIRCUITS**124****5**

5-1	Resistors in Parallel	126
5-2	Voltage in a Parallel Circuit	129
5-3	Kirchhoff's Current Law	130
5-4	Total Parallel Resistance	134
5-5	Ohm's Law in Parallel Circuits	140
5-6	The Current Divider Principle	143
5-7	Power in a Parallel Circuit	147
5-8	How Parallel Circuits Are Used	148
5-9	Troubles in Parallel Circuits	151

SERIES-PARALLEL CIRCUITS**164****6**

6-1	Identifying Series-Parallel Relationships	166
6-2	Analysis of Series-Parallel Circuits	171
6-3	Circuit Ground	176
6-4	Loaded Voltage Dividers	180
6-5	The Wheatstone Bridge	185
6-6	Circuits with More than One Voltage Source	188
6-7	Thevenin's Theorem	191
6-8	Troubles in Series-Parallel Circuits	198

MAGNETISM AND ELECTROMAGNETISM**212****7**

7-1	The Magnetic Field	214
7-2	Electromagnetism	218
7-3	Electromagnetic Induction	226
7-4	Applications of Electromagnetic Induction	229

MEASURING INSTRUMENTS**238****8**

- 8-1 Analog Meter Movements 240
- 8-2 Basic Analog dc Meter Circuitry 242
- 8-3 Reading Analog Multimeters 250
- 8-4 Digital Multimeters (DMMs) 252
- 8-5 The Oscilloscope 255

PART TWO AC CIRCUITS**INTRODUCTION TO ALTERNATING
CURRENT AND VOLTAGE****268****9**

- 9-1 The Sine Wave 270
- 9-2 Voltage and Current Values of a Sine Wave 275
- 9-3 Sine Wave Voltage Sources 278
- 9-4 Angular Relationships of a Sine Wave 283
- 9-5 The Sine Wave Equation 288
- 9-6 Introduction to Phasors 290
- 9-7 Ohm's Law and Kirchhoff's Laws 294
- 9-8 Nonsinusoidal Waveforms 296

CAPACITORS**314****10**

- 10-1 The Capacitor 316
- 10-2 Types of Capacitors 322
- 10-3 Series Capacitors 327
- 10-4 Parallel Capacitors 331
- 10-5 Capacitors in dc Circuits 334
- 10-6 Capacitors in ac Circuits 340
- 10-7 Capacitor Applications 346
- 10-8 Testing Capacitors 349

INDUCTORS**360****11**

- 11-1 The Inductor 362
- 11-2 Types of Inductors 367
- 11-3 Series Inductors 368
- 11-4 Parallel Inductors 368
- 11-5 Inductors in dc Circuits 370
- 11-6 Inductors in ac Circuits 379
- 11-7 Inductor Applications 384
- 11-8 Testing Inductors 386

TRANSFORMERS**394****12**

- 12-1 The Basic Transformer 396
- 12-2 Step-Up Transformers 401
- 12-3 Step-Down Transformers 402
- 12-4 Transformer Power 402
- 12-5 Reflected Load in a Transformer 404
- 12-6 The Transformer as an Isolation Device 411
- 12-7 Nonideal Transformer Characteristics 413
- 12-8 Other Types of Transformers 416
- 12-9 Troubles in Transformers 421

FREQUENCY RESPONSE OF RC CIRCUITS**432****13**

- 13-1 Sinusoidal Response of RC Circuits 434
- 13-2 Impedance and Phase Angle of a Series RC Circuit 435
- 13-3 Analysis of Series RC Circuits 438
- 13-4 Impedance and Phase Angle of a Parallel RC Circuit 445
- 13-5 Analysis of Parallel RC Circuits 448
- 13-6 Series-Parallel Analysis 452
- 13-7 Power in RC Circuits 458
- 13-8 Basic Applications of RC Circuits 463

FREQUENCY RESPONSE OF RL CIRCUITS**484****14**

- 14-1 Sinusoidal Response of RL Circuits 486
- 14-2 Impedance and Phase Angle of a Series RL Circuit 486
- 14-3 Analysis of Series RL Circuits 488
- 14-4 Impedance and Phase Angle of a Parallel RL Circuit 494
- 14-5 Analysis of Parallel RL Circuits 497
- 14-6 Series-Parallel Analysis 499
- 14-7 Power in RL Circuits 502
- 14-8 Basic Applications of RL Circuits 506

RESONANT CIRCUITS**522****15**

- 15-1 Impedance and Phase Angle of Series RLC Circuits 524
- 15-2 Analysis of Series RLC Circuits 525
- 15-3 Series Resonance 529
- 15-4 Series Resonant Filters 537
- 15-5 Parallel RLC Circuits 546
- 15-6 Parallel Resonance 551
- 15-7 Parallel Resonant Filters 559
- 15-8 System Applications 565

PULSE RESPONSE OF RC AND RL CIRCUITS **576**

16	16-1 The RC Integrator	578
	16-2 Response of an RC Integrator to a Single Pulse	579
	16-3 Response of an RC Integrator to Repetitive Pulses	584
	16-4 Response of an RC Differentiator to a Single Pulse	591
	16-5 Response of an RC Differentiator to Repetitive Pulses	596
	16-6 The RL Integrator	599
	16-7 The RL Differentiator	604

PART THREE DEVICES

INTRODUCTION TO SEMICONDUCTOR DEVICES **616**

17	17-1 The Atomic Structure of Semiconductors	618
	17-2 Atomic Bonding	620
	17-3 Conduction in Semiconductor Materials	621
	17-4 N-Type and P-Type Semiconductors	625
	17-5 PN Junctions	626
	17-6 Biasing the Diode	629
	17-7 Diode Characteristics	634

DIODES AND APPLICATIONS **644**

18	18-1 Half-Wave Rectifiers	646
	18-2 Full-Wave Rectifiers	649
	18-3 Rectifier Filters	655
	18-4 Troubleshooting Rectifier Circuits	659
	18-5 Diode Clipping and Clamping Circuits	663
	18-6 Zener Diodes	670
	18-7 Varactor Diodes	677
	18-8 LEDs and Photodiodes	680
	18-9 Diode Data Sheets	684

TRANSISTORS AND THYRISTORS **694**

19	19-1 Bipolar Junction Transistors (BJTs)	696
	19-2 Voltage Divider Bias	701
	19-3 The Bipolar Transistor as an Amplifier	703
	19-4 The Bipolar Transistor as a Switch	710
	19-5 Bipolar Transistor Parameters and Ratings	712
	19-6 Transistor Testing	715
	19-7 The Junction Field-Effect Transistor (JFET)	717

19-8	JFET Characteristics	719	
19-9	The Metal Oxide Semiconductor FET (MOSFET)		723
19-10	FET Biasing	727	
19-11	Unijunction Transistors (UJTs)	731	
19-12	Thyristors	732	
19-13	Transistor Packages and Terminal Identification		735

AMPLIFIERS AND OSCILLATORS

746

20

20-1	Common-Emitter (CE) Amplifiers	748
20-2	Common-Collector (CC) Amplifiers	754
20-3	Common-Base (CB) Amplifiers	757
20-4	FET Amplifiers	760
20-5	Multistage Amplifiers	768
20-6	Class A Operation	771
20-7	Class B Push-Pull Operation	774
20-8	Class C Operation	780
20-9	Troubleshooting an Amplifier	784
20-10	Oscillators	786

OPERATIONAL AMPLIFIERS (OP-AMPS)

800

21

21-1	Introduction to Operational Amplifiers	802
21-2	The Differential Amplifier	804
21-3	Op-Amp Data Sheet Parameters	813
21-4	Op-Amps with Negative Feedback	819
21-5	Effects of Negative Feedback on Op-Amp Impedances	824

BASIC APPLICATIONS OF OP-AMPS

836

22

22-1	Comparators	838
22-2	Summing Amplifiers	840
22-3	Integrators and Differentiators	845
22-4	Sawtooth Generator	851
22-5	Wien-Bridge Oscillator	854
22-6	Active Filters	858
22-7	Three Terminal Regulators	867

APPENDICES

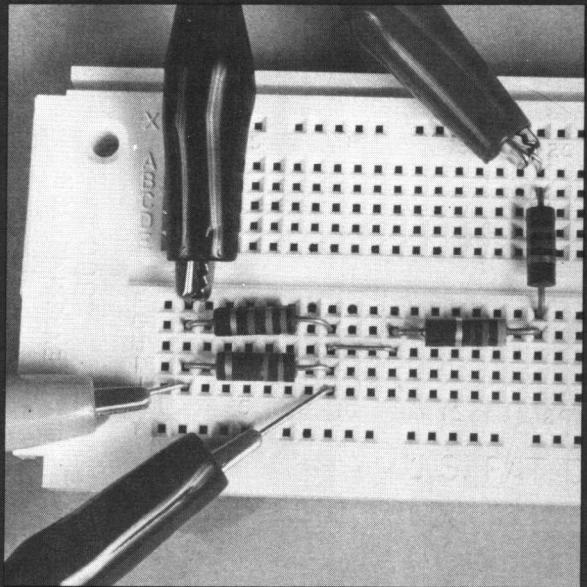
A	Wire Sizes	A-1	
B	Standard Resistance Values		B-1
C	Devices Data Sheets	C-1	
	Solutions to Self-Tests	D-1	
	Answers to Odd-Numbered Problems		E-1
	Glossary	F-1	
	Index	G-1	

COLOR INSERT: Actual Circuits for Examples, Section Reviews, and Problems

This special 16-page full-color insert illustrates actual color-coded resistors and real-world circuits that are used in examples, section reviews, and end-of-chapter problems, thereby taking the student "into the lab" and placing him or her "on the job."

- 1 INTRODUCTION
- 2 THE BASIC ELECTRICAL QUANTITIES
- 3 OHM'S LAW AND POWER
- 4 SERIES CIRCUITS
- 5 PARALLEL CIRCUITS
- 6 SERIES-PARALLEL CIRCUITS
- 7 MAGNETISM AND ELECTROMAGNETISM
- 8 MEASURING INSTRUMENTS

PART ONE DC CIRCUITS



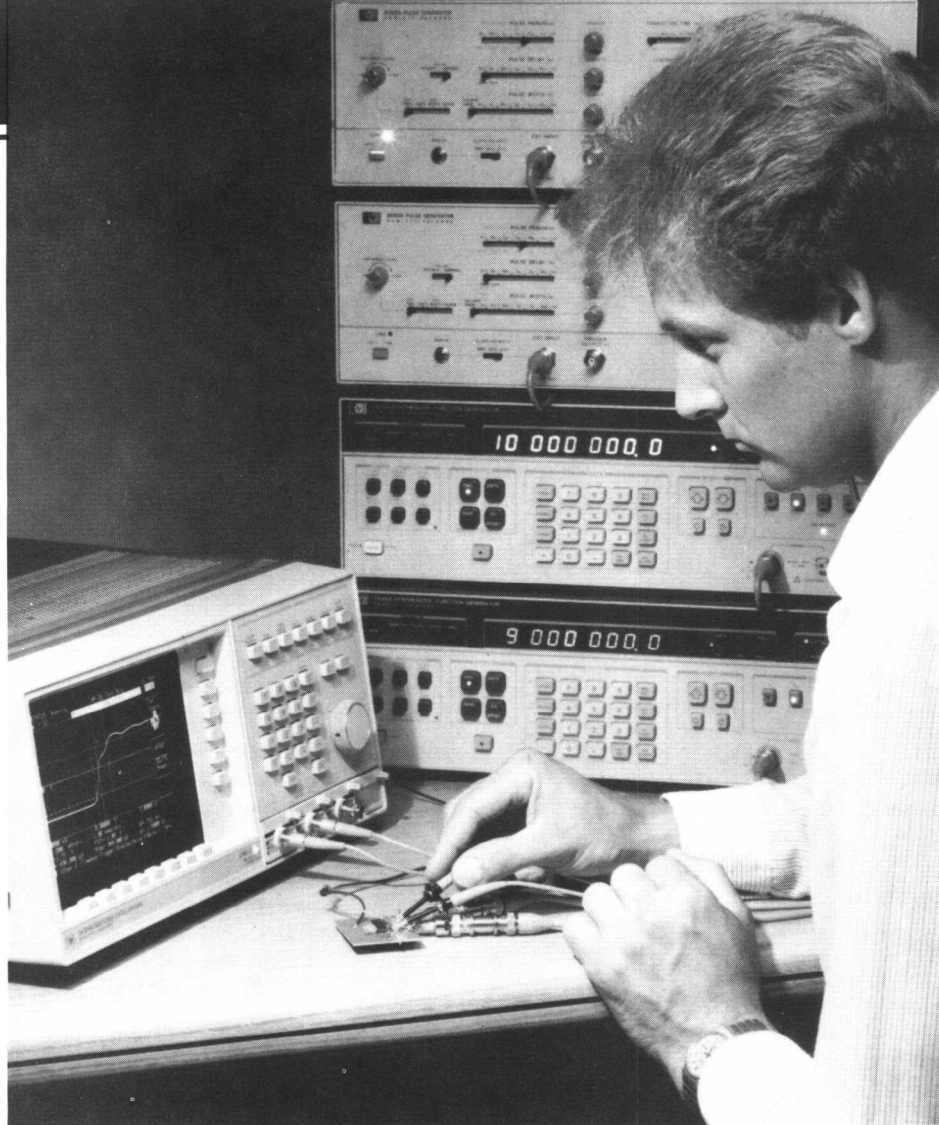
Introduction

- 1-1 History of Electricity and Electronics
- 1-2 Careers in Electronics
- 1-3 Applications of Electricity and Electronics
- 1-4 Circuit Components and Measuring Instruments
- 1-5 Electrical Units
- 1-6 Scientific Notation
- 1-7 Metric Prefixes

This chapter presents a brief history of the fields of electricity and electronics and discusses some of the many areas of application. Also, to aid you throughout the book, the basics of scientific notation and metric prefixes are reviewed, and the quantities and units commonly used in electronics are introduced.

In this chapter you will learn:

- A brief history of electricity and electronics.
- Some of the important areas in which electronics technology is applied.
- How to recognize some important electrical components and measuring instruments.
- The electrical quantities and their units.
- How to use scientific notation (powers of ten).
- The metric prefixes and how to use them.



1

APPLICATION ASSIGNMENT

At the beginning of each chapter starting with Chapter 2, you will find an Application Assignment that relates to that chapter. These assignments present a variety of practical job situations that a technician might encounter in industry.

As you study each chapter, think about how to approach the Application Assignment. When you have completed each chapter, you should have a sufficient knowledge of the topics covered to enable you to carry out the assignment. An Application Note at the end of the chapter suggests an approach or offers a solution to the assignment.