国外电子与通信教材系列

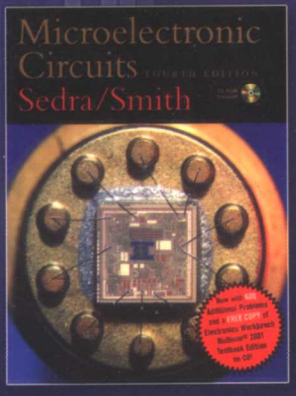
英文版

# 微电子电路

## （第四版）

## Microelectronic Circuits

### Fourth Edition

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## 内 容 简 介

本书是电子和计算机工程专业的一本权威的经典教材。全书由三个部分构成：第一部分介绍器件和基本电路，内容包括运算放大器、二极管、双极型晶体管、场效应晶体管；第二部分讲解模拟电路，内容包括差分和多级放大器、频率响应、反馈、输出级和功率放大器、模拟集成电路、滤波和调谐放大器、信号生成和波形整形电路；第三部分介绍数字电路，内容包括MOS数字电路、双极和先进的数字电路。本书既可作为电子与计算机工程专业的教材，也适合其他专业的工程师们作为自学参考书。



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# 序

2001年7月间，电子工业出版社的领导同志邀请各高校十几位通信领域方面的老师，商量引进国外教材问题。与会同志对出版社提出的计划十分赞同，大家认为，这对我国通信事业、特别是对高等院校通信学科的教学工作会很有好处。

教材建设是高校教学建设的主要内容之一。编写、出版一本好的教材，意味着开设了一门好的课程，甚至可能预示着一个崭新学科的诞生。20世纪40年代MIT林肯实验室出版的一套28本雷达丛书，对近代电子学科、特别是对雷达技术的推动作用，就是一个很好的例子。

我国领导部门对教材建设一直非常重视。20世纪80年代，在原教委教材编审委员会的领导下，汇集了高等院校几百位富有教学经验的专家，编写、出版了一大批教材；很多院校还根据学校的特点和需要，陆续编写了大量的讲义和参考书。这些教材对高校的教学工作发挥了极好的作用。近年来，随着教学改革不断深入和科学技术的飞速进步，有的教材内容已比较陈旧、落后，难以适应教学的要求，特别是在电子学和通信技术发展神速、可以讲是日新月异的今天，如何适应这种情况，更是一个必须认真考虑的问题。解决这个问题，除了依靠高校的老师和专家撰写新的符合要求的教科书外，引进和出版一些国外优秀电子与通信教材，尤其是有选择地引进一批英文原版教材，是会有好处的。

一年多来，电子工业出版社为此做了很多工作。他们成立了一个“国外电子与通信教材系列”项目组，选派了富有经验的业务骨干负责有关工作，收集了230余种通信教材和参考书的详细资料，调来了100余种原版教材样书，依靠由20余位专家组成的出版委员会，从中精选了40多种，内容丰富，覆盖了电路理论与应用、信号与系统、数字信号处理、微电子、通信系统、电磁场与微波等方面，既可作为通信专业本科生和研究生的教学用书，也可作为有关专业人员的参考材料。此外，这批教材，有的翻译为中文，还有部分教材直接影印出版，以供教师用英语直接授课。希望这些教材的引进和出版对高校通信教学和教材改革能起一定作用。

在这里，我还要感谢参加工作的各位教授、专家、老师与参加翻译、编辑和出版的同志们。各位专家认真负责、严谨细致、不辞辛劳、不怕琐碎和精益求精的态度，充分体现了中国教育工作者和出版工作者的良好美德。

随着我国经济建设的发展和科学技术的不断进步，对高校教学工作会不断提出新的要求和希望。我想，无论如何，要做好引进国外教材的工作，一定要联系我国的实际。教材和学术专著不同，既要注意科学性、学术性，也要重视可读性，要深入浅出，便于读者自学；引进的教材要适应高校教学改革的需要，针对目前一些教材内容较为陈旧的问题，有目的地引进一些先进的和正在发展中的交叉学科的参考书；要与国内出版的教材相配套，安排好出版英文原版教材和翻译教材的比例。我们努力使这套教材能尽量满足上述要求，希望它们能放在学生们的课桌上，发挥一定的作用。

最后，预祝“国外电子与通信教材系列”项目取得成功，为我国电子与通信教学和通信产业的发展培土施肥。也恳切希望读者能对这些书籍的不足之处、特别是翻译中存在的问题，提出意见和建议，以便再版时更正。

吴佑寿

中国工程院院士、清华大学教授

“国外电子与通信教材系列”出版委员会主任

# 出 版 说 明

进入21世纪以来，我国信息产业在生产和科研方面都大大加快了发展速度，并已成为国民经济发展的支柱产业之一。但是，与世界上其他信息产业发达的国家相比，我国在技术开发、教育培训等方面都还存在着较大的差距。特别是在加入WTO后的今天，我国信息产业面临着国外竞争对手的严峻挑战。

作为我国信息产业的专业科技出版社，我们始终关注着全球电子信息技术的发展方向，始终把引进国外优秀电子与通信信息技术教材和专业书籍放在我们工作的重要位置上。在2000年至2001年间，我社先后从世界著名出版公司引进出版了40余种教材，形成了一套“国外计算机科学教材系列”，在全国高校以及科研部门中受到了欢迎和好评，得到了计算机领域的广大教师与科研工作者的充分肯定。

引进和出版一些国外优秀电子与通信教材，尤其是有选择地引进一批英文原版教材，将有助于我国信息产业培养具有国际竞争能力的技术人才，也将有助于我国国内在电子与通信教学工作中掌握和跟踪国际发展水平。根据国内信息产业的现状、教育部《关于“十五”期间普通高等教育教材建设与改革的意见》的指示精神以及高等院校老师们反映的各种意见，我们决定引进“国外电子与通信教材系列”，并随后开展了大量准备工作。此次引进的国外电子与通信教材均来自国际著名出版商，其中影印教材约占一半。教材内容涉及的学科方向包括电路理论与应用、信号与系统、数字信号处理、微电子、通信系统、电磁场与微波等，其中既有本科专业课程教材，也有研究生课程教材，以适应不同院系、不同专业、不同层次的师生对教材的需求，广大师生可自由选择和自由组合使用。我们还将与国外出版商一起，陆续推出一些教材的教学支持资料，为授课教师提供帮助。

此外，“国外电子与通信教材系列”的引进和出版工作得到了教育部高等教育司的大力支持和帮助，其中的部分引进教材已通过“教育部高等学校电子信息科学与工程类专业教学指导委员会”的审核，并得到教育部高等教育司的批准，纳入了“教育部高等教育司推荐——国外优秀信息科学与技术系列教学用书”。

为做好该系列教材的翻译工作，我们聘请了清华大学、北京大学、北京邮电大学、东南大学、西安交通大学、天津大学、西安电子科技大学、电子科技大学等著名高校的教授和骨干教师参与教材的翻译和审校工作。许多教授在国内电子与通信专业领域享有较高的声望，具有丰富的教学经验，他们的渊博学识从根本上保证了教材的翻译质量和专业学术方面的严格与准确。我们在此对他们的辛勤工作与贡献表示衷心的感谢。此外，对于编辑的选择，我们达到了专业对口；对于从英文原书中发现的错误，我们通过与作者联络、从网上下载勘误表等方式，逐一进行了修订；同时，我们对审校、排版、印制质量进行了严格把关。

今后，我们将进一步加强同各高校教师的密切关系，努力引进更多的国外优秀教材和教学参考书，为我国电子与通信教材达到世界先进水平而努力。由于我们对国内外电子与通信教育的发展仍存在一些认识上的不足，在选题、翻译、出版等方面的工作中还有许多需要改进的地方，恳请广大师生和读者提出批评及建议。

电子工业出版社

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# PREFACE

*Microelectronic Circuits*, fourth edition, is intended as a text for the core courses in electronic circuits taught to majors in electrical and computer engineering. It should also prove useful to engineers and other professionals wishing to update their knowledge through self-study.

As was the case with the first three editions, the objective of this book is to develop in the reader the ability to analyze and design electronic circuits, both analog and digital, discrete and integrated. While the application of integrated circuits is covered, emphasis is placed on transistor circuit design. This is done because of our belief that even if the majority of those studying the book were not to pursue a career in IC design, knowledge of what is inside the IC package would enable intelligent and innovative application of such chips. Furthermore, with the advances in VLSI technology and design methodology, IC design itself is becoming accessible to an increasing number of engineers.

## PREREQUISITES

The prerequisite for studying the material in this book is a first course in circuit analysis. As a review, some linear circuits material is included here in appendixes: specifically, two-port network parameters in Appendix B, some useful network theorems in Appendix E, and single-time-constant circuit responses in Appendix F. No prior knowledge of physical electronics is assumed. All required device physics is included, and Appendix A provides a brief description of IC fabrication.

## ORGANIZATION

Although the philosophy and pedagogical approach of the first three editions have been retained, several changes have been made in both organization and coverage. The most significant change in organization is the inclusion of material on digital electronics in the early chapters of the book. This has been done in recognition of the tremendous expansion of the digital electronics area in the past few years. In our view, it is now imperative that students of electrical engineering, and certainly students of computer engineering, should be exposed to the introductory concepts of digital electronic circuits in their first electronics course. The reorganization of the early chapters of the book will make this possible. However, the organization is sufficiently flexible to permit postponing coverage of the digital circuits material to a later point in the course, or to a second course, in order to suit a particular curriculum structure.

Another significant organizational change is the inclusion of the more formal material on device modelling in the early chapters: for instance, Chapter 4 on the bipolar transistor now includes the Ebers-Moll model, and Chapter 5 on field-effect transistors now includes a discussion of the MOSFET internal capacitances. This has been done in order to facilitate the understanding of the SPICE models for those who wish to include the use of SPICE in the first electronics course. Here again, the organization is sufficiently flexible, easily permitting postponing the study of the more rigorous models to a later stage. This flexibility is further manifested by organizing each chapter so that the more advanced material, which usually can be skipped or postponed to a later point in the course, is placed in the latter part of each chapter.

Of course, those who prefer a more complete coverage of a particular topic (e.g., the BJT or the MOSFET) can simply continue with the respective chapter as presented.

Apart from these changes, the chapter sequence of the third edition has been maintained. This should minimize disruption to existing curricula and course outlines. Following an introductory chapter that presents some of the basic electronics concepts and establishes notation and conventions, the book is divided into three parts. Part I, Devices and Basic Circuits, is composed of Chapters 2 through 5 and deals with the op amp, the diode, the bipolar junction transistor (BJT), and the field-effect transistor (FET). It constitutes the bulk of a first course in electronics, and most of the material is considered prerequisite to the study of further electronic circuits topics.*

Part II (Chapters 6–12) deals with analog circuits, and Part III (Chapters 13 and 14) deals with digital circuits. Except for requiring some knowledge of the differential pair from Chapter 6 in order to fully understand emitter-coupled logic in Chapter 14, the order of Parts II and III can be reversed. Thus it is possible to study the digital electronics topics of Part III immediately after coverage of the basic devices and circuits of Part I. Such an order of coverage might be preferred for computer engineering students.

Although we recognize that certain economies can be achieved by presenting the BJT and the MOSFET together from the outset, as special cases of a general three-terminal device, we have opted to introduce them separately in Part I and to combine them as much as possible in Part II. It has been our experience that the two devices are sufficiently different that in a first encounter, a separate presentation of each device—its structure and physical operation, its characteristics, and its basic circuit applications—is appropriate. Specifically, in the first course the student needs to "live" with each of the two basic devices for a while in order to become comfortable with it. Subsequently, however, a combined treatment is possible and indeed desirable.

Although the BJT (Chapter 4) is placed before the MOSFET (Chapter 5), the order of these two topics can be easily reversed. This flexibility is obtained at the expense of a slight redundancy. However, the redundancy can be used to reinforce learning or it can be minimized by a quicker coverage of whichever device is studied second.

## MAJOR CHANGES IN COVERAGE

In addition to the reorganization outlined above, and other less apparent but significant restructuring of some chapters (e.g., Chapter 7), important changes in coverage have been made in the fourth edition. The major changes are: increased coverage of device physics (Chapters 3, 4, and 5); inclusion of the SPICE device models (Chapters 3, 4, and 5); SPICE examples (Chapters 3–14); complete revision of the digital circuits material (mostly Chapter 13, some in Chapter 14, and of course the additions, mentioned earlier, to Chapters 1, 4, and 5); complete revision of the MOSFET coverage (Chapter 5 as well as changes throughout the rest of the book and notably in Chapter 13). In the following, we provide additional information on each of these major changes.

### Device Physics

The material on the physical operation of devices has been expanded in this edition. There are three reasons for this change: (1) The continuing pressures on the curriculum have resulted in

*A possible exception is Chapter 2 on op amps whose study can be postponed in whole or in part to a later stage. Also, mentioned earlier, some of the more advanced materials in Chapters 4 and 5 can be postponed to a subsequent course. (See the section on course organization later in this Preface.)

the traditional device course no longer being part of the core electrical engineering program in many universities. (2) To be able to use SPICE simulation more effectively, one needs to have a basic understanding of the device models used by SPICE which in turn requires a somewhat greater knowledge of the physical operation of devices (than was presented in the third edition). (3) A much greater proportion of the circuit design and application activity is now concerned with integrated circuits, and IC design requires a greater understanding of device physics than that needed for designing with discrete components.

Rather than placing device physics in a separate chapter we have opted to present such material where it is needed (in each of Chapters 3, 4, and 5). Thus the material can and is immediately applied to device modelling and to facilitate the use of the device in circuit design, which after all is the main objective of this book. Finally, it should be noted that the new material on device physics can be speedily covered or even skipped altogether by students who already have taken a course on physical electronics.

## SPICE

Instructors of introductory courses on electronic circuits have traditionally faced a difficult dilemma: should they use SPICE simulation in their courses and thus risk diverting student attention from the basic principles of circuit analysis and design, or should they ignore SPICE altogether and thus deprive their students from learning about what is perhaps the most powerful circuit-design aid. This same dilemma has been reflected in textbooks on electronic circuits, including the previous editions of this book. In this edition we believe we have taken a major step toward a satisfactory resolution of the dilemma. We include two aspects of SPICE: the models that it uses for the electronic devices, and examples that illustrate the great advantages that can be gained from the *proper* use of SPICE. Equally important to *what* is covered on SPICE is *where* it is presented. In order to avoid cluttering the body of each chapter with SPICE programs and results, we have instead placed the SPICE material in the last section of each chapter (except for Chapters 1 and 2). In this way, the SPICE examples can serve to tie together a number of the ideas presented in the chapter as well as to check the validity of the various approximations and simplifying assumptions used. Equally important, the last section of a chapter can be easily skipped by the instructor who for one reason or another does not wish to include SPICE in the course.

Except for a brief appendix (Appendix C) our coverage of SPICE does not deal with how to write SPICE programs. For that, we refer the reader to the available books on SPICE, including the book *SPICE,* 2nd edition, by Gordon Roberts and Adel Sedra, Oxford University Press, 1997. The latter book also includes many more examples that follow the order of topic presentation of this book. The input files of our SPICE examples are listed in Appendix D as well as being included on the CD-ROM that accompanies the book and the web site of the book.

## MOSFETs

There is no doubt that the MOSFET is at this time the most significant electronic device, and that it will remain so for some time to come. Also, during the past half dozen years or so, there have been significant changes in the range of application of the MOSFET. Thus, although there is very little activity in the use of discrete MOSFETs except in high power applications, most modern IC design, both analog and digital, is MOSFET-based. To reflect these changes and trends, we have completely rewritten Chapter 5.

### Digital Electronics

The material on digital electronics has been updated and expanded, and as mentioned earlier, reorganized. Coverage begins in Chapter 1 with an introduction to the basic element of digital circuits, the logic inverter. It is introduced there alongside its counterpart in analog electronics, the amplifier. This is followed in Chapter 4 with a section on the basic BJT inverter and in Chapter 5 with a study of the CMOS inverter. Part III, dealing with digital circuits, has been reorganized and its main chapter (13) has been completely rewritten. It now includes a careful selection of topics on MOS digital circuits that is both pedagogically sound and practically relevant. Chapter 14 then completes the study of digital circuits with a presentation of bipolar (TTL and ECL), BiCMOS, and GaAs circuits. We believe that the material on digital circuits included in this edition is of sufficient scope and depth so as to enable teaching a digital-circuits-oriented course as either the first or the second in the sequence of electronic circuits courses.

## THE CD-ROM AND THE WEB SITE

A CD-ROM accompanies this book. It contains much useful supplementary information and material intended to enrich the student's learning experience. These include: (1) A number of animated examples that attempt to recreate the dynamics of classroom learning. (2) A demonstration of Electronics Workbench, one of the most innovative software products that is intended to simulate a rich laboratory experience for the student. The software is available from Interactive Image Technologies Ltd.* The CD shows how Electronics Workbench can be used and includes fourteen carefully selected circuit examples covering the topics studied in this book. It should also be noted that Electronics Workbench now has a supplement that includes the code for over one hundred of the circuits that appear in this book; making it easy for the user of Electronics Workbench to experiment with these circuits for greater understanding and additional practice. (3) A compendium of "Design Ideas" from EDN magazine, containing many useful and practical circuits. (4) The input files for all the SPICE examples in this book. The CD-ROM was produced by Oberon Interactive Inc. of Toronto, Canada. The CD icon which appears in the margin will appear next to examples and figures throughout the text, easily identifying these as examples which have been animated or as circuits used in an Electronics Workbench demonstration.

A web-site for the book has been set up (http://www.sedrasmith.org/). It will include data sheets and SPICE models for selected devices, input files for the SPICE examples, additional problems, design problems, free downloadable circuits for use with Electronics Workbench, links to industrial and academic sites of related interest, a link to Oxford's College Division for complete professor text support, a message center for the authors, etc.

## EMPHASIS ON DESIGN

It has been our philosophy that circuit design is best taught by pointing out the various trade-offs available in selecting a circuit configuration and in selecting component values for a given configuration. The emphasis on design has been increased in this edition by including more design examples, exercise problems, and end-of-chapter problems. Those exercises and end-of-chapter problems that are considered "design-oriented" are indicated with a D. Also, the most valuable design aid, SPICE, is utilized throughout the book, as already outlined.

*Interactive Image Technologies Ltd., 111 Peter Street, Suite 801, Toronto, Ont., Canada M5V 2H1.

## EXERCISES, END-OF-CHAPTER PROBLEMS, AND ADDITIONAL SOLVED PROBLEMS

Over 400 exercises are integrated throughout the text. The answer to each exercise is given below the exercise so students can check their understanding of the material as they read. Solving these exercises should enable the reader to gauge his or her grasp of the preceding material. In addition, more than 1250 end-of-chapter problems, about a third of which are new to this edition, are provided. The problems are keyed to the individual sections and their degree of difficulty is indicated by a rating system: difficult problems are marked with as asterisk (*); more difficult problems with two asterisks (**); and very difficult (and/or time consuming) problems with three asterisks (***). We must admit, however, that this classification is by no means exact. Our rating no doubt had depended to some degree on our thinking (and mood!) at the time a particular problem was created. Answers to about half the problems are given in Appendix I. Complete solutions for all exercises and problems are included in the *Instructor's Manual,* which is available from the publisher for those instructors who adopt the book.

As in the previous three editions, many examples are included. The examples, and indeed most of the problems and exercises, are based on real circuits and anticipate the applications encountered in designing real-life circuits. This edition continues the use of numbered solution steps in the figures for many examples, as an attempt to recreate the dynamics of the classroom.

A recurring request from many of the students who used earlier editions of the book has been for solved problems. To satisfy this need, a book of additional problems with solutions is available with this edition (see the list of available ancillaries later in this preface).

## AN OUTLINE FOR THE READER

The book starts with an introduction to the basic concepts of electronics in Chapter 1. Signals, their frequency spectra, and their analog and digital forms are presented. Amplifiers are introduced as circuit-building blocks and their various types and models are studied. The basic element of digital electronics, the digital logic inverters, is defined in terms of its voltage-transfer characteristic, and its various implementations using voltage and current switches are discussed. This chapter also establishes some of the terminology and conventions used throughout the text.

The next four chapters are devoted to the study of electronic devices and basic circuits and constitute Part I of the text. Chapter 2 deals with operational amplifiers, their terminal characteristics, simple applications, and limitations. We have chosen to discuss the op amp as a circuit building block at this early stage simply because it is easy to deal with and because the student can experiment with op-amp circuits that perform non-trivial tasks with relative ease and with a sense of accomplishment. We have found this approach to be highly motivating to the student. We should point out, however, that part or all of this chapter can be skipped and studied at a later stage (for instance in conjunction with Chapter 6 or Chapter 8) with no loss of continuity.

Chapter 3 is devoted to the study of the most fundamental electronic device, the *pn* junction diode. The diode terminal characteristics and its hierarchy or models are presented. To understand the physical operation of the diode, and indeed of the BJT and the MOSFET, a concise but substantial introduction to semiconductors and the *pn* junction is provided. We then return to diode circuits and study some of the fundamental applications of diodes, especially those related to power-supply design.

Chapter 4 introduces the bipolar junction transistor (BJT): its structure, physical operation, terminal characteristics, large- and small-signal models, its operation as an amplifier and as a

switch, the basic configurations of single-stage BJT amplifiers, and the basic BJT logic inverter.

The field-effect transistor (FET) family of devices is covered in Chapter 5 where the emphasis, however, is placed on the MOS transistor. Here again the structure, physical operation, terminal characteristics, models, and basic circuit applications (analog and digital) of the various FET types are presented. As mentioned earlier, this chapter can, if desired, be studied before the BJT chapter. Our hope is that each of these chapters will make the reader thoroughly familiar and intimately comfortable with the device treated.

By the end of Chapter 5 the reader will have learned about the basic building blocks of electronic circuits and will be ready to consider the more advanced topics of Part II (analog circuits) and Part III (digital circuits). As mentioned earlier, the order of study of Parts II and III can be easily reversed.

Chapter 6 is the first of a sequence of five chapters dealing with more advanced topics in amplifier design. The main topic of Chapter 6 is the differential amplifier, in both its bipolar and MOSFET forms.

In Chapter 7 we study the frequency response of amplifiers. Here emphasis is placed on the choice of configuration to obtain wideband operation.

Chapter 8 deals with the important topic of feedback. Practical circuit applications of negative feedback are presented. We also discuss the stability problem in feedback amplifiers and treat frequency compensation in some detail.

Chapter 9 deals with various types of amplifier output stages. Thermal design is studied and examples of IC power amplifiers are presented.

Chapter 10 presents an introduction to analog integrated circuits. Bipolar, CMOS, and BiCMOS op amps are discussed. Also, basic circuits for the design of data converters are studied. This chapter ties together many of the ideas the methods presented in the previous chapters.

The last two chapters of Part II, Chapters 11 and 12, are application or system oriented. Chapter 11 is devoted to the study of analog filter design and tuned amplifiers. Chapter 12 presents a study of sinusoidal oscillators, waveform generators, and other nonlinear signal processing circuits.

The last two chapters of the book, Chapters 13 and 14, constitute Part III, digital circuits. They present a concise, modern treatment of digital electronics and should serve as the basis for a more detailed study of digital circuits and systems and/or VLSI design.

The nine appendices contain much useful supplementary material. We wish to draw the reader's attention in particular to Appendix A which provides a concise introduction to the important topic of IC fabrication technology including chip layout.

## COURSE ORGANIZATION

The book contains sufficient material for a sequence of two single-semester courses (each of 40 to 50 lecture hours). The organization of the book provides considerable flexibility in course design.

Three possibilities for the first course are

a. Chapters 1 through 5. If time is limited, the following sections can be postponed to the second course: 2.8, 2.9, 3.9, 4.13– 4.15, and 5.8–5.12.

b. Chapters 1, 3, 4, 5, and selected topics of Chapters 6 and 7 (e.g., Sections 6.1, 6.2, 6.6, and 7.1–7.6). If time is limited some sections can be skipped, such as 3.9, 4.12– 4.14, 5.8, 5.9, 5.11, and 5.12.

c. Chapters 1, 3, 4, 5, and selected topics of Chapters 13 and 14 as time permits. Here, again if time is limited some sections of Chapters 3–5 can be skipped in this digital-circuits oriented course.

Two possibilities for the second course are

a. Chapters 6–12. If time is limited, some sections of Chapters 9, 10, 11, and 12 can be postponed to a third course dealing with analog circuits.

b. Chapters 6, 7, 8, 13, and 14.

## ANCILLARIES

A complete set of ancillary materials is available with this text to support your course:

For the Instructor.

The *Instructor's Manual with Transparency Masters* provides complete solutions to all the exercises and problems in the text. It also contains 200 transparency masters that duplicate important figures in the text, the ones most often used in class.

*Transparency Acetates:* A set of 200 two-color transparencies of the most important figures in the book.

For the Student and the Instructor.

*The CD-ROM,* see description in separate section.

The *Laboratory Manual,* written by K. C. Smith, contains approximately 20 experiments covering the major topics studied in the text.

*KC's Problems with Solutions,* written by K. C. Smith, contains approximately 600 additional problems with complete solutions for students who want more practice.

*SPICE,* 2nd edition, by Gordon Roberts of McGill University and Adel Sedra, provides a detailed treatment of SPICE and its application in the analysis and design of circuits of the type studied in this book.

*A Practical Guide for Selecting Electronic Components,* by Wai-Tung Ng of the University of Toronto, deals with the specification and selection of practical electronic components for the variety of applications studied in this book. It includes sample manufacturer's data sheets and explains the intricacies of component specifications.

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Adel S. Sedra
Kenneth C. Smith

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