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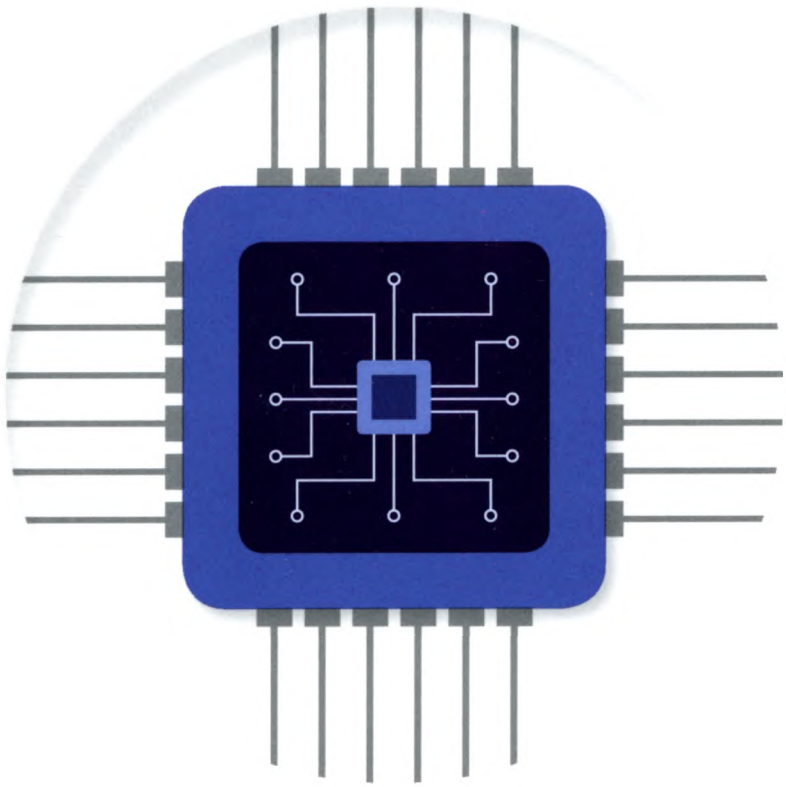

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PREFACE

Microelectronic Circuits, Eighth 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 seven 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 this 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 has become 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 the appendices: specifically, two-port network parameters in Appendix C; some useful network theorems in Appendix D; single-time-constant circuits in Appendix E; and s-domain analysis in Appendix F. In addition, a number of relevant circuit analysis problems are included at the beginning of the end-of-chapter problems section of Chapter 1. No prior knowledge of physical electronics is assumed. All required semiconductor device physics is included, and Appendix A provides a brief description of IC fabrication. All these appendices can be found on the book's website.

Emphasis on Design

It has been our philosophy that circuit design is best taught by pointing out the various tradeoffs available in selecting a circuit configuration and in selecting component values for a given configuration. The emphasis on design has been retained in this edition. In addition to design examples, and design-oriented exercises and end-of-chapter problems (indicated with a D), the book includes on its website an extensive appendix (Appendix B) where a large number of simulation and design examples are presented. These emphasize the use of SPICE, the most valuable circuit-design aid.

New to the Eighth Edition

The most important change in the eighth edition is that two new coauthors have joined our team: Tony Chan Carusone of the University of Toronto and Vincent Gaudet of the University of Waterloo.

While maintaining the philosophy and pedagogical approach of the first seven editions, several changes have been made to both organization and coverage. Our goal in making structural changes has been to increase modularity and thus flexibility for the instructor, without causing disturbance to courses currently using the seventh edition. Changes in coverage are necessitated by the continuing advances in technology which make some topics of greater relevance and others of less interest. As well, advances in IC process technology require that the numbers used in the examples, exercises, and end-of-chapter problems be updated to reflect the parameters of newer generations of IC technologies (e.g., some problems utilize the parameters of the 28-nm CMOS process). This ensures that students are acquiring a real-world perspective on technology.

The guiding principle in this revision has been *to make the book easier to teach and learn from*. In pursuit of this goal, the following specific and noteworthy changes have been made:

1. **New End-of-Chapter Problems.** About half of the approximately 1400 end-of-chapter problems are new or revised. To aid the instructor in deciding which of this large number of problems to assign, we have carefully selected a subset that we have designated **essential problems**. This should also be helpful to students using the book for self-study. The Instructor's Solutions Manual (ISM) has been thoroughly revised by the authors. It includes complete solutions for all exercises and end-of-chapter problems.
2. **Video Examples.** For the first time, we are including forty video examples. For each, the problem statement is provided and the student is directed to a video on the website to watch the authors solve the problem. Also, a directly related end-of-chapter problem is highlighted for the student to solve after watching the video.
3. **Summary Tables.** New and existing summary tables have been combined together and made available on the website. This collection of tables is an important resource for the student in studying and as a reference while doing homework problems.
4. **Improved Organization.** While maintaining the very successful modular organization of the seventh edition, we have reduced the number of parts of the eighth edition to three. Specifically, the filters and oscillators chapters are now in Part II: Analog Integrated Circuits.
5. **Streamlined Coverage and Book Size.** Almost every chapter has been revised and streamlined with emphasis on the essentials. This has resulted in a substantial reduction in the size of the book (by almost 200 pages). However, removed material has been made available on the website for those who want to continue to use it. Particular chapters that have been reduced are: Chapter 12 (Output Stages and Power Amplifiers); Chapter 13 (Op Amp Circuits); Chapter 14 (Filters); Chapter 15 (Oscillators); and Part III: Digital Integrated Circuits.
6. **Early Coverage of Technology Scaling and Moore's Law.** The discussion of technology scaling and Moore's law is now started in Chapter 5 (MOSFETs). It is then referenced throughout the book, and resumed in Chapter 17 (Digital Design) where the effects of scaling on the trinity of digital design—speed, power, and area—are considered.
7. **Modernizing the Study of Diodes.** Chapter 4 has been reorganized to highlight the different levels of abstraction and accuracy in diode modeling. While the coverage of standard material has been streamlined and reduced somewhat, newer topics have been expanded and/or included such as photodiodes, light-emitting diodes, application of diodes in electronic discharge (ESD) protection, etc.
8. **Clearer Derivations and Better Explanations.** Three chapters in Part II: Analog Integrated Circuits, have been thoroughly revised to simplify and clarify the presentation and to provide better derivations. These are Chapter 8 (Building Blocks of IC Amplifiers), specifically the treatment of the CG and CB amplifiers and the study of advanced current mirrors; Chapter 9 (Differential and Multistage Amplifiers), specifically the treatment of common-mode gain

and CMRR, DC offsets, and the current-mirror-loaded differential amplifier; and Chapter 10 (Frequency Response), which has been reorganized to deemphasize the study of the low-frequency response of discrete-circuit amplifiers (now placed at the end of the chapter).

9. **Clearer, Improved, and Simplified Study of Feedback.** Substantial improvements have been made to Chapter 11 (Feedback) to make the subject easier to understand and use.
10. **Streamlined and Better Organized Coverage of the Digital Topics.** Part III: Digital Integrated Circuits has undergone a thorough re-organization making it easier to integrate its topics into the first and/or the second electronics course. Its first chapter, now Chapter 16, emphasizes the basics of digital CMOS design, culminating in an in-depth study of the CMOS inverter's static characteristic. Then, Chapter 17 covers the three main metrics that are commonly used in digital circuit design and optimization, namely speed, power, and area. We then complete the discussion of technology scaling, first started in Chapter 5, by looking at how scaling impacts these three metrics. Finally, Chapter 18 focuses on transistor-level memory circuits and clocking circuits. Many of the examples, exercises, and problems in Part III have been redesigned to use newer technologies.

The Book's Website

The companion website for the book (www.oup.com/he/sedra-smith8e) contains important materials that will change frequently to reflect new developments. Here is a list of some of the materials available on the website:

1. Summary tables useful for studying and practice problems.
2. Resources to support the use of Spice with problems and examples including
   - Links to circuit simulation tools.
   - The input files needed to perform simulations of problems from the book identified with a SIM icon.
   - Additional Spice examples and the associated files.
   - Step-by-step guidance to help performing the Spice simulations.
3. Bonus text material of specialized topics that are either not covered or covered briefly in the current edition of the textbook. These include:
   - Precision Rectifier Circuits
   - Junction Field-Effect Transistors (JFETs)
   - Gallium Arsenide (GaAs) Devices and Circuits
   - Specialty Diode Topics: Diode Logic Gates, Temperature Effects in Zener Diodes, and the Schottky-Barrier Diode (SBD)
   - Useful Transistor Pairings
   - Selected Topics in BJT Ouput Stages: Class B Power Dissipation and Improvements, and Protection Circuitry
   - The Classical CMOS Class AB Configuration
   - IC Power Amplifiers
   - Power Transistor Thermal Considerations
   - The 741 Op-Amp Circuit
   - Selected Analog Filter Topics
     - First- and Second-Order Filter Functions
     - Single-Amplifier Biquadratic Active Filters
     - Sensitivity
     - Transconductance-C Filters
     - Tuned Amplifiers
   - Waveform Generators: The Monostable Multivibrator, IC Timers, and Waveform-Shaping Circuits

- MOS Velocity Saturation and Subthreshold Leakage
- Alternative Digital Logic Families
  - Pseudo-NMOS Logic Circuits
  - Dynamic MOS Logic Circuits
  - Transistor-Transistor Logic (TTL) Circuits
  - Emitter-Coupled Logic (ECL) Circuits
  - Bipolar and BiCMOS Digital Circuits
- Memory Architectures and Read-Only Memory (ROM)
- CMOS Image Sensors

4. Data sheets for hundreds of useful devices to help in laboratory experiments as well as in design projects.
5. Appendices for the Book:
   - Appendix A: VLSI Fabrication Technology
   - Appendix B: Spice Design and Simulation Examples
   - Appendix C: Two-Port Network Parameters
   - Appendix D: Some Useful Network Theorems
   - Appendix E: Single-Time-Constant Circuits
   - Appendix F: *s*-Domain Analysis: Poles, Zeros and Bode Plots
   - Appendix G: Comparison of the MOSFET and the BJT
   - Appendix H: Filter Design Tools
   - Appendix I: Bibliography
   - Appendix L: Answers to Selected Problems

Exercises and End-of-Chapter Problems

Over 450 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 1400 end-of-chapter problems, half of which are new or revised in this edition, are provided. The problems are keyed to the individual chapter sections and their degree of difficulty is indicated by a rating system: difficult problems are marked with an 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 depended to some degree on our thinking (and mood!) at the time a particular problem was created. Answers to sample problems are given in Appendix L (on the website), so students have a checkpoint to tell if they are working out the problems correctly. Complete solutions for all exercises and problems are included in the *Instructor's Solutions Manual*, which is available from the publisher to those instructors who adopt the book.

As an aid to the instructor on deciding which to assign of this large number of problems, we have carefully selected a subset and designated it essential problems. (These are the problems with blue numbers). This should also be helpful to students using the book for self-study.

As in the previous seven 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.

Summary Tables

New and existing summary tables are presented together on the website. This collection of tables is an important resource for the student studying for exams or doing homework problems.

Video Examples

Today's students learn by watching, and they appreciate video for the ability to control the pace of presentation. For this edition, we have introduced video as a way to help students connect the text's examples to the homework problems they are assigned to solve. In 40 professionally produced videos, we walk students step by step through the procedures required to solve some of the most common, and complex, circuits they will have to master. We then provide related problems so that they can apply the strategies they have just learned to comparable circuits. We believe these videos will help students close the gap between learning and application. These videos are included in the enhanced ebook and are available to purchasers of the print book using the access code packaged with new print copies. Students with rented or used print copies can gain access to the videos by purchasing access to the ARC Premium site for *Microelectronic Circuits* at www.oup.com/he/sedra-smith8e. Videos are also available on the ARC site for instructors using *Microelectronic Circuits*.

Course Organization

The book contains sufficient material for a sequence of two single-semester courses, each of 40–50 lecture hours. The modular organization of the book provides considerable flexibility for course design. In the following, we suggest content for a sequence of two classical or standard courses. We also describe some variations on the content of these two courses and specify supplemental material for a possible third course.

The First Course

The first course is based on Part I of the book, that is, Chapters 1–7. It can be taught, most simply by starting at the beginning of Chapter 1 and concluding with the end of Chapter 7. However, as guidance to instructors who wish to follow a different order of presentation or a somewhat modified coverage, or to deal with situations where time might be constrained, we offer the following remarks:

The core of the first course is the study of the two transistor types, Chapters 5 and 6, in whatever order the instructor wishes, and transistor amplifiers in Chapter 7. These three chapters must be covered in full.

Another important part of the first course is the study of diodes (Chapter 4). Here, however, if time does not permit, some of the applications in the later part of the chapter can be skipped.

We have found it highly motivational to cover op amps (Chapter 2) near the beginning of the course. This provides the students with the opportunity to work with a practical integrated circuit and to experiment with nontrivial circuits.

Coverage of Chapter 1, at least of the amplifier sections, should prove helpful. Here the sections on signals can be either covered in class or assigned as reading material. Section 1.6 on frequency response is needed if the frequency-response of op-amp circuits is to be studied; otherwise this section can be delayed to the second course.

Finally, if the students have not taken a course on physical electronics, Chapter 3 needs to be covered. Otherwise, it can be used as review material or skipped altogether.

The Second Course

The main subject of the second course is integrated-circuit amplifiers and is based on Part II of the book, that is, Chapters 8–15. These eight chapters, however, contain more material than can be taught in one course. Thus, a judicious selection of topics to cover is called for. We hope that the following remarks can be helpful in making these choices:

The core material of Part II is presented in Chapters 8–11 and these four chapters must be covered, though not necessarily in their entirety. For instance, some of the sections near the end of a chapter and identified by the "advanced material" icon can be skipped, usually with no loss of continuity.

Beyond the required chapters (8–11), the instructor has many possibilities for the remainder of the course. These include a selection of topics from the remaining four chapters of Part II (12–15). Another possibility, is to include an introduction to digital integrated circuits by covering Chapter 16, and if time permits, selected topics of Chapters 17 and 18.

A Digitally Oriented First Course

A digitally-oriented first course can include the following: Chapter 1 (without Section 1.6), Chapter 2, Chapter 3 (if the students have not had any exposure to physical electronics), Chapter 4 (perhaps without some of the later applications sections), Chapter 5, selected topics from Chapter 7 emphasizing the basics of the application of the MOSFET as an amplifier, Chapter 16, and selected topics from Chapters 17 and 18. Such a course would be particularly suited for Computer Engineering students.

Supplemental Material/Third Course

Depending on the selection of topics for the first and second courses, some material will remain and can be used for part of a third course or as supplemental material to support student design projects. These can include Chapter 12 (Output Stages and Power Amplifiers), Chapter 13 (Op-Amp Circuits), Chapter 14 (Filters), and Chapter 15 (Oscillators), which can be used together with the advanced topics of Chapters 8–11 to support a third course on analog circuits. These can also include Chapters 16, 17, and 18 which can be used for a portion of a senior-level course on digital IC design.

The Accompanying Laboratory

Courses in electronic circuits are usually accompanied by laboratory experiments. To support the laboratory component for courses using this book, Vincent Gaudet has, in collaboration with K.C. Smith, authored a laboratory manual. *Laboratory Explorations*, together with an Instructor's Manual, is available from Oxford University Press.

An alternative approach for laboratory experimentation involves the use of pre-wired circuit boards with the experiments digitally controlled. Products that support this approach include AELabs, by Illuster Technologies, and Analog Electronic Board, by Texas Instruments; both work on the NI Elvis platform. More information can be found on the companion website (www.oup.com/he/sedra-smith8e).

An Outline for the Reader

Part I, *Devices and Basic Circuits*, includes the most fundamental and essential topics for the study of electronic circuits. At the same time, it constitutes a complete package for a first course on the subject.

Chapter 1. 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. This chapter also establishes some of the terminology and conventions used throughout the text.

Chapter 2. Chapter 2 deals with operational amplifiers, their terminal characteristics, simple applications, and practical limitations. We chose 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 nontrivial 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 9, Chapter 11, and/or Chapter 13) with no loss of continuity.

Chapter 3. Chapter 3 provides an overview of semiconductor concepts at a level sufficient for understanding the operation of diodes and transistors in later chapters. Coverage of this material is useful in particular for students who have had no prior exposure to device physics. Even those with such a background would find a review of Chapter 3 beneficial as a refresher. The instructor can choose to cover this material in class or assign it for outside reading.

Chapter 4. The first electronic device, the diode, is studied in Chapter 4. The diode terminal characteristics, the circuit models that are used to represent it, and its circuit applications are presented. Depending on the time available in the course, some of the diode applications and special diode types (Section 4.7) can be skipped or left for the student to read.

Chapters 5 and 6. The foundation of electronic circuits is established by the study of the two transistor types in use today: the MOS transistor in Chapter 5 and the bipolar transistor in Chapter 6. ***These two chapters have been written to be completely independent of one another and thus can be studied in either order, as desired.*** Furthermore, the two chapters have the same structure, making it easier and faster to study the second device, as well as to draw comparisons between the two device types.

Each of Chapters 5 and 6 begins with a study of the device structure and its physical operation, leading to a description of its terminal characteristics. Then, to allow the student to become very familiar with the operation of the transistor as a circuit element, a large number of examples are presented of dc circuits utilizing the device. The last section of each of Chapters 5 and 6 deals with second-order effects that are included for completeness, but that can be skipped if time does not permit detailed coverage. Nevertheless, we strongly recommend coverage of the newly introduced section on Moore's law and tehnology scaling in Chapter 5.

Chapter 7. The heart of a first course in electronics is the study of transistor amplifiers. Chapter 7 presents a unified treatment of the subject. It begins with the basic principles that underlie the operation of a transistor, of either type, as an amplifier, and proceeds to present the important concepts of small-signal operation and modeling. This is followed by a study of the basic configurations of single-transistor amplifiers. After a presentation of dc biasing methods, the chapter concludes with practical examples of discrete-circuit amplifiers. The combined presentation emphasizes the unity of the basic principles while allowing for separate treatment of the two device types where this is warranted. Very importantly, we are able to compare the two devices and to draw conclusions about their unique areas of application.

After the study of Part I, the reader will be fully prepared to study either analog integrated-circuits in Part II, or digital integrated circuits in Part III.

Part II, *Analog Integrated Circuits*, is devoted to the study of practical amplifier circuits that can be fabricated in the integrated-circuit (IC) form and their application in the design of filters and oscillators. Its eight chapters constitute a coherent treatment of IC amplifier design and applications and can thus serve as a second course in electronic circuits.

MOS and Bipolar. Throughout Part II, both MOS and bipolar circuits are presented side-by-side. Because the MOSFET is by far the dominant device, its circuits are presented first. Bipolar circuits are discussed to the same depth but occasionally more briefly.

Chapter 8. Beginning with a brief introduction to the philosophy of IC design, Chapter 8 presents the basic circuit building blocks that are used in the design of IC amplifiers. These include current mirrors, current sources, gain cells, and cascode amplifiers.

Chapter 9. The most important IC building block, the differential pair, is the main topic of Chapter 9. The last section of Chapter 9 is devoted to the study of multistage amplifiers.

Chapter 10. Chapter 10 presents a comprehensive treatment of the important subject of amplifier frequency response. Here, Sections 10.1 and 10.2 contain essential material; Section 10.3 provides a very useful analysis method; Sections 10.4 to 10.7 present the frequency response analysis of a variety of amplifier configurations; and Section 10.8 presents the low-frequency response of discrete-circuit amplifiers. A selection of the later sections can be made depending on the time available and the instructor's preference.

Chapter 11. The fourth of the essential topics of Part II, feedback, is the subject of Chapter 11. Both the theory of negative feedback and its application in the design of practical feedback amplifiers are presented. We also discuss the stability problem in feedback amplifiers and treat frequency compensation in some detail.

Chapter 12. In Chapter 12 we switch gears from dealing with small-signal amplifiers to those that are required to handle large signals and large amounts of power. Here we study the different amplifier classes—A, B, and AB—and their realization in bipolar and CMOS technologies. We also briefly consider power BJTs and power MOSFETs, and introduce the increasingly popular Class D amplifier. Depending on the availability of time, some of the later sections can be skipped in a first reading.

Chapter 13. Chapter 13 brings together the topics of Part II in an important application; namely, the design of operational amplifier circuits. We study both CMOS and bipolar op amps. We focus on the most fundamental circuits: the two-stage and the folded cascode op amps. We also present biasing circuits and techniques for low-voltage operation.

The last portion of Part III, Chapters 14 and 15, deals with *Filters and Oscillators*, and is intentionally oriented toward applications and systems. The two topics illustrate powerfully and dramatically the application of both negative and positive feedback.

Chapter 14. Chapter 14 deals with the design of filters, which are important building blocks of communication and instrumentation systems. A comprehensive, design-oriented treatment of the subject is presented. The material provided, together with the supplemental material in Appendix H, should allow the reader to perform a complete filter design, starting from specification and ending with a complete circuit realization. A wealth of design material is included.

Chapter 15. Chapter 15 deals with circuits for the generation of sinusoidal signals. It also includes a section on nonlinear oscillators or function generators.

Part III, *Digital Integrated Circuits*, provides a brief but nonetheless comprehensive and sufficiently detailed study of digital IC design. Our treatment is almost self-contained, requiring for the most part only a thorough understanding of the MOSFET material presented in Chapter 5. Thus Part III can be studied right after Chapter 5. The only exception to this is that knowledge of the internal capacitances of a MOSFET (Section 10.1) will be needed before taking on Chapter 17.

Chapter 16. Chapter 16 is the foundation of Part III. It begins with the motivating topic of CMOS logic-gate circuits, with a focus on switch-level implementaion of logic functions and gates. Then, following a detailed study of digital logic inverters, we concentrate on the CMOS inverter, its static characteristics, and its design. This chapter is the minimum needed to learn something meaningful about ditigal circuits.

Chapter 17. Chapter 17 presents a comprehensive overview of the so-called trinity of digital design metrics: speed, area, and power. The chapter starts by thoroughly analyzing the dynamic characteristics of a CMOS inverter. Then, transistor sizing is discussed, including the impact of sizing on speed and circuit area. Afterwards, sources of power dissipation in digital circuits are introduced. The chapter concludes by investigating the impact of semiconductor scaling—first introduced in Chapter 5—on digital circuit performance metrics.

Chapter 18. Digital circuits can be broadly divided into logic and memory circuits. The latter is the subject of Chapter 18, which first looks at the design of latches and flip-flops, and then goes into

static and dynamic cell designs for memory arrays. Finally, the chapter also introduces several useful peripheral circuits used in synchronous systems.

Appendices. The twelve appendices contain much useful background and supplementary material. We wish to draw the reader's attention in particular to the first two: Appendix A provides a concise introduction to the important topic of IC fabrication technology including IC layout. Appendix B provides SPICE device models as well as a large number of design and simulation examples in PSpice® and Multisim™. The examples are keyed to the book chapters. These Appendices and a great deal more material on these simulation examples can be found on the Companion Website.

Ancillaries

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

For the Instructor

The Ancillary Resource Center (ARC) at www.oup.com/he/sedra-smith8e is a convenient destination for all the instructor resources that accompany *Microelectronic Circuits*. Accessed online through individual user accounts, the ARC provides instructors with access to up-to-date ancillaries at any time while guaranteeing the security of grade-significant resources. On the ARC, you will find:

- **An electronic version of the Instructor's Solutions Manual.**
- **Video examples** that take students step by step through the procedures required to solve 40 problems presented in the text.
- **PowerPoint-based figure slides** that feature all the images and summary tables from the text, with their captions, so they can easily be displayed and explained in class.
- Detailed **instructor's support** for the SPICE circuit simulations.
- A set of 65 exam questions, grouped by chapter, with complete solutions, suggested time allocations, and a recommended breakdown of points per question.

The **Instructor's Solutions Manual** (ISBN 9780190853488), written by Adel Sedra, contains detailed solutions to all chapter exercises and end-of-chapter problems found in *Microelectronic Circuits*. The Instructor's Solutions Manual for ***Laboratory Explorations to Accompany Microelectronic Circuits*** (ISBN 9780197508589) contains detailed solutions to all the exercises and problems found in this student's laboratory guide; these solutions are also available online on the ARC instructor site for *Microelectronic Circuits* (www.oup.com/he/sedra-smith8e).

For the Student and Instructor

The **ARC Premium site,** available at www.oup.com/he/sedra-smith8e, features 40 professionally produced videos in which we walk students step by step through the procedures required to solve some of the most common, and complex, circuits they will have to master. ***Solved Problems*** is a set of 150 additional homework problems with complete solutions, covering concepts from the nine most used chapters in the book. This self-study aid will help students master core concepts and prepare for homework assignments and exams. Premium ARC content is included in the enhanced ebook. It is also available to purchasers of the print book using the access code packaged with new print copies. Students with rented or used print copies can purchase access codes to the ARC premium site for *Microelectronic Circuits* at www.oup.com/he/sedra-smith8e.

A Companion Website at www.oup.com/he/sedra-smith8e features permanently cached versions of device datasheets, so students can design their own circuits in class. The website also contains

SPICE circuit simulation examples and lessons. Bonus text topics and the Appendices are also featured on the website. Another very important item on the website is the Summary Tables (ST) supplement. This compilation of reference tables will benefit students completing homework assignments and studying for exams.

The ***Laboratory Explorations to Accompany Microelectronic Circuits*** (ISBN 9780197508572) invites students to explore the realm of real-world engineering through practical, hands-on experiments. Keyed to sections in the text and taking a "learn-by-doing" approach, it presents labs that focus on the development of practical engineering skills and design practices.

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