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Fundamentals of Electric Circuits

(Fourth Edition)

电路基础

（第四版）

Charles K. Alexander
Matthew N. O. Sadiku 著

（英文影印版）

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内 容 简 介

本书讲述了电路课程的基础知识，分为三个部分：第一部分是直流电路，包括基本定律和定理、无源元件及有源元件。第二部分是交流电路，包括相量、正弦稳态分析、功率、有效值、三相电路和频率响应。第三部分包括拉普拉斯变换、傅里叶级数、傅里叶变换和二端口网络分析。本书以电路的基础知识、分析方法为主体，并在此基础上适当地做了有创意的延伸与发展，加强了它与新技术的联系。

本书可作为电类各专业课程的双语教材或参考书，也可供工程技术人员参考。

Charles K. Alexander, Matthew N. O. Sadiku
Fundamentals of Electric Circuits (Fourth Edition)
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Dedicated to our wives, Kikelomo and Hannah, whose understanding and support have truly made this book possible.

Matthew
and
Chuck

Preface

You may be wondering why we chose a photo of astronauts working in space on the Space Station for the cover. We actually chose it for several reasons. Obviously, it is very exciting; in fact, space represents the most exciting frontier for the entire world! In addition, much of the station itself consists of all kinds of circuits! One of the most significant circuits within the station is its power distribution system. It is a complete and self contained, modern power generation and distribution system. That is why NASA (especially NASA-Glenn) continues to be at the forefront of both theoretical as well as applied power system research and development. The technology that has gone into the development of space exploration continues to find itself impacting terrestrial technology in many important ways. For some of you, this will be an important career path.

FEATURES

New to This Edition

A course in circuit analysis is perhaps the first exposure students have to electrical engineering. This is also a place where we can enhance some of the skills that they will later need as they learn how to design.

In the fourth edition, we have included a very significant new feature to help students enhance skills that are an important part of the design process. We call this new feature, ***design a problem.***

We know it is not possible to fully develop a student's design skills in a fundamental course like circuits. To fully develop design skills a student needs a design experience normally reserved for their senior year. This does not mean that some of those skills cannot be developed and exercised in a circuits course. The text already included open-ended questions that help students use creativity, which is an important part of learning how to design. We already have some questions that are open desired to add much more into our text in this important area and have developed an approach to do just that. When we develop problems for the student to solve our goal is that in solving the problem the student learn more about the theory and the problem solving process. Why not have the students design problems like we do? That is exactly what we will do in each chapter. Within the normal problem set, we have a set of problems where we ask the student to design a problem. This will have two very important results. The first will be a better understanding of the basic theory and the second will be the enhancement of some of the student's basic design skills.

We are making effective use of the principle of learning by teaching. Essentially we all learn better when we teach a subject. Designing effective problems is a key part of the teaching process. Students

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should also be encouraged to develop problems, when appropriate, which have nice numbers and do not necessarily overemphasize complicated mathematical manipulations.

Additionally we have changed almost 40% of the Practice Problems with the idea to better reflect more real component values and to help the student better understand the problem and have added 121 *design a problem* problems. We have also changed and added a total of 357 end-of-chapter problems (this number contains the new *design a problem* problems). This brings up a very important advantage to our textbook, we have a total of 2404 Examples, Practice Problems, Review Questions, and end-of-chapter problems!

Retained from Previous Editions

The main objective of the fourth edition of this book remains the same as the previous editions—to present circuit analysis in a manner that is clearer, more interesting, and easier to understand than other circuit text, and to assist the student in beginning to see the "fun" in engineering. This objective is achieved in the following ways:

- **Chapter Openers and Summaries**
  Each chapter opens with a discussion about how to enhance skills which contribute to successful problem solving as well as successful careers or a career-oriented talk on a sub-discipline of electrical engineering. This is followed by an introduction that links the chapter with the previous chapters and states the chapter objectives. The chapter ends with a summary of key points and formulas.
- **Problem Solving Methodology**
  Chapter 1 introduces a six-step method for solving circuit problems which is used consistently throughout the book and media supplements to promote best-practice problem-solving procedures.
- **Student Friendly Writing Style**
  All principles are presented in a lucid, logical, step-by-step manner. As much as possible, we avoid wordiness and giving too much detail that could hide concepts and impede overall understanding of the material.
- **Boxed Formulas and Key Terms**
  Important formulas are boxed as a means of helping students sort out what is essential from what is not. Also, to ensure that students clearly understand the key elements of the subject matter, key terms are defined and highlighted.
- **Margin Notes**
  Marginal notes are used as a pedagogical aid. They serve multiple uses such as hints, cross-references, more exposition, warnings, reminders not to make some particular common mistakes, and problem-solving insights.
- **Worked Examples**
  Thoroughly worked examples are liberally given at the end of every section. The examples are regarded as a part of the text and are clearly explained without asking the reader to fill in missing steps. Thoroughly worked examples give students a good understanding of the solution process and the confidence to solve problems

themselves. Some of the problems are solved in two or three different ways to facilitate a substantial comprehension of the subject material as well as a comparison of different approaches.

- **Practice Problems**
  To give students practice opportunity, each illustrative example is immediately followed by a practice problem with the answer. The student can follow the example step by step to aid in the solution of the practice problem without flipping pages or looking at the end of the book for answers. The practice problem is also intended to test a student's understanding of the preceding example. It will reinforce their grasp of the material before the student can move on to the next section. Complete solutions to the practice problems are available to students on ARIS.
- **Application Sections**
  The last section in each chapter is devoted to practical application aspects of the concepts covered in the chapter. The material covered in the chapter is applied to at least one or two practical problems or devices. This helps students see how the concepts are applied to real-life situations.
- **Review Questions**
  Ten review questions in the form of multiple-choice objective items are provided at the end of each chapter with answers. The review questions are intended to cover the little "tricks" that the examples and end-of-chapter problems may not cover. They serve as a self-test device and help students determine how well they have mastered the chapter.
- **Computer Tools**
  In recognition of the requirements by ABET® on integrating computer tools, the use of *PSpice, MATLAB, KCIDE for Circuits,* and developing design skills are encouraged in a student-friendly manner. *PSpice* is covered early on in the text so that students can become familiar and use it throughout the text. Appendix D serves as a tutorial on *PSpice* for Windows. *MATLAB* is also introduced early in the book with a tutorial available in Appendix E. *KCIDE for Circuits* is a brand new, state-of-the-art software system designed to help the students maximize their chance of success in problem solving. It is introduced in Appendix F. Finally, *design a problem* problems have been introduced, for the first time. These are meant to help the student develop skills that will be needed in the design process.
- **Historical Tidbits**
  Historical sketches throughout the text provide profiles of important pioneers and events relevant to the study of electrical engineering.
- **Early Op Amp Discussion**
  The operational amplifier (op amp) as a basic element is introduced early in the text.
- **Fourier and Laplace Transforms Coverage**
  To ease the transition between the circuit course and signals and systems courses, Fourier and Laplace transforms are covered lucidly and thoroughly. The chapters are developed in a manner that the interested instructor can go from solutions of first-order

circuits to Chapter 15. This then allows a very natural progression from Laplace to Fourier to AC.

- **Four Color Art Program**
  A completely redesigned interior design and four color art program bring circuit drawings to life and enhance key pedagogical elements throughout the text.
- **Extended Examples**
  Examples worked in detail according to the six-step problem solving method provide a roadmap for students to solve problems in a consistent fashion. At least one example in each chapter is developed in this manner.
- **EC 2000 Chapter Openers**
  Based on ABET's new skill-based CRITERION 3, these chapter openers are devoted to discussions as to how students can acquire the skills that will lead to a significantly enhanced career as an engineer. Because these skills are so very important to the student while in college as well as in their career, we will use the heading, *"Enhancing your Skills and your Career."*
- **Homework Problems**
  There are 358 new or changed end-of-chapter problems which will provide students with plenty of practice as well as reinforce key concepts.
- **Homework Problem Icons**
  Icons are used to highlight problems that relate to engineering design as well as problems that can be solved using *PSpice* or *MATLAB*.
- ***KCIDE for Circuits* Appendix F**
  A new Appendix F provides a tutorial on the Knowledge Capturing Integrated Design Environment (*KCIDE for Circuits*) software, available on ARIS.

Organization

This book was written for a two-semester or three-quarter course in linear circuit analysis. The book may also be used for a one-semester course by a proper selection of chapters and sections by the instructor. It is broadly divided into three parts.

- Part 1, consisting of Chapters 1 to 8, is devoted to dc circuits. It covers the fundamental laws and theorems, circuits techniques, and passive and active elements.
- Part 2, which contains Chapter 9 to 14, deals with ac circuits. It introduces phasors, sinusoidal steady-state analysis, ac power, rms values, three-phase systems, and frequency response.
- Part 3, consisting of Chapters 15 to 19, is devoted to advanced techniques for network analysis. It provides students with a solid introduction to the Laplace transform, Fourier series, Fourier transform, and two-port network analysis.

The material in three parts is more than sufficient for a two-semester course, so the instructor must select which chapters or sections to cover. Sections marked with the dagger sign (†) may be skipped, explained briefly, or assigned as homework. They can be omitted without loss of

continuity. Each chapter has plenty of problems grouped according to the sections of the related material and diverse enough that the instructor can choose some as examples and assign some as homework. As stated earlier, we are using three icons with this edition. We are using PS to denote problems that either require *PSpice* in the solution process, where the circuit complexity is such that *PSpice* would make the solution process easier, and where *PSpice* makes a good check to see if the problem has been solved correctly. We are using ML to denote problems where *MATLAB* is required in the solution process, where *MATLAB* makes sense because of the problem makeup and its complexity, and where *MATLAB* makes a good check to see if the problem has been solved correctly. Finally, we use e2d to identify problems that help the student develop skills that are needed for engineering design. More difficult problems are marked with an asterisk (*). Comprehensive problems follow the end-of-chapter problems. They are mostly applications problems that require skills learned from that particular chapter.

Prerequisites

As with most introductory circuit courses, the main prerequisites, for a course using the text, are physics and calculus. Although familiarity with complex numbers is helpful in the later part of the book, it is not required. A very important asset of this text is that ALL the mathematical equations and fundamentals of physics needed by the student, are included in the text.

Supplements

McGraw-Hill's ARIS—Assessment, Review, and Instruction System is a complete, online tutorial, electronic homework, and course management system, designed for greater ease of use than any other system available. Available on adoption, instructors can create and share course materials and assignments with other instructors, edit questions and algorithms, import their own content, and create announcements and due dates for assignments. ARIS has automatic grading and reporting of easy-to-assign algorithmically-generated homework, quizzing, and testing. Once a student is registered in the course, all student activity within McGraw-Hill's ARIS is automatically recorded and available to the instructor through a fully integrated grade book that can be downloaded to Excel. Also included on ARIS are a solutions manual, text image files, transition guides to instructors, and Network Analysis Tutorials, software downloads, complete solutions to text practice problems, FE Exam questions, flashcards, and web links to students. Visit www.mhhe.com/alexander.

Knowledge Capturing Integrated Design Environment for Circuits (*KCIDE for Circuits*) This new software, developed at Cleveland State University and funded by NASA, is designed to help the student work through a circuits problem in an organized manner using the six-step problem-solving methodology in the text. *KCIDE for Circuits* allows students to work a circuit problem in *PSpice* and *MATLAB*, track the

evolution of their solution, and save a record of their process for future reference. In addition, the software automatically generates a Word document and/or a PowerPoint presentation. Appendix F contains a description of how to use the software. Additional examples can be found at the web site, http://kcide.fennresearch.org/, which is linked from ARIS. The software package can be downloaded for free.

Problem Solving Made *Almost* Easy, a companion workbook to *Fundamentals of Electric Circuits,* is available on ARIS for students who wish to practice their problem-solving techniques. The workbook contains a discussion of problem-solving strategies and 150 additional problems with complete solutions provided.

C.O.S.M.O.S This CD, available to instructors only, is a powerful solutions manual tool to help instructors streamline the creation of assignments, quizzes, and tests by using problems and solutions from the textbook, as well as their own custom material. Instructors can edit textbook end-of-chapter problems as well as track which problems have been assigned.

Although the textbook is meant to be self-explanatory and act as a tutor for the student, the personal contact in teaching is not forgotten. It is hoped that the book and supplemental materials supply the instructor with all the pedagogical tools necessary to effectively present the material.

Acknowledgements

We would like to express our appreciation for the loving support we have received from our wives (Hannah and Kikelomo), daughters (Christina, Tamara, Jennifer, Motunrayo, Ann, and Joyce), son (Baixi), and our extended family members.

At McGraw-Hill, we would like to thank the following editorial and production staff: Raghu Srinivasan, publisher and senior sponsoring editor; Lora Kalb-Neyens, developmental editors; Joyce Watters, project manager; Carrie Burger, photo researcher; and Brenda Rolwes, designer. Also, we appreciate the hard work of Tom Hartley at the University of Akron for his very detailed evaluation of various elements of the text and his many valued suggestions for continued improvement of this textbook.

We wish to thank Yongjian Fu and his outstanding team of students, Bramarambha Elka and Saravaran Chinniah, for their efforts in the development of *KCIDE for Circuits.* Their efforts to help us continue to improve this software are also appreciated.

The fourth edition has benefited greatly from the many outstanding reviewers and symposium attendees who contributed to the success of the first three editions! In addition, the following have made important contributions to the fourth edition (in alphabetical order):

Tom Brewer, Georgia Tech
Andy Chan, City University of Hong Kong
Alan Tan Wee Chiat, Multimedia University
Norman Cox, University of Missouri-Rolla
Walter L. Green, University of Tennessee

Dr. Gordon K. Lee, San Diego State University
Gary Perks, Cal Poly State University, San Luis Obispo
Dr. Raghu K. Settaluri, Oregon State University
Ramakant Srivastava, University of Florida
John Watkins, Wichita State University
Yik-Chung Wu, The University of Hong Kong
Xiao-Bang Xu, Clemson University

Finally, we appreciate the feedback received from instructors and students who used the previous editions. We want this to continue, so please keep sending us emails or direct them to the publisher. We can be reached at c.alexander@ieee.org for Charles Alexander and sadiku@ieee.org for Matthew Sadiku.

C. K. Alexander and M.N.O. Sadiku

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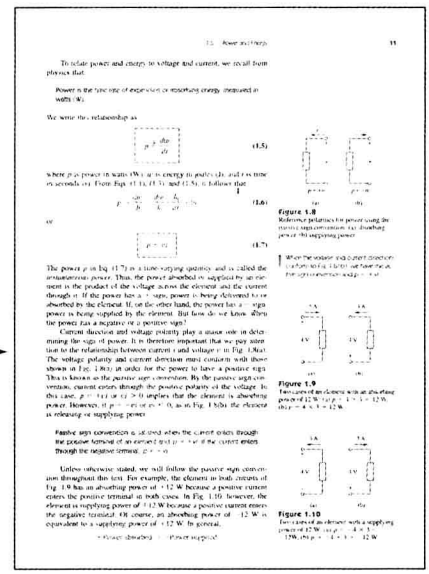
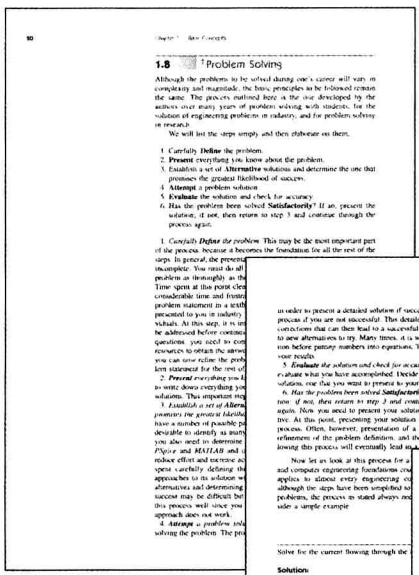
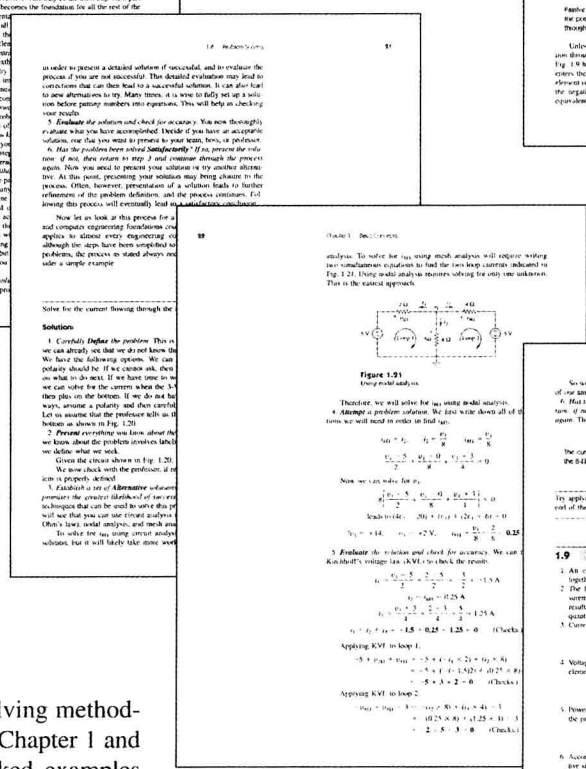
GUIDED TOUR

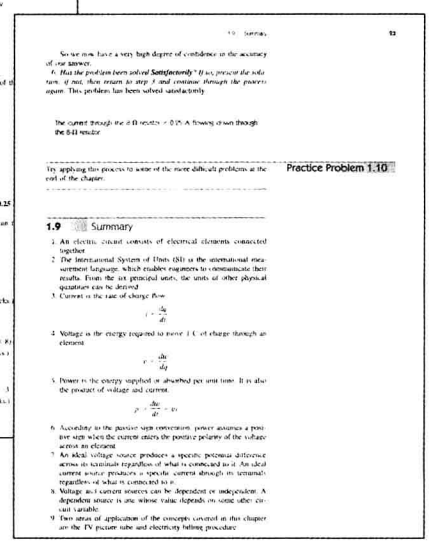
The main objective of this book is to present circuit analysis in a manner that is clearer, more interesting, and easier to understand than other texts. For you, the student, here are some features to help you study and be successful in this course.

The four color art program brings circuit drawings to life and enhances key concepts throughout the text.

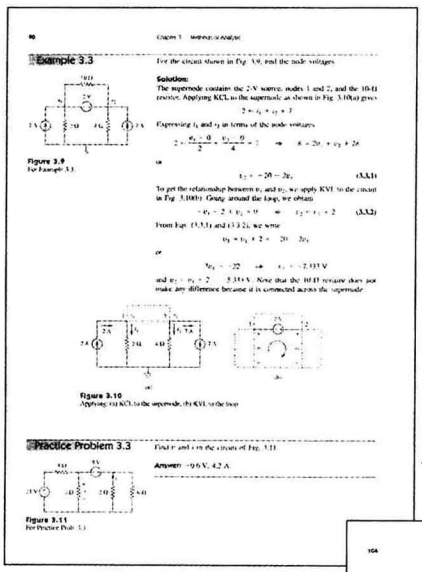








A six-step problem-solving methodology is introduced in Chapter 1 and incorporated into worked examples throughout the text to promote sound, step-by-step problem-solving practices.

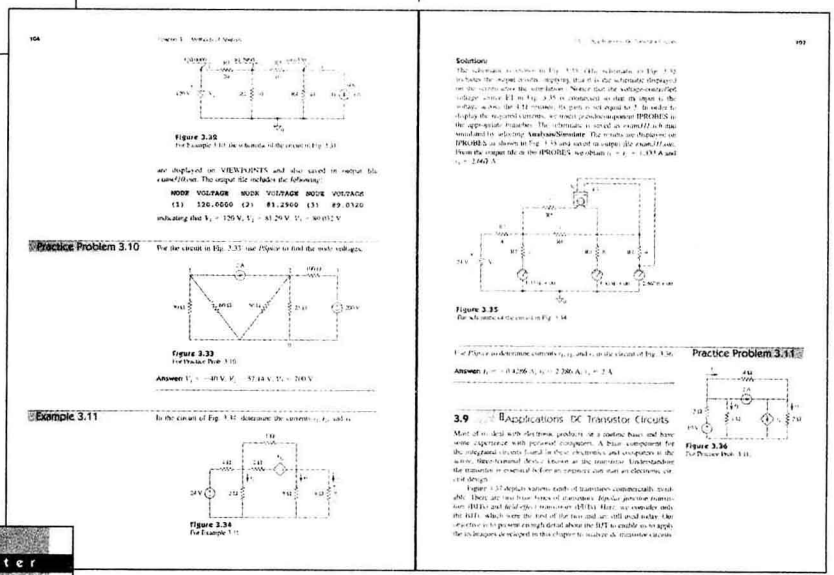

Example 3.3

Practice Problem 3.3

Each illustrative example is immediately followed by a practice problem and answer to test understanding of the preceding example.

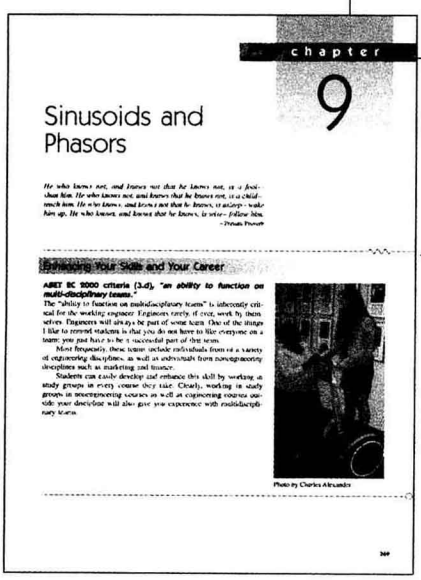
PSpice® for Windows is a student-friendly tool introduced to students early in the text and used throughout, with discussions and examples at the end of each appropriate chapter.

The last section in each chapter is devoted to applications of the concepts covered in the chapter to help students apply the concepts to real-life situations.


Practice Problem 3.10

Example 3.11

Practice Problem 3.11


chapter 9

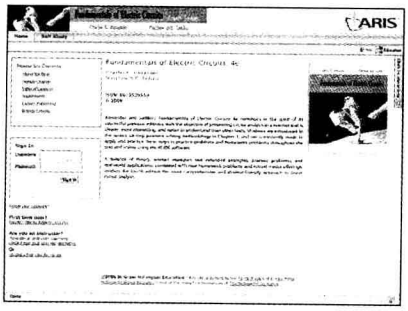
Sinusoids and Phasors

Enhancing Your Skills and Your Career

Each chapter opens with a discussion about how to enhance skills that contribute to successful problem solving as well as successful careers or a career-oriented talk on a sub-discipline of electrical engineering to give students some real-world applications of what they are learning.

e2d Icons next to the end-of-chapter homework problems let students know which problems relate to engineering design and which problems can be solved using *PSpice* or *MATLAB*. Appendices on these computer programs provide tutorials for their use.

Supplements for Students and Instructors



McGraw-Hill's ARIS—Assessment, Review, and Instruction System is a complete, online tutorial, electronic homework, and course management system, designed for greater ease of use than any other system available. With ARIS, instructors can create and share course materials and assignments with other instructors, edit questions and algorithms, import their own content, and create announcements and due dates for assignments. ARIS has automatic grading and reporting of easy-to-assign algorithmically-generated homework, quizzing, and testing. Once a student is registered in the course, all student activity within McGraw-Hill's ARIS is automatically recorded and available to the instructor through a fully integrated grade book that can be downloaded to Excel.

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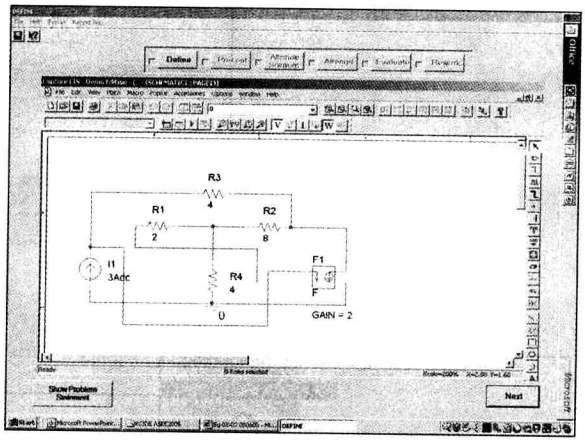
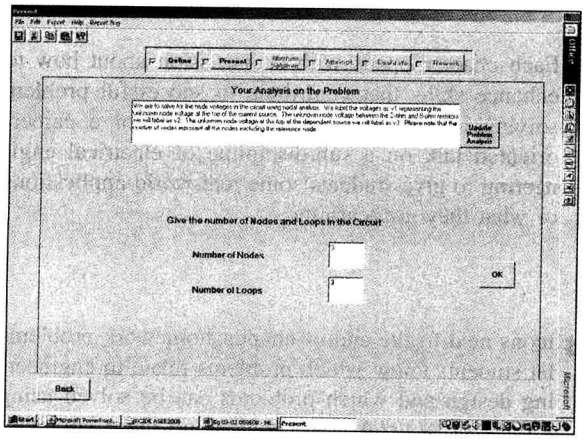
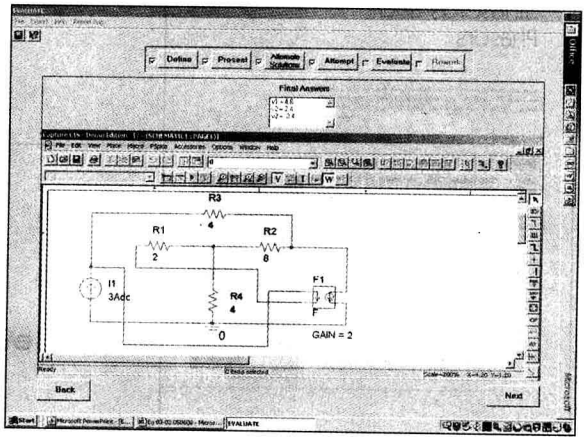
Knowledge Capturing Integrated Design Environment for Circuits (*KCIDE for Circuits*) software, linked from ARIS, enhances student understanding of the six-step problem-solving methodology in the book. *KCIDE for Circuits* allows students to work a circuit problem in *PSpice* and *MATLAB*, track the evolution of their solution, and save a record of their process for future reference. Appendix F walks the user through this program.







Other resources provided on ARIS.

For Students:
— Network Analysis Tutorials—a series of interactive quizzes to help students practice fundamental concepts in circuits.
— FE Exam Interactive Review Quizzes—chapter based self-quizzes provide hints for solutions and correct solution methods, and help students prepare for the NCEES Fundamentals of Engineering Examination.
— Problem Solving Made *Almost* Easy—a companion workbook to the text, featuring 150 additional problems with complete solutions.
— Complete solutions to Practice Problems in the text
— Flashcards of key terms
— Web links

For Instructors:
— Image Sets—electronic files of text figures for easy integration into your course presentations, exams, and assignments.
— Transition Guides—compare coverage of the third edition to other popular circuits books at the section level to aid transition to teaching from our text.

A Note to the Student

This may be your first course in electrical engineering. Although electrical engineering is an exciting and challenging discipline, the course may intimidate you. This book was written to prevent that. A good textbook and a good professor are an advantage—but you are the one who does the learning. If you keep the following ideas in mind, you will do very well in this course.

- This course is the foundation on which most other courses in the electrical engineering curriculum rest. For this reason, put in as much effort as you can. Study the course regularly.
- Problem solving is an essential part of the learning process. Solve as many problems as you can. Begin by solving the practice problem following each example, and then proceed to the end-of-chapter problems. The best way to learn is to solve a lot of problems. An asterisk in front of a problem indicates a challenging problem.
- *Spice*, a computer circuit analysis program, is used throughout the textbook. *PSpice*, the personal computer version of *Spice*, is the popular standard circuit analysis program at most universities. *PSpice for Windows* is described in Appendix D. Make an effort to learn *PSpice*, because you can check any circuit problem with *PSpice* and be sure you are handing in a correct problem solution.
- *MATLAB* is another software that is very useful in circuit analysis and other courses you will be taking. A brief tutorial on *MATLAB* is given in Appendix E to get you started. The best way to learn *MATLAB* is to start working with it once you know a few commands.
- Each chapter ends with a section on how the material covered in the chapter can be applied to real-life situations. The concepts in this section may be new and advanced to you. No doubt, you will learn more of the details in other courses. We are mainly interested in gaining a general familiarity with these ideas.
- Attempt the review questions at the end of each chapter. They will help you discover some "tricks" not revealed in class or in the textbook.
- Clearly a lot of effort has gone into making the technical details in this book easy to understand. It also contains all the mathematics and physics necessary to understand the theory and will be very useful in your other engineering courses. However, we have also focused on creating a reference for you to use both in school as well as when working in industry or seeking a graduate degree.
- It is very tempting to sell your book after you have completed your classroom experience; however, our advice to you is *DO NOT SELL YOUR ENGINEERING BOOKS!* Books have always been expensive, however, the cost of this book is virtually the same as I paid for my circuits text back in the early 60s in terms of real dollars. In fact, it is actually cheaper. In addition, engineering books of the past are no where near as complete as what is available now.

When I was a student, I did not sell any of my engineering textbooks and was very glad I did not! I found that I needed most of them throughout my career.

A short review on finding determinants is covered in Appendix A, complex numbers in Appendix B, and mathematical formulas in Appendix C. Answers to odd-numbered problems are given in Appendix G.

Have fun!

C. K. A. and M. N. O. S.

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