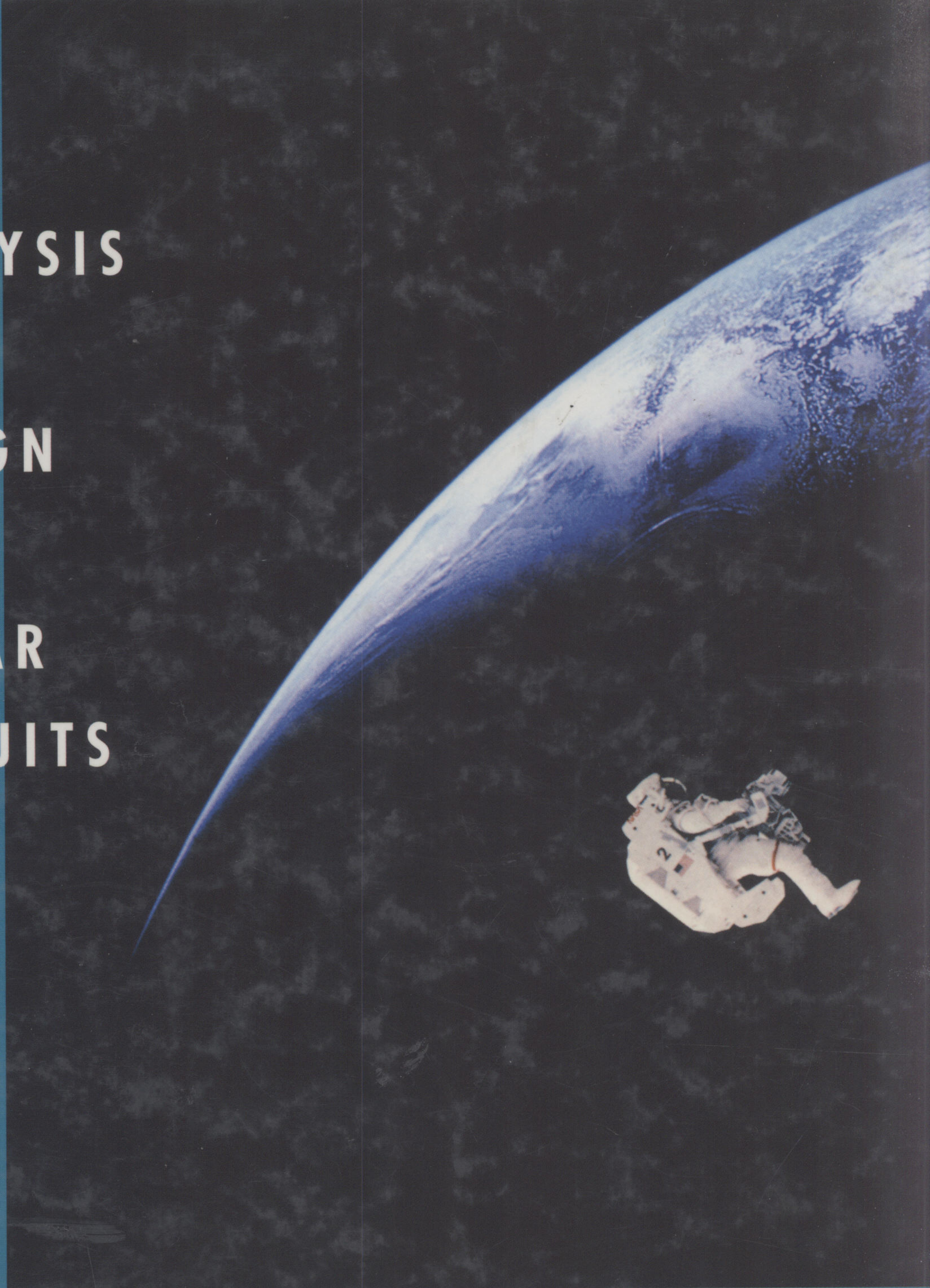
The Analysis and Design of Linear Circuits



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Fourth Edition

FOURTH EDITION

THE ANALYSIS AND DESIGN OF LINEAR CIRCUITS

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To our wives
Juanita and Kathleen

PREFACE

There are two versions of the fourth edition of *The Analysis and Design of Linear Circuits.* The standard version (ISBN 0-471-27213-2) is an incremental revision and updating of the third edition. The new *Laplace Early Version* (ISBN 0-471-43299-7) retains the core features of the third edition, but uses a new chapter sequencing that emphasizes transform methods. Both versions are aimed at introductory circuit analysis courses, and both assume the same student prerequisites. Although the sequencing is different, the two versions cover the same range of topics. John Wiley & Sons, Inc. offers two versions of this book as part of a continuing commitment to supplying a diversity of resources for teaching circuit courses.

The *standard version* continues the authors' two decade commitment to a modern approach to classical circuit analysis and design. Although this edition is a periodic update that stresses modern applications, it does so within a framework of continuing features that remain unchanged.

CONTINUING FEATURES

CIRCUIT DESIGN

Experience convinces us that students' grasp of circuit fundamentals is reinforced by an interweaving of analysis and design. Early involvement in design provides motivation as students apply their newly acquired knowledge in practical situations. The evaluation of alternative designs also introduces them to real-world engineering practices. Including design in the introductory course makes students aware that circuits perform useful functions and are not simply academic vehicles for teaching node-voltage and mesh-current analysis.

THE OP AMP

The ubiquitous OP AMP is the work horse of linear circuit analysis and design. Its early introduction and integration throughout the first circuit course offers the following advantages. The modular form of OP AMP circuits simplifies analog circuit analysis and design. The OP AMP plays an important role by relating the abstract concept of a dependent source to a real device. The close agreement between theory and laboratory results allows students to analyze, design, and successfully build meaningful OP AMP circuits in the laboratory.

Laplace Transforms

Laplace transforms are used to treat important dynamic circuit concepts such as zero-state and zero-input responses, impulse and step responses, convolution, frequency response, Bode plots, and analog filter design. An early treatment of Laplace transforms actually saves classroom time because students spend less time studying transitional techniques that will be superseded later. Students are also better prepared to handle the profusion of transforms in subsequent courses when the circuits course is based on a transform method.

Signal Processing

An emphasis on signal processing and systems is achieved through use of block diagrams, input-output relationships, and transform methods. The study of dynamic circuits is preceded by a separate chapter on waveforms and signal characteristics. This chapter gives students an early familiarity with all of the important input and output signals encountered in linear circuits. The ultimate goal is for students to understand that time-domain waveforms and frequency-domain transforms are simply alternative ways to characterize signals and signal processing.

Computer Tools

Three types of computer programs are used to illustrate computer-aided circuit analysis, namely spreadsheets (Excel®), math solvers (Mathcad® & MATLAB®), and circuit simulators (PSpice® and Electronics Workbench®). Examples of computer-aided circuit analysis are integrated into all chapters beginning with Chapter 2. The purpose of these examples is to help students develop a problem-solving style that includes the intelligent use of the productivity tools routinely used by practicing engineers.

En Route Objectives

The book is structured around a sequence of carefully defined learning objectives and related evaluation tools. Each objective is explicitly stated in terms of expected student proficiency, and each is supported by at least ten homework problems specifically designed to evaluate student mastery of the objective. This framework has been a standard feature of all four editions of this book and has enabled us to maintain a consistent level of expected student performance over the years.

New Features

- New application examples have been added, emphasizing computer engineering, signal processing, and bioengineering.
- All PSpice examples are updated to Orcad Release 9.2.
- Examples of CMOS voltage-controlled switch models include digitally controlled analog circuits in Chapters 3 and 4 as well as the *RC* switching response of digital circuits in Chapter 7.

- Chapter 6 includes a new treatment of the sample-hold circuit and introduces the integrating A/D converter.
- A new section in Chapter 11 develops the equivalence of time-domain and s-domain convolution.
- The en route objectives and related homework problems are now cross-referenced to in-text worked examples and exercises. Cross-referencing allows students to review the solution of problems similar to those in their assigned homework.
- The fourth edition adds chapter length treatment of Fourier transforms and two-port networks as Web appendices. These appendices are fully integrated into the text with index references and answers to selected homework problems. These appendices are available at: *http://www.wiley.com/college/thomas.*

CHAPTER FEATURES

Chapter Openers provide a brief discussion of the historical context as well as an overview of the topical content of the chapter.

Examples provide students with a detailed discussion of the steps involved in solving an analysis or design problem. There are nearly 300 worked examples distributed throughout the text, including more than 30 *design examples.* Several of the design examples involve evaluating alternative solutions. Examples that use *computer tools* also show how to translate a problem statement into a form amenable to computer solution.

Exercises with answers are placed immediately after worked examples. These exercises give students an opportunity to practice the techniques illustrated in the preceding example. Providing answers allows students to test their proficiency before proceeding.

Chapter Summaries contain concise statements that help students review the chapter before tackling the homework problems that follow.

Homework Problems are directly related to and grouped with the En Route Objectives. The En route Objectives are cross-referenced to related in-text examples and exercises. About one-third of the nearly 900 homework problems have answers in the back of the book. Problems involving design are labeled with a **D** icon.

Integrating Problems are comprehensive problems that appear at the very end of a chapter. To solve these problems, students must combine several previously mastered skills. Integrating problems are labeled with **A**, **D**, and **E** icons to indicate whether analysis, design, and evaluation methods are required.

Computer Problems Homework problems for which computer tools offer a significant advantage are marked with a computer icon in the text. We do not specify a computer tool for each problem, but expect students to choose. To assist students in developing this ability, there is a separately bound **Student Solution Manual** (ISBN

0-471-46968-8 in which about 100 of the homework problems are solved using computer tools. Problems whose solutions are included in this manual are labeled with an icon in the text.

SUPPLEMENTS

INSTRUCTOR'S MANUAL

A complete set of detailed solutions to all of the end-of-chapter problems is available free to all adopting faculty. Solutions were double checked and documented using Mathcad.

EGRADE ONLINE ASSESSMENT

eGrade is an online problem-solving, quizzing, and testing tool. It also provides interactive self-scoring practice problems to help students learn the skills involved in solving circuits problems. For more information and to see a demonstration visit *www.wiley.com/college/egrade.*

CIRCUIT WORKS SOFTWARE

Circuit Works is a simulator based on a set library of 100 circuits, with adjustable parameters. Circuit Works is a tool for teaching and learning the principles and relationships that underlie basic first- and second-order circuits having resistors, capacitors, inductors, op-amps, dependent and independent sources, and transformers.

STUDENT SOLUTIONS MANUAL

Selected homework problems are solved using one or more of the computer tools demonstrated in the text. These worked-out solutions are available in a separately bound manual that is sold separately. Faculty can order a student bundle containing both the text and the Student Solutions Manual at a special reduced price.

CIRCUITS EXTRA

This Web site is designed to support excellence in teaching and student learning. Circuits Extra is a valuable tool for all instructors and students using Wiley circuits texts. This site contains student and instructor resources for all of the Wiley circuits texts, as well as circuits links and resources of general interest. It will be continually updated to provide enrichment for students and instructors alike. You can access this site at *www.wiley.com/college/circuits.*

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ing circuits. We cannot fail to mention our Production Manager Suzanne Ingrao whose professionalism has made the task of converting manuscripts into books an experience in the vicinity of enjoyable.

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CHAPTER 1

INTRODUCTION

The electromotive action manifests itself in the form of two effects which I believe must be distinguished from the beginning by a precise definition. I will call the first of these "electric tension," the second "electric current."

André-Marie Ampère, 1820,
French Mathematician/Physicist

1–1 About This Book
1–2 Symbols and Units
1–3 Circuit Variables
Summary
Problems
Integrating Problems

This book deals with the analysis and design of linear electric circuits. A circuit is an interconnection of electric devices that processes energy or information. Understanding circuits is important because energy and information are the underlying technological commodities in electrical engineering. The study of circuits provides a foundation for areas of electrical engineering such as electronics, power systems, communication systems, and control systems.

This chapter describes the structure of this book, introduces basic notation, and defines the primary physical variables in electric circuits—voltage and current. André Ampère (1775–1836) was the first to recognize the importance of distinguishing between the electrical effects now called voltage and current. He also invented the galvanometer, the forerunner of today's voltmeter and ammeter. A natural genius who had mastered all the then-known mathematics by age 12, he is best known for defining the mathematical relationship between electric current and magnetism. This relationship, now known as Ampère's law, is one of the basic concepts of modern electromagnetics.

The first section of this chapter describes the pedagogical framework and terminology that must be understood to use this book effectively. It describes how the learning objectives are structured to help the student develop the problem-solving abilities needed to analyze and design circuits. The second section provides some of the standard scientific notation and conventions used throughout the book. The last section introduces electric voltage, current, and power—the physical variables used throughout the book to describe the signal-processing and energy-transfer capabilities of linear circuits.

1–1 About This Book

The basic purpose of this book is to introduce the analysis and design of linear circuits. Circuits are important in electrical engineering because they process electrical signals that carry energy and information. For the present we can define a **circuit** as an interconnection of electrical devices, and a **signal** as a time-varying electrical entity. For example, the information stored on a compact disk is recovered in the CD-ROM player as electronic signals that are processed by circuits to generate audio and video outputs. In an electrical power system some form of stored energy is converted to electrical form and transferred to loads, where the energy is converted into the form required by the customer. The CD-ROM player and the electrical power system both involve circuits that process and transfer electrical signals carrying energy and information.

In this text we are primarily interested in **linear circuits**. An important feature of a linear circuit is that the amplitude of the output signal is proportional to the input signal amplitude. The proportionality property of linear circuits greatly simplifies the process of circuit analysis and design. Most circuits are only linear within a restricted range of signal levels. When driven outside this range they become nonlinear, and proportionality no longer applies. Although we will treat a few examples of nonlinear circuits, our attention is focused on circuits operating within their linear range.

Our study also deals with interface circuits. For the purposes of this book, we define an **interface** as a pair of accessible terminals at which signals may be observed or specified. The interface idea is particularly important with integrated circuit (IC) technology. Integrated circuits involve many thousands of interconnections, but only a small number are accessible to the user. Designing systems using integrated circuits involves interconnecting complex circuits that have only a few accessible terminals. This often involves relatively simple circuits whose purpose is to change signal levels or formats. Such interface circuits are intentionally introduced to ensure that the appropriate signal conditions exist at the connections between complex integrated circuits.