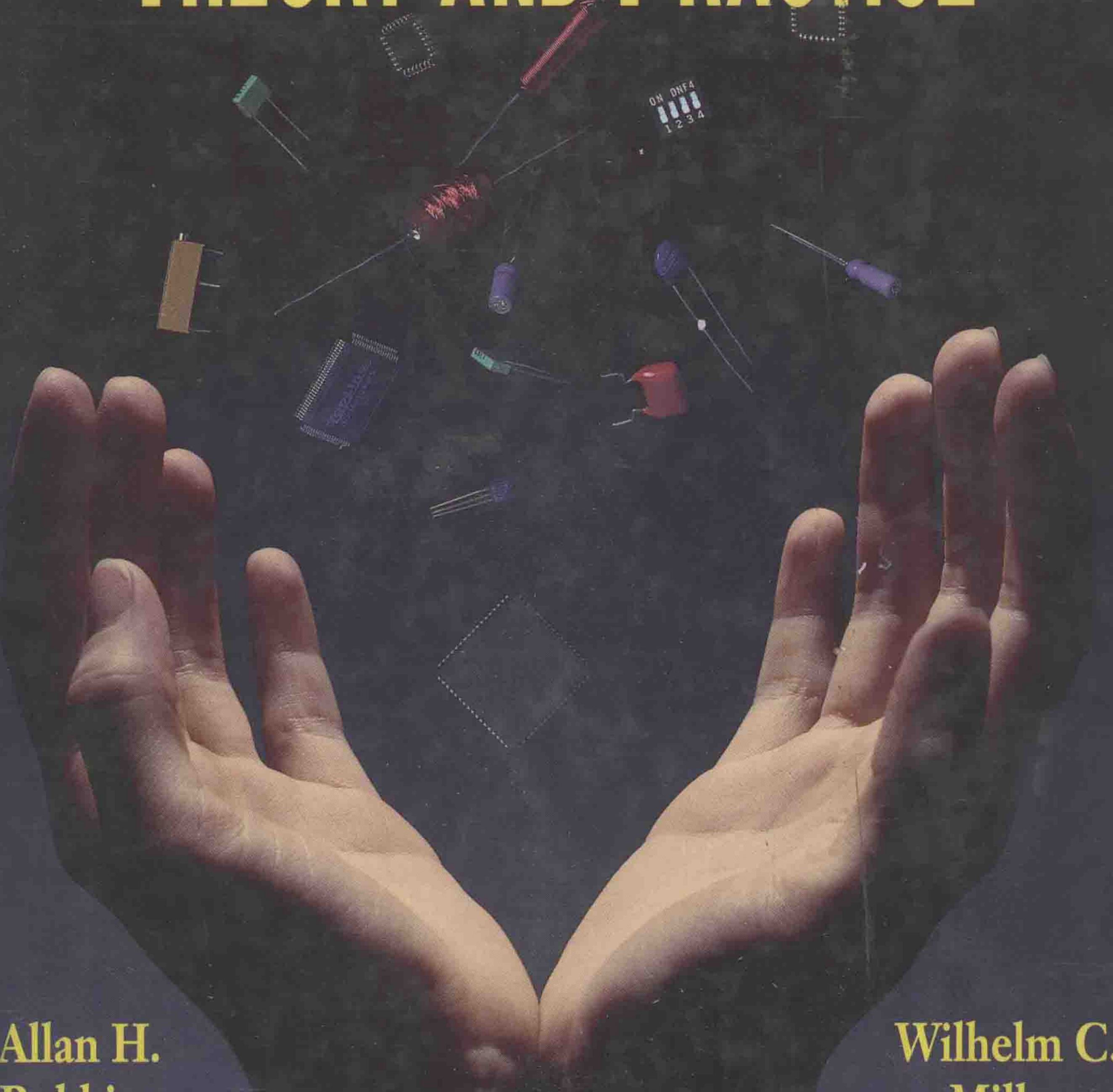
CIRCUIT ANALYSIS

THEORY AND PRACTICE



Allan H. Robbins

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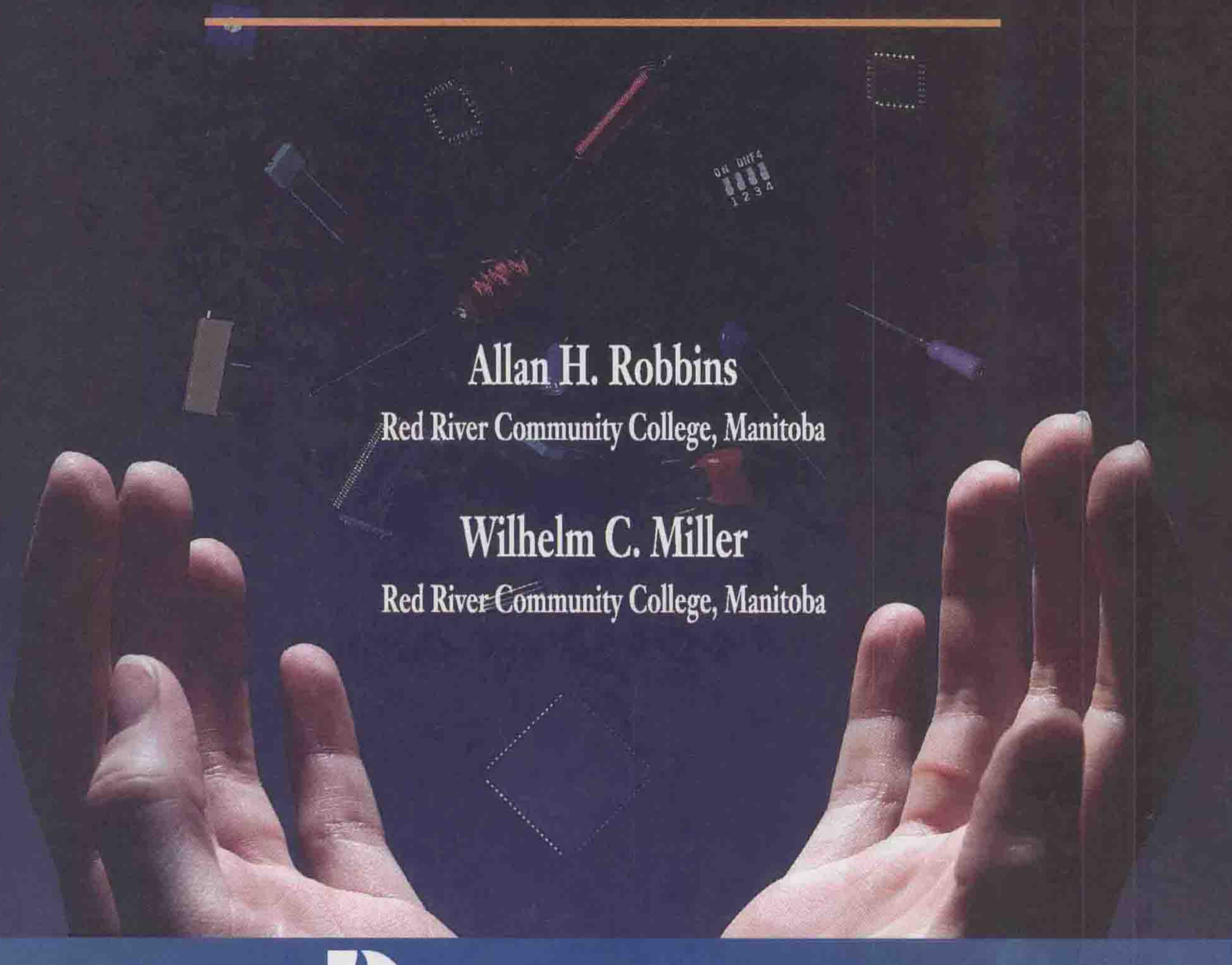

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Red River Community College, Manitoba

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Preface

This text is written primarily for students in electrical, electronic, and related engineering technology programs who are taking their first course in electric circuit theory. It covers fundamentals of dc and ac circuits, methods of analysis, capacitance, inductance, magnetism, simple transients, and other topics that are usually taught in an introductory circuit analysis course. While aimed primarily at students in two- and three-year technology programs, it may also serve as an introductory text in four-year university programs.

Features of the Book

- Clearly written, easy-to-understand style emphasizes principles and concepts.

- Hundreds of worked-out examples promote student understanding.

- Over 1200 diagrams and photographs illustrate the text. Full-color photographs and full-color diagrams with color-coded symbols and waveforms make visualizing important ideas easier.

- *In-Process Learning Checks* help identify learning gaps before students move on to new material.

- *Chapter Previews* provide a brief overview to prepare students for what is coming in the chapter.

- *Competency-based objectives* define the knowledge or skill that the student is expected to gain from each chapter.

- *Key terms* at the beginning of each chapter identify new terms to be introduced.

- A wide selection of end-of-chapter problems includes answers to odd-numbered problems.

- Computer-aided circuit analysis using PSpice illustrates how computer techniques may be used to analyze electric circuit problems.

- End-of-chapter problems are keyed to section numbers. Difficult problems are identified by having their number printed in red.

- Boxed articles and icons help locate important ideas.

Required Background

A working knowledge of basic algebra and trigonometry is required. In addition, students should be familiar with some linear algebra. Notably, they should be able to solve second-order linear equations. (However, a review of determinants and the solution of simultaneous equations is included in Appendix B.) Calculus is introduced gradually in later chapters to aid in the development of ideas. (This is in keeping with ABET guidelines, which require the use of some calculus in accredited engineering technology programs. It is expected that the student will be taking a concurrent calculus course.) Optional derivations using calculus are included for those colleges that stress calculus. They are identified by an ∫ icon. These derivations may be omitted by those colleges that do not require calculus.

In terms of electrical background, no previous knowledge is assumed other than that gained through everyday exposure. That is, we expect that students will be generally familiar with the terms voltage, current, and power through their association with common electrical and electronic devices. In terms of physics, we expect that students will know the MKS (meter-kilogram-second) metric system and the atomic nature of matter.

Text Organization

The book is divided into five main parts: Foundation dc Concepts, Basic dc Analysis, Capacitance and Inductance, Foundation ac Concepts, and Impedance Networks. Each part begins with an overview that provides a context for the material to come, while individual chapters include previews that set the stage for the chapter itself.

Chapters 1 to 4 are introductory. They cover foundation concepts including voltage, current, resistance, Ohm's law, and power. Chapters 5 to 9 focus on dc analysis. Covered here are Kirchhoff's laws, series and parallel circuits, mesh and nodal analysis, wye and delta transformations, source transformations, superposition, Thévenin's theorem, the maximum power theorem, and so on. Chapters 10 to 14 cover basic concepts of capacitance, magnetism, and inductance as well as the analysis of simple transients in dc circuits. Chapters 15 to 17 cover foundation concepts of ac, ac voltage generation, the basic ideas of frequency, period, phase angle, and so on. Phasors and the impedance concept are introduced and used to solve simple problems. Lastly, power in ac circuits is investigated. Chapters 18 to 25 then apply these ideas to the analysis of ac circuits. Topics covered include ac equivalents of earlier dc techniques (e.g., mesh and nodal analysis, superposition, Thevénin's theorem, and so on), as well as new ideas such as resonance, filters and Bode plots, three-phase systems, transformers, and the analysis of nonsinusoidal waveforms.

Several appendices round out the book. Appendix A provides a minitutorial on PSpice and the solution of circuit problems by computer. Appendix B reviews determinants and the solution of simultaneous linear equations. Appendix C contains answers to odd-numbered end-of-chapter problems.

The Ancillary Support Package

A comprehensive set of ancillaries support this book.

Instructor's Solution Manual: Contains step-by-step solutions to all end-of-chapter problems.

Test Bank: Contains problems and multiple-choice questions in computerized form.

Student Laboratory Manual: Contains instructions for hands-on laboratory work. Includes a brief theory overview for each lab exercise.

Transparencies and Transparency Masters: Selected diagrams from the book have been reproduced as full-color overhead transparencies; others have been packaged in a form suitable for making overhead transparencies.

Suggestions for Use

The presentation and format are such that an instructor can either follow the sequence as laid out or design his or her own course by selecting topics and omitting others as needed. For example, the two chapters on basic transients (Chapters 11 and 14) can be postponed until later without loss of continuity. The sections on resonance (Chapter 21), filters and Bode plots (Chapter 22), and nonsinusoidal waveforms (Chapter 25) can also be covered in a different order or omitted without serious discontinuity. Topics omitted can then be covered in a later sequence of study as needed.

To The Student

Learning circuit theory should be challenging, interesting, and hopefully, fun. However, it is also hard work as knowledge and skills can only be acquired through practice. We offer a few guidelines.

1. As you go through the material, try to gain an appreciation of where circuit theory comes from—i.e., the basic experimental laws on which it is based. This will help you better understand the foundation ideas on which the theory is built.

2. Learn the terminology and definitions. Important new terms are introduced frequently. Learn what they mean and where they are used.

3. Study each section carefully and be sure you understand the basic ideas and how they are put together. Work your way through the examples with your calculator. Try the practice problems and end-of-chapter problems. (Answers are in Appendices C and D.)

4. When you are ready, test your understanding using the *In-Process Learning Checks* located in each chapter.

5. Finally, when you have mastered the material, move on to the next block. For those concepts with which you are having difficulty, consult your instructor or some other authoritative source.

Calculators for Circuit Analysis

You will need a good scientific calculator. A good calculator will permit you to more easily master the numerical aspect of problem solving and leave you more time to concentrate on circuit theory itself. (Many calculators are difficult/complex to use and thereby make the manipulation of numbers an impediment to learning. This is especially true for ac, where complex number work dominates.) There are some very inexpensive, nonprogrammable calculators on the market that handle complex-number arithmetic almost as easily as real-number arithmetic. Such calculators save an enormous amount of time. If your school permits their use in introductory courses, we strongly recommend that you acquire one.

Getting the Most Out of This Book

Circuit Analysis: Theory and Practice is a learning tool with many in-text learning features that you should find useful. It uses full-color photos and diagrams (many of which incorporate 3-D effects) to illustrate and clarify ideas. Voltages and currents are color-coded, and color is used to highlight definitions, terminology, and so on. Icons are used to help locate features such as In-Process Learning Checks and Practical Notes, while marginal notes are used to define key terms and expand on ideas. Some of these features are illustrated below.

262 Chapter 8 Methods of Analysis

But, when converting the source, we get

$$I = \frac{E}{R_S}$$

And so

$$I_L = \left(\frac{R_S}{R_S + R_L}\right)\left(\frac{E}{R_S}\right)$$

This result is equivalent to the current obtained in Equation 8–4. The voltage across the resistor is given as

$$\begin{aligned} V_L &= I_L R_L \\ &= \left(\frac{E}{R_S + R_L}\right) R_L \end{aligned}$$

The voltage across the resistor is precisely the same as the result obtained in Equation 8–3. We therefore conclude that the load current and voltage drop are the same whether the source is a voltage source or an equivalent current source.

note

Although the sources are equivalent, currents and voltages within the sources may no longer be the same. The sources are only equivalent with respect to elements connected exernal to the terminals.

■ **EXAMPLE 8–4** Convert the voltage source of Figure 8–9(a) into a current source and verify that the current, I_L, through the load is the same for each source.

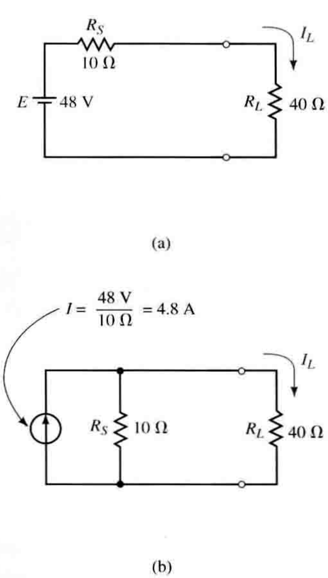

Figure 8–9

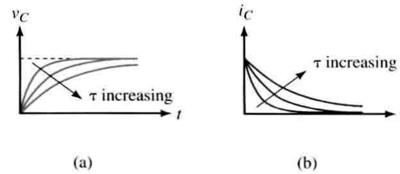

Figure 11–15 The larger the time constant, the longer the capacitor takes to charge.

Figure 11–15 shows how voltage and current are affected by the time constant. The larger the resistance and capacitance, the larger the time constant and hence the longer it takes for the capacitor to charge.

practical notes

Since resistors and capacitors have tolerances, their actual values may be different from their marked values. This will make the actual time constant of the circuit different than the computed time constant. In many cases, this is not important. However, it may be. In critical applications, you should check the effect that R *and* C *tolerances have on* τ.

in process learning check 1

1. If the capacitor of Figure 11–16 is uncharged, what is the current immediately after closing the switch?

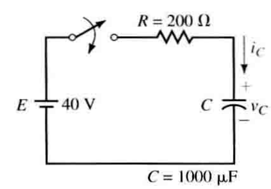

Figure 11–16

2. Given $i_C = 50e^{-20t}$ mA.
   a. What is τ?
   b. Compute the current at $t = 0^+$ s, 25 ms, 50 ms, 75 ms, 100 ms, and 500 ms and sketch it.
3. Repeat Problem 2 for $v_C = 100(1 - e^{-50t})$ V.
4. For Figure 11–16, determine expressions for v_C and i_C.
5. Refer to Figure 11–10:
   a. What are $v_C(0^-)$ and $v_C(0^+)$?
   b. What are $i_C(0^-)$ and $i_C(0^+)$?
   c. What are the steady state voltage and current?
6. For the circuit of Figure 11–11, the current just after the switch is closed is 2 mA. The transient lasts 40 ms and the capacitor charges to 80 V. Determine E, R, and C.

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Allan H. Robbins
Wilhelm C. Miller
November, 1993

Contents

P A R T
I

Foundation dc Concepts

Circuit theory provides the tools and concepts needed to understand and analyze electrical and electronic circuits. The foundations of this theory were laid down well over a hundred years ago by a number of pioneer researchers. In 1780, Alessandro Volta of Italy developed an electric cell (battery) that provided the first source of what we now call dc voltage. Around the same time, the concept of current was evolved (even though nothing was known about the atomic structure of matter until much later). In 1826, Georg Simon Ohm of Germany brought the two ideas together and experimentally determined the relationship between voltage and current in a resistive circuit. This result, known as Ohm's law, set the stage for the development of modern-day circuit theory.

In Part I, we examine the foundation of this theory. We look at voltage, current, power, energy, and the relationships between them. The ideas developed here are used throughout the remainder of the book and in practice.