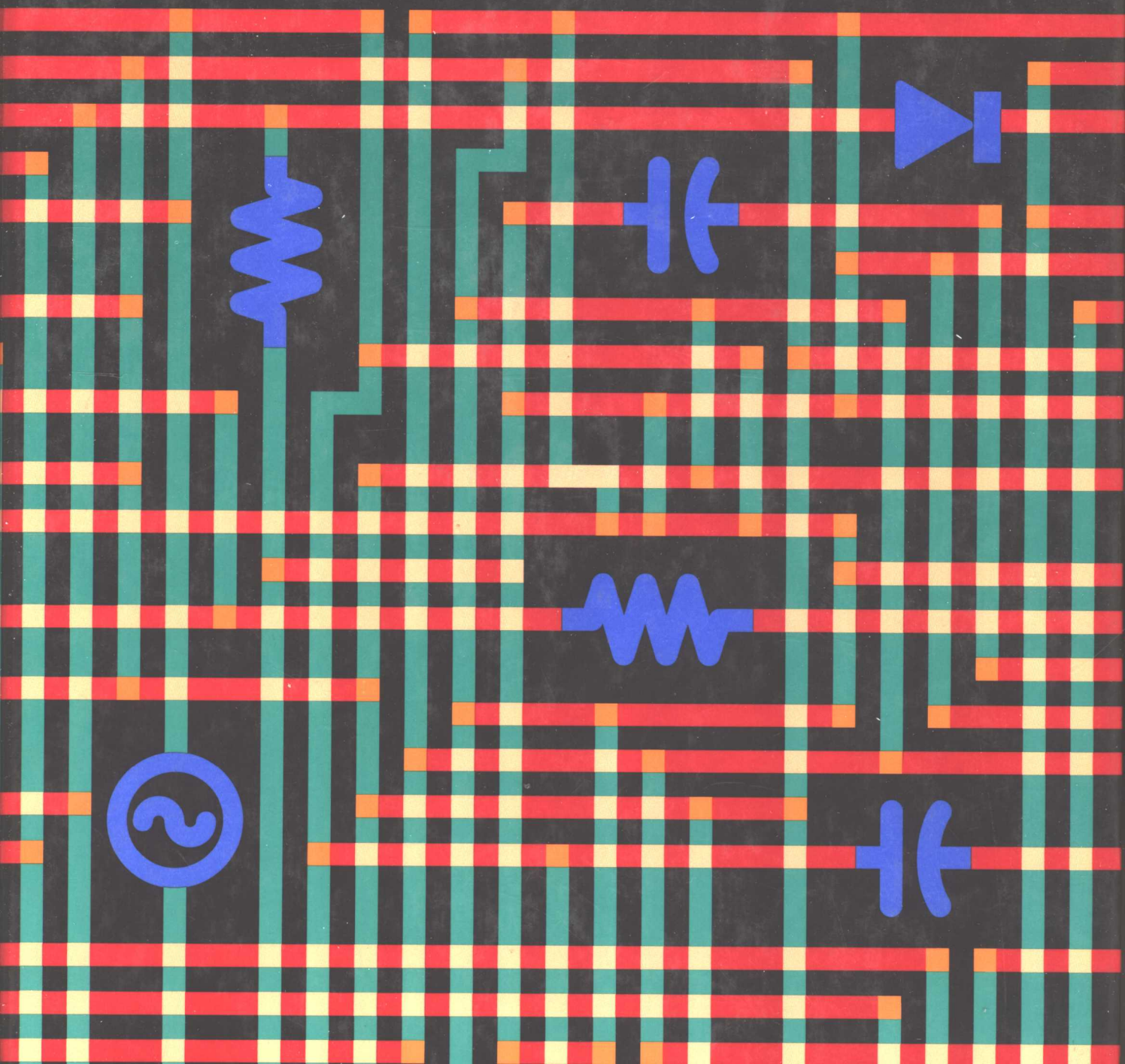


ELECTRIC CIRCUITS

NORMAN BALABANIAN



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To Wilbur R. LePage

**Profound scholar, dedicated teacher,
colleague, and friend**

PREFACE

Pedagogical Issues

By now, circuit theory as a college subject is more than a century old. Nevertheless, textbooks on the subject still make their appearance regularly. They vary in level, in profundity, in degree of detail, in organization, in reliance on software, and in pedagogical approach.

In seeking to explain and predict electrical phenomena in the physical world of circuits, this book follows the approach that is generally described as the “scientific method.” Over the years, observations and experiments in the physical world have led to a set of laws (including Ohm’s law, Kirchhoff’s laws, Faraday’s law, and Ampère’s law) that are enunciated in terms of a hypothetical model of the part of the physical world under discussion. The model consists of a number of components. These elements do not actually exist in the physical world, although the behavior of *some* physical devices, under *some* conditions of operation, may approximate that of one or another of the hypothetical components, or some combination of them. When practical circuits are under consideration in the book, they are replaced by models appropriate to the specific conditions of operation.

The deductive process—applying general principles to specific cases—is usually well illustrated in textbooks. In this book, I have also tried to emphasize the inductive process—the development of a generally valid law or procedure from an examination of specific cases. Sometimes, the study of one or more specific cases leads to a conjecture about something generally valid. The student might then find that this same conjecture can be deduced from a reexamination of previously established principles. This text follows such a pattern in several places.

When a subject like circuit theory reaches a

degree of maturity, there is a tendency for a textbook to acquire some of the characteristics of an encyclopedia; every conceivable topic is “covered.” This robs the learner of all the joys of discovery. The learner is given the complete story and told to learn it, mainly by practicing on exercises and problems just like detailed examples provided. I have tried to avoid the pitfall of cataloging for students all that we know on a subject and have left for them the pleasure of developing (with guidance) some results which, though known to those familiar with circuit theory, are not essential for going on with the subject matter being developed.

At key points in the exposition, I have tried to raise questions about a conclusion just reached, to explore the alternatives it presents for going on and the reasonableness of pursuing a particular line of attack. *Why* we are pursuing a particular thread and *how* a particular component in our model is created are just as important to explain as the details of manipulating this model, of following that specific procedure, or of applying some algorithm. The tenor of the text is that we are conducting an investigative exploration, almost like a research project, for the purpose of discovering and assimilating knowledge about the subject. When a topic is introduced, I make an effort to help the student understand why we ought to devote time to it. Why study the sinusoidal steady state, for example? When some step has to be taken, alternatives are explored. “We could do this or we could do that,” the commentary might go; “let’s first try this, for the following reasons.”

Students learn best if they are engaged. If teachers (or authors) could ensure that, their day would be made. Therefore, I try to remind readers now and then that they should participate in the

derivation of an equation by performing missing steps, observe the relevant features of a diagram by describing it to themselves, or think through a proposed plan before going on.

Level of Presentation

The subject of circuits is taught in engineering schools at different levels. At some universities, the subject is delayed until the third year, when more background in physics and mathematics is expected. This will influence the level at which the subject is approached. At most other schools, the subject is introduced sometimes in the second year. Students have taken a course in differential and integral calculus but perhaps not yet in differential equations. They might have studied electricity and magnetism in physics (or might be doing so concurrently), as well as statics and dynamics in mechanical engineering. This book is aimed at this level. Regardless of the level, I have not compromised in the rigor of presentation of any topic.

The book is suitable for use in courses spanning an academic year, either two semesters or three quarters. By proper selection of chapters and of topics within chapters, a one-semester course can also be accommodated.

Topic Selection

This book deals mainly with linear circuits, although nonlinear diode circuits are treated briefly. Because nonlinear circuits are treated to such a limited extent and no general propositions are discussed in this area, the wisdom of including them at all might be questioned. Normally, if one covers only linear circuits, then no matter how often one cautions students that the rules and procedures being studied apply only to linear circuits, they tend to believe that what they are studying is quite general—unless they see cases of nonlinear circuits where the methods don't apply. Furthermore, even the linear models we use have a limited dynamic range. This is especially true for such things as controlled sources and op amps. It is important to ensure that the conditions of a problem are such that the model is truly operating in the linear region. Sensitivity to these matters cannot be raised if only linear circuits are treated.

Topics have been selected and ordered so that the book can be used at institutions with different calendars and a variety of emphases. Several "enrichment" topics are introduced in sections that can be omitted without incurring a subsequent penalty. Later sections or problems based on this material can be similarly omitted. The most salient are a section on transistors, the material on gyrators and negative converters, the proof of Thévenin's theorem, the coverage of stagger-tuned circuits, the Fourier transforms of certain functions, and the derivation of the convolution integral. Including such material permits students with more time or curiosity to benefit without penalizing others.

Auxiliary material is provided in two forms. Inside the book covers are four tables of reference information. One gives the SI prefix names, symbols, and corresponding powers of 10. The second is a short list of useful trigonometric identities. The third is a brief table of commonly encountered integrals. A table listing the Greek alphabet is also provided. Because they are easy to locate without riffling through pages, these tables are easy to use. The remaining auxiliary material is in the form of two appendices on a number of topics in mathematics that students have probably encountered but don't necessarily have at their fingertips. They serve as memory aids, not as thorough expositions. Appendix A treats matrix algebra, the solution of linear algebraic equations, Cramer's rule, and pivotal condensation. Appendix B treats the arithmetic and algebra of complex numbers; it also provides a brief look at complex variables, Euler's theorem, and the law of exponents.

Numbering Scheme for Equations and Figures

Some schemes for numbering equations and figures, and the manner of referring to them, can cause students to be distracted as they engage unproductively in reading the numbers and searching for them. In this book a sequential numbering system, starting fresh within each chapter, for both equations and figures is used, without attached prefixes consisting of chapter numbers or section numbers. (On those few occasions when reference is made to an equation in an earlier chapter, the

chapter number does have to be stated.) Not all equations are numbered, only significant ones or those to which reference might be made later. No special identifying “tag,” such as *Eq.*, is used when referring to an equation, but when referring to a figure, the word *Figure* is used.

Illustrations, Examples, Exercises, and Problems

When a particular topic is first being developed, illustrations are used to illuminate it. Indeed, an illustration might precede the theoretical development of the topic as part of the process of induction. *Illustrations*, thus, are incorporated in the development of the material. There are also numbered *examples*, separated from the text and easily distinguished, which are worked out using the concepts just developed, together with other recently assimilated ideas. Both literal and numerical illustrations and examples are used.

Scattered throughout, but in a format that distinguishes them from the text, are numbered *exercises* for students to work out at the time they are studying the relevant sections. The purpose of these exercises is to provide reinforcement for the concepts under study by having students carry out some simple calculations applying results just encountered.

At the end of each chapter there is a set of *problems*. The problems in each set range from a simple application of procedures developed in the book to a challenging solution of a practical problem. Sometimes a problem requires students to apply a specified technique for its solution. At other times they are asked to solve a problem by two or more specified approaches and to compare the ease or difficulty. This is so that students can practice specific techniques and reinforce their understanding of them. Sometimes the problem is open-ended, so that students have to make decisions about the methods to use and then apply them. Certain types of problems specify a circuit structure and component and excitation values and then ask for the solution for certain values of voltage or current, power dissipated or supplied, or energy stored. In other problems, not all element values are specified but certain other desired outcomes are, such as the

voltages or currents somewhere. The unknown component values are to be determined in order to achieve the specified goals. Such problems have a design flavor.

Unrealistic circuits that throw together an arbitrary collection of circuit elements, even though the resulting circuit model does not remotely correspond to a practical circuit, are avoided. Among such culprits are resistors across voltage sources or in series with current sources, and contrived circuits that include control sources in unrealistic configurations that do not correspond to models of real devices; their effect is often nothing more than that of a resistor.

From Chapter 3 on, there is, in addition, a category called *design problems*. The objective in these problems is the design of an engineering circuit to achieve specified goals—say, a sawtooth wave. At the level of this book it may be necessary to specify the structure of a specific design and require the students to determine the parameter values that will achieve specified values of peak and valley voltage, repetition rate, or return time, for example. The design problems are all realistic. (In the context of this book, however, it is not possible to include all the factors that come into play in a real design, such as cost, for example.)

Use of Software

I am ambivalent about students' use of circuit analysis software during the study of circuits. For professionals, such software is indispensable, and familiarity with it is a requirement for being a professional. The real question for the author of a textbook is how valuable such software is during the early stages of study. My decision has been not to incorporate the use of circuit analysis software directly into the text but to orient specific topics in a way that is consistent with the availability and use of PSpice and MATLAB. Thus, for example, the usual approach in mesh and node analysis of *RLC* circuits that emphasizes the writing of the coefficient matrix by inspection is downplayed, explicitly because such a skill is of no value when using PSpice, besides being applicable only to *RLC* circuits. (On the other hand, note the section on supplements that follows.)

Text Supplements

There are two varieties of supplements. One variety is provided to instructors who adopt this book for use in their courses and is not available to students. It includes a *Solutions Manual*, which contains full solutions of all the problems in the book. It also includes a set of *transparency masters* of appropriate figures from the book. The figures are enlarged so that instructors can use them in the classroom.

The second is a separate *Study Guide* intended for student use. The Study Guide is keyed to the chapters in the book and provides instruction in problem solving and solution checking, using a step-by-step, programmed approach. It also includes a tutorial in the use of PSpice and MATLAB in circuit analysis, giving examples of problem solutions using this software. The greatest part of the Study Guide consists of worked-out problems covering the entire range of topics in the book. Many of the problems are explicitly phrased for use of PSpice or MATLAB. Instructors adopting the book for their courses will be provided a copy of the Study Guide for their use.

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I owe a debt of gratitude to the Department of Electrical and Computer Engineering at Syracuse University for making available to me a year's free time to devote to this book. I am grateful also to the faculty of the Department of Electrical Engineering at Tufts University and to its Chairman, Prof. Dennis Fermental, for their generosity in providing me, for several years, an office, facilities, and collegiality while this book was being completed.

The one individual who has influenced me the most is my teacher and mentor, Wilbur R. LePage. We have spent countless days and nights discussing this or that esoteric topic in circuit theory, arguing about interpretations and nuances and how best to think of, and to present to students, this or that topic.

Norman Balabanian

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