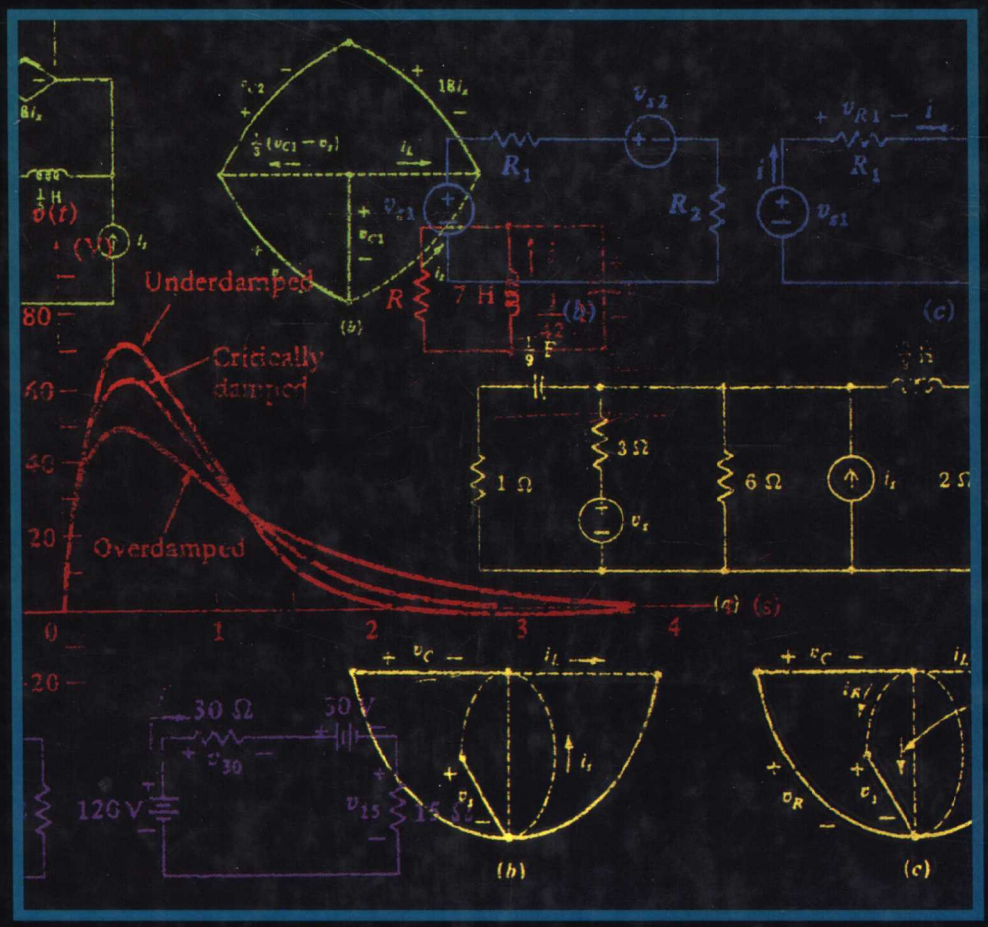
Engineering Circuit Analysis



FIFTH EDITION

WILLIAM H. HAYT, JR. • JACK E. KEMMERLY

ENGINEERING CIRCUIT ANALYSIS

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McGRAW-HILL, INC.

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2 3 4 5 6 7 8 9 0 DOW DOW 9 0 9 8 7 6 5 4 3

ISBN 0-07-027410-X

This book was set in Times Roman by Bi-Comp, Inc.
The editors were Anne T. Brown and Jack Maisel;
the designer was Joan Greenfield;
the production supervisor was Kathryn Porzio.
New drawings were done by Fine Line Illustrations, Inc.
R. R. Donnelley & Sons Company was printer and binder.

Library of Congress Cataloging-in-Publication Data

Hayt, William Hart, (date).
Engineering circuit analysis/William H. Hayt, Jr., Jack E. Kemmerly.—5th ed.
p. cm.—(McGraw-Hill series in electrical and computer engineering. Circuits and systems)
Includes index.
ISBN 0-07-027410-X
1. Electric circuit analysis. 2. Electric network analysis. I. Kemmerly, Jack E., (date). II. Title. III. Series.
TK454.H4 1993
621.319'2—dc20 92-37799

INTERNATIONAL EDITION

When ordering this title, use ISBN 0-07-112961-8.

Preface

Reading this book is intended to be an enjoyable experience, even though the text is indeed scientifically rigorous and somewhat mathematical. Typical readers are in their early twenties, full of enthusiasm, and just beginning to study engineering—particularly *electrical* engineering.

We, the authors, are trying to sell the premise that circuit analysis can be fun. Not only is it useful and downright essential to the study of engineering, it is a marvelous education in logical thinking, good even for those who may never analyze another circuit in their professional lifetime. Students are truly impressed by all the excellent analytical tools that can be derived from only three simple scientific laws—Ohm's law and Kirchhoff's voltage and current laws.

In many colleges and universities, the introductory course in electrical engineering will be preceded or accompanied by an introductory physics course in which the basic concepts of electricity and magnetism are introduced, most often from the field aspect. Such a background is not a prerequisite, however. Instead, several of the requisite basic concepts of electricity and magnetism are discussed (or reviewed) in the first chapter. Only an introductory calculus course need be considered as a prerequisite—or possibly a co-requisite—to the reading of the book. Circuit elements are introduced and defined here in terms of their circuit equations; only incidental comments are offered about the pertinent field relationships. In the past, we have tried introducing the basic circuit analysis course with three or four weeks of electromagnetic field theory, so as to be able to define circuit elements more precisely in terms of Maxwell's equations. The results, especially in terms of students' acceptance, were not good.

We intend that this text be one from which students may teach the science of circuit analysis to themselves. It is written to the student, and not to the instructor, because the student is probably going to spend more time than the instructor in reading it. If at all possible, each new term is clearly defined when it is first introduced. The basic material appears toward the beginning of each chapter and is explained carefully and in detail; numerical examples are usually used to introduce and suggest general results. Drill problems appear at the ends of most sections; they are generally simple, and answers to the several parts are given in order. The more difficult problems appear at the ends of the

chapters and follow the general order of presentation of the text material. These problems are occasionally used to introduce less important or more advanced topics through a guided step-by-step procedure, as well as to introduce topics which will appear in the following chapter. The introduction and resulting repetition are both important to the learning process. In all, there are 860 problems: 231 drill problems, each consisting of several parts, and 629 additional problems at the ends of the chapters. Most of these problems are new in this edition and, unfortunately for us authors, each problem had to be solved by both of us, independently. Then we argued over disagreements on answers until they were resolved.

The general order of the material has been selected so that the student may learn as many of the techniques of circuit analysis as possible in the simplest context, namely, the resistive circuit which is the subject of the first part of this text. Fundamental laws, a few theorems, and some elementary network topology enable most of the basic analytical techniques to be developed. Numerous examples and problems are possible since the solutions are not mathematically complicated. By means of many example problems, particular emphasis is placed on the use of Thévenin's theorem, a topic that is perennially troublesome to students. The extension of these techniques to more advanced circuits in subsequent parts of the text affords the opportunity for both review and generalization. Part 1 of the text may be covered in four to six weeks, depending on the students' background and ability, and on the course intensity.

Part 2 is devoted to the natural response and the complete response to dc excitation of the simpler *RL*, *RC*, and *RLC* circuits. Facility in differential and integral calculus is necessary, of course, but a background in differential equations is not really required. The unit-step function is introduced as an important singularity function in this part, but the introduction of the unit-impulse function is withheld until transform techniques are introduced in Chapter 18.

Part 3 of the text introduces the frequency domain and initiates operations with complex numbers by concentrating on sinusoidal analysis in the steady state. This part also includes a discussion of average power, rms values, and polyphase circuits, all of which are associated with the sinusoidal steady state.

In Part 4 the complex-frequency concept is introduced, and its use in relating the forced response and the natural response is emphasized. The determination of the complete response of sinusoidally excited circuits begins to tie together the material of the first three parts.

Part 5 begins with a consideration of magnetic coupling, which is basically a two-part phenomenon, and logically leads into a consideration of two-part network analysis and the linear modeling of various electronic devices, especially transistors.

Part 6 introduces more powerful techniques of network analysis. Some instructors are inclined to introduce these techniques, Laplace transforms in particular, much earlier in a basic circuit analysis course. However, we are very reluctant to do this, feeling as we do that this tends to discourage students from a deeper familiarity with the simpler circuits they encounter. The first of these analysis techniques is state-variable analysis. Following this is the Fourier series description of periodic waveforms. The treatment of Fourier series is then extended to nonperiodic forcing and response functions by use of the Fourier transform in Chapter 18. Numerous example problems illustrating the technique of convolving time functions—certainly not easy, bed-time reading for many students—are included in this chapter. The final chapter covers the

more important Laplace transform techniques and their use in obtaining the complete response of more complicated circuits.

The material in this book is more than adequate for a two-semester course, but some selection may be made from the last four or five chapters. No material is included in the text which will not be of some value in the following term; thus, signal-flow graphs, the relationship of circuit theory to field theory, and advanced topological concepts are among those subjects which are relegated to subsequent courses.

A number of changes have been made in this edition: Chapters 1 and 2 of the previous edition have been combined into a new Chapter 1. We concluded that some of that old Chapter 1 was a bit too longwinded; so, with a sigh, we pared it down. The subject of state-variable analysis has been added, at the request of a considerable number of instructors and reviewers. Example problems—126 of them, mostly new—have been included in a different format. That is, they have been set off somewhat from the body of the text so that they can be identified or located quickly. They are indented slightly more than the main text, and the end of each example is identified by means of a small blue rectangle close to the right margin. Numerous other example problems are also included, but are woven into the text's narrative for illustrative purposes.

Computer-aided analysis is now included in this edition. Some instructors virtually *demand* that this topic be included; others, in almost equal numbers are adamantly opposed to its inclusion in an introductory text. So, we hope we have struck a proper compromise. Problems that are specifically intended for analysis using the popular SPICE (or PSpice®) programs are included at the *ends* of many of the chapter-end sets of problems; and they are identified by the designation (SPICE). In addition, Appendix 5 presents a simple tutorial on the use of SPICE, adequate for solving most of the analysis problems which are encountered here. For those who want a more detailed treatment, a new book is recommended as a companion text: Roger C. Conant's *Engineering Circuit Analysis with PSpice and PROBE* (available in PC and Macintosh versions), McGraw-Hill, Inc., 1993. The consequence of this method of handling computer-aided analysis is that those instructors who do not wish to use it at this level of instruction can easily omit it; whereas those who wish to use it can do so with alacrity.

A somewhat expanded treatment of the operational amplifier is introduced as one of today's most important devices, and it is used to provide examples of circuits containing dependent sources, such as the voltage follower, the integrator and differentiator, the multiplier, the inverting amplifier, and circuits which can simulate lossless *LC* circuits and voltage-gain transfer functions.

Added help is offered for both students and instructors: Appendix 6, which now includes answers to every odd-numbered problem; and a *Solutions Manual,* which includes detailed solutions of all drill problems and chapter-end problems, is available for the instructor. Moreover, a *Students' Solutions Manual* is available in which about 800 problems *similar* to the ones in the text, are stated and solved. So much for material that is new in this edition.

Throughout the book there is a logical trail leading from definition, through explanation, description, illustration, and numerical example, to problem-solving ability; and this new-found ability often tends to make students excited, and gets them to asking themselves, "Why does this happen? How is it related to last week's work? Where do we logically go next?" There is a tremendous amount of enthusiastic momentum in most beginning engineering students, and this may be preserved by providing frequent drill problems whose success-

ful solution confirms progress in their minds by integrating the various sections into a coherent whole, by pointing out future applications and more advanced techniques, and by maintaining in them interested, inquisitive attitudes.

If the book occasionally appears to be informal, or even lighthearted, it is because we feel that it is not necessary to be dry or pompous to be educational. Amused smiles on the faces of our students are seldom obstacles to their absorbing information. If the writing of the text had its entertaining moments, then why not the reading too?

Much of the material in the text is based on courses taught at Purdue University and the California State University, Fullerton.

We would like to express our thanks for the many useful comments and suggestions provided by colleagues who reviewed this text during the course of its development, especially to Roger H. Baumann, University of Massachusetts, Lowell; Richard B. Brown, Michigan Technological University; Roger C. Conant, University of Illinois at Chicago; James F. Delansky, The Pennsylvania State University; John A. Fleming, Texas A&M University; Yusuf Leblebici, University of Illinois at Urbana-Champaign; William Oliver, Boston University; Sheila Prasad, Northeastern University; and Rolf Schaumann, Portland State University.

We, the authors, have already thanked each other for our invaluable contributions. Modesty precludes further elaboration.

William H. Hayt, Jr.
Jack E. Kemmerly

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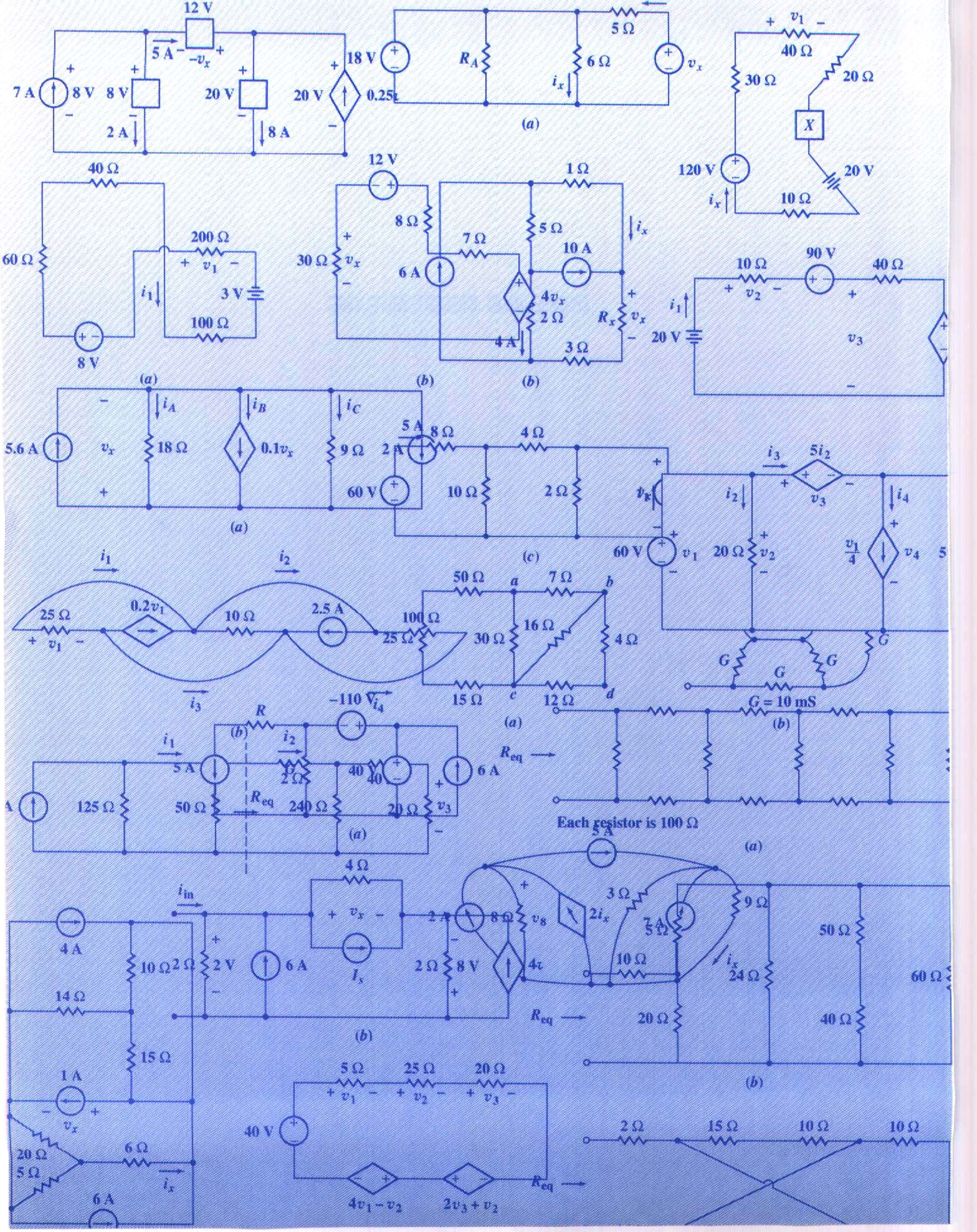
ENGINEERING CIRCUIT ANALYSIS



12 V
5 A
$-v_x$
7 A
8 V
2 A
20 V
8 A
18 V
0.25
R_A
6 Ω
i_x
5 Ω
v_x
(a)
v_1
40 Ω
30 Ω
20 Ω
X
120 V
20 V
10 Ω
i_x
40 Ω
60 Ω
200 Ω
v_1
3 V
i_1
100 Ω
8 V
(a)
12 V
8 Ω
30 Ω
6 A
7 Ω
1 Ω
5 Ω
10 A
$4v_x$
2 Ω
4 A
3 Ω
R_x
(b)
(b)
10 Ω
90 V
40 Ω
v_2
v_3
20 V
i_A
i_B
i_C
5.6 A
18 Ω
$0.1v_x$
9 Ω
(a)
60 V
5 A
8 Ω
2 A
4 Ω
10 Ω
2 Ω
(c)
i_3
$5i_2$
i_2
i_4
60 V
20 Ω
v_4
i_1
i_2
25 Ω
$0.2v_1$
10 Ω
2.5 A
i_3
50 Ω
7 Ω
100 Ω
25 Ω
30 Ω
16 Ω
4 Ω
15 Ω
12 Ω
(a)
G
G = 10 mS
(b)
R
−110 V
i_1
5 A
125 Ω
50 Ω
R_{eq}
240 Ω
40 Ω
20 Ω
6 A
(a)
R_{eq}
Each resistor is 100 Ω
(a)
5 A
4 Ω
i_{in}
v_x
I_x
4 A
10 Ω
2 Ω
2 V
6 A
2 Ω
8 V
8 Ω
v_8
$2i_x$
3 Ω
7 A
9 Ω
10 Ω
24 Ω
50 Ω
60 Ω
14 Ω
15 Ω
R_{eq}
20 Ω
40 Ω
(b)
(b)
1 A
v_x
20 Ω
5 Ω
6 Ω
i_x
6 A
5 Ω
25 Ω
20 Ω
40 V
$4v_1 - v_2$
$2v_3 + v_2$
R_{eq}
2 Ω
15 Ω
10 Ω
10 Ω

Part One:
The Resistive Circuit