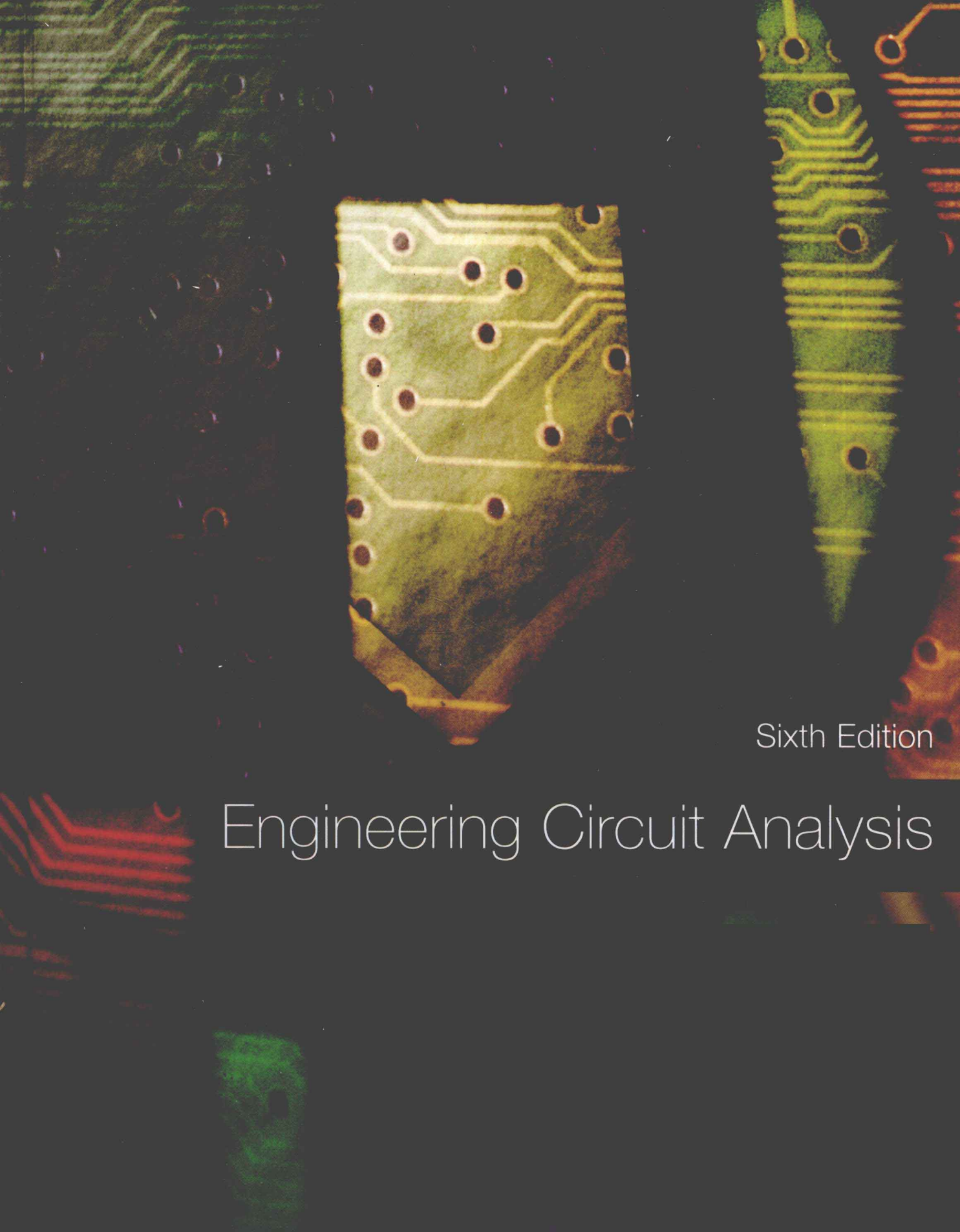

Sixth Edition

Engineering Circuit Analysis

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William H. Hayt, Jr. (late)
Purdue University

Jack E. Kemmerly (late)
California State University

Steven M. Durbin
University of Canterbury

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ABOUT THE AUTHORS

William H. Hayt, Jr. received his B.S. and M.S. at Purdue University and his Ph.D. from the University of Illinois. After spending four years in industry, Professor Hayt joined the faculty of Purdue University, where he served as Professor and Head of the School of Electrical Engineering, and as Professor Emeritus after retiring in 1986. Besides *Engineering Circuit Analysis,* Professor Hayt authored three other texts, including *Engineering Electromagnetics,* now in its sixth edition with McGraw-Hill. Professor Hayt's professional society memberships included Eta Kappa Nu, Tau Beta Pi, Sigma Xi, Sigma Delta Chi, Fellow of IEEE, ASEE, and NAEB. While at Purdue, he received numerous teaching awards, including the university's Best Teacher Award. He is also listed in Purdue's Book of Great Teachers, a permanent wall display in the Purdue Memorial Union, dedicated on April 23, 1999. The book bears the names of the inaugural group of 225 faculty members, past and present, who have devoted their lives to excellence in teaching and scholarship. They were chosen by their students and their peers as Purdue's finest educators.

Jack E. Kemmerly received his B.S. magna cum laude from The Catholic University of America, M.S. from University of Denver, and Ph.D. from Purdue University. Professor Kemmerly first taught at Purdue University and later worked as principal engineer at the Aeronutronic Division of Ford Motor Company. He then joined California State University, Fullerton, where he served as Professor, Chairman of the Faculty of Electrical Engineering, Chairman of the Engineering Division, and Professor Emeritus. Professor Kemmerly's professional society memberships included Eta Kappa Nu, Tau Beta Pi, Sigma Xi, ASEE, and IEEE (Senior Member). His pursuits outside of academe included being an officer in the Little League and a scoutmaster in the Boy Scouts.

Steven M. Durbin received the B.S.E.E., M.S.E., and Ph.D. from Purdue University, West Lafayette, Indiana. After receiving the Ph.D., he joined the faculty of the Department of Electrical Engineering at Florida A&M University and The Florida State University. In August of 2000, he accepted a faculty position at the University of Canterbury, Christchurch, New Zealand, where he teaches circuits, electronics, and solid-state related courses, and conducts research into novel electronic materials and device structures. He is a member of Eta Kappa Nu, the IEEE, the Electron Devices Society, the American Physical Society, and the Royal Society of New Zealand.

PREFACE

Reading this book is intended to be an enjoyable experience, even though the text is by necessity scientifically rigorous and somewhat mathematical. We, the authors, are trying to share the idea 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. Looking back after finishing the course, many students are truly amazed by all the excellent analytical tools that are 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) as needed. 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 used to introduce and suggest general results. Practice problems appear throughout each chapter; 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 over 950 end-of-chapter problems in addition to numerous practice problems and worked examples. Most of the exercises are new in this edition, and, with the assistance of several colleagues, each problem was solved by hand and checked by computer when appropriate.

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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; the California State University, Fullerton; Fort Lewis College in Durango; the joint engineering program of Florida A&M University and The Florida State University; and the University of Canterbury.

New in the Sixth Edition

Revising this text has been a daunting task, to say the very least. I used it as an undergraduate at Purdue University, where I was fortunate to take circuits from Professor Hayt himself—one of the best professors I ever had. In looking back, it's sometimes hard to remember how exactly I came to be invited to join the team of such a famous textbook. I met the sponsoring editor, Catherine Shultz, through my participation in the review of another textbook, and the fact that McGraw-Hill was planning to add a new coauthor to *Engineering Circuit Analysis* eventually came up in conversation. She invited me to review the Fifth Edition, and summarize my thoughts as to where the Sixth Edition needed to go. That was back in March of 1999—and I've been working on this project ever since.

There are several very noteworthy features of *Engineering Circuit Analysis* that are responsible for its success. It is a very well structured book—key concepts are presented in a logical format, but also interlinked seamlessly into a larger framework. Bill Hayt and Jack Kemmerly put a great deal of work into the creation of the First Edition, and their desire to impart some of their boundless enthusiasm to the reader comes through in every chapter.

My first impressions were that not only did the figures need redrawing and updating, but that the numerous examples were often very difficult to locate. Also, the Fifth Edition relied very heavily upon the premise that students would work each and every Drill Problem; as such, Drill Problems were used as key vehicles to transfer concepts regarding methodology and basic problem-solving skills. Further, there was a need to inject more practical flavor into the text to capture the attention of today's students, to increase the number of examples, and to provide a larger assortment of end-of-chapter problems for instructors.

Each and every chapter in this book received careful attention. Some of the key changes users of the Fifth Edition will observe include:

1. A new introductory chapter has been written to provide students with a brief overview as well as key reasons for requiring them to study circuit analysis early in their program.
2. Chapter 1 has been split into two chapters, as has Chap. 2; this was done so that this important material could be introduced at a less rushed, more leisurely pace. The network topology material in Secs. 2.7 and 2.8 has been moved to an appendix.
3. In keeping with reviewer comments and the modern trend to reduce the amount of lecture time spent in time-domain analysis, the material in Chaps. 4 and 5 has been combined into a single chapter.

4. The material on op amps has been relocated from Chap. 1 to a self-contained chapter (Chap. 6). To the degree possible, the remainder of the text was written so that instructors who prefer to leave the teaching of op amp circuits to later electronics courses can do so without undue distraction. The common approach to op amps in circuit analysis textbooks is to attempt to use them as a "practical" application of dependent sources. This doesn't work perfectly, however, since almost as soon as we establish that model for op amps, we discard it in favor of the ideal op amp model. In this treatment, the ideal op amp is presented in the same way as the ideal resistor, capacitor, and inductor. Practical op amp analysis skills are emphasized in the introductory sections. Once the students develop some confidence with this eminently practical device, the ideal op amp model is derived from a more accurate (but nevertheless still approximate) dependent voltage source model.
5. Sinusoidal steady-state response concepts have been consolidated into a single chapter for a more streamlined approach.
6. A section on three-phase power measurement has been updated and reintroduced from an earlier version.
7. The chapter dealing with transformers has been relocated to immediately following the three-phase power chapter for the convenience of instructors.
8. Perhaps one of the largest reorganizations is the combination of the original treatment of complex frequency with the introduction to the Laplace transform. The modern trend has been to introduce Laplace transforms earlier in the course. However, students are almost always completely confounded when first confronted with the notion of a complex frequency, and so it was felt that a more gentle introduction to some of the related concepts was still appropriate.
9. Several new sections have been added, including discussions of how to choose from among the various circuit analysis techniques explained in the different chapters, and the design of filter circuits from a general perspective.
10. The chapter on state-variable analysis has been removed from the bound version of the text. However, depending on the interests of the instructor, this material can provide a useful perspective of general circuit analysis theory. For this reason, it was decided to make the original material available through the textbook website.
11. Over 300 new end-of-chapter problems have been added.
12. Practical Application sections have been added to many of the chapters, with the intention of showing how the many equations and theories presented apply to the real world.
13. PSpice® and MATLAB® examples have been added to almost every chapter. However, the authors feel strongly that computer-aided engineering should be just that—an aid, not a substitute for developing problem-solving skills. Thus, the introduction of computer tools has been carefully timed with the aid of many reviewer suggestions. Computer-aided analysis is introduced into homework problems only as the last part of a regular problem in order to encourage students to compare hand calculations to digital results. PSpice® student version 9.1 and MATLAB student version 5.0 were used.

14. The introduction to each chapter has been shortened, and now includes a Goals and Objectives section. Each chapter concludes with a short summary of key concepts to aid in review.
15. A series of margin icons has been introduced:

to indicate common errors;

highlights points to note carefully; and

indicates a design problem.

16. This edition of Engineering Circuit Analysis introduces a new multimedia supplement, *Virtual Professor*. Educators are slowly beginning to understand how different people learn in different fashions. For example, some students tend to be more visually oriented, while others are more audio-oriented. Others prefer to obtain the majority of their information directly from the written word. Accounting for variations in learning preferences, however, can be a daunting task in writing a textbook. The introductory set of eleven *Virtual Professor* modules has been developed as one means of combining the best of all worlds. Each module contains a narrated, animated mini-lecture on a particular introductory circuit analysis topic, along with one or more worked examples. The media player allows the module to be paused to allow notes to be taken, as well as to allow the student to attempt to finish an example before the solution is given. It also allows the user to replay a particular portion of any module as often as desired. The eleven modules are

    Current, Voltage, and Power
    Kirchhoff's Current Law
    Kirchhoff's Voltage Law
    Basic Nodal Analysis
    Advanced Nodal Analysis
    The Supernode
    Basic Mesh Analysis
    Advanced Mesh Analysis
    The Supermesh
    Source Transformation
    Thévenin's Theorem

    One perspective, I suppose, is that the movie came out at the same time as the book!

The unexpected passing of Bill Hayt at the very beginning of this revision was an enormous shock. I never had the opportunity to talk to him about the intended changes—I can only hope that the revisions have helped this book to speak to yet another generation of bright young engineering students. In the meantime, we (durbin@ieee.org and the editors at McGraw-Hill) welcome comments and feedback from both students and instructors.

The ever-present support of the McGraw-Hill editorial and production staff, including Tom Casson, Betsy Jones, Michelle Flomenhoft, James Labeots, John Wannemacher, Kelley Butcher, Heather Sabo, Phil Meek, and Linda Avenarius is gratefully acknowledged. Catherine Shultz, the sponsoring editor for Electrical Engineering, deserves a special acknowledgement for

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steven m. durbin

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