

# ELECTRIC CIRCUITS

ELEVENTH EDITION



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Courtesy of Anna Nilsson

## In Memoriam

We remember our beloved author, James W. Nilsson, for his lasting legacy to the electrical and computer engineering field.

The first edition of *Electric Circuits* was published in 1983. As this book evolved over the years to better meet the needs of both students and their instructors, the underlying teaching methodologies Jim established remain relevant, even in the Eleventh Edition.

Jim earned his bachelor's degree at the University of Iowa (1948), and his master's degree (1952) and Ph.D. (1958) at Iowa State University. He joined the ISU faculty in 1948 and taught electrical engineering there for 39 years.

He became an IEEE fellow in 1990 and earned the prestigious IEEE Undergraduate Teaching Award in 1992.

For Anna



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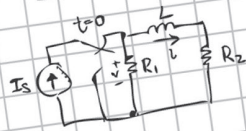


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# Combine this...

PART A



Given:  
 $I_s = 51.0 \text{ mA}$   
 $R_1 = 54.0 \text{ k}\Omega$   
 $R_2 = 51.0 \text{ k}\Omega$   
 $L = 51.0 \text{ mH}$

Find:  
 initial current  $i(0^-)$   
 before break switch



$$I_s = i$$

$$i = 51.0 \text{ mA}$$

Assume when circuit is in steady state, inductor acts as a short



Use Kirchhoff's current law

$$I_s = i + i_R$$

$$I_s = i + \frac{V}{R}$$

$$I_s = i + \frac{iR_1}{R_2}$$

$$I_s = i \left( 1 + \frac{R_1}{R_2} \right)$$

$$\frac{I_s}{\left( 1 + \frac{R_1}{R_2} \right)} = i$$

$$i = \frac{51.0 \text{ mA}}{\left( 1 + \frac{54.0 \text{ k}\Omega}{51.0 \text{ k}\Omega} \right)} = 24.77 \text{ mA}$$

$$V = iR$$

$$i = \frac{V}{R}$$

# With the Power of Mastering Engineering for Electric Circuits 11/e

Mastering is the teaching and learning platform that empowers every student. By combining trusted authors' content with digital tools developed to engage students and emulate the office hours experience, Mastering personalizes learning and improves results for each student.

The screenshot shows a laptop displaying the Mastering Engineering interface. The left pane shows the problem title "The Natural Response of an RL Circuit" and a learning goal. The right pane shows "Part A" of the problem, which asks for the initial current through an inductor in a circuit with a switch, a current source, and two resistors. The user has entered "51 mA" for the initial current, but the system has marked it as incorrect. A feedback message states: "Incorrect; Try Again; 4 attempts remaining. Note that elements in series have the same current but the inductor is not in series with the current source. Use Kirchhoff's current law or the current divider to find the initial inductor current."

**The Natural Response of an RL Circuit**

**Learning Goal:**  
To analyze an RL circuit to determine the initial current through an inductor, the time constant, and the expression for the natural response of the inductor current, and to use the expression for the inductor current to find other circuit quantities, such as current, voltage, power, or energy.

The natural response of an RL circuit is the response of the inductor current to the sudden removal of a DC source. When this occurs, the inductor releases the stored energy.

**Figure 1** | 1 of 2

**Part A**

For the given circuit (Figure 1), assume the make-before-break switch has been up for a long time and moves down at  $t = 0$ . Find the initial current through the inductor. Assume that  $I_s = 51.0 \text{ mA}$ ,  $R_1 = 54.0 \text{ k}\Omega$ ,  $R_2 = 51.0 \text{ k}\Omega$ , and  $L = 51.0 \text{ mH}$ .

Express your answer to three significant figures and include the appropriate units.

**Hints**

$i(0^-) = i(0^+) =$   mA

Submit My Answers Give Up

**Incorrect; Try Again; 4 attempts remaining**

Note that elements in series have the same current but the inductor is not in series with the current source. Use Kirchhoff's current law or the current divider to find the initial inductor current.

**Part B**

**Incorrect; Try Again; 4 attempts remaining**

Note that elements in series have the same current but the inductor is not in series with the current source. Use Kirchhoff's current law or the current divider to find the initial inductor current.

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# Preface

The Eleventh Edition of *Electric Circuits* represents the most extensive revision to the text since the Fifth Edition, published in 1996. Every sentence, paragraph, subsection, and chapter has been examined to improve clarity, readability, and pedagogy. Yet the fundamental goals of the text are unchanged. These goals are:

- To build new concepts and ideas on concepts previously presented. This challenges students to see the explicit connections among the many circuit analysis tools and methods.
- To develop problem-solving skills that rely on a solid conceptual foundation. This challenges students to examine many different approaches to solving a problem before writing a single equation.
- To introduce realistic engineering experiences at every opportunity. This challenges students to develop the insights of a practicing engineer and exposes them to practice of engineering.

## Why This Edition?

The Eleventh Edition of *Electric Circuits* incorporates the following new and revised elements:

- Analysis Methods – This new feature identifies the steps needed to apply a particular circuit analysis technique. Many students struggle just to get started when analyzing a circuit, and the analysis methods will reduce that struggle. Some of the analysis methods that are used most often can be found inside the book's covers for easy reference.
- Examples – Many students rely on examples when developing and refining their problem-solving skills. We identified many places in the text that needed additional examples, and as a result the number of examples has increased by nearly 35% to 200.
- End-of-chapter problems – Problem solving is fundamental to the study of circuit analysis. Having a wide variety of problems to assign and work is a key to success in any circuits course. Therefore, some existing end-of-chapter problems were revised, and some new end-of-chapter problems were added. Approximately 30% of the problems in the Eleventh Edition were rewritten.
- Fundamental equations and concepts – These important elements in the text were previously identified with margin notes. In this edition, the margin notes have been replaced by a second-color background, enlarged fonts, and a descriptive title for each fundamental equation and concept. In addition, many equation numbers have been eliminated to make it easier to distinguish fundamental equations from the many other equations in the text.
- Circuit simulation software – The PSpice® and Multisim® manuals have been revised to include screenshots from the most recent versions of these software simulation applications. Each manual presents the simulation material in the same order as the material is encountered in the text. These manuals include example simulations of circuits from the text. Icons identify end-of-chapter problems that are good candidates for simulation using either PSpice or Multisim.

- Solving simultaneous equations – Most circuit analysis techniques in this text eventually require you to solve two or more simultaneous linear algebraic equations. Appendix A has been extensively revised and includes examples of paper-and-pencil techniques, calculator techniques, and computer software techniques.
- Student workbook – Students who could benefit from additional examples and practice problems can use the Student Workbook, which has been revised for the Eleventh Edition of the text. This workbook has examples and problems covering the following material: balancing power, simple resistive circuits, node voltage method, mesh current method, Thévenin and Norton equivalents, op amp circuits, first-order circuits, second-order circuits, AC steady-state analysis, and Laplace transform circuit analysis.
- The Student Workbook now includes access to Video Solutions, complete, step-by-step solution walkthroughs to representative homework problems.
- Learning Catalytics, a “bring your own device” student engagement, assessment, and classroom intelligence system is available with the Eleventh Edition. With Learning Catalytics you can:
  - Use open-ended questions to get into the minds of students to understand what they do or don’t know and adjust lectures accordingly.
  - Use a wide variety of question types to sketch a graph, annotate a circuit diagram, compose numeric or algebraic answers, and more.
  - Access rich analytics to understand student performance.
  - Use pre-built questions or add your own to make Learning Catalytics fit your course exactly.
- Pearson Mastering Engineering is an online tutorial and assessment program that provides students with personalized feedback and hints and instructors with diagnostics to track students’ progress. With the Eleventh Edition, Mastering Engineering will offer new enhanced end-of-chapter problems with hints and feedback, Coaching Activities, and Adaptive Follow-Up assignments. Visit [www.masteringengineering.com](http://www.masteringengineering.com) for more information.

## Hallmark Features

### Analysis Methods

Students encountering circuit analysis for the first time can benefit from step-by-step directions that lead them to a problem’s solution. We have compiled these directions in a collection of analysis methods, and revised many of the examples in the text to employ these analysis methods.

### Chapter Problems

Users of *Electric Circuits* have consistently rated the Chapter Problems as one of the book’s most attractive features. In the Eleventh Edition, there are 1185 end-of-chapter problems with approximately 30% that have been revised from the previous edition. Problems are organized at the end of each chapter by section.

### Practical Perspectives

The Eleventh Edition continues using Practical Perspectives to introduce the chapter. They provide real-world circuit examples, taken from real-world devices. Every chapter begins by describing a practical application of the

material that follows. After presenting that material, the chapter revisits the Practical Perspective, performing a quantitative circuit analysis using the newly introduced chapter material. A special icon identifies end-of-chapter problems directly related to the Practical Perspective application. These problems provide additional opportunities for solving real-world problems using the chapter material.

### Assessment Problems

Each chapter begins with a set of chapter objectives. At key points in the chapter, you are asked to stop and assess your mastery of a particular objective by solving one or more assessment problems. The answers to all of the assessment problems are given at the conclusion of each problem, so you can check your work. If you are able to solve the assessment problems for a given objective, you have mastered that objective. If you need more practice, several end-of-chapter problems that relate to the objective are suggested at the conclusion of the assessment problems.

### Examples

Every chapter includes many examples that illustrate the concepts presented in the text in the form of a numeric example. There are now nearly 200 examples in this text, an increase of about 35% when compared to the previous edition. The examples illustrate the application of a particular concept, often employ an Analysis Method, and exemplify good problem-solving skills.

### Fundamental Equations and Concepts

Throughout the text, you will see fundamental equations and concepts set apart from the main text. This is done to help you focus on some of the key principles in electric circuits and to help you navigate through the important topics.

### Integration of Computer Tools

Computer tools can assist students in the learning process by providing a visual representation of a circuit's behavior, validating a calculated solution, reducing the computational burden of more complex circuits, and iterating toward a desired solution using parameter variation. This computational support is often invaluable in the design process. The Eleventh Edition supports PSpice and Multisim, both popular computer tools for circuit simulation and analysis. Chapter problems suited for exploration with PSpice and Multisim are marked accordingly.

### Design Emphasis

The Eleventh Edition continues to support the emphasis on the design of circuits in many ways. First, many of the Practical Perspective discussions focus on the design aspects of the circuits. The accompanying Chapter Problems continue the discussion of the design issues in these practical examples. Second, design-oriented Chapter Problems have been labeled explicitly, enabling students and instructors to identify those problems with a design focus. Third, the identification of problems suited to exploration with PSpice or Multisim suggests design opportunities using these software tools. Fourth, some problems in nearly every chapter focus on the use of realistic component values in achieving a desired circuit design. Once such a problem has been analyzed, the student can proceed to a laboratory to build and test the circuit, comparing the analysis with the measured performance of the actual circuit.

## Accuracy

All text and problems in the Eleventh Edition have undergone our strict hallmark accuracy checking process, to ensure the most error-free book possible.

## Resources For Students

**Mastering Engineering.** Mastering Engineering provides tutorial homework problems designed to emulate the instructor’s office hour environment, guiding students through engineering concepts with self-paced individualized coaching. These in-depth tutorial homework problems provide students with feedback specific to their errors and optional hints that break problems down into simpler steps. Visit [www.masteringengineering.com](http://www.masteringengineering.com) for more information.

**Learning Catalytics.** Learning Catalytics is an interactive student response tool that encourages team-based learning by using student’s smartphones, tablets, or laptops to engage them in interactive tasks and thinking. Visit [www.learningcatalytics.com](http://www.learningcatalytics.com) for more information.

**Student Workbook.** This resource teaches students techniques for solving problems presented in the text. Organized by concepts, this is a valuable problem-solving resource for all levels of students. The Student Workbook now includes access to Video Solutions, complete, step-by-step solution walkthroughs to representative homework problems.

**Introduction to Multisim and Introduction to PSpice Manuals**—Updated for the Eleventh Edition, these manuals are excellent resources for those wishing to integrate PSpice or Multisim into their classes.

## Resources for Instructors

All instructor resources are available for download at [www.pearsonhighered.com](http://www.pearsonhighered.com). If you are in need of a login and password for this site, please contact your local Pearson representative.

**Instructor Solutions Manual**—Fully worked-out solutions to Assessment Problems and end-of-chapter problems.

**PowerPoint lecture images**—All figures from the text are available in PowerPoint for your lecture needs. An additional set of full lecture slides with embedded assessment questions are available upon request.

**MasteringEngineering.** This online tutorial and assessment program allows you to integrate dynamic homework with automated grading and personalized feedback. MasteringEngineering allows you to easily track the performance of your entire class on an assignment-by-assignment basis, or the detailed work of an individual student. For more information visit [www.masteringengineering.com](http://www.masteringengineering.com).

**Learning Catalytics**—This “bring your own device” student engagement, assessment and classroom intelligence system enables you to measure student learning during class, and adjust your lectures accordingly. A wide variety of question and answer types allows you to author your own questions, or you can use questions already authored into the system. For more information visit [www.learningcatalytics.com](http://www.learningcatalytics.com) or click on the Learning Catalytics link inside Mastering Engineering.

## Prerequisites

In writing the first 12 chapters of the text, we have assumed that the reader has taken a course in elementary differential and integral calculus. We have

also assumed that the reader has had an introductory physics course, at either the high school or university level, that introduces the concepts of energy, power, electric charge, electric current, electric potential, and electromagnetic fields. In writing the final six chapters, we have assumed the student has had, or is enrolled in, an introductory course in differential equations.

## Course Options

The text has been designed for use in a one-semester, two-semester, or a three-quarter sequence.

- *Single-semester course:* After covering Chapters 1–4 and Chapters 6–10 (omitting Sections 7.7 and 8.5) the instructor can develop the desired emphasis by covering Chapter 5 (operational amplifiers), Chapter 11 (three-phase circuits), Chapters 13 and 14 (Laplace methods), or Chapter 18 (Two-Port Circuits).
- *Two-semester sequence:* Assuming three lectures per week, cover the first nine chapters during the first semester, leaving Chapters 10–18 for the second semester.
- *Academic quarter schedule:* Cover Chapters 1–6 in the first quarter, Chapters 7–12 in the second quarter, and Chapters 13–18 in the third quarter.

Note that the introduction to operational amplifier circuits in Chapter 5 can be omitted with minimal effect on the remaining material. If Chapter 5 is omitted, you should also omit Section 7.7, Section 8.5, Chapter 15, and those assessment problems and end-of-chapter problems that pertain to operational amplifiers.

There are several appendixes at the end of the book to help readers make effective use of their mathematical background. Appendix A presents several different methods for solving simultaneous linear equations; complex numbers are reviewed in Appendix B; Appendix C contains additional material on magnetically coupled coils and ideal transformers; Appendix D contains a brief discussion of the decibel; Appendix E is dedicated to Bode diagrams; Appendix F is devoted to an abbreviated table of trigonometric identities that are useful in circuit analysis; and an abbreviated table of useful integrals is given in Appendix G. Appendix H provides tables of common standard component values for resistors, inductors, and capacitors, to be used in solving many end-of-chapter problems. Selected Answers provides answers to selected end-of-chapter problems.

## Acknowledgments

I will be forever grateful to Jim Nilsson for giving me the opportunity to collaborate with him on this textbook. I started by revising the PSpice supplement for the Third Edition, and became a co-author of the Fifth Edition. Jim was a patient and gracious mentor, and I learned so much from him about teaching and writing and hard work. It is a great honor to be associated with him through this textbook, and to impact the education of the thousands of students who use this text.

There were many hard-working people behind the scenes at our publisher who deserve my thanks and gratitude for their efforts on behalf of the Eleventh Edition. At Pearson, I would like to thank Norrin Dias, Erin Ault, Rose Kernan, and Scott Disanno for their continued support and encouragement, their professional demeanor, their willingness to lend an ear, and their months of long hours and no weekends. The author would also like to



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I am very grateful for the many instructors and students who have done formal reviews of the text or offered positive feedback and suggestions for improvement more informally. I am pleased to receive email from instructors and students who use the book, even when they are pointing out an error I failed to catch in the review process. I have been contacted by people who use our text from all over the world, and I thank all of you for taking the time to do so. I use as many of your suggestions as possible to continue to improve the content, the pedagogy, and the presentation in this text. I am privileged to have the opportunity to impact the educational experience of the many thousands of future engineers who will use this text.

SUSAN A. RIEDEL



# ELECTRIC CIRCUITS

ELEVENTH EDITION