Making Everything Easier!™

Circuit Analysis FOR DUMMIES®

A Wiley Brand

Learn to:

- Grasp resistive circuits, Kirchhoff's laws, equivalent subcircuits, and more
- Supplement your classroom learning
- Score high in your Circuit Analysis course

John M. Santiago Jr., PhD

Professor of Electrical and Systems Engineering, Colonel (Ret) USAF

Circuit Analysis FOR DUMMIES®

A Wiley Brand

Circuit Analysis For Dummies

A Wiley Brand

by John M. Santiago, Jr., PhD

Professor of Electrical and Systems
Engineering, Colonel (Ret) USAF

For Dummies
A Wiley Brand

Circuit Analysis For Dummies®

Published by
John Wiley & Sons, Inc.
111 River St.
Hoboken, NJ 07030-5774
www.wiley.com

Published by John Wiley & Sons, Inc., Hoboken, New Jersey

Published simultaneously in Canada

For general information on our other products and services, please contact our Customer Care Department within the U.S. at 877-762-2974, outside the U.S. at 317-572-3993, or fax 317-572-4002.

For technical support, please visit www.wiley.com/techsupport.

Wiley publishes in a variety of print and electronic formats and by print-on-demand. Some material included with standard print versions of this book may not be included in e-books or in print-on-demand. If this book refers to media such as a CD or DVD that is not included in the version you purchased, you may download this material at http://booksupport.wiley.com. For more information about Wiley products, visit www.wiley.com.

Library of Congress Control Number: 2013932101

ISBN 978-1-118-49312-0 (pbk); ISBN 978-1-118-59050-8 (ebk); ISBN 978-1-118-59052-2 (ebk); ISBN 978-1-118-59056-0 (ebk)

Manufactured in the United States of America

10 9 8 7 6 5 4 3 2 1

About the Author

John Santiago retired from the military in 2003 with 26 years of service in the United States Air Force (USAF). John has served in a variety of leadership positions in technical program management, acquisition development, and operation research support. While assigned in Europe for three years with the USAF, he spearheaded more than 40 international scientific and engineering conferences/workshops as a steering committee member.

John has experience in many engineering disciplines and missions, including control and modeling of large, flexible space structures; communications systems; electro-optics; high-energy lasers; missile seekers/sensors for precision-guided munitions; image processing/recognition; information technologies; space, air, and missile warning; missile defense; and homeland defense.

One of John's favorite assignments was serving as an associate professor at the USAF Academy during his tour from 1984 through 1989. John is currently a professor of Electrical and Systems Engineering at Colorado Technical University, where he has taught 26 different undergraduate and graduate courses in electrical and systems engineering.

Some of his awards include Faculty of the Year at Colorado Technical University in 2008; USAF Academy Outstanding Military Educator in 1989; and USAF Academy Outstanding Electrical Engineering Educator in 1998.

During his USAF career, John received his PhD in Electrical Engineering from the University of New Mexico; his Master of Science in Resource Strategy at the Industrial College of the Armed Forces; his Master of Science in Electrical Engineering from the Air Force Institute of Technology, specializing in electro-optics; and his Bachelor of Science from the University of California, Los Angeles.

On February 14, 1982, John married Emerenciana F. Manaois.

More information about John's background and experience is available at `www.FreedomUniversity.TV`.

Dedication

To my heavenly Father, thank you for all the many blessings, especially the gift of family and friends.

To my lovely Emily, thank you for your loving and continued support, always and forever.

To my parents, who bravely immigrated here from the Philippines to live in this great nation.

To the Founding Fathers, who were engineers and visionary leaders in creating this great country called the United States. To their creative genius and to all those standing on their shoulders, especially the next generation of engineers.

To all those who wondered if there's anything more to circuit analysis than Ohm's law and Kirchhoff's laws.

Author's Acknowledgments

Many people have been involved in this book, and I thank them all. First, to all the former cadets at the United States Air Force Academy, the students at the University of West Florida, and the students at the Colorado Technical University who endured my class lessons and asked a gazillion questions over the years as I continued to learn to become a better teacher.

I'd like to thank a team of players who've made my writing presentable. First, I'd like to thank Matt Wagner, my agent, who contacted me about writing this book. I'd also especially like to thank the folks at Wiley who made this book possible: Erin Mooney, my acquisitions editor; Jennifer Tebbe, my project editor; and Danielle Voirol, my copy editor.

I'd again like to thank my wife for her encouragement and for keeping me straight about the things going on at home and in the community as I went through this writing adventure.

Publisher's Acknowledgments

We're proud of this book; please send us your comments at http://dummies.custhelp.com. For other comments, please contact our Customer Care Department within the U.S. at 877-762-2974, outside the U.S. at 317-572-3993, or fax 317-572-4002.

Some of the people who helped bring this book to market include the following:

Acquisitions, Editorial, and Vertical Websites

Project Editor: Jennifer Tebbe

Acquisitions Editor: Erin Calligan Mooney

Senior Copy Editor: Danielle Voirol

Assistant Editor: David Lutton

Editorial Program Coordinator: Joe Niesen

Technical Editor: Chang Liu, Dan Moore

Editorial Manager: Christine Meloy Beck

Editorial Assistant: Alexa Koschier, Rachelle S. Amick

Cover Photo: © VOLODYMYR GRINKO/ iStockphoto.com

Composition Services

Project Coordinator: Katherine Crocker

Layout and Graphics: Carl Byers, Carrie A. Cesavice, Amy Hassos, Joyce Haughey, Christin Swinford

Proofreaders: Tricia Liebig, Dwight Ramsey

Indexer: Ty Koontz

Publishing and Editorial for Consumer Dummies

Kathleen Nebenhaus, Vice President and Executive Publisher

David Palmer, Associate Publisher

Kristin Ferguson-Wagstaffe, Product Development Director

Publishing for Technology Dummies

Andy Cummings, Vice President and Publisher

Composition Services

Debbie Stailey, Director of Composition Services

Contents at a Glance

Table of Contents

Introduction

Circuit analysis is often one of those weed-out classes in engineering schools. Either you pass the class to study engineering, or you don't pass and start thinking about something else. Well, I don't want you to get weeded out, because engineering is such a rewarding field. This book is here to help you make sense of circuit analysis concepts that may be puzzling you. Along the way, you explore a number of analytical tools that give you shortcuts and insight into circuit behavior.

You can take the tools you find here and apply them to whatever high-tech gizmo or craze is out there. And not only can you pass your class, but you can also take these concepts to the real world, enriching human lives with comfort and convenience and rewarding you with more time to do useful activities.

About This Book

Like all other *For Dummies* books, *Circuit Analysis For Dummies* isn't a tutorial. Rather, it's a reference book, which means you don't have to read it from cover to cover, although you certainly can if that's your preference. You can jump right to the topics or concepts you're having trouble with. Either way, you'll find helpful information along with some real-world examples of electrical concepts that may be hard to visualize otherwise.

Conventions Used in This Book

I use the following conventions throughout the text to make things consistent and easy to understand:

- New terms appear in *italics* and are closely followed by an easy-to-understand definition. Variables likewise appear in italics.
- **Bold** is used to highlight keywords in bulleted lists and the action parts of numbered steps. It also indicates vectors.
- Lowercase variables indicate signals that change with time, and uppercase variables indicate signals that are constant. For example, $v(t)$ and $i(t)$ denote voltage and current signals that change with time. If, however V and I are capitalized, then those signals don't vary in time.

What You're Not to Read

Although it'd be great if you read every word, you're welcome to skip the sidebars (the shaded boxes sprinkled throughout the book) and paragraphs flagged with a Technical Stuff icon.

Foolish Assumptions

I may be going out on a limb, but as I wrote this book, here's what I assumed about you:

- You're currently taking an introductory circuit analysis course, and you need help with certain concepts and techniques. Or you're planning to take a circuit analysis course in the next semester, and you want to be prepared with some supplementary material.
- You have a good grasp of linear algebra and differential equations.
- You've taken an introductory physics class, which exposed you to the concepts of power, positive and negative charges, voltage, and current.

How This Book Is Organized

Circuit analysis integrates a variety of topics from your math and physics courses, and it introduces a variety of techniques to solve for circuit behavior. To help you grasp the concepts in manageable bites, I've split the book into several parts, each consisting of chapters on related topics.

Part I: Getting Started with Circuit Analysis

This part gives you the engineering lingo, concepts, and techniques necessary for tackling circuit analysis. Here, I help you quickly grasp the main aspects of circuit analysis so you can analyze circuits, build things, and predict what's going to happen. If you're familiar with current, voltage, power, and Ohm's and Kirchhoff's laws, you can use this part as a refresher.

Part II: Applying Analytical Methods for Complex Circuits

This part looks at general analytical methods to use when dealing with more complicated circuits. When you have many simultaneous equations to solve or too many inputs, you can use various techniques to reduce the number of equations and simplify circuits to a manageable level.

Part III: Understanding Circuits with Transistors and Operational Amplifiers

This part deals with two devices that require power to make them work. You can use transistors as current amplifiers, and you can use operational amplifiers as voltage amplifiers.

Part IV: Applying Time-Varying Signals to First- and Second-Order Circuits

This part gets tougher because you're dealing with changing signals and with circuits that have passive energy-storage devices such as inductors and capacitors. You also need to know differential equations in order to analyze circuit behavior for first- and second-order circuits.

Part V: Advanced Techniques and Applications in Circuit Analysis

This part takes the problems described in Part IV and changes a calculus-based problem into one requiring only algebra. You do this conversion by using phasor and Laplace techniques. You can gather additional insight into circuit behavior from the poles and zeros of an equation, which shape the frequency response of circuits called filters.

Part VI: The Part of Tens

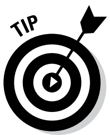
Here you find out about ten applications and ten technologies that make circuits more interesting.

Icons Used in This Book

To make this book easier to read and simpler to use, I include some icons to help you find key information.

Anytime you see this icon, you know the information that follows will be worth recalling after you close this book — even if you don't remember anything else you just read.

This icon appears next to information that's interesting but not essential. Don't be afraid to skip these paragraphs.



This bull's-eye points out advice that can save you time when analyzing circuits.

This icon is here to prevent you from making fatal mistakes in your analysis.

Where to Go from Here

This book isn't a novel — you can start at the beginning and read it through to the end, or you can jump right in the middle. If you like the calculus approach to solving circuits, head to the chapters on first- and second-order circuits. If calculus doesn't suit your fancy or if you're itching to find out what the Laplace transform is all about, flip straight to Chapter 16.

If you're not sure where to start, or you don't know enough about circuit analysis to even *have* a starting point in mind yet, no problem — that's exactly what this book is for. Just hop right in and get your feet wet. I recommend starting with the chapters in Part I and moving forward from there.

Part I

Getting Started with Circuit Analysis

Visit `www.dummies.com` to learn more and do more with *For Dummies.*

In this part . . .

- Discover what circuit analysis is all about.
- Get the scoop on current and voltage behaviors in common circuit components and find out how to read circuit diagrams.
- Familiarize yourself with Kirchhoff's voltage law and Kirchhoff's current law — two laws essential for creating connection equations.
- Use source transformation and current and voltage divider techniques to simplify circuit analysis.

Chapter 1

Introducing Circuit Analysis

In This Chapter

- Understanding current and voltage
- Applying laws when you connect circuit devices
- Analyzing circuits with algebra and calculus
- Taking some mathematical shortcuts

Circuit analysis is like the psychoanalysis of the electrical engineering world because it's all about studying the behavior of circuits. With any circuit, you have an input signal, such as a battery source or an audio signal. What you want to figure out is the circuit's *output* — how the circuit responds to a given input.

A circuit's output is either a voltage or a current. You have to analyze the voltages and currents traveling through each element or component in the circuit in order to determine the output, although many times you don't have to find *every* voltage and *every* current within the circuit.

Circuit analysis is challenging because it integrates a variety of topics from your math and physics courses in addition to introducing techniques specific to determining circuit behavior. This chapter gives you an overview of circuit analysis and some of the key concepts you need to know before you can begin understanding circuits.

Getting Started with Current and Voltage

Being able to analyze circuits requires having a solid understanding of how voltage and current interact within a circuit. Chapter 2 gives you insight into how voltage and current behave in the types of devices normally found in circuits, such as resistors and batteries. That chapter also presents the basic features of circuit diagrams, or *schematics*.

The following sections introduce you to current and voltage as well as a direction-based convention that's guaranteed to come in handy in circuit analysis.

Going with the flow with current

Current is a way of measuring the amount of electric charge passing through a given point within a certain amount of time. Current is a flow rate. The mathematical definition of a current is as follows:

$$i = \frac{dq}{dt}$$

The variable i stands for the current, q stands for the electrical charge, and t stands for time.

The charge of one electron is 1.609×10^{-19} coulombs (C).

Current measures the flow of charges with dimensions of coulombs per second (C/s), or *amperes* (A). In engineering, the current direction describes the net flow of positive charges. Think of current as a *through variable,* because the flow of electrical charge passes through a point in the circuit. The arrow in Figure 1-1 shows the current direction.

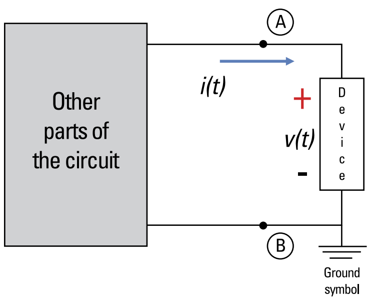


Figure 1-1: Current direction, voltage polarities, and the passive sign convention.

Illustration by Wiley, Composition Services Graphics

Measuring current through a device requires just one point of measurement. As an analogy, say you're asked to count the number of cars flowing through your long stretch of residential street for 10 minutes. You can count the number of cars from your home or your friend's home next door or the house across the street. You need just one location point to measure the flow of cars.

Two types of current exist: alternating current (AC) and direct current (DC). With AC, the charges flow in both directions. With DC, the charges flow in just one direction.