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John M. Santiago Jr., PhD

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



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by John M. Santiago, Jr., PhD

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

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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.

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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.

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Contents at a Glance

.....

<i>Introduction</i>	<i>1</i>
<i>Part I: Getting Started with Circuit Analysis.....</i>	<i>5</i>
Chapter 1: Introducing Circuit Analysis.....	7
Chapter 2: Clarifying Basic Circuit Concepts and Diagrams	15
Chapter 3: Exploring Simple Circuits with Kirchhoff's Laws	25
Chapter 4: Simplifying Circuit Analysis with Source Transformation and Division Techniques	41
<i>Part II: Applying Analytical Methods for Complex Circuits.....</i>	<i>65</i>
Chapter 5: Giving the Nod to Node-Voltage Analysis.....	67
Chapter 6: Getting in the Loop on Mesh Current Equations	83
Chapter 7: Solving One Problem at a Time Using Superposition	95
Chapter 8: Applying Thévenin's and Norton's Theorems	113
<i>Part III: Understanding Circuits with Transistors and Operational Amplifiers.....</i>	<i>131</i>
Chapter 9: Dependent Sources and the Transistors That Involve Them	133
Chapter 10: Letting Operational Amplifiers Do the Tough Math Fast.....	155
<i>Part IV: Applying Time-Varying Signals to First- and Second-Order Circuits.....</i>	<i>173</i>
Chapter 11: Making Waves with Funky Functions	175
Chapter 12: Spicing Up Circuit Analysis with Capacitors and Inductors	193
Chapter 13: Tackling First-Order Circuits.....	211
Chapter 14: Analyzing Second-Order Circuits.....	233
<i>Part V: Advanced Techniques and Applications in Circuit Analysis.....</i>	<i>253</i>
Chapter 15: Phasing in Phasors for Wave Functions	255
Chapter 16: Predicting Circuit Behavior with Laplace Transform Techniques.....	273
Chapter 17: Implementing Laplace Techniques for Circuit Analysis	295
Chapter 18: Focusing on the Frequency Responses.....	313

<i>Part VI: The Part of Tens</i>	335
Chapter 19: Ten Practical Applications for Circuits.....	337
Chapter 20: Ten Technologies Affecting Circuits	341
<i>Index</i>	345

Table of Contents

<i>Introduction</i>	1
About This Book	1
Conventions Used in This Book	1
What You're Not to Read	2
Foolish Assumptions	2
How This Book Is Organized	2
Part I: Getting Started with Circuit Analysis	2
Part II: Applying Analytical Methods for Complex Circuits	3
Part III: Understanding Circuits with Transistors and Operational Amplifiers	3
Part IV: Applying Time-Varying Signals to First- and Second-Order Circuits	3
Part V: Advanced Techniques and Applications in Circuit Analysis	3
Part VI: The Part of Tens	3
Icons Used in This Book	4
Where to Go from Here	4
 <i>Part I: Getting Started with Circuit Analysis</i>	5
 Chapter 1: Introducing Circuit Analysis	7
Getting Started with Current and Voltage	7
Going with the flow with current	8
Recognizing potential differences with voltage	9
Staying grounded with zero voltage	9
Getting some direction with the passive sign convention	10
Beginning with the Basic Laws	11
Surveying the Analytical Methods for More-Complex Circuits	11
Introducing Transistors and Operational Amplifiers	12
Dealing with Time-Varying Signals, Capacitors, and Inductors	13
Avoiding Calculus with Advanced Techniques	13
 Chapter 2: Clarifying Basic Circuit Concepts and Diagrams	15
Looking at Current-Voltage Relationships	15
Absorbing energy with resistors	16
Applying Ohm's law to resistors	16
Calculating the power dissipated by resistors	18
Offering no resistance: Batteries and short circuits	18
Batteries: Providing power independently	19
Short circuits: No voltage, no power	19

Facing infinite resistance: Ideal current sources and open circuits	20
All or nothing: Combining open and short circuits with ideal switches	20
Mapping It All Out with Schematics	21
Going in circles with loops	22
Getting straight to the point with nodes	24

Chapter 3: Exploring Simple Circuits with Kirchhoff's Laws. 25

Presenting Kirchhoff's Famous Circuit Laws	25
Kirchhoff's voltage law (KVL): Conservation of energy	26
Identifying voltage rises and drops	26
Forming a KVL equation	27
Kirchhoff's current law (KCL): Conservation of charge	29
Tracking incoming and outgoing current	29
Calculating KCL	30
Tackling Circuits with KVL, KCL, and Ohm's Law	31
Getting batteries and resistors to work together	31
Starting with voltage	32
Bringing in current	32
Combining device equations with KVL	33
Summarizing the results	34
Sharing the same current in series circuits	34
Climbing the ladder with parallel circuits	36
Describing total resistance using conductance	37
Using a shortcut for two resistors in parallel	38
Finding equivalent resistor combinations	38
Combining series and parallel resistors	40

Chapter 4: Simplifying Circuit Analysis with Source Transformation and Division Techniques 41

Equivalent Circuits: Preparing for the Transformation	42
Transforming Sources in Circuits	45
Converting to a parallel circuit with a current source	45
Changing to a series circuit with a voltage source	47
Divvying It Up with the Voltage Divider	49
Getting a voltage divider equation for a series circuit	49
Figuring out voltages for a series circuit with two or more resistors	51
Finding voltages when you have multiple current sources	52
Using the voltage divider technique repeatedly	55
Cutting to the Chase Using the Current Divider Technique	57
Getting a current divider equation for a parallel circuit	57
Figuring out currents for parallel circuits	59
Finding currents when you have multiple voltage sources	60
Using the current divider technique repeatedly	63

Part II: Applying Analytical Methods for Complex Circuits..... 65

Chapter 5: Giving the Nod to Node-Voltage Analysis 67

Getting Acquainted with Node Voltages and Reference Nodes.....	67
Testing the Waters with Node Voltage Analysis	69
What goes in must come out: Starting with KCL at the nodes.....	70
Describing device currents in terms of node voltages with Ohm's law	70
Putting a system of node voltage equations in matrix form	72
Solving for unknown node voltages.....	73
Applying the NVA Technique.....	74
Solving for unknown node voltageswith a current source	74
Dealing with three or more node equations.....	76
Working with Voltage Sources in Node-Voltage Analysis	80

Chapter 6: Getting in the Loop on Mesh Current Equations 83

Windowpanes: Looking at Meshes and Mesh Currents.....	83
Relating Device Currents to Mesh Currents.....	84
Generating the Mesh Current Equations	86
Finding the KVL equations first.....	87
Ohm's law: Putting device voltages in terms of mesh currents	87
Substituting the device voltages into the KVL equations.....	88
Putting mesh current equations into matrix form.....	89
Solving for unknown currents and voltages	89
Crunching Numbers: Using Meshes to Analyze Circuits	90
Tackling two-mesh circuits.....	90
Analyzing circuits with three or more meshes	92

Chapter 7: Solving One Problem at a Time Using Superposition . . . 95

Discovering How Superposition Works.....	95
Making sense of proportionality	96
Applying superposition in circuits	98
Adding the contributions of each independent source	100
Getting Rid of the Sources of Frustration.....	101
Short circuit: Removing a voltage source.....	101
Open circuit: Taking out a current source	102
Analyzing Circuits with Two Independent Sources	103
Knowing what to do when the sources are two voltage sources	103
Proceeding when the sources are two current sources	105
Dealing with one voltage source and one current source.....	107
Solving a Circuit with Three Independent Sources.....	108

Chapter 8: Applying Thévenin's and Norton's Theorems113

Showing What You Can Do with Thévenin's and Norton's Theorems	114
Finding the Norton and Thévenin Equivalents for Complex Source Circuits.....	115
Applying Thévenin's theorem	117
Finding the Thévenin equivalent of a circuit with a single independent voltage source.....	117
Applying Norton's theorem.....	119
Using source transformation to find Thévenin or Norton.....	122
A shortcut: Finding Thévenin or Norton equivalents with source transformation	122
Finding the Thévenin equivalent of a circuit with multiple independent sources	122
Finding Thévenin or Norton with superposition	124
Gauging Maximum Power Transfer: A Practical Application of Both Theorems	127

***Part III: Understanding Circuits with Transistors
and Operational Amplifiers..... 131*****Chapter 9: Dependent Sources and
the Transistors That Involve Them133**

Understanding Linear Dependent Sources: Who Controls What	134
Classifying the types of dependent sources.....	134
Recognizing the relationship between dependent and independent sources.....	136
Analyzing Circuits with Dependent Sources	136
Applying node-voltage analysis	137
Using source transformation.....	138
Using the Thévenin technique	140
Describing a JFET Transistor with a Dependent Source	142
Examining the Three Personalities of Bipolar Transistors	145
Making signals louder with the common emitter circuit.....	146
Amplifying signals with a common base circuit	149
Isolating circuits with the common collector circuit.....	151

**Chapter 10: Letting Operational Amplifiers
Do the Tough Math Fast155**

The Ins and Outs of Op-Amp Circuits	155
Discovering how to draw op amps	156
Looking at the ideal op amp and its transfer characteristics	157
Modeling an op amp with a dependent source.....	158
Examining the essential equations for analyzing ideal op-amp circuits.....	159

Looking at Op-Amp Circuits	160
Analyzing a noninverting op amp	160
Following the leader with the voltage follower	162
Turning things around with the inverting amplifier	163
Adding it all up with the summer	164
What's the difference? Using the op-amp subtractor	166
Increasing the Complexity of What You Can Do with Op Amps.....	168
Analyzing the instrumentation amplifier	168
Implementing mathematical equations electronically.....	170
Creating systems with op amps.....	171

Part IV: Applying Time-Varying Signals to First- and Second-Order Circuits 173

Chapter 11: Making Waves with Funky Functions.175

Spiking It Up with the Lean, Mean Impulse Function.....	176
Changing the strength of the impulse.....	178
Delaying an impulse.....	178
Evaluating impulse functions with integrals	179
Stepping It Up with a Step Function.....	180
Creating a time-shifted, weighted step function.....	181
Being out of step with shifted step functions	182
Building a ramp function with a step function.....	182
Pushing the Limits with the Exponential Function	184
Seeing the Signs with Sinusoidal Functions	186
Giving wavy functions a phase shift.....	187
Expanding the function and finding Fourier coefficients.....	189
Connecting sinusoidal functions to exponentials with Euler's formula.....	190

Chapter 12: Spicing Up Circuit Analysis with Capacitors and Inductors193

Storing Electrical Energy with Capacitors.....	193
Describing a capacitor	194
Charging a capacitor (credit cards not accepted)	195
Relating the current and voltage of a capacitor	195
Finding the power and energy of a capacitor.....	196
Calculating the total capacitance for parallel and series capacitors	199
Finding the equivalent capacitance of parallel capacitors	199
Finding the equivalent capacitance of capacitors in series.....	200
Storing Magnetic Energy with Inductors	200
Describing an inductor.....	201
Finding the energy storage of an attractive inductor	202

Calculating total inductance for series and parallel inductors	203
Finding the equivalent inductance for inductors in series	203
Finding the equivalent inductance for inductors in parallel	204
Calculus: Putting a Cap on Op-Amp Circuits	205
Creating an op-amp integrator	205
Deriving an op-amp differentiator	207
Using Op Amps to Solve Differential Equations Really Fast	208

Chapter 13: Tackling First-Order Circuits211

Solving First-Order Circuits with Diff EQ	211
Guessing at the solution with the natural exponential function	213
Using the characteristic equation for a first-order equation	214
Analyzing a Series Circuit with a Single Resistor and Capacitor	215
Starting with the simple RC series circuit	215
Finding the zero-input response	217
Finding the zero-state response by focusing on the input source	219
Adding the zero-input and zero-state responses to find the total response	222
Analyzing a Parallel Circuit with a Single Resistor and Inductor	224
Starting with the simple RL parallel circuit	225
Calculating the zero-input response for an RL parallel circuit	226
Calculating the zero-state response for an RL parallel circuit	228
Adding the zero-input and zero-state responses to find the total response	230

Chapter 14: Analyzing Second-Order Circuits233

Examining Second-Order Differential Equations with Constant Coefficients	233
Guessing at the elementary solutions: The natural exponential function	235
From calculus to algebra: Using the characteristic equation	236
Analyzing an RLC Series Circuit	236
Setting up a typical RLC series circuit	237
Determining the zero-input response	239
Calculating the zero-state response	242
Finishing up with the total response	245
Analyzing an RLC Parallel Circuit Using Duality	246
Setting up a typical RLC parallel circuit	247
Finding the zero-input response	249
Arriving at the zero-state response	250
Getting the total response	251

Part V: Advanced Techniques and Applications in Circuit Analysis..... 253

Chapter 15: Phasing in Phasors for Wave Functions.....255

Taking a More Imaginative Turn with Phasors.....	256
Finding phasor forms	256
Examining the properties of phasors	258
Using Impedance to Expand Ohm's	
Law to Capacitors and Inductors.....	259
Understanding impedance.....	260
Looking at phasor diagrams	261
Putting Ohm's law for capacitors in phasor form	262
Putting Ohm's law for inductors in phasor form	263
Tackling Circuits with Phasors	263
Using divider techniques in phasor form	264
Adding phasor outputs with superposition	266
Simplifying phasor analysis with Thévenin and Norton.....	268
Getting the nod for nodal analysis.....	270
Using mesh-current analysis with phasors	271

Chapter 16: Predicting Circuit Behavior with Laplace Transform Techniques273

Getting Acquainted with the Laplace Transform	
and Key Transform Pairs	273
Getting Your Time Back with the Inverse Laplace Transform.....	276
Rewriting the transform with partial fraction expansion	276
Expanding Laplace transforms with complex poles	278
Dealing with transforms with multiple poles	280
Understanding Poles and Zeros of $F(s)$	282
Predicting the Circuit Response with Laplace Methods	285
Working out a first-order RC circuit	286
Working out a first-order RL circuit	290
Working out an RLC circuit	292

Chapter 17: Implementing Laplace Techniques for Circuit Analysis295

Starting Easy with Basic Constraints	296
Connection constraints in the s-domain.....	296
Device constraints in the s-domain	297
Independent and dependent sources.....	297
Passive elements: Resistors, capacitors, and inductors.....	297
Op-amp devices	299
Impedance and admittance	299
Seeing How Basic Circuit Analysis Works in the s-Domain.....	300
Applying voltage division with series circuits	300
Turning to current division for parallel circuits.....	302

Conducting Complex Circuit Analysis in the s-Domain	303
Using node-voltage analysis	303
Using mesh-current analysis	304
Using superposition and proportionality	305
Using the Thévenin and Norton equivalents	309

Chapter 18: Focusing on the Frequency Responses. 313

Describing the Frequency Response and Classy Filters	314
Low-pass filter	315
High-pass filter	316
Band-pass filters	316
Band-reject filters	317
Plotting Something: Showing Frequency Response à la Bode	318
Looking at a basic Bode plot	319
Poles, zeros, and scale factors: Picturing	
Bode plots from transfer functions	320
Turning the Corner: Making Low-Pass and	
High-Pass Filters with RC Circuits	325
First-order RC low-pass filter (LPF)	325
First-order RC high-pass filter (HPF)	326
Creating Band-Pass and Band-Reject Filters	
with RLC or RC Circuits	327
Getting serious with RLC series circuits	327
RLC series band-pass filter (BPF)	327
RLC series band-reject filter (BRF)	330
Climbing the ladder with RLC parallel circuits	330
RC only: Getting a pass with a band-pass	
and band-reject filter	332

Part VI: The Part of Tens 335

Chapter 19: Ten Practical Applications for Circuits 337

Potentiometers	337
Homemade Capacitors: Leyden Jars	338
Digital-to-Analog Conversion Using Op Amps	338
Two-Speaker Systems	338
Interface Techniques Using Resistors	338
Interface Techniques Using Op Amps	339
The Wheatstone Bridge	339
Accelerometers	339
Electronic Stud Finders	340
555 Timer Circuits	340

Chapter 20: Ten Technologies Affecting Circuits. 341

Smartphone Touchscreens	341
Nanotechnology.....	341
Carbon Nanotubes.....	342
Microelectromechanical Systems	342
Supercapacitors.....	343
The Memristor	343
Superconducting Digital Electronics.....	343
Wide Bandgap Semiconductors.....	343
Flexible Electronics	344
Microelectronic Chips that Pair Up with Biological Cells	344

***Index* 345**

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 short-cuts 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

getting started
with
**circuit
analysis**



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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.

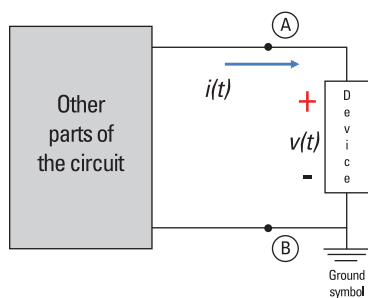


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Measuring current through a device requires just one point of measurement. As an analogy, say you're asked to count the number of cars flowing through your long stretch of residential street for 10 minutes. You can count the number of cars from your 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.