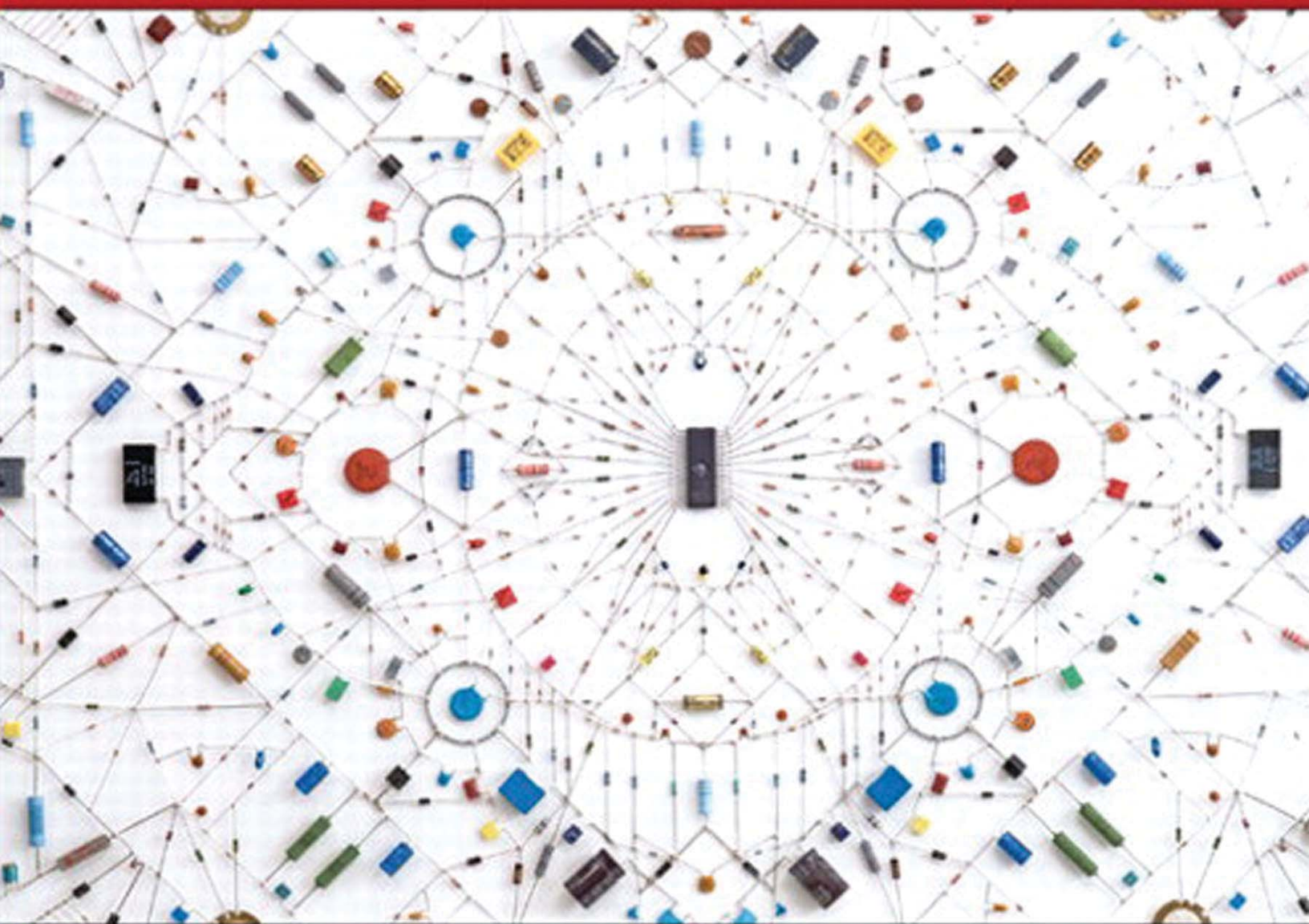


NILSSON • RIEDEL



ELECTRIC CIRCUITS

10th Edition

ELECTRIC CIRCUITS

TENTH EDITION

James W. Nilsson

*Professor Emeritus
Iowa State University*

Susan A. Riedel

Marquette University

PEARSON

Boston Columbus Indianapolis New York San Francisco Upper Saddle River
Amsterdam Cape Town Dubai London Madrid Milan Munich Paris Montréal Toronto
Delhi Mexico City São Paulo Sydney Hong Kong Seoul Singapore Taipei Tokyo

Vice President and Editorial Director:

Marcia J. Horton

Executive Editor: Andrew Gilfillan

Editorial Assistant: Sandra Rodriguez

Marketing Manager: Tim Galligan

Senior Managing Editor: Scott Disanno

Production Editor: Rose Kernan

Cover Design: Black Horse Designs

Cover Art: Inverter 04 Oil painting by Ben Leone

“TechScape” Collection. www.benleone.com

Manager, Cover Visual Research & Permissions:

Karen Sanatar

Photo Researcher: Marta Samsel

Composition: Integra Publishing Services

Credits and acknowledgments borrowed from other sources and reproduced, with permission, in this textbook appear on appropriate page within text.

Copyright © 2015, 2008, 2005 Pearson Education, Inc., publishing as Prentice Hall, One Lake Street, Upper Saddle River, New Jersey, 07458. All rights reserved. Manufactured in the United States of America.

This publication is protected by Copyright, and permission should be obtained from the publisher prior to any prohibited reproduction, storage in a retrieval system, or transmission in any form or by any means, electronic, mechanical, photocopying, recording, or likewise. To obtain permission(s) to use material from this work, please submit a written request to Pearson Education, Inc., Permissions Department, One Lake Street, Upper Saddle River, New Jersey, 07458.

Library of Congress Cataloging-in-Publication Data

Nilsson, James William.

Electric circuits / James W. Nilsson, Professor Emeritus, Iowa State University, Susan A. Riedel, Marquette University. — Tenth edition.

pages cm

ISBN-13: 978-0-13-376003-3

ISBN-10: 0-13-376003-0

1. Electric circuits. I. Riedel, Susan A. II. Title.

TK545.N54 2015

621.319'2—dc23

2013037725

10 9 8 7 6 5 4 3 2

PEARSON

ISBN-13: 978-0-13-376003-3

ISBN-10: 0-13-376003-0



Brief Contents

	List of Examples	xiii
	Preface	xvii
Chapter 1	Circuit Variables	2
Chapter 2	Circuit Elements	24
Chapter 3	Simple Resistive Circuits	56
Chapter 4	Techniques of Circuit Analysis	88
Chapter 5	The Operational Amplifier	144
Chapter 6	Inductance, Capacitance, and Mutual Inductance	174
Chapter 7	Response of First-Order <i>RL</i> and <i>RC</i> Circuits	212
Chapter 8	Natural and Step Responses of <i>RLC</i> Circuits	264
Chapter 9	Sinusoidal Steady-State Analysis	304
Chapter 10	Sinusoidal Steady-State Power Calculations	358
Chapter 11	Balanced Three-Phase Circuits	396
Chapter 12	Introduction to the Laplace Transform	426
Chapter 13	The Laplace Transform in Circuit Analysis	464
Chapter 14	Introduction to Frequency Selective Circuits	520
Chapter 15	Active Filter Circuits	556
Chapter 16	Fourier Series	602
Chapter 17	The Fourier Transform	642
Chapter 18	Two-Port Circuits	676
Appendix A	The Solution of Linear Simultaneous Equations	703
Appendix B	Complex Numbers	723
Appendix C	More on Magnetically Coupled Coils and Ideal Transformers	729
Appendix D	The Decibel	737
Appendix E	Bode Diagrams	739
Appendix F	An Abbreviated Table of Trigonometric Identities	757
Appendix G	An Abbreviated Table of Integrals	759
Appendix H	Common Standard Component Values	761
	Answers to Selected Problems	763
	Index	775



Contents

List of Examples xiii

Preface xvii

Chapter 1 Circuit Variables 2

- Practical Perspective: Balancing Power* 3
- 1.1 Electrical Engineering: An Overview 4
- 1.2 The International System of Units 8
- 1.3 Circuit Analysis: An Overview 10
- 1.4 Voltage and Current 11
- 1.5 The Ideal Basic Circuit Element 12
- 1.6 Power and Energy 14
- Practical Perspective: Balancing Power* 17
- Summary* 18
- Problems* 19

Chapter 2 Circuit Elements 24

- Practical Perspective: Heating with Electric Radiators* 25
- 2.1 Voltage and Current Sources 26
- 2.2 Electrical Resistance (Ohm's Law) 30
- 2.3 Construction of a Circuit Model 34
- 2.4 Kirchhoff's Laws 37
- 2.5 Analysis of a Circuit Containing Dependent Sources 42
- Practical Perspective: Heating with Electric Radiators* 46
- Summary* 48
- Problems* 48

Chapter 3 Simple Resistive Circuits 56

- Practical Perspective: Resistive Touch Screens* 57
- 3.1 Resistors in Series 58
- 3.2 Resistors in Parallel 59
- 3.3 The Voltage-Divider and Current-Divider Circuits 61
- 3.4 Voltage Division and Current Division 64
- 3.5 Measuring Voltage and Current 66
- 3.6 Measuring Resistance—The Wheatstone Bridge 69
- 3.7 Delta-to-Wye (Pi-to-Tee) Equivalent Circuits 71
- Practical Perspective: Resistive Touch Screens* 73
- Summary* 75
- Problems* 76

Chapter 4 Techniques of Circuit Analysis 88

- Practical Perspective: Circuits with Realistic Resistors* 89
- 4.1 Terminology 90
- 4.2 Introduction to the Node-Voltage Method 93
- 4.3 The Node-Voltage Method and Dependent Sources 95
- 4.4 The Node-Voltage Method: Some Special Cases 96
- 4.5 Introduction to the Mesh-Current Method 99
- 4.6 The Mesh-Current Method and Dependent Sources 102
- 4.7 The Mesh-Current Method: Some Special Cases 103
- 4.8 The Node-Voltage Method Versus the Mesh-Current Method 106
- 4.9 Source Transformations 109
- 4.10 Thévenin and Norton Equivalents 113
- 4.11 More on Deriving a Thévenin Equivalent 117
- 4.12 Maximum Power Transfer 120
- 4.13 Superposition 122
- Practical Perspective: Circuits with Realistic Resistors* 125
- Summary* 129
- Problems* 130

Chapter 5 The Operational Amplifier 144

- Practical Perspective: Strain Gages* 145
- 5.1 Operational Amplifier Terminals 146
- 5.2 Terminal Voltages and Currents 146
- 5.3 The Inverting-Amplifier Circuit 150
- 5.4 The Summing-Amplifier Circuit 152
- 5.5 The Noninverting-Amplifier Circuit 153
- 5.6 The Difference-Amplifier Circuit 155
- 5.7 A More Realistic Model for the Operational Amplifier 159
- Practical Perspective: Strain Gages* 162
- Summary* 164
- Problems* 165

Chapter 6 Inductance, Capacitance, and Mutual Inductance 174

Practical Perspective: Capacitive Touch Screens 175

- 6.1 The Inductor 176
- 6.2 The Capacitor 182
- 6.3 Series-Parallel Combinations of Inductance and Capacitance 187
- 6.4 Mutual Inductance 189
- 6.5 A Closer Look at Mutual Inductance 193
- Practical Perspective: Capacitive Touch Screens* 200
- Summary* 202
- Problems* 204

Chapter 7 Response of First-Order RL and RC Circuits 212

Practical Perspective: Artificial Pacemaker 213

- 7.1 The Natural Response of an RL Circuit 214
- 7.2 The Natural Response of an RC Circuit 220
- 7.3 The Step Response of RL and RC Circuits 224
- 7.4 A General Solution for Step and Natural Responses 231
- 7.5 Sequential Switching 236
- 7.6 Unbounded Response 240
- 7.7 The Integrating Amplifier 241
- Practical Perspective: Artificial Pacemaker* 245
- Summary* 246
- Problems* 247

Chapter 8 Natural and Step Responses of RLC Circuits 264

Practical Perspective: Clock for Computer Timing 265

- 8.1 Introduction to the Natural Response of a Parallel RLC Circuit 266
- 8.2 The Forms of the Natural Response of a Parallel RLC Circuit 270
- 8.3 The Step Response of a Parallel RLC Circuit 280
- 8.4 The Natural and Step Response of a Series RLC Circuit 285
- 8.5 A Circuit with Two Integrating Amplifiers 289
- Practical Perspective: Clock for Computer Timing* 293
- Summary* 295
- Problems* 296

Chapter 9 Sinusoidal Steady-State Analysis 304

Practical Perspective: A Household Distribution Circuit 305

- 9.1 The Sinusoidal Source 306
- 9.2 The Sinusoidal Response 309
- 9.3 The Phasor 310
- 9.4 The Passive Circuit Elements in the Frequency Domain 315
- 9.5 Kirchhoff's Laws in the Frequency Domain 319
- 9.6 Series, Parallel, and Delta-to-Wye Simplifications 320
- 9.7 Source Transformations and Thévenin-Norton Equivalent Circuits 327
- 9.8 The Node-Voltage Method 330
- 9.9 The Mesh-Current Method 331
- 9.10 The Transformer 332
- 9.11 The Ideal Transformer 336
- 9.12 Phasor Diagrams 342
- Practical Perspective: A Household Distribution Circuit* 344
- Summary* 345
- Problems* 346

Chapter 10 Sinusoidal Steady-State Power Calculations 358

Practical Perspective: Vampire Power 359

- 10.1 Instantaneous Power 360
- 10.2 Average and Reactive Power 361
- 10.3 The rms Value and Power Calculations 366
- 10.4 Complex Power 368
- 10.5 Power Calculations 369
- 10.6 Maximum Power Transfer 376
- Practical Perspective: Vampire Power* 382
- Summary* 384
- Problems* 385

Chapter 11 Balanced Three-Phase Circuits 396

Practical Perspective: Transmission and Distribution of Electric Power 397

- 11.1 Balanced Three-Phase Voltages 398
- 11.2 Three-Phase Voltage Sources 399
- 11.3 Analysis of the Wye-Wye Circuit 400
- 11.4 Analysis of the Wye-Delta Circuit 405
- 11.5 Power Calculations in Balanced Three-Phase Circuits 408
- 11.6 Measuring Average Power in Three-Phase Circuits 413
- Practical Perspective: Transmission and Distribution of Electric Power* 416
- Summary* 417
- Problems* 418

Chapter 12 Introduction to the Laplace Transform 426

- Practical Perspective: Transient Effects* 427
- 12.1 Definition of the Laplace Transform 428
 - 12.2 The Step Function 429
 - 12.3 The Impulse Function 431
 - 12.4 Functional Transforms 434
 - 12.5 Operational Transforms 435
 - 12.6 Applying the Laplace Transform 440
 - 12.7 Inverse Transforms 442
 - 12.8 Poles and Zeros of $F(s)$ 452
 - 12.9 Initial- and Final-Value Theorems 453
- Practical Perspective: Transient Effects* 456
- Summary* 457
- Problems* 458

Chapter 13 The Laplace Transform in Circuit Analysis 464

- Practical Perspective: Surge Suppressors* 465
- 13.1 Circuit Elements in the s Domain 466
 - 13.2 Circuit Analysis in the s Domain 468
 - 13.3 Applications 470
 - 13.4 The Transfer Function 482
 - 13.5 The Transfer Function in Partial Fraction Expansions 484
 - 13.6 The Transfer Function and the Convolution Integral 487
 - 13.7 The Transfer Function and the Steady-State Sinusoidal Response 493
 - 13.8 The Impulse Function in Circuit Analysis 496
- Practical Perspective: Surge Suppressors* 503
- Summary* 504
- Problems* 505

Chapter 14 Introduction to Frequency Selective Circuits 520

- Practical Perspective: Pushbutton Telephone Circuits* 521
- 14.1 Some Preliminaries 522
 - 14.2 Low-Pass Filters 524
 - 14.3 High-Pass Filters 530
 - 14.4 Bandpass Filters 534
 - 14.5 Bandreject Filters 543
- Practical Perspective: Pushbutton Telephone Circuits* 548
- Summary* 548
- Problems* 549

Chapter 15 Active Filter Circuits 556

- Practical Perspective: Bass Volume Control* 557
- 15.1 First-Order Low-Pass and High-Pass Filters 558
 - 15.2 Scaling 562
 - 15.3 Op Amp Bandpass and Bandreject Filters 564
 - 15.4 Higher Order Op Amp Filters 571
 - 15.5 Narrowband Bandpass and Bandreject Filters 584
- Practical Perspective: Bass Volume Control* 589
- Summary* 592
- Problems* 593

Chapter 16 Fourier Series 602

- Practical Perspective: Active High-Q Filters* 603
- 16.1 Fourier Series Analysis: An Overview 605
 - 16.2 The Fourier Coefficients 606
 - 16.3 The Effect of Symmetry on the Fourier Coefficients 609
 - 16.4 An Alternative Trigonometric Form of the Fourier Series 615
 - 16.5 An Application 617
 - 16.6 Average-Power Calculations with Periodic Functions 621
 - 16.7 The rms Value of a Periodic Function 624
 - 16.8 The Exponential Form of the Fourier Series 625
 - 16.9 Amplitude and Phase Spectra 628
- Practical Perspective: Active High-Q Filters* 630
- Summary* 632
- Problems* 633

Chapter 17 The Fourier Transform 642

- Practical Perspective: Filtering Digital Signals* 643
- 17.1 The Derivation of the Fourier Transform 644
 - 17.2 The Convergence of the Fourier Integral 646
 - 17.3 Using Laplace Transforms to Find Fourier Transforms 648
 - 17.4 Fourier Transforms in the Limit 651
 - 17.5 Some Mathematical Properties 653
 - 17.6 Operational Transforms 655
 - 17.7 Circuit Applications 659
 - 17.8 Parseval's Theorem 662
- Practical Perspective: Filtering Digital Signals* 669
- Summary* 670
- Problems* 670

Chapter 18 Two-Port Circuits 676

Practical Perspective: Characterizing an Unknown Circuit 677

- 18.1 The Terminal Equations 678
- 18.2 The Two-Port Parameters 679
- 18.3 Analysis of the Terminated Two-Port Circuit 687
- 18.4 Interconnected Two-Port Circuits 692
 - Practical Perspective: Characterizing an Unknown Circuit* 695
 - Summary* 696
 - Problems* 696

Appendix A The Solution of Linear Simultaneous Equations 703

- A.1 Preliminary Steps 703
- A.2 Cramer's Method 704
- A.3 The Characteristic Determinant 704
- A.4 The Numerator Determinant 704
- A.5 The Evaluation of a Determinant 705
- A.6 Matrices 707
- A.7 Matrix Algebra 708
- A.8 Identity, Adjoint, and Inverse Matrices 712
- A.9 Partitioned Matrices 715
- A.10 Applications 718

Appendix B Complex Numbers 723

- B.1 Notation 723
- B.2 The Graphical Representation of a Complex Number 724
- B.3 Arithmetic Operations 725
- B.4 Useful Identities 726
- B.5 The Integer Power of a Complex Number 727
- B.6 The Roots of a Complex Number 727

Appendix C More on Magnetically Coupled Coils and Ideal Transformers 729

- C.1 Equivalent Circuits for Magnetically Coupled Coils 729
- C.2 The Need for Ideal Transformers in the Equivalent Circuits 733

Appendix D The Decibel 737

Appendix E Bode Diagrams 739

- E.1 Real, First-Order Poles and Zeros 739
- E.2 Straight-Line Amplitude Plots 740
- E.3 More Accurate Amplitude Plots 744
- E.4 Straight-Line Phase Angle Plots 745
- E.5 Bode Diagrams: Complex Poles and Zeros 747
- E.6 Amplitude Plots 749
- E.7 Correcting Straight-Line Amplitude Plots 750
- E.8 Phase Angle Plots 753

Appendix F An Abbreviated Table of Trigonometric Identities 757

Appendix G An Abbreviated Table of Integrals 759

Appendix H Common Standard Component Values 761

Answers to Selected Problems 763

Index 775