

---

# CONTENTS

	<b>Preface</b>	<b>xxiii</b>
	<b>Acknowledgments</b>	<b>xxv</b>
<b>CHAPTER 1</b>	<b>Introduction to Electronics</b>	<b>1</b>
<b>CHAPTER 2</b>	<b>Theory</b>	<b>5</b>
2.1	Theory of Electronics	5
2.2	Electric Current	6
2.2.1	Currents in Perspective	9
2.3	Voltage	9
2.3.1	The Mechanisms of Voltage	11
2.3.2	Definition of Volt and Generalized Power Law	14
2.3.3	Combining Batteries	15
2.3.4	Other Voltage Sources	16
2.3.5	Water Analogies	17
2.4	A Microscopic View of Conduction (for Those Who Are Interested)	18
2.4.1	Applying a Voltage	21
2.5	Resistance, Resistivity, Conductivity	23
2.5.1	How the Shape of a Conductor Affects Resistance	24
2.5.2	Resistivity and Conductivity	25
2.6	Insulators, Conductors, and Semiconductors	28
2.7	Heat and Power	31
2.8	Thermal Heat Conduction and Thermal Resistance	34
2.8.1	Importance of Heat Production	37
2.9	Wire Gauges	39
2.10	Grounds	40
2.10.1	Earth Ground	42
2.10.2	Different Types of Ground Symbols	45
2.10.3	Loose Ends on Grounding	47

2.11	Electric Circuits	49
2.12	Ohm's Law and Resistors	50
	2.12.1 Resistor Power Ratings	51
	2.12.2 Resistors in Parallel	52
	2.12.3 Resistors in Series	55
	2.12.4 Reducing a Complex Resistor Network	58
	2.12.5 Multiple Voltage Dividers	61
2.13	Voltage and Current Sources	62
2.14	Measuring Voltage, Current, and Resistance	65
2.15	Combining Batteries	67
2.16	Open and Short Circuits	68
2.17	Kirchhoff's Laws	69
2.18	Superposition Theorem	74
2.19	Thevenin's and Norton's Theorems	76
	2.19.1 Thevenin's Theorem	76
	2.19.2 Norton's Theorem	77
2.20	AC Circuits	80
	2.20.1 Generating AC	81
	2.20.2 Water Analogy of AC	82
	2.20.3 Pulsating DC	82
	2.20.4 Combining Sinusoidal Sources	83
	2.20.5 AC Waveforms	84
	2.20.6 Describing an AC Waveform	84
	2.20.7 Frequency and Period	85
	2.20.8 Phase	86
2.21	AC and Resistors, RMS Voltage, and Current	87
2.22	Mains Power	92
2.23	Capacitors	94
	2.23.1 Determining Capacitance	97
	2.23.2 Commercial Capacitors	99
	2.23.3 Voltage Rating and Dielectric Breakdown	99
	2.23.4 Maxwell's Displacement Current	100
	2.23.5 Charge-Based Model of Current Through a Capacitor	102
	2.23.6 Capacitor Water Analogy	104
	2.23.7 Energy in a Capacitor	105
	2.23.8 RC Time Constant	105
	2.23.9 Stray Capacitance	108
	2.23.10 Capacitors in Parallel	108
	2.23.11 Capacitors in Series	109
	2.23.12 Alternating Current in a Capacitor	110
	2.23.13 Capacitive Reactance	111
	2.23.14 Capacitive Divider	113
	2.23.15 Quality Factor	113
2.24	Inductors	113
	2.24.1 Electromagnetism	114
	2.24.2 Magnetic Fields and Their Influence	117

---

2.24.3	Self-Inductance	120
2.24.4	Inductors	121
2.24.5	Inductor Water Analogy	127
2.24.6	Inductor Equations	128
2.24.7	Energy Within an Inductor	133
2.24.8	Inductor Cores	133
2.24.9	Understanding the Inductor Equations	138
2.24.10	Energizing RL Circuit	142
2.24.11	Deenergizing RL Circuit	144
2.24.12	Voltage Spikes Due to Switching	147
2.24.13	Straight-Wire Inductance	147
2.24.14	Mutual Inductance and Magnetic Coupling	148
2.24.15	Unwanted Coupling: Spikes, Lightning, and Other Pulses	149
2.24.16	Inductors in Series and Parallel	149
2.24.17	Alternating Current and Inductors	150
2.24.18	Inductive Reactance	151
2.24.19	Nonideal Inductor Model	153
2.24.20	Quality Factor	154
2.24.21	Inductor Applications	155
2.25	Modeling Complex Circuits	155
2.26	Complex Numbers	159
2.27	Circuit with Sinusoidal Sources	164
2.27.1	Analyzing Sinusoidal Circuits with Complex Impedances	165
2.27.2	Sinusoidal Voltage Source in Complex Notation	167
2.27.3	Odd Phenomena in Reactive Circuits	175
2.28	Power in AC Circuits (Apparent Power, Real Power, Reactive Power)	176
2.28.1	Power Factor	178
2.29	Thevenin's Theorem in AC Form	186
2.30	Resonant Circuits	188
2.30.1	Resonance in RLC Circuits	191
2.30.2	$Q$ (Quality Factor) and Bandwidth	193
2.30.3	Bandwidth	194
2.30.4	Voltage Drop Across Components in RLC Resonant Circuit	195
2.30.5	Capacitor Losses	195
2.30.6	Parallel-Resonant Circuits	196
2.30.7	The $Q$ of Loaded Circuits	202
2.31	Lecture on Decibels	204
2.31.1	Alternative Decibel Representations	207
2.32	Input and Output Impedance	207
2.32.1	Input Impedance	207
2.32.2	Output Impedance	208
2.33	Two-Port Networks and Filters	210
2.33.1	Filters	210
2.33.2	Attenuators	221

2.34	Transient Circuits	223
2.34.1	Series RLC Circuit	231
2.35	Circuits with Periodic Nonsinusoidal Sources	235
2.35.1	Fourier Series	236
2.36	Nonperiodic Sources	243
2.37	SPICE	245
2.37.1	How SPICE Works	246
2.37.2	Limitations of SPICE and Other Simulators	249
2.37.3	A Simple Simulation Example	249
<b>CHAPTER 3 Basic Electronic Circuit Components</b>		<b>253</b>
3.1	Wires, Cables, and Connectors	253
3.1.1	Wires	253
3.1.2	Cables	256
3.1.3	Connectors	256
3.1.4	Wiring and Connector Symbols	261
3.1.5	High-Frequency Effects Within Wires and Cables	262
3.2	Batteries	271
3.2.1	How a Cell Works	272
3.2.2	Primary Batteries	274
3.2.3	Comparing Primary Batteries	275
3.2.4	Secondary Batteries	279
3.2.5	Battery Capacity	287
3.2.6	Note on Internal Voltage Drop of a Battery	289
3.3	Switches	290
3.3.1	How a Switch Works	291
3.3.2	Describing a Switch	291
3.3.3	Kinds of Switches	292
3.3.4	Simple Switch Applications	294
3.4	Relays	295
3.4.1	Specific Kinds of Relays	297
3.4.2	A Few Notes about Relays	298
3.4.3	Some Simple Relay Circuits	299
3.5	Resistors	299
3.5.1	Resistance and Ohm's Law	301
3.5.2	Resistors in Series and Parallel	302
3.5.3	Reading Resistor Labels	304
3.5.4	Real Resistor Characteristics	306
3.5.5	Types of Resistors	314
3.5.6	Variable Resistors (Rheostats, Potentiometers, Trimmers)	320
3.5.7	Potentiometer Characteristics	322
3.6	Capacitors	324
3.6.1	Capacitance	326
3.6.2	Capacitors in Parallel	326
3.6.3	Capacitors in Series	327

---

3.6.4	RC Time Constant	327
3.6.5	Capacitive Reactance	328
3.6.6	Real Capacitors	329
3.6.7	Capacitor Specifications	329
3.6.8	Types of Capacitors	333
3.6.9	Capacitor Applications	341
3.6.10	Timing and Sample and Hold	347
3.6.11	RC Ripple Filter	348
3.6.12	Arc Suppression	350
3.6.13	Supercapacitor Applications	352
3.6.14	Problems	352
3.7	Inductors	355
3.7.1	Inductance	357
3.7.2	Constructing Inductors	357
3.7.3	Inductors in Series and Parallel	357
3.7.4	RL Time Constant	359
3.7.5	Inductive Reactance	360
3.7.6	Real Inductors	361
3.7.7	Inductor Specifications	361
3.7.8	Types of Inductors	363
3.7.9	Reading Inductor Labels	367
3.7.10	Inductor Applications	369
3.7.11	EMI/EMC Design Tips	373
3.8	Transformers	374
3.8.1	Basic Operations	374
3.8.2	Transformer Construction	385
3.8.3	Autotransformers and Variable Transformers	387
3.8.4	Circuit Isolation and the Isolation Transformer	389
3.8.5	Various Standard and Specialized Transformers	390
3.8.6	Transformer Applications	392
3.9	Fuses and Circuit Breakers	397
3.9.1	Types of Fuses and Circuit Breakers	398
<b>CHAPTER 4 Semiconductors</b>		<b>401</b>
4.1	Semiconductor Technology	401
4.1.1	What Is a Semiconductor?	401
4.1.2	Applications of Silicon	406
4.2	Diodes	407
4.2.1	How p-n Junction Diodes Work	407
4.2.2	Diode Water Analogy	409
4.2.3	Kinds of Rectifiers/Diodes	409
4.2.4	Practical Considerations	411
4.2.5	Diode/Rectifier Applications	412
4.2.6	Zener Diodes	420
4.2.7	Zener Diode Applications	423
4.2.8	Varactor Diodes (Variable Capacitance Diodes)	424

4.2.9	PIN Diodes	426
4.2.10	Microwave Diodes (IMPATT, Gunn, Tunnel, etc.)	426
4.2.11	Problems	427
4.3	Transistors	429
4.3.1	Introduction to Transistors	429
4.3.2	Bipolar Transistors	430
4.3.3	Junction Field-Effect Transistors	449
4.3.4	Metal Oxide Semiconductor Field-Effect Transistors	459
4.3.5	Insulated Gate Bipolar Transistors (IGBTs)	468
4.3.6	Unijunction Transistors	468
4.4	Thyristors	472
4.4.1	Introduction	472
4.4.2	Silicon-Controlled Rectifiers	473
4.4.3	Silicon-Controlled Switches	476
4.4.4	Triacs	477
4.4.5	Four-Layer Diodes and Diacs	480
4.5	Transient Voltage Suppressors	481
4.5.1	Lecture on Transients	482
4.5.2	Devices Used to Suppress Transients	483
4.6	Integrated Circuits	491
4.6.1	IC Packages	492

## **CHAPTER 5 Optoelectronics 495**

5.1	A Little Lecture on Photons	495
5.2	Lamps	497
5.3	Light-Emitting Diodes	499
5.3.1	How an LED Works	500
5.3.2	Kinds of LEDs	501
5.3.3	More on LEDs	502
5.3.4	LED Applications	505
5.3.5	Laser Diodes	506
5.4	Photoresistors	512
5.4.1	How a Photoresistor Works	512
5.4.2	Technical Stuff	513
5.4.3	Applications	513
5.5	Photodiodes	514
5.5.1	How a Photodiode Works	514
5.5.2	Basic Operations	515
5.5.3	Kinds of Photodiodes	515
5.6	Solar Cells	516
5.6.1	Basic Operations	517
5.7	Phototransistors	517
5.7.1	How a Phototransistor Works	518
5.7.2	Basic Configurations	518
5.7.3	Kinds of Phototransistors	519
5.7.4	Technical Stuff	519
5.7.5	Applications	520

5.8	Photothyristors	521
5.8.1	How LASCRs Work	521
5.8.2	Basic Operation	521
5.9	Optoisolators	522
5.9.1	Integrated Optoisolators	522
5.9.2	Applications	523
5.10	Optical Fiber	524

## **CHAPTER 6 Sensors 525**

6.1	General Principals	525
6.1.1	Precision, Accuracy, and Resolution	525
6.1.2	The Observer Effect	526
6.1.3	Calibration	526
6.2	Temperature	528
6.2.1	Thermistors	529
6.2.2	Thermocouples	531
6.2.3	Resistive Temperature Detectors	532
6.2.4	Analog Output Thermometer ICs	532
6.2.5	Digital Thermometer ICs	533
6.2.6	Infrared Thermometers/Pyrometers	534
6.2.7	Summary	534
6.3	Proximity and Touch	535
6.3.1	Touch Screens	535
6.3.2	Ultrasonic Distance	536
6.3.3	Optical Distance	537
6.3.4	Capacitive Sensors	539
6.3.5	Summary	539
6.4	Movement, Force, and Pressure	540
6.4.1	Passive Infrared	540
6.4.2	Acceleration	541
6.4.3	Rotation	542
6.4.4	Flow	543
6.4.5	Force	544
6.4.6	Tilt	545
6.4.7	Vibration and Mechanical Shock	545
6.4.8	Pressure	545
6.5	Chemical	546
6.5.1	Smoke	546
6.5.2	Gas	546
6.5.3	Humidity	547
6.6	Light, Radiation, Magnetism, and Sound	547
6.6.1	Light	547
6.6.2	Ionizing Radiation	547
6.6.3	Magnetic Fields	548
6.6.4	Sound	549
6.7	GPS	549

---

<b>CHAPTER 7</b>	<b>Hands-on Electronics</b>	<b>551</b>
7.1	Safety	551
	7.1.1 Lecture on Safety	551
	7.1.2 Damaging Components with Electrostatic Discharge	555
	7.1.3 Component Handling Precautions	555
7.2	Constructing Circuits	556
	7.2.1 Drawing a Circuit Schematic	556
	7.2.2 A Note on Circuit Simulator Programs	558
	7.2.3 Making a Prototype of Your Circuit	558
	7.2.4 The Final Circuit	559
	7.2.5 Making a PCB	562
	7.2.6 Special Pieces of Hardware Used in Circuit Construction	567
	7.2.7 Soldering	568
	7.2.8 Desoldering	569
	7.2.9 Enclosing the Circuit	569
	7.2.10 Useful Items to Keep Handy	570
	7.2.11 Troubleshooting the Circuits You Build	570
7.3	Multimeters	571
	7.3.1 Basic Operation	572
	7.3.2 How Analog VOMs Work	573
	7.3.3 How Digital Multimeters Work	574
	7.3.4 A Note on Measurement Errors	574
7.4	Oscilloscopes	575
	7.4.1 How Scopes Work	576
	7.4.2 Interior Circuitry of a Scope	578
	7.4.3 Aiming the Beam	579
	7.4.4 Scope Usage	580
	7.4.5 What All the Little Knobs and Switches Do	581
	7.4.6 Measuring Things with Scopes	586
	7.4.7 Scope Applications	590
	7.4.8 Measuring Impedances	592
7.5	The Electronics Laboratory	594
	7.5.1 Work Area	594
	7.5.2 Test Equipment	595
	7.5.3 Multimeters	596
	7.5.4 DC Power Supplies	597
	7.5.5 Oscilloscope	598
	7.5.6 Oscilloscope Probes	600
	7.5.7 General-Purpose Function Generator	607
	7.5.8 Frequency Counter	608
	7.5.9 Computer	608
	7.5.10 Miscellaneous Test Equipment	609
	7.5.11 Multifunction PC Instruments	610
	7.5.12 Isolation Transformers	611
	7.5.13 Variable Transformers, or Variacs	613

7.5.14	Substitution Boxes	614
7.5.15	Test Cables, Connectors, and Adapters	616
7.5.16	Soldering Equipment	618
7.5.17	Prototyping Boards	621
7.5.18	Hand Tools	622
7.5.19	Wires, Cables, Hardware, and Chemicals	624
7.5.20	Electronics Catalogs	626
7.5.21	Recommended Electronics Parts	627
7.5.22	Electronic CAD Programs	630
7.5.23	Building Your Own Workbench	631
<b>CHAPTER 8</b>	<b>Operational Amplifiers</b>	<b>635</b>
8.1	Operational Amplifier Water Analogy	636
8.2	How Op Amps Work (The “Cop-Out” Explanation)	637
8.3	Theory	638
8.4	Negative Feedback	639
8.5	Positive Feedback	644
8.6	Real Kinds of Op Amps	645
8.7	Op Amp Specifications	647
8.8	Powering Op Amps	649
8.9	Some Practical Notes	650
8.10	Voltage and Current Offset Compensation	651
8.11	Frequency Compensation	652
8.12	Comparators	652
8.13	Comparators with Hysteresis	654
8.13.1	Inverting Comparator with Hysteresis	654
8.13.2	Noninverting Comparator with Hysteresis	655
8.14	Using Single-Supply Comparators	656
8.15	Window Comparator	656
8.16	Voltage-Level Indicator	657
8.17	Instrumentation Amplifiers	657
8.18	Applications	658
<b>CHAPTER 9</b>	<b>Filters</b>	<b>663</b>
9.1	Things to Know Before You Start Designing Filters	664
9.2	Basic Filters	665
9.3	Passive Low-Pass Filter Design	666
9.4	A Note on Filter Types	670
9.5	Passive High-Pass Filter Design	670
9.6	Passive Bandpass Filter Design	672
9.7	Passive Notch Filter Design	674
9.8	Active Filter Design	675
9.8.1	Active Low-Pass Filter Example	676
9.8.2	Active High-Pass Filter Example	677
9.8.3	Active Bandpass Filters	678
9.8.4	Active Notch Filters	680
9.9	Integrated Filter Circuits	681

---

<b>CHAPTER 10</b>	<b>Oscillators and Timers</b>	<b>683</b>
10.1	<i>RC</i> Relaxation Oscillators	684
10.2	The 555 Timer IC	686
10.2.1	How a 555 Works (Astable Operation)	687
10.2.2	Basic Astable Operation	688
10.2.3	How a 555 Works (Monostable Operation)	689
10.2.4	Basic Monostable Operation	690
10.2.5	Some Important Notes about 555 Timers	690
10.2.6	Simple 555 Applications	691
10.3	Voltage-Controlled Oscillators	692
10.4	Wien-Bridge and Twin-T Oscillators	693
10.5	<i>LC</i> Oscillators (Sinusoidal Oscillators)	693
10.6	Crystal Oscillators	696
10.7	Microcontroller Oscillators	698
<b>CHAPTER 11</b>	<b>Voltage Regulators and Power Supplies</b>	<b>699</b>
11.1	Voltage-Regulator ICs	701
11.1.1	Fixed-Regulator ICs	701
11.1.2	Adjustable-Regulator ICs	702
11.1.3	Regulator Specifications	702
11.2	A Quick Look at a Few Regulator Applications	702
11.3	The Transformer	703
11.4	Rectifier Packages	703
11.5	A Few Simple Power Supplies	704
11.6	Technical Points about Ripple Reduction	707
11.7	Loose Ends	709
11.8	Switching Regulator Supplies (Switchers)	710
11.9	Switch-Mode Power Supplies (SMPS)	713
11.10	Kinds of Commercial Power Supply Packages	714
11.11	Power Supply Construction	716
<b>CHAPTER 12</b>	<b>Digital Electronics</b>	<b>717</b>
12.1	The Basics of Digital Electronics	717
12.1.1	Digital Logic States	717
12.1.2	Number Codes Used in Digital Electronics	718
12.1.3	Clock Timing and Parallel versus Serial Transmission	725
12.2	Logic Gates	726
12.2.1	Multiple-Input Logic Gates	727
12.2.2	Digital Logic Gate ICs	727
12.2.3	Applications for a Single Logic Gate	728
12.2.4	Combinational Logic	730
12.2.5	Keeping Circuits Simple (Karnaugh Maps)	738
12.3	Combinational Devices	740
12.3.1	Multiplexers (Data Selectors) and Bilateral Switches	741

---

12.3.2	Demultiplexers (Data Distributors) and Decoders	743
12.3.3	Encoders and Code Converters	746
12.3.4	Binary Adders	749
12.3.5	Binary Adder/Subtractor	751
12.3.6	Comparators and Magnitude Comparator ICs	751
12.3.7	A Note on Obsolescence and the Trend Toward Microcontroller Control	752
12.4	Logic Families	753
12.4.1	CMOS Family of ICs	754
12.4.2	I/O Voltages and Noise Margins	755
12.4.3	Current Ratings, Fanout, and Propagation Delays	756
12.5	Powering and Testing Logic ICs	756
12.5.1	Power Supply Decoupling	756
12.5.2	Unused Inputs	757
12.5.3	Logic Probes and Logic Pulsers	757
12.6	Sequential Logic	758
12.6.1	SR Flip-Flops	759
12.6.2	SR Flip-Flop ICs	763
12.6.3	D-Type Flip-Flops	764
12.6.4	Quad and Octal D Flip-Flops	768
12.6.5	JK Flip-Flops	769
12.6.6	Practical Timing Considerations with Flip-Flops	773
12.6.7	Digital Clock Generators and Single-Pulse Generators	774
12.6.8	Automatic Power-Up Clear (Reset) Circuits	777
12.6.9	Pullup and Pulldown Resistors	779
12.7	Counter ICs	780
12.7.1	Asynchronous Counter (Ripple Counter) ICs	780
12.7.2	Synchronous Counter ICs	782
12.7.3	A Note on Counters with Displays	787
12.8	Shift Registers	789
12.8.1	Serial-In/Serial-Out Shift Registers	789
12.8.2	Serial-In/Parallel-Out Shift Registers	790
12.8.3	Parallel-In/Serial-Out Shift Registers	790
12.8.4	Ring Counter (Shift Register Sequencer)	791
12.8.5	Johnson Shift Counter	791
12.8.6	Shift Register ICs	792
12.8.7	Simple Shift Register Applications	796
12.9	Analog/Digital Interfacing	799
12.9.1	Triggering Simple Logic Responses from Analog Signals	799
12.9.2	Using Logic to Drive External Loads	800
12.9.3	Analog Switches	802
12.9.4	Analog Multiplexer/Demultiplexer	802
12.9.5	Analog-to-Digital and Digital-to-Analog Conversion	803
12.9.6	Analog-to-Digital Converters	811

12.10	Displays	813
12.10.1	LED Displays	813
12.10.2	Liquid-Crystal Displays	815
12.11	Memory Devices	828
12.11.1	Read-Only Memory	829
12.11.2	Simple ROM Made Using Diodes	830
12.11.3	Memory Size and Organization	830
12.11.4	Simple Programmable ROM	831
12.11.5	ROM Devices	832
12.11.6	RAM	836
<b>CHAPTER 13 Microcontrollers</b>		<b>843</b>
13.1	Basic Structure of a Microcontroller	844
13.2	Example Microcontrollers	844
13.2.1	The ATtiny85 Microcontroller	845
13.2.2	The PIC16Cx Microcontrollers	849
13.2.3	32-Bit Microcontrollers	862
13.2.4	Digital Signal Processing	862
13.3	Evaluation/Development Boards	863
13.4	Arduino	864
13.4.1	A Tour of Arduino	864
13.4.2	The Arduino IDE	865
13.4.3	Arduino Board Models	865
13.4.4	Shields	866
13.4.5	The Arduino C Library	868
13.4.6	Arduino Example Project	870
13.4.7	Taking the Arduino Offboard	872
13.5	Interfacing with Microcontrollers	874
13.5.1	Switches	874
13.5.2	Analog Inputs	878
13.5.3	High-Power Digital Outputs	879
13.5.4	Sound Interfaces	883
13.5.5	Serial Interfaces	884
13.5.6	Level Conversion	892
13.5.7	LED Display Interfaces	892
<b>CHAPTER 14 Programmable Logic</b>		<b>897</b>
14.1	Programmable Logic	898
14.2	FPGAs	899
14.3	ISE and the Elbert V2	900
14.3.1	Installing ISE	901
14.4	The Elbert 2 Board	901
14.4.1	Installing the Elbert Software	902
14.5	Downloads	903
14.6	Drawing Your FPGA Logic Design	903
14.6.1	Example 1: A Data Selector	903
14.6.2	Example 2: A 4-bit Ripple Counter	912

---

14.7	Verilog	914
14.7.1	Modules	915
14.7.2	Wires, Registers, and Busses	915
14.7.3	Parallel Execution	915
14.7.4	Number Format	915
14.8	Describing Your FPGA Design in Verilog	916
14.8.1	A Data Selector in Verilog	916
14.8.2	A Ripple Counter in Verilog	919
14.9	Modular Design	920
14.9.1	Counter/Decoder Example	921
14.9.2	Multiplexed 7-Segment Counter Example	924
14.9.3	Parameterized Modules	928
14.10	Simulation	928
14.11	VHDL	931
<b>CHAPTER 15</b>	<b>Motors</b>	<b>933</b>
15.1	DC Continuous Motors	933
15.2	Speed Control of DC Motors	934
15.3	Directional Control of DC Motors	935
15.4	RC Servos	936
15.5	Stepper Motors	938
15.6	Kinds of Stepper Motors	939
15.7	Driving Stepper Motors	941
15.8	Controlling the Driver with a Translator	943
15.9	A Final Word on Identifying Stepper Motors	945
<b>CHAPTER 16</b>	<b>Audio Electronics</b>	<b>947</b>
16.1	A Little Lecture on Sound	947
16.2	Microphones	949
16.3	Microphone Specifications	950
16.4	Audio Amplifiers	951
16.4.1	Inverting Amplifier	951
16.4.2	Noninverting Amplifier	952
16.4.3	Digital Amplifiers	952
16.4.4	Reducing Hum in Audio Amplifiers	954
16.5	Preamplifiers	954
16.6	Mixer Circuits	955
16.7	A Note on Impedance Matching	955
16.8	Speakers	956
16.9	Crossover Networks	957
16.10	Simple ICs Used to Drive Speakers	959
16.11	Audible-Signal Devices	960
16.12	Miscellaneous Audio Circuits	960
<b>CHAPTER 17</b>	<b>Modular Electronics</b>	<b>963</b>
17.1	There's an IC for It	963
17.2	Breakout Boards and Modules	963

17.2.1	Radio Frequency Modules	964
17.2.2	Audio Modules	967
17.3	Plug-and-Play Prototyping	968
17.4	Open Source Hardware	970
<b>APPENDIX A</b>	<b>Power Distribution and Home Wiring</b>	<b>973</b>
A.1	Power Distribution	973
A.2	A Closer Look at Three-Phase Electricity	974
A.3	Home Wiring	976
A.4	Electricity in Other Countries	977
<b>APPENDIX B</b>	<b>Error Analysis</b>	<b>979</b>
B.1	Absolute Error, Relative Error, and Percent Error	979
B.2	Uncertainty Estimates	980
<b>APPENDIX C</b>	<b>Useful Facts and Formulas</b>	<b>983</b>
C.1	Greek Alphabet	983
C.2	Powers of 10 Unit Prefixes	983
C.3	Linear Functions ( $y = mx + b$ )	983
C.4	Quadratic Equation ( $y = ax^2 + bx + c$ )	984
C.5	Exponents and Logarithms	984
C.6	Trigonometry	984
C.7	Complex Numbers	985
C.8	Differential Calculus	985
C.9	Integral Calculus	987
	<b>Index</b>	<b>989</b>