CONTENTS

Lists vii

Class Discussion Items vii
Examples ix
Design Examples x
Threaded Design Examples xi

Preface xiii

Chapter **1**
Introduction 1

1.1 Mechatronics 1
1.2 Measurement Systems 4
1.3 Threaded Design Examples 5

Chapter **2**
Electric Circuits and Components 11

2.1 Introduction 12
2.2 Basic Electrical Elements 14
2.2.1 Resistor 14
2.2.2 Capacitor 19
2.2.3 Inductor 20
2.3 Kirchhoff's Laws 22
2.3.1 Series Resistance Circuit 24
2.3.2 Parallel Resistance Circuit 26
2.4 Voltage and Current Sources and Meters 30
2.5 Thevenin and Norton Equivalent Circuits 35
2.6 Alternating Current Circuit Analysis 37
2.7 Power in Electrical Circuits 44
2.8 Transformer 46
2.9 Impedance Matching 47
2.10 Practical Considerations 50
2.10.1 Capacitor Information 50
2.10.2 Breadboad and Prototyping Advice 51
2.10.3 Voltage and Current Measurement 54
2.10.4 Soldering 54
2.10.5 The Oscilloscope 58
2.10.6 Grounding and Electrical Interference 61
2.10.7 Electrical Safety 63

Chapter **3**
Semiconductor Electronics 73

3.1 Introduction 74
3.2 Semiconductor Physics as the Basis for Understanding Electronic Devices 74
3.3 Junction Diode 75
3.3.1 Zener Diode 81
3.3.2 Voltage Regulators 85
3.3.3 Optoelectronic Diodes 87
3.3.4 Analysis of Diode Circuits 88
3.4 Bipolar Junction Transistor 90
3.4.1 Bipolar Transistor Physics 90
3.4.2 Common Emitter Transistor Circuit 92
3.4.3 Bipolar Transistor Switch 97
3.4.4 Bipolar Transistor Packages 99
3.4.5 Darlington Transistor 100
3.4.6 Phototransistor and Optoisolator 100
3.5 Field-Effect Transistors 102
3.5.1 Behavior of Field-Effect Transistors 103
3.5.2 Symbols Representing Field-Effect Transistors 106
3.5.3 Applications of MOSFETs 107

Chapter 4
System Response 117

4.1 System Response 118
4.2 Amplitude Linearity 118
4.3 Fourier Series Representation of Signals 120
4.4 Bandwidth and Frequency Response 124
4.5 Phase Linearity 129
4.6 Distortion of Signals 130
4.7 Dynamic Characteristics of Systems 131
4.8 Zero-Order System 132
4.9 First-Order System 134
4.9.1 Experimental Testing of a First-Order System 136
4.10 Second-Order System 137
4.10.1 Step Response of a Second-Order System 141
4.10.2 Frequency Response of a System 143
4.11 System Modeling and Analogies 150

Chapter 5
Analog Signal Processing Using Operational Amplifiers 161

5.1 Introduction 162
5.2 Amplifiers 162
5.3 Operational Amplifiers 164
5.4 Ideal Model for the Operational Amplifier 164
5.5 Inverting Amplifier 167
5.6 Noninverting Amplifier 169
5.7 Summer 173
5.8 Difference Amplifier 173
5.9 Instrumentation Amplifier 175
5.10 Integrator 177
5.11 Differentiator 179
5.12 Sample and Hold Circuit 180
5.13 Comparator 181
5.14 The Real Op Amp 182
5.14.1 Important Parameters from Op Amp Data Sheets 183

Chapter 6
Digital Circuits 197

6.1 Introduction 198
6.2 Digital Representations 199
6.3 Combinational Logic and Logic Classes 202
6.4 Timing Diagrams 205
6.5 Boolean Algebra 206
6.6 Design of Logic Networks 208
6.6.1 Define the Problem in Words 208
6.6.2 Write Quasi-Logic Statements 209
6.6.3 Write the Boolean Expression 209
6.6.4 And Realization 210
6.6.5 Draw the Circuit Diagram 210
6.7 Finding a Boolean Expression Given a Truth Table 211
6.8 Sequential Logic 214
6.9 Flip-Flops 214
6.9.1 Triggering of Flip-Flops 216
6.9.2 Asynchronous Inputs 218
6.9.3 D Flip-Flop 219
6.9.4 JK Flip-Flop 219
6.10 Applications of Flip-Flops 222
6.10.1 Switch Debouncing 222
6.10.2 Data Register 223
6.10.3 Binary Counter and Frequency Divider 224
6.10.4 Serial and Parallel Interfaces 224
6.11 TTL and CMOS Integrated Circuits 226
6.11.1 Using Manufacturer IC Data Sheets 228
6.11.2 Digital IC Output Configurations 230
6.11.3 Interfacing TTL and CMOS Devices 232
6.12 Special Purpose Digital Integrated Circuits 235
6.12.1 Decade Counter 235
6.12.2 Schmitt Trigger 239
6.12.3 555 Timer 240
6.13 Integrated Circuit System Design 245
6.13.1 IEEE Standard Digital Symbols 249

Chapter 7
Microcontroller Programming and Interfacing 258

7.1 Microprocessors and Microcomputers 259
7.2 Microcontrollers 261
7.3 The PIC16F84 Microcontroller 264
7.4 Programming a PIC 268
7.5 PicBasic Pro 274
7.5.1 PicBasic Pro Programming Fundamentals 274
7.5.2 PicBasic Pro Programming Examples 282
7.6 Using Interrupts 294
7.7 Interfacing Common PIC Peripherals 298
7.7.1 Numeric Keypad 298
7.7.2 LCD Display 301
7.8 Interfacing to the PIC 306
7.8.1 Digital Input to the PIC 306
7.8.2 Digital Output from the PIC 308
7.9 Method to Design a Microcontroller-Based System 309
7.10 Practical Considerations 336
7.10.1 PIC Project Debugging Procedure 336
7.10.2 Power Supply Options for PIC Projects 337
7.10.3 Battery Characteristics 339
7.10.4 Other Considerations for Project Prototyping and Design 342

Chapter 8
Data Acquisition 346

8.1 Introduction 347
8.2 Quantizing Theory 351
8.3 Analog-to-Digital Conversion 352
8.3.1 Introduction 352
8.3.2 Analog-to-Digital Converters 356
8.4 Digital-to-Analog Conversion 359
8.5 Virtual Instrumentation, Data Acquisition, and Control 363
8.6 Practical Considerations 365
8.6.1 Introduction to LabVIEW Programming 365
8.6.2 The USB 6009 Data Acquisition Card 367
8.6.3 Creating a VI and Sampling Music 369

Chapter 9
Sensors 375

9.1 Introduction 376
9.2 Position and Speed Measurement 376
9.2.1 Proximity Sensors and Switches 377
9.2.2 Potentiometer 379
9.2.3 Linear Variable Differential Transformer 380
9.2.4 Digital Optical Encoder 383
9.3 Stress and Strain Measurement 391
9.3.1 Electrical Resistance Strain Gage 392
9.3.2 Measuring Resistance Changes with a Wheatstone Bridge 396
9.3.3 Measuring Different States of Stress with Strain Gages 400
9.3.4 Force Measurement with Load Cells 405
9.4 Temperature Measurement 407
9.4.1 Liquid-in-Glass Thermometer 408
9.4.2 Bimetallic Strip 408
9.4.3 Electrical Resistance Thermometer 408
9.4.4 Thermocouple 409
9.5 Vibration and Acceleration Measurement 414
9.5.1 Piezoelectric Accelerometer 421
9.6 Pressure and Flow Measurement 425
9.7 Semiconductor Sensors and Microelectromechanical Devices 425

Chapter 10
Actuators 431

10.1 Introduction 432
10.2 Electromagnetic Principles 432
10.3 Solenoids and Relays 433
10.4 Electric Motors 435
10.5 DC Motors 441
10.5.1 DC Motor Electrical Equations 444

10.5.2 Permanent Magnet DC Motor Dynamic Equations 445
10.5.3 Electronic Control of a Permanent Magnet DC Motor 447
10.6 Stepper Motors 453
10.6.1 Stepper Motor Drive Circuits 460
10.7 Selecting a Motor 463
10.8 Hydraulics 468
10.8.1 Hydraulic Valves 470
10.8.2 Hydraulic Actuators 473
10.9 Pneumatics 474

Chapter **11**
Mechatronic Systems—Control Architectures and Case Studies 478

11.1 Introduction 479
11.2 Control Architectures 479
11.2.1 Analog Circuits 479
11.2.2 Digital Circuits 480
11.2.3 Programmable Logic Controller 480
11.2.4 Microcontrollers and DSPs 482
11.2.5 Single-Board Computer 483
11.2.6 Personal Computer 483
11.3 Introduction to Control Theory 483
11.3.1 Armature-Controlled DC Motor 484
11.3.2 Open-Loop Response 486
11.3.3 Feedback Control of a DC Motor 487
11.3.4 Controller Empirical Design 491
11.3.5 Controller Implementation 492
11.3.6 Conclusion 493
11.4 Case Study 1—Myoelectrically Controlled Robotic Arm 494
11.5 Case Study 2—Mechatronic Design of a Coin Counter 507
11.6 Case Study 3—Mechatronic Design of a Robotic Walking Machine 516
11.7 List of Various Mechatronic Systems 521

Appendix **A**
Measurement Fundamentals 523

A.1 Systems of Units 523
A.1.1 Three Classes of SI Units 525
A.1.2 Conversion Factors 527
A.2 Significant Figures 528
A.3 Statistics 530
A.4 Error Analysis 533
A.4.1 Rules for Estimating Errors 534

Appendix **B**
Physical Principles 536

Appendix **C**
Mechanics of Materials 541

C.1 Stress and Strain Relations 541

Index 545