Contents

Preface to the Second Edition		ix
Prefac	e to the First Edition	xi
1 Int	roduction	1
1.1	What Is Feedback?	1
1.2	What is Feedforward?	3
1.3	What Is Control?	4
1.4	Uses of Feedback and Control	6
1.5	Feedback Properties	13
1.6	Simple Forms of Feedback	18
17	Combining Feedback with Logic	21
1.8	Control System Architectures	24
1.0	Further Beading	27
Exe	rcises	29
LAC		10
2 Fee	dback Principles	31
21	Nonlinear Static Models	31
2.2	Linear Dynamical Models	35
2.2	Using Feedback to Attenuate Disturbances	42
2.0	Using Feedback to Track Reference Signals	46
2.1	Using Feedback to Provide Robustness	49
2.0	Positive Feedback	52
2.0	Further Reading	57
Eve	raises	57
LAC	101262	01
3 Svs	tem Modeling	61
31	Modeling Concepts	61
3.2	State Space Models	69
3.3	Modeling Methodology	82
3.4	Modeling Examples	89
3.5	Further Reading	103
Eve	reises	103
LAC		100
4 Ex	amples	108
4 1	Cruise Control	108
4.2	Bicycle Dynamics	112
43	Operational Amplifier Circuits	114
4.4	Computing Systems and Networks	118
4.5	Atomic Force Microscopy	124

CONTENTS

	4.6 Drug Administration4.7 Population DynamicsExercises	127 132 133
5	Dynamic Behavior5.1Solving Differential Equations5.2Qualitative Analysis5.3Stability5.4Lyapunov Stability Analysis5.5Parametric and Nonlocal Behavior5.6Further ReadingExercises	138 138 141 144 154 165 171
6	Linear Systems6.1Basic Definitions6.2The Matrix Exponential6.3Input/Output Response6.4Linearization6.5Further ReadingExercises	175 175 179 189 202 208 208
7	State Feedback7.1Reachability7.2Stabilization by State Feedback7.3Design Considerations7.4Integral Action7.5Linear Quadratic Regulators7.6Further ReadingExercises	213 213 221 229 236 239 244 245
8	Output Feedback8.1Observability8.2State Estimation8.3Control Using Estimated State8.4Kalman Filtering8.5State Space Controller Design8.6Further ReadingExercises	248 248 253 258 264 269 278 278
9	 Transfer Functions 9.1 Frequency Domain Modeling 9.2 Determining the Transfer Function 9.3 Laplace Transforms 9.4 Block Diagrams and Transfer Functions 9.5 Zero Frequency Gain, Poles, and Zeros 9.6 The Bode Plot 9.7 Further Reading Exercises 	281 283 294 297 303 308 320 320

 10 Frequency Domain Analysis 10.1 The Loop Transfer Function 10.2 The Nyquist Criterion 10.3 Stability Margins 10.4 Bode's Relations and Minimum Phase Systems 10.5 Generalized Notions of Gain and Phase 10.6 Further Reading Exercises 	 325 328 338 342 345 350 351
11 PID Control	355
11.1 Basic Control Functions	355
11.2 Simple Controllers for Complex Systems	361
11.3 PID Tuning	364
11.4 Integral Windup	309
11.6 Further Reading	377
Exercises	377
12 Frequency Domain Design	380
12.1 Sensitivity Functions	380
12.2 Performance Specifications	385
12.3 Feedback Design via Loop Shaping	391
12.4 Feedforward Design	397
12.5 The Root Locus Method 12.6 Degign Evenuela	402
12.0 Design Example	400
Exercises	409
13 Robust Performance	413
13.1 Modeling Uncertainty	413
13.2 Stability in the Presence of Uncertainty	421
13.3 Performance in the Presence of Uncertainty	427
13.4 Design for Robust Performance	431
13.5 Further Reading	439
Exercises	440
14 Fundamental Limits	443
14.1 System Design Considerations	443
14.2 Bode's Integral Formula	447
14.3 Gain Crossover Frequency Inequality	452
14.4 The Maximum Modulus Frinciple	407
14.6 Nonlinear Effects	467
14.7 Further Reading	471
Exercises	472
Bibliography	475
Index	491