CONTENTS

PART I. INTRODUCTION AND CONTROL SYSTEM MODELING

CHAPTER 1. INTRODUCTION TO AUTOMATIC CONTROL

1.1	Feedback and Its Significance	3
1.2	Open-Loop and Closed-Loop Systems	7
1.3	Transitions and Trends	12
1.4	System Classification and Linearization	14
1.5	An Overview of Feedback Control Concepts	17
	Summary and Projection	19
	References	19
	Problems	20

CHAPTER 2. MATHEMATICAL MODELS

2.1	Models of Some Control System Components	26
2.2	Block Diagram Reductions	43
2.3	State Variable Representation	56
2.4	State Variables from Transfer Functions	64
2.5	Controllability and Observability	76
2.6	Transfer Matrices from State Variable Forms	82
2.7	Linear Transformations	84
	Summary	88
	References	88
	Problems	89

CHAPTER 3. FEEDBACK CHARACTERISTICS

3.1 Feedback Effects 102
3.2 Gain Versus Bandwidth Tradeoffs 107
3.3 Steady-State Errors 110
3.4 System Sensitivity 119
3.5 PID Control 130
3.6 Linear State Variable Feedback Control 140

Summary 144

References 144

Problems 145

PART II. CONTROL SYSTEM ANALYSIS

CHAPTER 4. TIME RESPONSE

4.1 Performance Specifications 155
4.2 Second-Order Systems 159
4.3 The *s*-Plane and Time Response 178
4.4 The State Transition Matrix 189
4.5 The Complete Solution 200
4.6 Sensitivity Equations and Error Propagation 206
4.7 PID and Linear SVFB Control Time Response 213
4.8 Controllability and Observability Revisited 220

Summary 225

References 225

Problems 226

CHAPTER 5. STABILITY ANALYSIS IN THE *s*-PLANE

5.1 Stability Definitions and Properties 234
5.2 The Routh-Hurwitz Criterion 236
5.3 The Root Locus Method 247
5.4 Angles of Departure and Breakaway Points 256

5.5 Root Loci for Negative K or Positive Feedback 272
5.6 Root Contours 287

• Summary 293

References 293

Problems 294

CHAPTER 6. STABILITY ANALYSIS IN THE FREQUENCY DOMAIN

6.1 Frequency Response Performance Specifications 305
6.2 Underdamped Second-Order Systems 309
6.3 Frequency Response Plots 315
6.4 Contour Mappings 324
6.5 The Nyquist Criterion 328
6.6 Relative Stability 349
6.7 Combined Root Locus and Nyquist Approaches 359
6.8 Closed-Loop Frequency Response 363

Summary 378

References 378

Problems 379

PART III. CONTROL SYSTEM DESIGN

CHAPTER 7. CLASSICAL DESIGN BY SERIES COMPENSATION

7.1 Design Specifications Revisited 396
7.2 The Series Compensation Approach 408
7.3 Phase-Lead Design by Root Locus 413
7.4 Phase-Lead Compensation Using Bode Diagrams 423
7.5 Phase-Lag Compensation by Root Locus 431
7.6 Phase-Lag Compensation by Bode Procedures 440
7.7 Design Comparisons and Extensions 445

Discussion and Summary 452

References 453

Problems 453

CHAPTER 8. STATE VARIABLE DESIGN USING OPTIMAL CONTROL THEORY

8.1 Reformulation of the Design Problem 458

8.2 Introduction to Optimal Control 463

8.3 Design Comparisons 476

8.4 Multivariable Optimal Control 482

8.5 Reduced-Order Observers 485

8.6 Advanced Topics in Control 488

Summary 489

References 489

Problems 490

ANSWERS TO SELECTED PROBLEMS 496

INDEX 505