
CONTENTS

PREFACE, xi

1. INTRODUCTION, 1

- 1.1 Introduction, 2
- 1.2 A History of Control Systems, 4
- 1.3 System Configurations, 8
- 1.4 Analysis and Design Objectives, 10
 - Introduction to a Case Study, 12
- 1.5 The Design Process, 15
- 1.6 Computer-Aided Design, 20
- 1.7 The Control Systems Engineer, 22
 - Summary, 23
 - Review Questions, 23
 - Problems, 24
 - Progressive Analysis and Design Problems, 28
 - Bibliography, 29

2. MODELING IN THE FREQUENCY DOMAIN, 31

- 2.1 Introduction, 32
- 2.2 Laplace Transform Review, 32
- 2.3 The Transfer Function, 42
- 2.4 Electrical Network Transfer Functions, 45
- 2.5 Translational Mechanical System Transfer Functions, 59
- 2.6 Rotational Mechanical System Transfer Functions, 66
- 2.7 Transfer Functions for Systems with Gears, 71

- 2.8 Electromechanical System Transfer Functions, 75
- 2.9 Electric Circuit Analogs, 81
- 2.10 Nonlinearities, 84
- 2.11 Linearization, 85
 - Case Studies, 90
 - Summary, 93
 - Review Questions, 93
 - Problems, 94
 - Progressive Analysis and Design Problems, 105
 - Cyber Exploration Laboratory, 106
 - Bibliography, 109

3. MODELING IN THE TIME DOMAIN, 111

- 3.1 Introduction, 112
- 3.2 Some Observations, 112
- 3.3 The General State-Space Representation, 116
- 3.4 Applying the State-Space Representation, 118
- 3.5 Converting a Transfer Function to State Space, 126
- 3.6 Converting from State Space to a Transfer Function, 133
- 3.7 Linearization, 135
 - Case Studies, 138
 - Summary, 142
 - Review Questions, 143
 - Problems, 144

- Progressive Analysis and Design Problems, 149
 - Cyber Exploration Laboratory, 150
 - Bibliography, 151
- 4. TIME RESPONSE, 153**
- 4.1 Introduction, 154
 - 4.2 Poles, Zeros, and System Response, 154
 - 4.3 First-Order Systems, 157
 - 4.4 Second-Order Systems: Introduction, 160
 - 4.5 The General Second-Order System, 165
 - 4.6 Underdamped Second-Order Systems, 168
 - 4.7 System Response with Additional Poles, 177
 - 4.8 System Response with Zeros, 181
 - 4.9 Effects of Nonlinearities upon Time Response, 187
 - 4.10 Laplace Transform Solution of State Equations, 190
 - 4.11 Time Domain Solution of State Equations, 193
 - Case Studies, 198
 - Summary, 203
 - Review Questions, 205
 - Problems, 206
 - Design Problems, 215
 - Progressive Analysis and Design Problems, 217
 - Cyber Exploration Laboratory, 218
 - Bibliography, 221
- 5. REDUCTION OF MULTIPLE SUBSYSTEMS, 223**
- 5.1 Introduction, 224
 - 5.2 Block Diagrams, 224
 - 5.3 Analysis and Design of Feedback Systems, 233
 - 5.4 Signal-Flow Graphs, 236
 - 5.5 Mason's Rule, 239
 - 5.6 Signal-Flow Graphs of State Equations, 242
 - 5.7 Alternative Representations in State Space, 244
- 5.8 Similarity Transformations, 254**
- Case Studies, 262
 - Summary, 268
 - Review Questions, 269
 - Problems, 270
 - Design Problems, 283
 - Progressive Analysis and Design Problems, 284
 - Cyber Exploration Laboratory, 285
 - Bibliography, 286
- 6. STABILITY, 287**
- 6.1 Introduction, 288
 - 6.2 Routh-Hurwitz Criterion, 291
 - 6.3 Routh-Hurwitz Criterion: Special Cases, 294
 - 6.4 Routh-Hurwitz Criterion: Additional Examples, 300
 - 6.5 Stability in State Space, 306
 - Case Studies, 309
 - Summary, 311
 - Review Questions, 311
 - Problems, 312
 - Design Problems, 317
 - Progressive Analysis and Design Problems, 319
 - Cyber Exploration Laboratory, 320
 - Bibliography, 321
- 7. STEADY-STATE ERRORS, 323**
- 7.1 Introduction, 324
 - 7.2 Steady-State Error for Unity Feedback Systems, 327
 - 7.3 Static Error Constants and System Type, 333
 - 7.4 Steady-State Error Specifications, 337
 - 7.5 Steady-State Error for Disturbances, 339
 - 7.6 Steady-State Error for Nonunity Feedback Systems, 341
 - 7.7 Sensitivity, 345
 - 7.8 Steady-State Error for Systems in State Space, 348
 - Case Studies, 352

- Summary, 355
 - Review Questions, 356
 - Problems, 357
 - Design Problems, 365
 - Progressive Analysis and Design Problems, 367
 - Cyber Exploration Laboratory, 368
 - Bibliography, 369
- 8. ROOT LOCUS TECHNIQUES, 370**
- 8.1 Introduction, 371
 - 8.2 Defining the Root Locus, 375
 - 8.3 Properties of the Root Locus, 378
 - 8.4 Sketching the Root Locus, 381
 - 8.5 Refining the Sketch, 386
 - 8.6 An Example, 395
 - 8.7 Transient Response Design via Gain Adjustment, 399
 - 8.8 Generalized Root Locus, 404
 - 8.9 Root Locus for Positive-Feedback Systems, 405
 - 8.10 Pole Sensitivity, 408
 - Case Studies, 410
 - Summary, 416
 - Review Questions, 416
 - Problems, 417
 - Design Problems, 427
 - Progressive Analysis and Design Problems, 430
 - Cyber Exploration Laboratory, 432
 - Bibliography, 433
- 9. DESIGN VIA ROOT LOCUS, 435**
- 9.1 Introduction, 436
 - 9.2 Improving Steady-State Error via Cascade Compensation, 439
 - 9.3 Improving Transient Response via Cascade Compensation, 449
 - 9.4 Improving Steady-State Error and Transient Response, 463
 - 9.5 Feedback Compensation, 476
 - 9.6 Physical Realization of Compensation, 485
 - Case Studies, 490
- Summary, 495
 - Review Questions, 496
 - Problems, 497
 - Design Problems, 503
 - Progressive Analysis and Design Problems, 510
 - Cyber Exploration Laboratory, 510
 - Bibliography, 512
- 10. FREQUENCY RESPONSE TECHNIQUES, 513**
- 10.1 Introduction, 514
 - 10.2 Asymptotic Approximations: Bode Plots, 520
 - 10.3 Introduction to the Nyquist Criterion, 539
 - 10.4 Sketching the Nyquist Diagram, 544
 - 10.5 Stability via the Nyquist Diagram, 549
 - 10.6 Gain Margin and Phase Margin via the Nyquist Diagram, 553
 - 10.7 Stability, Gain Margin, and Phase Margin via Bode Plots, 556
 - 10.8 Relation between Closed-Loop Transient and Closed-Loop Frequency Responses, 559
 - 10.9 Relation between Closed- and Open-Loop Frequency Responses, 563
 - 10.10 Relation between Closed-Loop Transient and Open-Loop Frequency Responses, 569
 - 10.11 Steady-State Error Characteristics from Frequency Response, 573
 - 10.12 Systems with Time Delay, 577
 - 10.13 Obtaining Transfer Functions Experimentally, 581
 - Case Study, 585
 - Summary, 587
 - Review Questions, 589
 - Problems, 590
 - Progressive Analysis and Design Problems, 599
 - Cyber Exploration Laboratory, 600
 - Bibliography, 601

11. DESIGN VIA FREQUENCY RESPONSE, 602

- 11.1 Introduction, 603
- 11.2 Transient Response via Gain Adjustment, 604
- 11.3 Lag Compensation, 607
- 11.4 Lead Compensation, 612
- 11.5 Lag-Lead Compensation, 618
 - Case Studies, 622
 - Summary, 625
 - Review Questions, 625
 - Problems, 626
 - Design Problems, 629
 - Progressive Analysis and Design Problems, 631
 - Cyber Exploration Laboratory, 632
 - Bibliography, 633

12. DESIGN VIA STATE SPACE, 635

- 12.1 Introduction, 636
- 12.2 Controller Design, 637
- 12.3 Controllability, 643
- 12.4 Alternative Approaches to Controller Design, 648
- 12.5 Observer Design, 653
- 12.6 Observability, 660
- 12.7 Alternative Approaches to Observer Design, 664
- 12.8 Steady-State Error Design via Integral Control, 671
 - Case Study, 674
 - Summary, 680
 - Review Questions, 681
 - Problems, 682
 - Design Problems, 686
 - Progressive Analysis and Design Problems, 689
 - Cyber Exploration Laboratory, 689
 - Bibliography, 690

13. DIGITAL CONTROL SYSTEMS, 692

- 13.1 Introduction, 693
- 13.2 Modeling the Digital Computer, 696

- 13.3 The z-Transform, 699
- 13.4 Transfer Functions, 704
- 13.5 Block Diagram Reduction, 708
- 13.6 Stability, 711
- 13.7 Steady-State Errors, 718
- 13.8 Transient Response on the z-Plane, 722
- 13.9 Gain Design on the z-Plane, 724
- 13.10 Cascade Compensation via the s-Plane, 728
- 13.11 Implementing the Digital Compensator, 731
 - Case Studies, 734
 - Summary, 739
 - Review Questions, 740
 - Problems, 741
 - Design Problems, 744
 - Progressive Analysis and Design Problems, 746
 - Cyber Exploration Laboratory, 747
 - Bibliography, 748

Appendix A List of Symbols, 750

Appendix B MATLAB Tutorial, 754

Appendix C MATLAB's Simulink Tutorial, 807

Glossary, 830

Answers to Selected Problems, 839

Credits, 845

Index, 847

Appendix D MATLAB's GUI Tools Tutorial, Web site

Appendix E MATLAB's Symbolic Math Toolbox Tutorial, Web site

Appendix F Matrices, Determinants, and Systems of Equations, Web site

F.1 Matrix Definitions and Notations

F.2 Matrix Operations

F.3 Matrix and Determinant Identities

- F.4 Systems of Equations
Bibliography**
- Appendix G Control System
Computational
Aids, Web site**
- G.1 Step Response of a System Represented
in State Space**
- G.2 Root Locus and Frequency Response**
- Appendix H Derivation of a Schematic for
a DC Motor, Web site**
- Appendix I Derivation of the Time
Domain Solution of State
Equations, Web site**
- Appendix J Solution of State Equations
for $t_0 \neq 0$, Web site**
- Appendix K Derivation of Similarity
Transformations,
Web site**
- Appendix L Root Locus Rules:
Derivations, Web site**
- L.1 Behavior of the Root Locus at Infinity**
- L.2 Derivation of Transition Method for
Breakaway and Break-in Points**
- Solutions to Skill-Assessment Exercises,
Web site**
- Control Systems Engineering Toolbox,
Web site**
- Lecture Graphics, Web site**
- Cyber Exploration Laboratory Experiments,
Web site**

Web site location is www.wiley.com/college/nise.