CONTENTS

1 INTRODUCTION 1

1.1 Models of Systems, 4
1.2 Systems, Subsystems, and Components, 7
1.3 State-Determined Systems, 9
1.4 Uses of Dynamic Models, 10

2 MULTIPORT SYSTEMS AND BOND GRAPHS 13

2.1 Engineering Multiports, 13
2.2 Ports, Bonds, and Power, 21
2.3 Bond Graphs, 24
2.4 Inputs, Outputs, and Signals, 27

3 BASIC COMPONENT MODELS 33

3.1 Basic 1-Port Elements, 33
3.2 Basic 2-Port Elements, 45
3.3 The 3-Port Junction Elements, 52
3.4 Causality Considerations for the Basic Multiports, 58
3.5 Causality and Block Diagrams, 63
3.6 Pseudo Bond Graphs and Thermal Systems, 65

4 SYSTEM MODELS 73

4.1 Electrical Systems, 74
4.2 Mechanics of Translation, 90
4.3 Fixed-Axis Rotation, 99
4.4 Hydraulic Systems, 104
4.5 Simple Transducer Models, 109

5 STATE-SPACE EQUATIONS 129

5.1 Standard Form for System Equations, 129
5.2 Augmenting the Bond Graph, 132
5.3 Basic Formulation and Reduction, 141
5.4 Extended Formulation Methods—Part 1, 150
5.5 Extended Formulation Methods—Part 2, 156
5.6 Output Variable Formulation, 162

6 ANALYSIS OF LINEAR SYSTEMS 174

6.1 Introduction, 174
6.2 Solution Techniques for Ordinary Differential Equations, 175
6.3 Free Response, 179
6.4 Forced Response, 202
6.5 Transfer Functions, 218
6.6 Total Response, 221
6.7 Other Remarks, 225

7 MULTIPORT FIELDS AND JUNCTION STRUCTURES 233

7.1 Energy-Storing Fields, 233
7.2 Resistive Fields, 258
7.3 Modulated 2-Port Elements, 263
7.4 Junction Structures, 267
7.5 Classification of Bonds and Fields, 270

8 TRANSDUCERS, AMPLIFIERS, AND INSTRUMENTS 283

8.1 Power Transducers, 284
8.2 Energy-Storing Transducers, 293
8.3 Amplifiers and Instruments, 298

9 OTHER APPLICATIONS OF MULTIPORT MODELING 317

9.1 Introduction, 317
9.2 Multiport Models in Mechanics, 317
9.3 Magnetic Circuits and Devices, 339
9.4 Thermodynamic Systems, 351
9.5 Fluid-Dynamic Systems, 366

INDEX 399