

Contents

Preface *v*

Acknowledgments *vii*

The *Nodal* Package and Disk *vii*

1 Groundwork *1*

1.1 The Symbolic Advantage *1*

1.2 Computer-Aided Engineering *2*

 1.2.1 How Do You Want CAD to Help You? *3*

 1.2.2 *Mathematica* and *Nodal* *5*

1.3 First Steps *5*

1.4 Foundation Skills *6*

 1.4.1 Basic Electronics Knowledge *6*

 1.4.2 A Little *Mathematica* *6*

 1.4.3 Differences Between Linear and Nonlinear Circuit Analysis *7*

 1.4.4 Netlists *7*

 1.4.5 Value Scaling with Qualifiers *11*

 1.4.6 Naming of Objects *14*

 1.4.7 On-Line Help *14*

 1.4.8 Options *16*

 1.4.9 Layout and Style *17*

1.5 Error Messages *18*

1.6 Summary *19*

1.7 References *19*

2 DC Circuits *21*

2.1 Voltage and Current in Resistive Circuits *21*

 2.1.1 Mesh Analysis *26*

 2.1.2 Multistate DC Circuits *33*

2.2 Power-Conversion Utilities *36*

2.3 Attenuator Design *41*

2.4 Nonlinear DC Circuits	43
2.4.1 Device Characterization Using Experimental Data	44
2.4.2 Nonlinear Circuit Analysis	52
2.5 Summary	59
2.6 Exercises	59
2.7 References	60
 3 Small-Signal Circuits I: Introduction	 61
3.1 Magnitude and Phase Calculation in RLC Circuits	61
3.1.1 Elementary Technique	61
3.1.2 Mesh Analysis	68
3.1.3 Nodal Analysis	71
3.2 Small-Signal Analysis Techniques	74
3.2.1 Preparation for Analysis	74
3.2.2 Dynamic and Static Device Properties	76
3.3 Analysis of Circuits Containing Active Devices	79
3.3.1 Voltage-Controlled Voltage Sources	79
3.3.2 Operational Amplifiers	83
3.3.3 Voltage-Controlled Current Sources	85
3.3.4 Current-Controlled Current Sources	89
3.3.5 Current-Controlled Voltage Sources	89
3.4 Device-Equivalent Circuits	90
3.4.1 The FET Model	90
3.4.2 The BJT Model	91
3.5 Oscillators and Feedback Network Design	92
3.6 Summary	97
3.7 Exercises	97
3.8 References	98
 4 Small-Signal Circuits II: Multiport Analysis	 99
4.1 Introduction to the Analysis Method	100
4.1.1 Y-Parameters	100
4.1.2 Z-Parameters	101

4.1.3 ABCD-Parameters	102
4.1.4 Parameter Calculation	102
4.2 Matrix Analysis with <i>Mathematica</i>	105
4.3 General Matrix Analysis	112
4.3.1 ABCD-Matrices	113
4.4 Matrix Transformations	115
4.4.1 Object-Oriented Technique	116
4.5 CAD Program	117
4.6 S-Parameters	121
4.6.1 Reflections and Matched Terminations	122
4.6.2 Use of S-Parameters in Analysis	123
4.6.3 Conversion of Z-Parameters to S-Parameters	127
4.6.4 Properties of S-Parameters	128
4.7 Summary	131
4.8 Exercises	131
4.9 References	132
5 Component Design and Sensitivity Analysis	133
5.1 Component Value Functions and Utilities	133
5.2 RLC Filter Design	134
5.3 What-If Sensitivity Analysis	138
5.4 Differential Sensitivity Analysis	145
5.5 Cost Minimization	148
5.6 Summary	150
5.7 Exercises	151
6 Time Series and Spectral Analysis	153
6.1 Time Series	153
6.1.1 Generation of Time Series	153
6.1.2 Statistical Analysis and Plotting	154
6.1.3 Generation of Time Series with Specific Noise Properties	157

6.1.4 Correlation and Convolution	160
6.1.5 Synthesis of Functions	163
6.2 Fourier Analysis	165
6.3 Frequency-Domain Filtering	167
6.4 Summary	169
6.5 Exercises	170
6.6 References	170
7 s-Domain (Laplace) Analysis	171
7.1 Laplacian Description of Signals	171
7.2 s-Domain Transfer Functions	173
7.3 Visualization of Pole-Zero Descriptions	174
7.4 Determination of Circuit Impulse and Step Responses	176
7.5 Summary	186
7.6 Exercises	186
7.7 References	187
8 Filter Design	189
8.1 Transfer Functions	189
8.1.1 The Butterworth Response	191
8.1.2 The Chebyshev Response	192
8.1.3 Pole-Zero Locations	193
8.1.4 Component Values	196
8.2 Transformations	199
8.2.1 Impedance Scaling	199
8.2.2 Frequency Scaling	201
8.2.3 High-Pass Transformation	204
8.2.4 Band-Pass Transformation	206
8.3 Basic Synthesis	210
8.3.1 Singly Terminated Synthesis	211
8.3.2 Component Values by Continued Fraction Expansion	211

8.4 Advanced Synthesis	215
8.4.1 Doubly Terminated Synthesis	216
8.4.2 Spectral Factorization	216
8.4.3 A Butterworth Example	219
8.4.4 Pole-Zero Extraction	220
8.4.5 Design by Optimization	224
8.5 Digital Filtering	230
8.5.1 Sampling of Signals	231
8.5.2 Mapping of s - to z -Plane	233
8.5.3 Infinite Impulse Response Filters	233
8.5.4 Finite Impulse Response Filters	238
8.6 Summary	241
8.7 Exercises	241
8.8 References	242

9 High-Frequency Circuits and Analysis 245

9.1 The Smith Chart	245
9.1.1 Impedance and Reflection	245
9.1.2 Generation of a Smith Chart	248
9.1.3 Smith Chart Function	250
9.2 Stability Analysis Using S-Parameters	254
9.2.1 Device K Factor	255
9.2.2 CAD and the Stability Factor	256
9.3 Stability Circles	258
9.3.1 Gain Circles	260
9.3.2 A Gain Circle Example	263
9.4 Matching-Network Design	265
9.4.1 Smith Chart Impedance Traces	265
9.4.2 Smith Chart Admittance Traces	267
9.4.3 Matching-Network Design	268
9.4.4 Design Evaluation with Nodal	271
9.5 System Design	273
9.5.1 Cascade Analysis Mathematics	274
9.5.2 A Cascade-Analysis Program	276
9.5.3 Plotting the Cascade Analysis	279
9.5.4 Drawing the Cascade	280

9.6 Summary	281
9.7 Exercises	282
9.8 References	283
10 Noise Analysis	285
10.1 Random Signals	285
10.1.1 White Noise	286
10.1.2 Brown Noise	290
10.1.3 Pink Noise	292
10.2 Autocorrelation and Power	295
10.3 Multiple Signals and Correlation Matrices	299
10.3.1 The Correlation Matrix	300
10.3.2 Resistor Noise	300
10.3.3 Circuit Noise	301
10.4 Noise Matrix Analysis	304
10.4.1 Noise Matrix Description	304
10.4.2 Converting Correlation Z-Matrix to Y-Matrix	305
10.4.3 The Correlation ABCD-Matrix	308
10.5 Noise Figure	310
10.5.1 Signal-to-Noise Degradation	310
10.5.2 Noise Figure and Noise Sources	311
10.5.3 Noise Figure Relationships	313
10.6 Noise Solutions with Nodal	315
10.7 Summary	317
10.8 Exercises	317
10.9 References	318
Appendix	319
A.1 <i>Mathematica</i> Functions	319
A.1.1 Syntax	319
A.1.2 Numbers	320
A.1.3 Lists	320
A.1.4 Manipulating Lists	320

A.1.5 Basic Arithmetic Operations	321
A.1.6 Complex Numbers	321
A.1.7 Rule Symbol and Replacement	321
A.1.8 Manipulating Expressions	321
A.1.9 Prefix, Infix, and Postfix Forms of Operators	322
A.1.10 Matrix Multiplication	322
A.1.11 User-Defined Functions	322
A.1.12 Reading Data from ASCII Files	322
A.1.13 Fitting Data to Functions	322
A.1.14 Manipulating Equations	322
A.1.15 Calculus	323
A.1.16 Anonymous Functions	323
A.1.17 Random Number Generation	323
A.1.18 Laplace Transform	324
A.1.19 Manipulating Polynomials	324
A.2 Nodal Components, Functions, Utilities, and Constants	324
A.2.1 Components	324
A.2.2 <i>Nodal</i> Functions	331
A.2.3 <i>Nodal</i> Utilities	333
A.3 Graphics	340
A.3.1 Lists	340
A.3.2 Log Plots	343
A.3.3 Adding a Legend	344
A.3.4 Multiline Plots	345
A.3.5 Magnitude and Phase Plots	346
A.3.6 Polar Plots	348
A.3.7 Smith Charts	351
A.4 Importing Data	351
A.5 Exporting Data	357
A.6 Example Code Usage	359
A.7 Complex Algebra	366
Index	371