
Contents

1	Block diagram algebra and system transfer functions	1
1.1	Fundamentals	1
1.1.1	List of symbols	1
1.1.2	Laplace transform and Laplace domain	1
1.1.3	Transfer function	2
1.1.4	Block diagram	2
1.1.5	Block diagram algebra	3
1.2	Worked examples	3
1.3	Proposed exercises	9
1.4	Block diagram analysis using computer packages	20
1.4.1	MATLAB	20
1.4.2	SCILAB	24
1.4.3	OCTAVE	26
2	Mathematical models	29
2.1	Fundamentals	29
2.1.1	List of symbols	29
2.1.2	Modeling of electrical systems	31
2.1.3	Modeling of mechanical systems	32
2.1.4	Modeling of liquid-level systems	36
2.1.5	Modeling of thermal systems	38
2.2	Worked examples	39
2.2.1	Electrical systems	39
2.2.2	Mechanical systems	40
2.2.3	Liquid-level systems	42
2.2.4	Thermal systems	45
2.3	Proposed exercises	47
2.3.1	Electrical systems	47
2.3.2	Mechanical systems	53
2.3.3	Liquid-level systems	60
2.3.4	Thermal systems	68
3	Analysis of continuous systems in the time domain	73
3.1	Fundamentals	73
3.1.1	List of symbols	73
3.1.2	Time response of a continuous LTI system	74
3.1.3	Time response of first-order systems	74

3.1.4	Time response of second-order systems	77
3.1.5	Routh's stability criterion	84
3.1.6	Steady-state errors	85
3.2	Worked examples	86
3.2.1	Routh–Hurwitz criterion	86
3.2.2	Transient response	87
3.2.3	Steady-state errors	89
3.3	Proposed exercises	89
3.3.1	Routh–Hurwitz criterion	89
3.3.2	Transient response	94
3.3.3	Steady-state errors	102
3.4	Time response analysis using computer packages	107
3.4.1	MATLAB	108
3.4.2	SCILAB	110
3.4.3	OCTAVE	112
4	Root-locus analysis	115
4.1	Fundamentals	115
4.1.1	List of symbols	115
4.1.2	Root-locus preliminaries	115
4.1.3	Root-locus practical sketching rules ($K \geq 0$)	117
4.1.4	Root-locus practical sketching rules ($K \leq 0$)	118
4.2	Solved problems	119
4.3	Proposed problems	124
4.4	Root-locus analysis using computer packages	131
4.4.1	MATLAB	131
4.4.2	SCILAB	132
4.4.3	OCTAVE	133
5	Frequency domain analysis	135
5.1	Fundamentals	135
5.1.1	List of symbols	135
5.1.2	Frequency response preliminaries	136
5.1.3	Bode diagram	136
5.1.4	Nyquist diagram	137
5.1.5	Nichols diagram	139
5.1.6	Nyquist stability	139
5.1.7	Relative stability	140
5.2	Solved problems	142
5.2.1	Bode diagram and phase margins	142
5.2.2	Nyquist and Nichols diagrams	145
5.3	Proposed problems	148
5.3.1	Bode diagram and phase margins	148
5.3.2	Nyquist and Nichols diagrams	160

5.3.3	Root-locus and frequency domain analysis	164
5.4	Frequency domain analysis using computer packages	173
5.4.1	MATLAB	173
5.4.2	SCILAB	177
5.4.3	OCTAVE	181
6	PID controller synthesis	185
6.1	Fundamentals	185
6.1.1	List of symbols	185
6.1.2	The PID controller	185
6.1.3	PID tuning	187
6.2	Solved problems	190
6.3	Proposed problems	191
7	State space analysis of continuous systems	195
7.1	Fundamentals	195
7.1.1	List of symbols	195
7.1.2	State space representation	196
7.1.3	The Cayley–Hamilton theorem	203
7.1.4	Matrix exponential	203
7.1.5	Computation of the matrix exponential	204
7.1.6	Solution of the state-space equation	206
7.1.7	Controllability	207
7.1.8	Observability	207
7.2	Solved problems	207
7.3	Proposed problems	215
7.4	State space analysis of continuous systems using computer packages	237
7.4.1	MATLAB	237
7.4.2	SCILAB	240
7.4.3	OCTAVE	242
8	Controller synthesis by pole placement	245
8.1	Fundamentals	245
8.1.1	List of symbols	245
8.1.2	Pole placement using an input–output representation	246
8.1.3	Preliminaries of pole placement in state space	248
8.1.4	Calculation of the feedback gain	250
8.1.5	Estimating the system state	250
8.1.6	Calculation of the state estimator gain	252
8.1.7	Simultaneous pole placement and state estimation	253
8.2	Solved problems	254
8.2.1	Pole placement using an input–output representation	254
8.2.2	Pole placement in state space	256

8.3	Proposed problems	257
8.3.1	Pole placement using an input–output representation	257
8.3.2	Pole placement in state space	262
9	Discrete-time systems and $\mathcal{Z}$-transform	265
9.1	Fundamentals	265
9.1.1	List of symbols	265
9.1.2	Discrete-time systems preliminaries	266
9.1.3	The $\mathcal{Z}$ -transform	267
9.1.4	Discrete-time models	268
9.1.5	Controllability and observability	271
9.1.6	Stability and the Routh–Hurwitz criterion	272
9.2	Solved problems	272
9.3	Proposed problems	276
9.4	Discrete-time systems and $\mathcal{Z}$ -transform analysis using computer packages	283
9.4.1	MATLAB	283
9.4.2	SCILAB	285
9.4.3	OCTAVE	286
10	Analysis of nonlinear systems with the describing function method	287
10.1	Fundamentals	287
10.1.1	List of symbols	287
10.1.2	The describing function	287
10.1.3	Describing functions of common nonlinearities	288
10.1.4	Nonlinear systems analysis	288
10.2	Solved problems	290
10.3	Proposed problems	292
10.4	Describing function method using computer packages	310
10.4.1	MATLAB	311
10.4.2	SCILAB	313
10.4.3	OCTAVE	315
11	Analysis of nonlinear systems with the phase plane method	317
11.1	Fundamentals	317
11.1.1	List of symbols	317
11.1.2	Phase plane method preliminaries	317
11.1.3	Singular points	318
11.1.4	Limit cycles	319
11.2	Solved problems	320
11.3	Proposed problems	324
11.4	Phase plane analysis using computer packages	336
11.4.1	MATLAB	336
11.4.2	SCILAB	337
11.4.3	OCTAVE	339

12 Fractional order systems and controllers	341
12.1 Fundamentals	341
12.1.1 List of symbols	341
12.1.2 Grünwald–Letnikov definition	341
12.1.3 Riemann–Liouville definition	342
12.1.4 Equivalence of definitions and Laplace transforms	343
12.1.5 Caputo definition	343
12.1.6 Fractional transfer functions	344
12.1.7 Fractional controllers	346
12.1.8 Integer approximations	346
12.2 Solved problems	347
12.3 Proposed problems	352
12.4 Fractional control using computer packages	358
12.4.1 MATLAB	358
12.4.2 SCILAB	361
12.4.3 OCTAVE	363
Appendix A	365
Solutions	379
References	433
Index	435