

Contents

PREFACE	xi
1 OPERATIONAL AMPLIFIERS	1
1.1 An Overview	1
1.2 Review of Bipolar Junction Transistors and Field Effect Transistors	3
1.3 Basic Differential Amplifiers	18
1.4 High-Gain Stage	34
1.5 Level-Shifting Amplifier	35
1.6 Output Stage	36
1.7 Biasing Techniques in Integrated Circuits	38
1.8 Analysis of a Complete Operational Amplifier	43
1.9 Feedback, Stability, and Compensation	54
1.10 Gain and Bandwidth of Finite Gain Amplifiers	79
1.11 Unity Gain Crossover Frequency, Full Power Response Frequency, and Slew Rate	82
1.12 Conclusions	86
References	86
Exercises	87
Appendix 1A: Spice Program Listings of Small-Signal Circuits of the Op Amp Circuit	93
	vii

2	APPROXIMATION PROBLEM AND TRANSFORMATIONS	95
2.1	Classification of Signal Processing Networks	96
2.2	Approximation Problem	100
2.3	Maximally Flat Approximation	103
2.4	Equiripple Approximation	109
2.5	Elliptic Approximation	114
2.6	Frequency Transformations	117
2.7	Conclusions	135
	Reference	136
	Exercises	136
	Appendix 2A: Program MAXCHY	138
	Appendix 2B: Program ELIPFT	141
3	SENSITIVITY ANALYSIS	144
3.1	Definition of Sensitivity	145
3.2	Function Sensitivity	146
3.3	Coefficient Sensitivity	151
3.4	Root Sensitivity	152
3.5	ω_p and Q_p Sensitivities	154
3.6	Function and Pole Sensitivities in Terms of ω_p and Q_p Sensitivities	160
3.7	Active Sensitivity	166
3.8	Predistortion	177
3.9	Conclusions	186
	References	187
	Exercises	187
	Appendix 3A: Program ROOT FINDER	189
4	ACTIVE FILTERS WITH FINITE GAIN AMPLIFIERS	192
4.1	Amplifier Filters	193
4.2	Active Lowpass Filters Using Noninverting Finite Gain Amplifiers	195
4.3	Sallen and Key Bandpass Filter	206
4.4	Sallen and Key Highpass Filter	214
4.5	Filter Network for Realizing $j\omega$ -Axis Zeros	215

4.6	Higher-Order Filters	219
4.7	Filters with Zero Active Pole Sensitivity	224
4.8	Conclusions	240
	Exercises	240
	Appendix 4A: Program SKLPN	243
	Appendix 4B: Program SKBPN	247
	Appendix 4C: Program THIRD	251
5	ACTIVE FILTERS USING A SINGLE OPERATIONAL AMPLIFIER	252
5.1	Second-Order Lowpass, Bandpass, and Highpass Filters	253
5.2	Notch Filters	259
5.3	Single-Amplifier Filter Networks with Both Negative and Positive Feedback	262
5.4	Actively Compensated Single-Amplifier Biquads	291
5.5	Conclusions	303
	References	303
	Exercises	303
	Appendix 5A: Program SALPN	306
	Appendix 5B: Program SABPN	310
6	MULTIPLE-AMPLIFIER FILTERS	314
6.1	Generalized Impedance Converter Circuits	314
6.2	Sensitivity Properties of Simulated Inductance and Frequency-Dependent Negative Resistance Elements	321
6.3	Biquads Derived from Generalized Impedance Converter Circuits	325
6.4	Integrators and Their Properties	332
6.5	Integrator Filters	343
6.6	Realization of Finite Transmission Zeros Using Double-Integrator Loops	359
6.7	A Three-Amplifier Biquad Derived from a Generalized Impedance Converter	364
6.8	Conclusions	368
	References	369
	Exercises	370
	Appendix 6A: Program GICBPN	374
	Appendix 6B: Program KHNB	377
	Appendix 6C: Program THN	380

7	HIGHER-ORDER ACTIVE FILTERS	383
7.1	Cascade Realizations	385
7.2	Follow-the-Leader Feedback Technique	397
7.3	Component Simulation of <i>LC</i> Ladders	403
7.4	Leapfrog Realizations	411
7.5	Conclusions	421
	References	422
	Exercises	423
	Appendix 7A: Program PRBN	426
8	SWITCHED CAPACITOR FILTERS	429
8.1	Sampled-data Signals and z Transforms	431
8.2	Waveforms and the Analysis of Switched Capacitor Filters	438
8.3	Synthesis Techniques	450
8.4	Switched Capacitor Resistor Equivalents	451
8.5	Analysis of Switched Capacitor Networks Using z -Domain Equivalent Circuits	460
8.6	Second-Order Switched Capacitor Filters	472
8.7	Higher-Order Switched Capacitor Filters	492
8.8	Conclusions	497
	References	498
	Exercises	499
	Bibliography	503
	Index	505