

Contents

Preface	VII
Chapter One: Circuit and System Fundamentals	1
1.1.0. Introduction	1
1.2.0. Thévenin's and Norton's Theorems	3
1.2.1. Thévenin and Norton Parameters	7
1.2.2. Engineering Observations	9
1.3.0. Dependent Sources and Amplifier Concepts	20
1.3.1. Voltage Amplifier	21
1.3.2. Transconductor	25
1.3.3. Transresistor	27
1.3.4. Current Amplifier	30
1.3.5. Buffers	32
1.3.5.1. Voltage Buffer	34
1.3.5.2. Current Buffer	40
1.3.6. Load Power Considerations	45
1.3.6.1. Maximum Power Transfer	48
1.3.6.2. The dBm Power Measure	50
1.3.6.3. Match Termination and Tuned Responses	51
1.4.0. Second Order Circuits and Systems	57
1.4.1. Second Order Filters	58
1.4.2. Frequency Response	63
1.4.2.1. Response Peaking	65
1.4.2.2. Bandwidth	66
1.4.2.3. Phase and Delay Responses	69

1.4.3. Poles and Second Order System	
Parameters	75
1.4.4. Time Domain Transient Responses	78
1.4.4.1. Impulse Response	79
1.4.4.2. Step Response	82
Exercises	89

Chapter Two: Two-Port Network Models and Analysis

111

2.1.0. Introduction	111
2.2.0. Two-Port Linearity Issues	112
2.3.0. Generalized Two-Port Parameters	117
2.3.1. Hybrid h -Parameters	118
2.3.1.1. Ideal Current Amplifier	122
2.3.1.2. Parameter Measurement Issues	124
2.3.2. Hybrid g -Parameters	128
2.3.2.1. g - and h -Parameter Interrelationships	130
2.3.2.2. Ideal Voltage Amplifier	132
2.3.3. Short Circuit y -Parameters	135
2.3.3.1. π -Type Network Model	137
2.3.3.2. Ideal Transconductor	141
2.3.3.3. Indefinite Admittance Matrix	142
2.3.4. Open Circuit z -Parameters	146
2.3.4.1. Tee-Type Network Model	148
2.3.4.2. Ideal Transresistor	149
2.3.5. Transmission Parameters	151
2.3.5.1. Input and Output Impedances	153
2.3.5.2. Voltage Transfer Function	154
2.3.5.3. Cascade Interconnection	154
2.3.5.4. Series and Shunt Branch Elements	156
2.4.0. Two-Port Methods of Circuit Analysis	158
2.4.1. Circuit Analysis in Terms of h -Parameters	159
2.4.1.1. Open Loop Gain and Loop Gain Concepts	160
2.4.1.2. I/O Impedances	164

2.4.2.	Circuit Analysis Via g -Parameters	167
2.4.3.	Circuit Analysis in Terms of y -Parameters	169
2.4.4.	Circuit Analysis in Terms of z -Parameters	171
2.4.5.	Generalized Analytical Disclosures	176
2.5.0.	Systems of Interconnected Two Ports	177
2.5.1.	Series-Shunt Feedback Architecture	178
2.5.2.	Shunt-Series Feedback	186
2.5.3.	Shunt-Shunt Feedback	188
2.5.4.	Series-Series Feedback	189
2.6.0.	Power Flow and Transfer	191
2.6.1.	Power Gain Expressions	192
2.6.2.	Stability Considerations	195
2.6.3.	Maximum Transducer Gain	201
2.6.4.	Unilateralization	204
	2.6.4.1. Shunt-Antiphase Shunt Compensation	204
	2.6.4.2. Shunt-Antiphase Shunt Network Realization	206
	References	208
	Exercises	208

Chapter Three: Scattering Parameters

225

3.1.0.	Introduction	225
3.2.0.	Reflection Coefficient	227
3.2.1.	Voltage Scattering	228
3.2.2.	Power Scattering	229
3.2.3.	Significance of the Reflection Coefficient	230
3.3.0.	Two-Port Scattering Parameters	239
3.3.1.	Parameters S_{11} and S_{21}	241
3.3.2.	Parameters S_{22} and S_{12}	243
3.3.3.	Port Voltage and Current Generalizations	244
3.3.4.	Scattering Analysis of a Generalized Two-Port	244
	3.3.4.1. Input and Output Reflection Coefficients	245
	3.3.4.2. Voltage Transfer Function	247
	3.3.4.3. Other Transfer Functions	249
3.3.5.	Scattering and Conventional Parameters	250

- 3.3.5.1. *S*-Parameters in Terms of *h*-Parameters 250
- 3.3.5.2. *h*-Parameters in Terms of Scattering Parameters 252
- 3.4.0. Lossless Two-Port Networks 255
 - 3.4.1. Average Power Delivered to Complex Load 256
 - 3.4.2. Average Power Delivered to Two-Port Network 258
 - 3.4.3. Lossless, Passive Two-Port Network 260
- References 266
- Exercises 266

Chapter Four: Feedback Circuit and System Theory 277

- 4.1.0. Introduction 277
- 4.2.0. System Level Model of Feedback Circuit 277
- 4.3.0. Feedback Network Frequency Response 285
 - 4.3.1. Single Pole Open Loop Transfer Function 286
 - 4.3.2. Second Order Open Loop Transfer Function 288
 - 4.3.3. Stability Issues 291
 - 4.3.3.1. Phase Margin 292
 - 4.3.3.2. Gain Margin 295
 - 4.3.3.3. Alternative Damping and Undamped Frequency Expressions 297
 - 4.3.4. Compensation for Closed Loop Stability 300
- 4.4.0. Time Domain Response 306
 - 4.4.1. Unit Step Response 306
 - 4.4.2. Settling Time 308
- References 312
- Exercises 312

Chapter Five: Signal Flow Methods of Feedback Network Analysis 321

- 5.1.0. Introduction 321
- 5.2.0. Feedback Network Analysis Fundamentals 322

5.2.1.	Calculation of Feedback Network Parameters	326
5.2.1.1.	Null Parameter Gain	327
5.2.1.2.	Normalized Return Ratio	328
5.2.1.3.	Normalized Null Return Ratio	330
5.2.2.	Input and Output Impedances	337
5.2.2.1	Driving Point Input Impedance	337
5.2.2.2	Driving Point Output Impedance	340
5.2.3	Output Port-to-Local Port Feedback	345
5.3.0	Special Case Feedback Network Examples	348
5.3.1.	Global Feedback	348
5.3.1.1.	Transimpedance Feedback Amplifier	348
5.3.1.2.	Transadmittance Feedback Amplifier	352
5.3.1.3.	Voltage Feedback Amplifier	354
5.3.1.4.	Current Feedback Amplifier	357
5.3.2.	Other Feedback Architectures	366
5.3.2.1.	Feedback Branch Admittance	366
5.3.2.2.	Feedback Branch Impedance	377
5.3.3.	Dual Loop Feedback	385
5.3.4	Series-Series/Shunt-Shunt Feedback	388
5.3.4.1.	Analysis of the Series-Series/Shunt-Shunt Feedback Pair	390
5.3.4.2.	Interpretation of Results and Design Considerations	398
5.3.5.	Series-Shunt/Shunt-Series Feedback	405
5.3.5.1.	Analysis of the Series-Shunt/Shunt-Series Feedback Pair	405
5.3.5.2.	Design Restrictions	416
	References	420
	Exercises	420

Chapter Six: Multiple Loop Feedback Amplifiers 441

6.1.0.	Introduction	441
6.2.0.	Indefinite Admittance Matrix	442
6.2.1.	Return Difference	448
6.2.2.	Null Return Difference	454
6.3.0.	Network Functions and Feedback	456

6.3.1. Blackman's Formula	457
6.3.2. Sensitivity Function	463
6.4.0. Measurement of Return Difference	467
6.4.1. Blecher's Procedure	469
6.4.2. Impedance Measurements	472
6.5.0. Multiloop Feedback	475
6.5.1. Multiloop Feedback Theory	476
6.5.2. Return Difference Matrix	480
6.5.3. Null Return Difference Matrix	482
6.5.4. Transfer Function Matrix	484
6.5.5. Sensitivity Matrix	488
6.5.6. Multi-Parameter Sensitivity	492
References	495

Chapter Seven: Analog MOS Technology Circuits 497

7.1.0. Introduction	497
7.2.0. MOS Transistor Models	499
7.2.1. Transistor Cross-Section and Electrical Symbol	500
7.2.2. Static Volt-Ampere Relationships	504
7.2.2.1. Cutoff	505
7.2.2.2. Ohmic Electrical Regime	509
7.2.2.3. Saturation Regime	512
7.2.3. Small Signal Models	514
7.2.3.1. Small Signal Model at High Frequencies	518
7.2.3.2. Unity Gain Frequency	522
7.3.0. Common Source Amplifier	524
7.3.1. Voltage Transfer Function	526
7.3.1.1. Poles and Time Constants	528
7.3.1.2. Miller-Limited Frequency Response	532
7.3.1.3. Output Port Time Constant Dominance	540
7.3.2. Input and Output Impedances	542
7.3.3. Variants of the Common Source Topology	544
7.3.3.1. NMOS Load	544
7.3.3.2. PMOS Load	548

7.4.0. Common Drain Amplifier	552
7.4.1. Source Follower Transfer Function	555
7.4.2. Source Follower I/O Impedances	560
7.5.0. Common Gate Amplifier	568
7.5.1. Common Gate I/O Characteristics	571
7.5.2. Common Source-Common Gate Cascode	575
7.5.3. Enhanced Common Gate Cell	581
7.5.3.1. Low Frequency Circuit Properties	584
7.5.3.2. High Frequency Circuit Properties	585
7.5.3.3. Integrator Application	591
References	604
Exercises	605

Chapter Eight: MOS Technology Operational Amplifiers 629

8.1.0. Introduction	629
8.2.0. Op-Amp System Architectures	630
8.2.1. Single Stage Architecture	630
8.2.2. Two-Stage Architecture	632
8.2.3. Input Stage Transconductor	634
8.3.0. CMOS Input Stage Analysis	637
8.3.1. P-Channel Transconductor	638
8.3.1.1. Transconductor Small Signal Analysis	640
8.3.1.2. Transconductor Output Macromodel	642
8.3.1.3. First Stage Output Macromodel	651
8.3.1.4. First Stage Static Analysis	654
8.3.2. N-Channel Transconductor	656
8.4.0. Phase Inverting Second Stage	657
8.4.1. Low Frequency Small Signal Analysis	658
8.4.2. Op-Amp Static Analysis	660
8.5.0. Frequency Compensation	661
8.5.1. Approximate High Frequency Analysis	662
8.5.2. Miller Compensation	664
8.5.3. Improved Frequency Compensation	669
8.5.3.1. Buffered Capacitive Feedback	670

8.5.3.2. Passive Highpass Feedback	677
8.6.0. Slew Rate Limitations	684
8.6.1. Fundamentals of Slew Rate Issues	685
8.6.2. Slew Rate Limiting due to Nonlinearity	688
8.6.3. Full Power Bandwidth	690
8.7.0. Biasing Subcircuits	691
8.7.1. Active Divider	692
8.7.2. Supply-Independent Biasing	702
References	710
Exercises	711

Chapter Nine: Broadband and Radio

Frequency MOS Technology Amplifiers

729

9.1.0. Introduction	729
9.2.0. Cascade of Dominant Pole Amplifiers	731
9.2.1. Bandwidth of N -Stage Cascade	732
9.2.2. Optimized Bandwidth of a Cascade	734
9.3.0. Degenerative RC Broadbanding	736
9.3.1. Gain and Dominant Pole	737
9.3.2. Broadband Compensation	742
9.4.0. Shunt Peaked Compensation	748
9.4.1. Common Source Stage Revisited	749
9.4.2. Shunt Peaked Amplifier Response	753
9.4.2.1. Maximally Flat Magnitude Response	756
9.4.2.2. Maximally Flat Delay Response	762
9.5.0. Series Peaked Compensation	765
9.5.1. Second Order Compensated Response	767
9.5.2. Third Order Compensated Response	768
9.6.0. Series-Shunt Peaked Compensation	771
9.6.1. Design Criteria	772
9.6.2. A Design Problem	774
9.6.2.1. Capacitance Bridged, Coupled Inductor Load	776
9.6.2.2. Constant Resistance Criteria	778
9.6.2.3. Transfer Relationship	781
9.7.0. Broadbanding via Feedback	787
9.7.1. Low Frequency Characteristics	789

9.7.2. Amplifier Bandwidth	793
9.7.3. Input Impedance	795
9.7.4. Input Impedance Compensation	797
9.7.5. Output Impedance	806
9.8.0. The f_T -Doubler	812
9.8.1. Small Signal Analysis	813
9.8.2. Realization of the f_T -Doubler	815
9.9.0. Bandpass Feedback Amplifier	816
9.9.1. Common Source RF Amplifier	821
9.9.2. Impedance and Transfer Characteristics	824
9.9.2.1. Gate Impedance	825
9.9.2.2. Voltage Transfer Function	832
References	841
Exercises	842

Index