

Overview

Part I. Device Models and Basic Circuits	1
1. Diodes	3
2. Bipolar Transistors	33
3. Field Effect Transistors	169
4. Amplifiers	269
5. Operational Amplifiers	483
6. Latching Circuits	587
7. Logic Families	611
8. Combinatorial Circuits	635
9. Sequential Logic Systems	659
10. Semiconductor Memories	689
 Part II. General Applications	 723
11. Operational Amplifier Applications	725
12. Controlled Sources and Impedance Converters	767
13. Active Filters	787
14. Signal Generators	843
15. Power Amplifiers	867
16. Power Supplies	885
17. Analog Switches and Sample-and-Hold Circuits	929
18. Digital-Analog and Analog-Digital Converters	945
19. Digital Filters	987
20. Measurement Circuits	1031
21. Sensors and Measurement Systems	1059
22. Electronic Controllers	1103
23. Optoelectronic Components	1127
 Part III. Communication Circuits	 1147
24. Basics	1149
25. Transmitters and Receivers	1237
26. Passive Components	1283
27. High-Frequency Amplifiers	1321
28. Mixers	1363
29. Appendix	1431
Bibliography	1525
Index	1529

Contents

Part I. Device Models and Basic Circuits	1
1. Diodes	3
1.1 Performance of the Diode	4
1.1.1 Characteristic Curve	4
1.1.2 Description by Equations	5
1.1.3 Switching Performance	8
1.1.4 Small-Signal Response	10
1.1.5 Limit Values and Reverse Currents	11
1.1.6 Thermal Performance	12
1.1.7 Temperature Sensitivity of Diode Parameters	12
1.2 Construction of a Diode	13
1.2.1 Discrete Diode	13
1.2.2 Integrated Diode	15
1.3 Model of a Diode	16
1.3.1 Static Performance	16
1.3.2 Dynamic Performance	19
1.3.3 Small-Signal Model	22
1.4 Special Diodes and Their Application	24
1.4.1 Zener Diode	24
1.4.2 Pin Diode	27
1.4.3 Varactor Diodes	28
1.4.4 Bridge Rectifier	30
1.4.5 Mixer	31
2. Bipolar Transistors	33
2.1 Performance of a Bipolar Transistor	34
2.1.1 Characteristics	34
2.1.2 Description by Way of Equations	36
2.1.3 Characteristic of the Current Gain	37
2.1.4 Operating Point and Small-Signal Response	39
2.1.5 Limit Data and Reverse Currents	45
2.1.6 Thermal Performance	49
2.1.7 Temperature Sensitivity of Transistor Parameters	53
2.2 Design of a Bipolar Transistor	54
2.2.1 Discrete Transistors	55
2.2.2 Integrated Transistors	56

2.3	Models of Bipolar Transistors	58
2.3.1	Static Performance	58
2.3.2	Dynamic Performance	68
2.3.3	Small-Signal Model	73
2.3.4	Noise	82
2.4	Basic Circuits	95
2.4.1	Common-Emitter Circuit	96
2.4.2	Common-Collector Circuit	131
2.4.3	Common-Base Circuit	148
2.4.4	Darlington Circuit	159
3.	Field Effect Transistors	169
3.1	Behavior of a Field Effect Transistor	170
3.1.1	Characteristic Curves	172
3.1.2	Description by Equations	175
3.1.3	Field Effect Transistor as an Adjustable Resistor	179
3.1.4	Operating Point and Small-Signal Behavior	181
3.1.5	Maximum Ratings and Leakage Currents	185
3.1.6	Thermal Behavior	189
3.1.7	Temperature Sensitivity of FET Parameters	189
3.2	Construction of the Field Effect Transistor	192
3.2.1	Integrated MOSFETs	192
3.2.2	Discrete MOSFETs	194
3.2.3	Junction FETs	197
3.2.4	Cases	197
3.3	Models of Field Effect Transistors	197
3.3.1	Static Behavior	198
3.3.2	Dynamic Behavior	206
3.3.3	Small-Signal Model	215
3.3.4	Noise	222
3.4	Basic Circuits	229
3.4.1	Common-Source Circuit	230
3.4.2	Common-Drain Circuit	252
3.4.3	Common-Gate Circuit	261
4.	Amplifiers	269
4.1	Circuits	271
4.1.1	Current Sources and Current Mirrors	277
4.1.2	Cascode circuit	312
4.1.3	Differential Amplifier	327
4.1.4	Impedance Converters	385
4.1.5	Circuits for Setting the Operating Point	395
4.2	Properties and Parameters	408

4.2.1	Characteristics	409
4.2.2	Small-Signal Characteristics	412
4.2.3	Nonlinear Parameters	426
4.2.4	Noise	443
5.	Operational Amplifiers	483
5.1	General	483
5.1.1	Types of Operational Amplifier	484
5.1.2	Principle of Negative Feedback	487
5.2	Normal Operational Amplifier (VV-OPA)	491
5.2.1	Principle	492
5.2.2	Multipurpose Amplifiers	494
5.2.3	Operating Voltages	497
5.2.4	Single-Supply Amplifiers	498
5.2.5	Rail-to-Rail Amplifiers	500
5.2.6	Wide-Band Operational Amplifiers	504
5.2.7	Frequency Compensation	509
5.2.8	Parameters of Operational Amplifiers	523
5.3	Transconductance Amplifier (VC-OPA)	540
5.3.1	Internal Construction	541
5.3.2	Typical Applications	543
5.4	Transimpedance Amplifier (CV-OPA)	544
5.4.1	Internal Design	545
5.4.2	Frequency Response	550
5.4.3	Typical Applications	551
5.5	The Current Amplifier (CC-OPA)	552
5.5.1	The Internal Design	552
5.5.2	Typical Applications	554
5.6	Comparison	568
5.6.1	Practical Implementation	570
5.6.2	Types	572
6.	Latching Circuits	587
6.1	Transistor as Switch	587
6.2	Latching Circuits Using Saturated Transistors	590
6.2.1	Bistable Circuits	591
6.2.2	Monostable Circuits	593
6.2.3	Astable Circuits (Multivibrators)	594
6.3	Latching Circuits with Emitter-Coupled Transistors	595
6.3.1	Emitter-Coupled Schmitt Trigger	595
6.3.2	Emitter-Coupled Multivibrator	595
6.4	Latching Circuits Using Gates	597
6.4.1	Flip-Flops	597

6.4.2	One-Shot	597
6.4.3	Multivibrator	598
6.5	Latching Circuits Using Comparators	600
6.5.1	Comparators	600
6.5.2	Schmitt Trigger	601
6.5.3	Multivibrators	604
6.5.4	One-Shots	607
7.	Logic Families	611
7.1	Basic Logic Functions	611
7.2	Construction of Logic Functions	614
7.2.1	Karnaugh Map	615
7.3	Extended Functions	617
7.4	Circuit Implementation of the Basic Functions	618
7.4.1	Resistor-Transistor Logic (RTL)	619
7.4.2	Diode-Transistor Logic (DTL)	620
7.4.3	High-Level Logic (HLL)	620
7.4.4	Transistor-Transistor Logic (TTL)	621
7.4.5	Emitter-Coupled Logic (ECL)	624
7.4.6	Complementary MOS Logic (CMOS)	627
7.4.7	NMOS Logic	631
7.4.8	Summary	631
7.5	Connecting Lines	633
8.	Combinatorial Circuits	635
8.1	Number Representation	636
8.1.1	Positive Integers in Straight Binary Code	636
8.1.2	Positive Integers in BCD Code	637
8.1.3	Binary Integers of Either Sign	637
8.1.4	Fixed-Point Binary Numbers	640
8.1.5	Floating-Point Binary Numbers	640
8.2	Multiplexer – Demultiplexer	643
8.2.1	1-of-n Decoder	643
8.2.2	Demultiplexer	644
8.2.3	Multiplexer	645
8.3	Priority Decoder	646
8.4	Combinatorial Shift Register (Barrel Shifter)	647
8.5	Digital Comparators	648
8.6	Adders	650
8.6.1	Half-Adder	650
8.6.2	Full-Adder	651
8.6.3	Look-Ahead Carry Logic	652
8.6.4	Subtraction	654

8.6.5	Two's-Complement Overflow	654
8.6.6	Addition and Subtraction of Floating-Point Numbers	655
8.7	Multipliers	656
8.7.1	Multiplication of Fixed-Point Numbers	656
8.7.2	Multiplication of Floating-Point Numbers	658
9.	Sequential Logic Systems	659
9.1	Integrated Flip-Flops	659
9.1.1	Transparent Flip-Flops	659
9.1.2	Flip-Flops with Intermediate Storage	661
9.2	Straight Binary Counters	666
9.2.1	Asynchronous Straight Binary Counters	667
9.2.2	Synchronous Straight Binary Counters	667
9.2.3	Up-Down Counters	669
9.3	BCD Counters	673
9.3.1	Asynchronous BCD Counters	673
9.3.2	Synchronous BCD Counters	674
9.4	Presetable Counters	675
9.5	Shift Registers	676
9.5.1	Basic Circuit	676
9.5.2	Shift Registers with Parallel Inputs	677
9.6	Processing of Asynchronous Signals	677
9.6.1	Debouncing of Mechanical Contacts	678
9.6.2	Edge-Triggered RS Flip-Flops	678
9.6.3	Pulse Synchronization	679
9.6.4	Synchronous One-Shot	680
9.6.5	Synchronous Edge Detector	681
9.6.6	Synchronous Clock Switch	681
9.7	Systematic Design of Sequential Circuits	682
9.7.1	State Diagram	682
9.7.2	Example for a Programmable Counter	684
9.8	Dependency notation	686
10.	Semiconductor Memories	689
10.1	Random Access Memories (RAMs)	690
10.1.1	Static RAMs	690
10.1.2	Dynamic RAMs	693
10.2	RAM Expansions	697
10.2.1	Two-Port Memories	697
10.2.2	RAMs as Shift Registers	698
10.2.3	First-In-First-Out Memories (FIFO)	700
10.2.4	Error Detection and Correction	702
10.3	Read-Only Memories (ROMs)	706

10.3.1	Mask-Programmed ROMs (MROMs)	706
10.3.2	Programmable ROMs (PROMs)	706
10.3.3	UV-Erasable PROMs (EPROMs)	707
10.3.4	Electrically Erasable PROMs (EEPROMs)	709
10.4	Programmable Logic Devices (PLDs)	711
10.4.1	Programmable Logic Array (PAL)	714
10.4.2	Computer-Aided PLD Design	715
10.4.3	Survey of Types Available	717
10.4.4	User Programmable Gate Arrays	719

Part II. General Applications **723**

11. Operational Amplifier Applications	725
11.1 Summing Amplifier	725
11.2 Subtracting Circuits	726
11.2.1 Reduction to an Addition	726
11.2.2 Subtraction Using a Single Operational Amplifier	727
11.3 Bipolar-Coefficient Circuit	729
11.4 Integrators	730
11.4.1 Inverting Integrator	730
11.4.2 Initial Condition	733
11.4.3 Summing Integrator	734
11.4.4 Noninverting Integrator	734
11.5 Differentiators	735
11.5.1 Basic Circuit	735
11.5.2 Practical Implementation	736
11.5.3 Differentiator with High Input Impedance	737
11.6 Solving Differential Equations	738
11.7 Function Networks	739
11.7.1 Logarithm	740
11.7.2 Exponential Function	743
11.7.3 Computation of Power Functions Using Logarithms	744
11.7.4 Sine and Cosine Functions	745
11.7.5 Arbitrary Function Networks	750
11.8 Analog Multipliers	753
11.8.1 Multipliers with Logarithmic Amplifiers	753
11.8.2 Transconductance Multipliers	754
11.8.3 Multipliers Using Electrically Controlled Resistors	759
11.8.4 Adjustment of Multipliers	761
11.8.5 Expansion to Four-Quadrant Multipliers	761
11.8.6 Multiplier as a Divider or Square Rooter	762
11.9 Transformation of Coordinates	763

11.9.1	Transformation from Polar to Cartesian Coordinates	763
11.9.2	Transformation from Cartesian to Polar Coordinates	764
12.	Controlled Sources and Impedance Converters	767
12.1	Voltage-Controlled Voltage Sources	767
12.2	Current-Controlled Voltage Sources	768
12.3	Voltage-Controlled Current Sources	769
12.3.1	Current Sources for Floating Loads	769
12.3.2	Current Sources for Grounded Loads	771
12.3.3	Precision Current Sources Using Transistors	772
12.3.4	Floating Current Sources	777
12.4	Current-Controlled Current Sources	778
12.5	NIC (Negative Impedance Converter)	779
12.6	Gyrator	781
12.7	Circulator	784
13.	Active Filters	787
13.1	Basic Theory of Lowpass Filters	787
13.1.1	Butterworth Lowpass Filters	791
13.1.2	Chebyshev Lowpass Filters	793
13.1.3	Bessel Lowpass Filters	796
13.1.4	Summary of the Theory	805
13.2	Lowpass/Highpass Transformation	806
13.3	Realization of First-Order Lowpass and Highpass Filters	807
13.4	Realization of Second-Order Lowpass and Highpass Filters	809
13.4.1	<i>LRC</i> Filters	809
13.4.2	Filters with Multiple Negative Feedback	809
13.4.3	Filter with Single Positive Feedback	810
13.5	Realization of Higher-Order Lowpass and Highpass Filters	813
13.6	Lowpass/Bandpass Transformation	815
13.6.1	Second-Order Bandpass Filters	816
13.6.2	Fourth-Order Bandpass Filters	816
13.7	Realization of Second-Order Bandpass Filters	819
13.7.1	<i>LRC</i> Bandpass Filter	820
13.7.2	Bandpass Filter with Multiple Negative Feedback	820
13.7.3	Bandpass Filter with Single Positive Feedback	822
13.8	Lowpass/Bandstop Filter Transformation	823
13.9	Realization of Second-Order Bandstop Filters	824
13.9.1	<i>LRC</i> Bandstop Filter	824
13.9.2	Active Parallel- <i>T</i> Bandstop Filter	825
13.9.3	Active Wien–Robinson Bandstop Filter	825
13.10	Allpass Filters	826
13.10.1	Basic Principles	826

13.10.2	Realization of First-Order Allpass Filters	829
13.10.3	Realization of Second-Order Allpass Filters	829
13.11	Adjustable Universal Filters	831
13.12	Switched Capacitor Filters	836
13.12.1	Principle	836
13.12.2	SC Integrator	836
13.12.3	First-Order SC Filter	837
13.12.4	Second-Order SC Filters	838
13.12.5	Implementation of SC Filters with ICs	840
13.12.6	General Considerations for Using SC Filters	840
13.12.7	A Survey of Available Types	840
14.	Signal Generators	843
14.1	LC Oscillators	843
14.1.1	Condition for Oscillation	843
14.1.2	Meissner Oscillator	845
14.1.3	Hartley Oscillator	846
14.1.4	Colpitts Oscillator	847
14.1.5	Emitter-Coupled LC Oscillator	847
14.1.6	Push-Pull Oscillators	848
14.2	Crystal Oscillators	849
14.2.1	Electrical Characteristics of a Quartz Crystal	849
14.2.2	Fundamental Frequency Oscillators	850
14.2.3	Harmonic Oscillators	852
14.3	Wien-Robinson Oscillator	853
14.4	Differential-Equation Oscillators	857
14.5	Function Generators	859
14.5.1	Basic Arrangement	860
14.5.2	Practical Implementation	861
14.5.3	Function Generators with a Controllable Frequency	862
14.5.4	Simultaneously Producing Sine and Cosine Signals	864
15.	Power Amplifiers	867
15.1	Emitter Follower as a Power Amplifier	867
15.2	Complementary Emitter Followers	869
15.2.1	Complementary Class-B Emitter Follower	869
15.2.2	Complementary Class-AB Emitter Followers	871
15.2.3	Generation of the Bias Voltage	872
15.3	Complementary Darlington Circuits	874
15.4	Complementary Source Followers	875
15.5	Current Limitation	876
15.6	Four-Quadrant Operation	878
15.7	Design of a Power Output Stage	879

15.8	Driver Circuits with Voltage Gain	882
15.9	Boosting the Output Current of Integrated Operational Amplifiers	884
16.	Power Supplies	885
16.1	Properties of Power Transformers	885
16.2	Power Rectifiers	886
16.2.1	Half-Wave Rectifier	886
16.2.2	Bridge Rectifier	887
16.2.3	Center-Tap Rectifier	891
16.3	Linear Voltage Regulators	892
16.3.1	Basic Regulator	892
16.3.2	Voltage Regulators with a Fixed Output Voltage	893
16.3.3	Voltage Regulators with an Adjustable Output Voltage	895
16.3.4	A Voltage Regulator with a Reduced Dropout Voltage	896
16.3.5	A Voltage Regulator for Negative Voltages	897
16.3.6	Symmetrical Division of a Floating Voltage	898
16.3.7	Voltage Regulator with Sensor Terminals	899
16.3.8	Bench Power Supplies	900
16.3.9	IC Voltage Regulators	901
16.4	Reference Voltage Generation	901
16.4.1	Zener Diode References	901
16.4.2	Bandgap Reference	904
16.4.3	Types	906
16.5	Switched-Mode Power Supplies	907
16.6	Secondary Switching Regulators	908
16.6.1	Step-Down Converters	908
16.6.2	Generating the Switching Signal	911
16.6.3	Step-Up Converters	913
16.6.4	Inverting Converter	914
16.6.5	Charge Pump Converter	914
16.6.6	Integrated Switching Regulators	915
16.7	Primary Switching Regulators	916
16.7.1	Single-Ended Converters	917
16.7.2	Push-Pull Converters	918
16.7.3	High-Frequency Transformers	920
16.7.4	Power Switches	921
16.7.5	Generating the Switching Signals	924
16.7.6	Loss Analysis	925
16.7.7	IC Drive Circuits	926
17.	Analog Switches and Sample-and-Hold Circuits	929
17.1	Principle	929

17.2	Electronic Switches	930
17.2.1	FET Switch	930
17.2.2	Diode Switch	933
17.2.3	Bipolar Transistor Switch	935
17.2.4	Differential Amplifier Switch	937
17.3	Analog Switches Using Amplifiers	939
17.3.1	Analog Switches for High Voltages	940
17.3.2	Amplifier with Switchable Gain	940
17.4	Sample-and-Hold Circuits	941
17.4.1	Basic Principles	941
17.4.2	Practical Implementation	943
18.	Digital-Analog and Analog-Digital Converters	945
18.1	Sampling Theorem	945
18.1.1	Practical Aspects	947
18.2	Resolution	950
18.3	Principles of D/A Conversion	951
18.4	D/A Converters in CMOS Technology	952
18.4.1	Summation of Weighted Currents	952
18.4.2	D/A Converters with Double-Throw Switches	952
18.4.3	Ladder Network	953
18.4.4	Inverse Operation of a Ladder Network	954
18.5	A Ladder Network for Decade Weighting	955
18.6	D/A Converters in Bipolar Technology	956
18.7	D/A Converters for Special Applications	958
18.7.1	Processing Signed Numbers	958
18.7.2	Multiplying D/A Converters	960
18.7.3	Dividing D/A Converters	960
18.7.4	D/A Converter as Function Generator	961
18.8	Accuracy of DA Converters	963
18.8.1	Static Errors	963
18.8.2	Dynamic Characteristics	964
18.9	Principles of A/D Conversion	966
18.10	Design of A/D Converters	967
18.10.1	Parallel Converter	967
18.10.2	Two Step Converters	969
18.10.3	Successive Approximation	972
18.10.4	Counting Method	975
18.10.5	Oversampling	979
18.11	Errors in AD-Converters	983
18.11.1	Static Errors	983
18.11.2	Dynamic Errors	984
18.12	Comparison of AD-Converters	985

19. Digital Filters	987
19.1 Digital Transfer Function	988
19.1.1 Time Domain Analysis	988
19.1.2 Frequency Domain Analysis	988
19.2 Basic Structures	991
19.3 Design Analysis of FIR Filters	994
19.3.1 Basic Equations	995
19.3.2 Simple Examples	996
19.3.3 Calculating the Filter Coefficients	1000
19.4 Realization of FIR Filters	1013
19.4.1 Realization of FIR Filters Using the Parallel Method	1014
19.4.2 Realization of FIR Filters Using the Serial Method	1014
19.5 Design of IIR Filters	1015
19.5.1 Calculating the Filter Coefficients	1016
19.5.2 IIR Filters in a Cascade Structure	1018
19.6 Realization of IIR Filters	1022
19.6.1 Construction from Simple Building Blocks	1022
19.6.2 Design Using LSI Devices	1025
19.7 Comparison of FIR and IIR Filters	1027
20. Measurement Circuits	1031
20.1 Measurement of Voltage	1031
20.1.1 Impedance Converter	1031
20.1.2 Measurement of Potential Difference	1032
20.1.3 Isolation Amplifiers	1037
20.2 Measurement of Current	1040
20.2.1 Floating Zero-Resistance Ammeter	1040
20.2.2 Measurement of Current at High Potentials	1041
20.3 AC/DC Converters	1042
20.3.1 Measurement of the Mean Absolute Value	1042
20.3.2 Measurement of the rms Value	1046
20.3.3 Measurement of the Peak Value	1050
20.3.4 Synchronous Demodulator	1053
21. Sensors and Measurement Systems	1059
21.1 Temperature Measurement	1059
21.1.1 Metals as PTC Thermistors	1062
21.1.2 Silicon-Based PTC Thermistors	1062
21.1.3 NTC Thermistors	1063
21.1.4 Operation of Resistive Temperature Detectors	1063
21.1.5 Transistors as Temperature Sensors	1068
21.1.6 Thermocouple	1071
21.1.7 An Overview of Types	1075

21.2	Pressure Measurement	1076
21.2.1	Design of Pressure Sensors	1077
21.2.2	The Operation of Temperature-Compensated Pressure Sensors ..	1079
21.2.3	Temperature Compensation for Pressure Sensors	1082
21.2.4	Commercially Available Pressure Sensors	1085
21.3	Humidity Measurement	1086
21.3.1	Humidity Sensors	1087
21.3.2	Interfacing Circuits for Capacitive Humidity Sensors	1088
21.4	The Transmission of Sensor Signals	1090
21.4.1	Electrical (Direct-Coupled) Signal Transmission	1090
21.4.2	Electrically Isolated Signal Transmission	1093
21.5	Calibration of Sensor Signals	1094
21.5.1	Calibration of the Analog Signal	1095
21.5.2	Computer-Aided Calibration	1098
22.	Electronic Controllers	1103
22.1	Underlying Principles	1103
22.2	Controller Types	1104
22.2.1	P-controller	1104
22.2.2	PI-Controller	1106
22.2.3	PID-Controller	1108
22.2.4	The PID-Controller with Adjustable Parameters	1110
22.3	Control of Nonlinear Systems	1112
22.3.1	Static Nonlinearity	1112
22.3.2	Dynamic Nonlinearity	1113
22.4	Phase-Locked Loop	1114
22.4.1	Sample-and-Hold Circuit as a Phase Detector	1116
22.4.2	Synchronous Demodulator as a Phase Detector	1118
22.4.3	The Frequency-Sensitive Phase Detector	1120
22.4.4	The Phase Detector with an Extensible Measuring Range	1122
22.4.5	The PLL as a Frequency Multiplier	1123
23.	Optoelectronic Components	1127
23.1	Basic Photometric Terms	1127
23.2	Photoconductive Cells	1129
23.3	Photodiodes	1130
23.4	Phototransistors	1132
23.5	Light-Emitting Diodes	1133
23.6	Optocouplers	1134
23.7	Visual Displays	1134
23.7.1	Binary Displays	1135
23.7.2	Analog Displays	1136
23.7.3	Numerical Displays	1138

23.7.4	Multiplex Displays	1139
23.7.5	Alphanumeric Displays	1141

Part III. Communication Circuits **1147**

24. Basics	1149
24.1 Telecommunication Systems	1149
24.2 Transmission Channels	1152
24.2.1 Cable	1152
24.2.2 Radio Communication	1163
24.2.3 Fibre Optic Links	1168
24.2.4 Comparison of Transmission Channels	1173
24.3 Reflection Coefficient and S Parameters	1174
24.3.1 Wave Parameters	1174
24.3.2 Reflection Coefficient	1175
24.3.3 Wave Source	1181
24.3.4 S Parameters	1183
24.4 Modulation Methods	1191
24.4.1 Amplitude Modulation	1194
24.4.2 Frequency Modulation	1202
24.4.3 Digital Modulation Methods	1209
24.5 Multiple Use and Grouping of Communication Channels	1227
24.5.1 Multiplex Operation	1227
24.5.2 Duplex Operation	1234
25. Transmitters and Receivers	1237
25.1 Transmitters	1237
25.1.1 Transmitters with Analogue Modulation	1237
25.1.2 Transmitters with Digital Modulation	1243
25.1.3 Generating Local Oscillator Frequencies	1244
25.2 Receivers	1245
25.2.1 Direct-Detection Receivers	1246
25.2.2 Superheterodyne Receivers	1247
25.2.3 Gain Control	1253
25.2.4 Dynamic Range of a Receiver	1259
25.2.5 Receivers for Digital Modulation	1265
26. Passive Components	1283
26.1 High-Frequency Equivalent Circuits	1283
26.1.1 Resistor	1284
26.1.2 Inductor	1286
26.1.3 Capacitor	1288
26.2 Filters	1289

26.2.1	LC-Filters	1290
26.2.2	Dielectric Filters	1296
26.2.3	SAW Filters	1298
26.3	Circuits for Impedance Transformation	1301
26.3.1	Impedance Matching	1301
26.3.2	Coupling	1311
26.4	Power Splitters and Hybrids	1314
26.4.1	Power Splitter	1315
26.4.2	Hybrids	1316
27.	High-Frequency Amplifiers	1321
27.1	Integrated High-Frequency Amplifiers	1321
27.1.1	Impedance Matching	1322
27.1.2	Noise Figure	1324
27.2	High-Frequency Amplifiers with Discrete Transistors	1327
27.2.1	Generalized Discrete Transistor	1327
27.2.2	Setting the Operating Point (Biasing)	1329
27.2.3	Impedance Matching for a Single-Stage Amplifier	1332
27.2.4	Impedance Matching in Multi-stage Amplifiers	1338
27.2.5	Neutralization	1340
27.2.6	Special Circuits for Improved Impedance Matching	1343
27.2.7	Noise	1346
27.3	Broadband Amplifiers	1349
27.3.1	Principle of a Broadband Amplifier	1349
27.3.2	Design of a Broadband Amplifier	1351
27.4	Power Gain	1354
27.4.1	Direct Power Gain	1355
27.4.2	Insertion Gain	1356
27.4.3	Transfer Gain	1357
27.4.4	Available Power Gain	1358
27.4.5	Comparison of Gain Definitions	1358
27.4.6	Gain with Impedance Matching at Both Sides	1359
27.4.7	Maximum Power Gain with Transistors	1360
28.	Mixers	1363
28.1	Functional Principle of an Ideal Mixer	1363
28.1.1	Up-Conversion Mixer	1364
28.1.2	Down-Conversion Mixer	1365
28.2	Functional Principles of Practical Mixers	1367
28.2.1	Additive Mixing	1367
28.2.2	Multiplicative Mixers	1376
28.3	Mixers with Diodes	1381
28.3.1	Unbalanced Diode Mixer	1381

28.3.2	Single Balanced Diode Mixers	1391
28.3.3	Double Balanced Diode Mixer	1395
28.3.4	Diode Mixers in Practical Use	1401
28.4	Mixers with Transistors	1404
28.4.1	Single Balanced Mixer	1404
28.4.2	Double Balanced Mixer (Gilbert Mixer)	1417
29.	Appendix	1431
29.1	PSpice – Brief User’s Guide	1431
29.1.1	General	1431
29.1.2	Programs and Files	1431
29.1.3	A Simple Example	1434
29.1.4	Further Examples	1450
29.1.5	Integrating Other Libraries	1455
29.1.6	Some Typical Errors	1457
29.2	ispLEVER – Brief User’s Guide	1459
29.2.1	Outline	1459
29.2.2	Circuit Entry	1461
29.2.3	Pin Assignment	1475
29.2.4	Simulation	1479
29.2.5	Optimization	1484
29.2.6	Programming	1484
29.2.7	Outlook	1487
29.3	Passiv RC and LRC Networks	1488
29.3.1	The Lowpass Filter	1488
29.3.2	The Highpass Filter	1491
29.3.3	Compensated Voltage Divider	1494
29.3.4	Passive RC Bandpass Filter	1495
29.3.5	Wien–Robinson Bridge	1495
29.3.6	Parallel-T Filter	1497
29.3.7	Resonant Circuit	1498
29.4	Definitions and Nomenclature	1500
29.5	Types of the 7400 Digital Families	1508
29.6	Standard Series	1515
29.7	Color code	1516
29.8	Manufacturers	1518
	Bibliography	1525
	Index	1529