

BRIEF TABLE OF CONTENTS

PART I

SEMICONDUCTOR DEVICES AND BASIC APPLICATIONS 1

Chapter 1
Semiconductor Materials and Diodes 3

Chapter 2
Diode Circuits 49

Chapter 3
The Bipolar Junction Transistor 97

Chapter 4
Basic BJT Amplifiers 163

Chapter 5
The Field-Effect Transistor 243

Chapter 6
Basic FET Amplifiers 313

Chapter 7
Frequency Response 383

Chapter 8
Output Stages and Power Amplifiers 469

PART II

ANALOG ELECTRONICS 519

Chapter 9
The Ideal Operational Amplifier 521

Chapter 10
Integrated Circuit Biasing and Active Loads 577

Chapter 11
Differential and Multistage Amplifiers 639

Chapter 12
Feedback and Stability 727

Chapter 13
Operational Amplifier Circuits 817

Chapter 14
Nonideal Effects in Operational Amplifier Circuits 871

Chapter 15
Applications and Design of Integrated Circuits 923

Brief Table of Contents

PART III

DIGITAL ELECTRONICS 1001

Chapter 16
MOSFET Digital Circuits 1003

Chapter 17
Bipolar Digital Circuits 1113

Appendixes 1173
Index 1211

C O N T E N T S

PART I

SEMICONDUCTOR DEVICES AND BASIC APPLICATIONS 1

Chapter 1

Semiconductor Materials and Diodes 3

- 1.0 Preview 3**
- 1.1 Semiconductor Materials and Properties 4**
 - 1.1.1 Intrinsic Semiconductors 4
 - 1.1.2 Extrinsic Semiconductors 7
 - 1.1.3 Drift and Diffusion Currents 9
 - 1.1.4 Excess Carriers 11
- 1.2 The pn Junction 12**
 - 1.2.1 The Equilibrium pn Junction 12
 - 1.2.2 Reverse-Biased pn Junction 14
 - 1.2.3 Forward-Biased pn Junction 16
 - 1.2.4 Ideal Current-Voltage Relationship 17
 - 1.2.5 pn Junction Diode 18
- 1.3 Diode Circuits: DC Analysis and Models 23**
 - 1.3.1 Iteration and Graphical Analysis Techniques 24
 - 1.3.2 Piecewise Linear Model 27
 - 1.3.3 Computer Simulation and Analysis 30
 - 1.3.4 Summary of Diode Models 31
- 1.4 Diode Circuits: AC Equivalent Circuit 31**
 - 1.4.1 Sinusoidal Analysis 31
 - 1.4.2 Small-Signal Equivalent Circuit 35
- 1.5 Other Diode Types 35**
 - 1.5.1 Solar Cell 35
 - 1.5.2 Photodiode 36
 - 1.5.3 Light-Emitting Diode 36
 - 1.5.4 Schottky Barrier Diode 37
 - 1.5.5 Zener Diode 39
- 1.6 Summary 41**
- Checkpoint 41**
- Review Questions 41**
- Problems 42**
- Computer Simulation Problems 47**
- Design Problems 47**

Contents

Chapter 2

Diode Circuits 49**2.0 Preview 49****2.1 Rectifier Circuits 50**

2.1.1 Half-Wave Rectification 50

Problem-Solving Technique: Diode Circuits 51

2.1.2 Full-Wave Rectification 53

2.1.3 Filters, Ripple Voltage, and Diode Current 56

2.1.4 Voltage Doubler Circuit 63

2.2 Zener Diode Circuits 64

2.2.1 Ideal Voltage Reference Circuit 64

2.2.2 Zener Resistance and Percent Regulation 67

2.3 Clipper and Clamper Circuits 68

2.3.1 Clippers 68

2.3.2 Clampers 72

2.4 Multiple-Diode Circuits 75

2.4.1 Example Diode Circuits 75

Problem-Solving Technique: Multiple Diode Circuits 79

2.4.2 Diode Logic Circuits 80

2.5 Photodiode and LED Circuits 82

2.5.1 Photodiode Circuit 82

2.5.2 LED Circuit 83

2.6 Summary 85**Checkpoint 85****Review Questions 86****Problems 86****Computer Simulation Problems 94****Design Problems 95**

Chapter 3

The Bipolar Junction Transistor 97**3.0 Preview 97****3.1 Basic Bipolar Junction Transistor 97**

3.1.1 Transistor Structures 98

3.1.2 npn Transistor: Forward-Active Mode Operation 99

3.1.3 pnp Transistor: Forward-Active Mode Operation 104

3.1.4 Circuit Symbols and Conventions 105

3.1.5 Current-Voltage Characteristics 107

3.1.6 Nonideal Transistor Leakage Currents and Breakdown Voltage 110

3.2 DC Analysis of Transistor Circuits 113

3.2.1 Common-Emitter Circuit 114

3.2.2 Load Line and Modes of Operation 117

Problem-Solving Technique: Bipolar DC Analysis 120

3.2.3	Common Bipolar Circuits: DC Analysis	121
3.3	Basic Transistor Applications	131
3.3.1	Switch	131
3.3.2	Digital Logic	133
3.3.3	Amplifier	134
3.4	Bipolar Transistor Biasing	138
3.4.1	Single Base Resistor Biasing	138
3.4.2	Voltage Divider Biasing and Bias Stability	140
3.4.3	Integrated Circuit Biasing	145
3.5	Multistage Circuits	147
3.6	Summary	150
	Checkpoint	151
	Review Questions	151
	Problems	151
	Computer Analysis Problems	160
	Design Problems	161

Chapter 4

Basic BJT Amplifiers 163

4.0	Preview	163
4.1	Analog Signals and Linear Amplifiers	163
4.2	The Bipolar Linear Amplifier	165
4.2.1	Graphical Analysis and AC Equivalent Circuit	166
4.2.2	Small-Signal Hybrid- π Equivalent Circuit of the Bipolar Transistor	170
	Problem-Solving Technique: Bipolar AC Analysis	175
4.2.3	Hybrid- π Equivalent Circuit, Including the Early Effect	176
4.2.4	Expanded Hybrid- π Equivalent Circuit	180
4.2.5	Other Small-Signal Parameters and Equivalent Circuits	180
4.3	Basic Transistor Amplifier Configurations	185
4.4	Common-Emitter Amplifiers	189
4.4.1	Basic Common-Emitter Amplifier Circuit	190
4.4.2	Circuit with Emitter Resistor	192
4.4.3	Circuit with Emitter-Bypass Capacitor	196
4.4.4	Advanced Common-Emitter Amplifier Concepts	199
4.5	AC Load Line Analysis	200
4.5.1	AC Load Line	200
4.5.2	Maximum Symmetrical Swing	203
	Problem-Solving Technique: Maximum Symmetrical Swing	204
4.6	Common-Collector (Emitter-Follower) Amplifier	205
4.6.1	Small-Signal Voltage Gain	205
4.6.2	Input and Output Impedance	207
4.6.3	Small-Signal Current Gain	209

4.7	Common-Base Amplifier	214
4.7.1	Small-Signal Voltage and Current Gains	214
4.7.2	Input and Output Impedance	216
4.8	The Three Basic Amplifiers: Summary and Comparison	218
4.9	Multistage Amplifiers	219
4.9.1	Multistage Analysis: Cascade Configuration	219
4.9.2	Cascode Configuration	223
4.10	Power Considerations	226
4.11	Summary	229
	Checkpoint	229
	Review Questions	229
	Problems	230
	Computer Simulation Problems	241
	Design Problems	242
	Chapter 5	
	The Field-Effect Transistor	243
5.0	Preview	243
5.1	MOS Field-Effect Transistor	243
5.1.1	Two-Terminal MOS Structure	244
5.1.2	n-Channel Enhancement-Mode MOSFET	246
5.1.3	Ideal MOSFET Current-Voltage Characteristics	248
5.1.4	Circuit Symbols and Conventions	253
5.1.5	Additional MOSFET Structures and Circuit Symbols	253
5.1.6	Summary of Transistor Operation	258
5.1.7	Nonideal Current-Voltage Characteristics	259
5.2	MOSFET DC Circuit Analysis	262
5.2.1	Common-Source Circuit	263
5.2.2	Load Line and Modes of Operation	267
	Problem-Solving Technique: MOSFET DC Analysis	268
5.2.3	Common MOSFET Configurations: DC Analysis	269
5.2.4	Constant-Current Source Biasing	281
5.3	Basic MOSFET Applications: Switch, Digital Logic Gate, and Amplifier	283
5.3.1	NMOS Inverter	283
5.3.2	Digital Logic Gate	285
5.3.3	MOSFET Small-Signal Amplifier	287
5.4	Junction Field-Effect Transistor	287
5.4.1	pn JFET and MESFET Operation	288
5.4.2	Current-Voltage Characteristics	292
5.4.3	Common JFET Configurations: DC Analysis	295
5.5	Summary	301
	Checkpoint	302
	Review Questions	302

Problems	303
Computer Simulation Problems	311
Design Problems	311

Chapter 6

Basic FET Amplifiers	313
6.0 Preview	313
6.1 The MOSFET Amplifier	313
6.1.1 Graphical Analysis, Load Lines, and Small-Signal Parameters	314
6.1.2 Small-Signal Equivalent Circuit	318
Problem-Solving Technique: MOSFET AC Analysis	320
6.1.3 Modeling the Body Effect	322
6.2 Basic Transistor Amplifier Configurations	323
6.3 The Common-Source Amplifier	324
6.3.1 A Basic Common-Source Configuration	324
6.3.2 Common-Source Amplifier with Source Resistor	329
6.3.3 Common-Source Circuit with Source Bypass Capacitor	331
6.4 The Source-Follower Amplifier	334
6.4.1 Small-Signal Voltage Gain	334
6.4.2 Input and Output Impedance	339
6.5 The Common-Gate Configuration	341
6.5.1 Small-Signal Voltage and Current Gains	341
6.5.2 Input and Output Impedance	343
6.6 The Three Basic Amplifier Configurations: Summary and Comparison	345
6.7 Single-Stage Integrated Circuit MOSFET Amplifiers	345
6.7.1 NMOS Amplifier with Enhancement Load	345
6.7.2 NMOS Amplifier with Depletion Load	350
6.7.3 NMOS Amplifier with PMOS Load	353
6.8 Multistage Amplifiers	355
6.8.1 DC Analysis	356
6.8.2 Small-Signal Analysis	360
6.9 Basic JFET Amplifiers	362
6.9.1 Small-Signal Equivalent Circuit	362
6.9.2 Small-Signal Analysis	364
6.10 Summary	368
Checkpoint	368
Review Questions	369
Problems	370
Computer Simulation Problems	380
Design Problems	380

Contents

Chapter 7

Frequency Response 383

7.0 Preview 383

7.1 Amplifier Frequency Response 384

- 7.1.1 Equivalent Circuits 384
- 7.1.2 Frequency Response Analysis 385

7.2 System Transfer Functions 386

- 7.2.1 s -Domain Analysis 386
- 7.2.2 First-Order Functions 388
- 7.2.3 Bode Plots 388
- 7.2.4 Short-Circuit and Open-Circuit Time Constants 394

7.3 Frequency Response: Transistor Amplifiers with Circuit Capacitors 398

- 7.3.1 Coupling Capacitor Effects 398
- Problem-Solving Technique: Bode Plot of Gain Magnitude 404
- 7.3.2 Load Capacitor Effects 405
- 7.3.3 Coupling and Load Capacitors 407
- 7.3.4 Bypass Capacitor Effects 410
- 7.3.5 Combined Effects: Coupling and Bypass Capacitors 414

7.4 Frequency Response: Bipolar Transistor 416

- 7.4.1 Expanded Hybrid- π Equivalent Circuit 416
- 7.4.2 Short-Circuit Current Gain 418
- 7.4.3 Cutoff Frequency 420
- 7.4.4 Miller Effect and Miller Capacitance 422

7.5 Frequency Response: The FET 426

- 7.5.1 High-Frequency Equivalent Circuit 426
- 7.5.2 Unity-Gain Bandwidth 428
- 7.5.3 Miller Effect and Miller Capacitance 431

7.6 High-Frequency Response of Transistor Circuits 433

- 7.6.1 Common-Emitter and Common-Source Circuits 433
- 7.6.2 Common-Base, Common-Gate, and Cascode Circuits 436
- 7.6.3 Emitter- and Source-Follower Circuits 444
- 7.6.4 High-Frequency Amplifier Design 448

7.7 Summary 450

Checkpoint 450

Review Questions 451

Problems 451

Computer Simulation Problems 463

Design Problems 466

Chapter 8

Output Stages and Power Amplifiers 469

8.0 Preview 469

8.1 Power Amplifiers 469

8.2	Power Transistors	470
8.2.1	Power BJTs	470
8.2.2	Power MOSFETs	474
8.2.3	Heat Sinks	477
8.3	Classes of Amplifiers	480
8.3.1	Class-A Operation	481
8.3.2	Class-B Operation	484
8.3.3	Class-AB Operation	489
8.3.4	Class-C Operation	493
8.4	Class-A Power Amplifiers	494
8.4.1	Inductively Coupled Amplifier	494
8.4.2	Transformer-Coupled Common-Emitter Amplifier	495
8.4.3	Transformer-Coupled Emitter-Follower Amplifier	497
8.5	Class-AB Push-Pull Complementary Output Stages	499
8.5.1	Class-AB Output Stage with Diode Biasing	499
8.5.2	Class-AB Biasing Using the V_{BE} Multiplier	501
8.5.3	Class-AB Output Stage with Input Buffer Transistors	504
8.5.4	Class-AB Output Stage Utilizing the Darlington Configuration	507
8.6	Summary	508
	Checkpoint	509
	Review Questions	509
	Problems	510
	Computer Simulation Problems	516
	Design Problems	517

PART II**ANALOG ELECTRONICS 519****Chapter 9****The Ideal Operational Amplifier 521**

9.0	Preview	521
9.1	The Operational Amplifier	521
9.1.1	Ideal Parameters	522
9.1.2	Development of the Ideal Parameters	523
9.1.3	Analysis Method	525
9.1.4	PSpice Modeling	526
9.2	Inverting Amplifier	526
9.2.1	Basic Amplifier	527
	Problem-Solving Technique: Ideal Op-Amp Circuits	529
9.2.2	Amplifier with a T-Network	530
9.2.3	Effect of Finite Gain	532
9.3	Summing Amplifier	534
9.4	Noninverting Amplifier	536

9.4.1	Basic Amplifier	536
9.4.2	Voltage Follower	537
9.5	Op-Amp Applications	539
9.5.1	Current-to-Voltage Converter	539
9.5.2	Voltage-to-Current Converter	540
9.5.3	Difference Amplifier	543
9.5.4	Instrumentation Amplifier	548
9.5.5	Integrator and Differentiator	550
9.5.6	Nonlinear Circuit Applications	553
9.6	Op-Amp Circuit Design	555
9.6.1	Summing Op-Amp Circuit Design	555
9.6.2	Reference Voltage Source Design	558
9.6.3	Difference Amplifier and Bridge Circuit Design	560
9.7	Summary	562
	Checkpoint	563
	Problems	563
	Computer Simulation Problems	575
Chapter 10		
	Integrated Circuit Biasing and Active Loads	577
10.0	Preview	577
10.1	Bipolar Transistor Current Sources	577
10.1.1	Two-Transistor Current Source	578
10.1.2	Improved Current-Source Circuits	583
	Problem-Solving Technique: BJT Current Source Circuits	589
10.1.3	Widlar Current Source	589
10.1.4	Multitransistor Current Mirrors	595
10.2	FET Current Sources	598
10.2.1	Basic Two-Transistor MOSFET Current Source	598
	Problem-Solving Technique: MOSFET Current-Source Circuit	602
10.2.2	Multi-MOSFET Current-Source Circuits	603
10.2.3	Bias-Independent Current Source	607
10.2.4	JFET Current Sources	609
10.3	Circuits with Active Loads	611
10.3.1	DC Analysis: BJT Active Load Circuit	612
10.3.2	Voltage Gain: BJT Active Load Circuit	614
10.3.3	DC Analysis: MOSFET Active Load Circuit	616
10.3.4	Voltage Gain: MOSFET Active Load Circuit	618
10.3.5	Discussion	618
10.4	Small-Signal Analysis: Active Load Circuits	619
10.4.1	Small-Signal Analysis: BJT Active Load Circuit	619
	Problem-Solving Technique: Active Loads	621
10.4.2	Small-Signal Analysis: MOSFET Active Load Circuit	622
10.4.3	Small-Signal Analysis: Advanced MOSFET Active Load	623

10.5 Summary	625
Checkpoint	625
Review Questions	626
Problems	626
Computer Simulation Problems	637
Design Problems	638

Chapter 11

Differential and Multistage Amplifiers	639
11.0 Preview	639
11.1 The Differential Amplifier	639
11.2 Basic BJT Differential Pair	640
11.2.1 Terminology and Qualitative Description	640
11.2.2 DC Transfer Characteristics	643
11.2.3 Small-Signal Equivalent Circuit Analysis	648
11.2.4 Differential- and Common-Mode Gains	653
Problem-Solving Technique: Diff-Amps with Resistive Loads	656
11.2.5 Common-Mode Rejection Ratio	657
11.2.6 Differential- and Common-Mode Input Impedances	659
11.3 Basic FET Differential Pair	663
11.3.1 DC Transfer Characteristics	663
11.3.2 Differential- and Common-Mode Input Impedances	668
11.3.3 Small-Signal Equivalent Circuit Analysis	669
11.3.4 JFET Differential Amplifier	672
11.4 Differential Amplifier with Active Load	674
11.4.1 BJT Diff-Amp with Active Load	674
11.4.2 Small-Signal Analysis of BJT Active Load	676
11.4.3 MOSFET Differential Amplifier with Active Load	679
11.4.4 MOSFET Diff-Amp with Cascode Active Load	683
11.5 BiCMOS Circuits	686
11.5.1 Basic Amplifier Stages	686
11.5.2 Current Sources	688
11.5.3 BiCMOS Differential Amplifier	688
11.6 Gain Stage and Simple Output Stage	690
11.6.1 Darlington Pair and Simple Emitter-Follower Output	690
11.6.2 Input Impedance, Voltage Gain, and Output Impedance	691
11.7 Simplified BJT Operational Amplifier Circuit	695
Problem-Solving Technique: Multistage Circuits	698
11.8 Diff-Amp Frequency Response	699
11.8.1 Due to Differential-Mode Input Signal	699
11.8.2 Due to Common-Mode Input Signal	700
11.8.3 With Emitter-Degeneration Resistors	703
11.8.4 With Active Load	704

11.9 Summary	705
Checkpoint	706
Review Questions	706
Problems	707
Computer Simulation Problems	723
Design Problems	724
Chapter 12	
Feedback and Stability	727
12.0 Preview	727
12.1 Introduction to Feedback	727
12.1.1 Advantages and Disadvantages of Negative Feedback	728
12.1.2 Use of Computer Simulation	729
12.2 Basic Feedback Concepts	729
12.2.1 Ideal Closed-Loop Gain	730
12.2.2 Gain Sensitivity	732
12.2.3 Bandwidth Extension	734
12.2.4 Noise Sensitivity	735
12.2.5 Reduction of Nonlinear Distortion	738
12.3 Ideal Feedback Topologies	738
12.3.1 Series-Shunt Configuration	739
12.3.2 Shunt-Series Configuration	743
12.3.3 Series-Series Configuration	746
12.3.4 Shunt-Shunt Configuration	747
12.3.5 Summary of Results	749
12.4 Voltage (Series-Shunt) Amplifiers	749
12.4.1 Op-Amp Circuit Representation	749
12.4.2 Discrete Circuit Representation	752
12.5 Current (Shunt-Series) Amplifiers	755
12.5.1 Op-Amp Circuit Representation	755
12.5.2 Simple Discrete Circuit Representation	757
12.5.3 Discrete Circuit Representation	758
12.6 Transconductance (Series-Series) Amplifiers	762
12.6.1 Op-Amp Circuit Representation	762
12.6.2 Discrete Circuit Representation	764
12.7 Transresistance (Shunt-Shunt) Amplifiers	768
12.7.1 Op-Amp Circuit Representation	768
12.7.2 Discrete Circuit Representation	770
12.8 Loop Gain	778
12.8.1 Basic Approach	779
12.8.2 Computer Analysis	781
12.9 Stability of the Feedback Circuit	784
12.9.1 The Stability Problem	785
12.9.2 Bode Plots: One-, Two-, and Three-Pole Amplifiers	785

12.9.3	Nyquist Stability Criterion	789
12.9.4	Phase and Gain Margins	793
12.10	Frequency Compensation	795
12.10.1	Basic Theory	795
	Problem-Solving Technique: Frequency Compensation	796
12.10.2	Closed-Loop Frequency Response	797
12.10.3	Miller Compensation	798
12.11	Summary	800
	Checkpoint	801
	Review Questions	801
	Problems	802
	Computer Simulation Problems	815
	Design Problems	816
Chapter 13		
	Operational Amplifier Circuits	817
13.0	Preview	817
13.1	General Op-Amp Circuit Design	817
13.1.1	General Design Philosophy	818
13.1.2	Circuit Element Matching	819
13.2	A Bipolar Operational Amplifier Circuit	820
13.2.1	Circuit Description	820
13.2.2	DC Analysis	823
13.2.3	Small-Signal Analysis	830
13.2.4	Frequency Response	838
	Problem-Solving Technique: Operational Amplifier Circuits	839
13.3	CMOS Operational Amplifier Circuits	839
13.3.1	MC14573 CMOS Operational Amplifier Circuit	840
13.3.2	Folded Cascode CMOS Operational Amplifier Circuit	843
13.3.3	CMOS Current-Mirror Operational Amplifier Circuit	846
13.3.4	CMOS Cascode Current-Mirror Op-Amp Circuit	847
13.4	BiCMOS Operational Amplifier Circuits	848
13.4.1	BiCMOS Folded Cascode Op-Amp	849
13.4.2	CA3140 BiCMOS Circuit Description	850
13.4.3	CA3140 DC Analysis	852
13.4.4	CA3140 Small-Signal Analysis	854
13.5	JFET Operational Amplifier Circuits	856
13.5.1	Hybrid FET Op-Amp, LH0022/42/52 Series	857
13.5.2	Hybrid FET Op-Amp, LF155 Series	858
13.6	Summary	859
	Checkpoint	860
	Review Questions	860
	Problems	861

Computer Simulation Problems 867**Design Problems 868****Chapter 14****Nonideal Effects in Operational Amplifier Circuits 871****14.0 Preview 871****14.1 Practical Op-Amp Parameters 871**

14.1.1 Practical Op-Amp Parameter Definitions 872

14.1.2 Input and Output Voltage Limitations 873

14.2 Finite Open-Loop Gain 875

14.2.1 Inverting Amplifier Closed-Loop Gain 875

14.2.2 Noninverting Amplifier Closed-Loop Gain 878

14.2.3 Inverting Amplifier Closed-Loop Input Resistance 879

14.2.4 Noninverting Amplifier Closed-Loop Input Resistance 881

14.2.5 Nonzero Output Resistance 883

14.3 Frequency Response 885

14.3.1 Open-Loop and Closed-Loop Frequency Response 885

14.3.2 Gain-Bandwidth Product 887

14.3.3 Slew Rate 888

14.4 Offset Voltage 892

14.4.1 Input Stage Offset Voltage Effects 893

14.4.2 Offset Voltage Compensation 901

14.5 Input Bias Current 906

14.5.1 Bias Current Effects 906

14.5.2 Bias Current Compensation 907

14.6 Additional Nonideal Effects 909

14.6.1 Temperature Effects 909

14.6.2 Common-Mode Rejection Ratio 911

14.7 Summary 911**Checkpoint 912****Review Questions 912****Problems 913****Computer Simulation Problems 921****Chapter 15****Applications and Design of Integrated Circuits 923****15.0 Preview 923****15.1 Active Filters 924**

15.1.1 Active Network Design 924

15.1.2 General Two-Pole Active Filter 926

15.1.3 Two-Pole Low-Pass Butterworth Filter 927

15.1.4 Two-Pole High-Pass Butterworth Filter 929

- 15.1.5 Higher-Order Butterworth Filters 931
- 15.1.6 Switched-Capacitor Filter 933
- 15.2 Oscillators 937**
 - 15.2.1 Basic Principles of Oscillation 937
 - 15.2.2 Phase-Shift Oscillator 938
 - 15.2.3 Wien-Bridge Oscillator 941
 - 15.2.4 Additional Oscillator Configurations 945
- 15.3 Schmitt Trigger Circuits 947**
 - 15.3.1 Comparator 948
 - 15.3.2 Basic Inverting Schmitt Trigger 951
 - 15.3.3 Additional Schmitt Trigger Configurations 954
 - 15.3.4 Schmitt Triggers with Limiters 959
- 15.4 Nonsinusoidal Oscillators and Timing Circuits 960**
 - 15.4.1 Schmitt Trigger Oscillator 961
 - 15.4.2 Monostable Multivibrator 963
 - 15.4.3 The 555 Circuit 965
- 15.5 Integrated Circuit Power Amplifiers 972**
 - 15.5.1 LM380 Power Amplifier 972
 - 15.5.2 PA12 Power Amplifier 975
 - 15.5.3 Bridge Power Amplifier 977
- 15.6 Voltage Regulators 978**
 - 15.6.1 Basic Regulator Description 978
 - 15.6.2 Output Resistance and Load Regulation 978
 - 15.6.3 Simple Series-Pass Regulator 980
 - 15.6.4 Positive Voltage Regulator 982
- 15.7 Summary 986**
- Checkpoint 987**
- Review Questions 988**
- Problems 988**
- Computer Simulation Problems 998**
- Design Problems 998**

PART III**DIGITAL ELECTRONICS 1001****Chapter 16****MOSFET Digital Circuits 1003****16.0 Preview 1003****16.1 NMOS Inverters 1003**

- 16.1.1 n-Channel MOSFET Revisited 1004
- 16.1.2 NMOS Inverter Transfer Characteristics 1007
- 16.1.3 Noise Margin 1019
- 16.1.4 Body Effect 1024
- 16.1.5 Transient Analysis of NMOS Inverters 1026

16.2	NMOS Logic Circuits	1028
16.2.1	NMOS NOR and NAND Gates	1028
16.2.2	NMOS Logic Circuits	1032
16.2.3	Fanout	1033
16.3	CMOS Inverter	1034
16.3.1	p-Channel MOSFET Revisited	1035
16.3.2	DC Analysis of the CMOS Inverter	1036
16.3.3	Power Dissipation	1043
16.3.4	Noise Margin	1045
16.4	CMOS Logic Circuits	1048
16.4.1	Basic CMOS NOR and NAND Gates	1048
16.4.2	Complex CMOS Logic Circuits	1052
16.4.3	Fanout and Propagation Delay Time	1054
16.5	Clocked CMOS Logic Circuits	1055
16.6	Transmission Gates	1058
16.6.1	NMOS Transmission Gate	1058
16.6.2	NMOS Pass Networks	1063
16.6.3	CMOS Transmission Gate	1065
16.6.4	CMOS Pass Networks	1067
16.7	Sequential Logic Circuits	1067
16.7.1	Dynamic Shift Registers	1068
16.7.2	R-S Flip-Flop	1070
16.7.3	D Flip-Flop	1072
16.7.4	CMOS Full-Adder Circuit	1074
16.8	Memories: Classifications and Architectures	1075
16.8.1	Classifications of Memories	1075
16.8.2	Memory Architecture	1076
16.8.3	Address Decoders	1077
16.9	RAM Memory Cells	1079
16.9.1	NMOS SRAM Cells	1079
16.9.2	CMOS SRAM Cells	1081
16.9.3	SRAM Read/Write Circuitry	1085
16.9.4	Dynamic RAM (DRAM) Cells	1087
16.10	Read-Only Memory	1089
16.10.1	ROM and PROM Cells	1089
16.10.2	EPROM and EEPROM Cells	1090
16.11	Summary	1093
	Checkpoint	1095
	Review Questions	1095
	Problems	1097
	Computer Simulation Problems	1110
	Design Problems	1111

Chapter 17**Bipolar Digital Circuits 1113****17.0 Preview 1113****17.1 Emitter-Coupled Logic (ECL) 1113**

17.1.1 Differential Amplifier Circuit Revisited 1114

17.1.2 Basic ECL Logic Gate 1116

17.1.3 ECL Logic Circuit Characteristics 1120

17.1.4 Voltage Transfer Characteristics 1124

17.2 Modified ECL Circuit Configurations 1125

17.2.1 Low-Power ECL 1125

17.2.2 Alternative ECL Gates 1128

17.2.3 Series Gating 1131

17.2.4 Propagation Delay Time 1134

17.3 Transistor-Transistor Logic 1135

17.3.1 Basic Diode-Transistor Logic Gate 1136

17.3.2 The Input Transistor of TTL 1138

17.3.3 Basic TTL NAND Circuit 1141

17.3.4 TTL Output Stages and Fanout 1143

17.3.5 Tristate Output 1148

17.4 Schottky Transistor-Transistor Logic 1149

17.4.1 Schottky Clamped Transistor 1149

17.4.2 Schottky TTL NAND Circuit 1152

17.4.3 Low-Power Schottky TTL Circuits 1153

17.4.4 Advanced Schottky TTL Circuits 1155

17.5 BiCMOS Digital Circuits 1157

17.5.1 BiCMOS Inverter 1157

17.5.2 BiCMOS Logic Circuit 1158

17.6 Summary 1159**Checkpoint 1160****Review Questions 1160****Problems 1161****Computer Simulation Problems 1171****Design Problems 1171****APPENDICES**

Appendix A**Physical Constants and Conversion Factors 1173**

Contents

Appendix B

Introduction to Pspice 1175

B.0 Preview 1175

B.1 Introduction 1175

B.2 Drawing the Circuit 1176

B.3 Type of Analysis 1176

B.4 Displaying Results of Simulation 1177

B.5 Example Analyses 1177

Appendix C

Selected Manufacturers' Data Sheets 1183

Appendix D

Standard Resistor and Capacitor Values 1195

D.1 Carbon Resistors 1195

D.2 Precision Resistors (One Percent Tolerance) 1196

D.3 Capacitors 1196

Appendix E

Reading List 1199

Appendix F

Answers to Selected Problems 1203

Index 1211