

CONTENTS

Preface	xiii
1 Number Systems and Binary Codes	1
1.1 Introduction	1
1.2 Decimal Numbers	1
1.3 Binary Numbers	2
1.3.1 Basic Binary Arithmetic	5
1.4 Octal Numbers	8
1.5 Hexadecimal Numbers	11
1.6 Signed Numbers	13
1.6.1 Diminished Radix Complement	14
1.6.2 Radix Complement	16
1.7 Floating-Point Numbers	19
1.8 Binary Encoding	20
1.8.1 Weighted Codes	20
1.8.2 Nonweighted Codes	22
Exercises	25
2 Fundamental Concepts of Digital Logic	29
2.1 Introduction	29
2.2 Sets	29
2.3 Relations	32
2.4 Partitions	34
2.5 Graphs	35
2.6 Boolean Algebra	37
2.7 Boolean Functions	41
2.8 Derivation and Classification of Boolean Functions	43
2.9 Canonical Forms of Boolean Functions	45
2.10 Logic Gates	48
Exercises	53

3	Combinational Logic Design	59
3.1	Introduction	59
3.2	Minimization of Boolean Expressions	60
3.3	Karnaugh Maps	63
3.3.1	Don't Care Conditions	68
3.3.2	The Complementary Approach	70
3.4	Quine–McCluskey Method	73
3.4.1	Simplification of Boolean Function with Don't Cares	78
3.5	Cubical Representation of Boolean Functions	79
3.5.1	Tautology	82
3.5.2	Complementation Using Shannon's Expansion	84
3.6	Heuristic Minimization of Logic Circuits	85
3.6.1	Expand	85
3.6.2	Reduce	88
3.6.3	Irredundant	90
3.6.4	Espresso	92
3.7	Minimization of Multiple-Output Functions	95
3.8	NAND–NAND and NOR–NOR Logic	98
3.8.1	NAND–NAND Logic	98
3.8.2	NOR–NOR Logic	101
3.9	Multilevel Logic Design	102
3.9.1	Algebraic and Boolean Division	105
3.9.2	Kernels	106
3.10	Minimization of Multilevel Circuits Using Don't Cares	109
3.10.1	Satisfiability Don't Cares	110
3.10.2	Observability Don't Cares	112
3.11	Combinational Logic Implementation Using EX-OR and AND Gates	114
3.12	Logic Circuit Design Using Multiplexers and Decoders	117
3.12.1	Multiplexers	117
3.12.2	Demultiplexers and Decoders	123
3.13	Arithmetic Circuits	125
3.13.1	Half-Adders	125
3.13.2	Full Adders	126
3.13.3	Carry-Lookahead Adders	129
3.13.4	Carry-Select Adder	130
3.13.5	Carry-Save Addition	130
3.13.6	BCD Adders	132
3.13.7	Half-Subtractors	133
3.13.8	Full Subtractors	135
3.13.9	Two's Complement Subtractors	135
3.13.10	BCD Subtractors	137

3.13.11	Multiplication	138	
3.13.12	Comparator	140	
3.14	Combinational Circuit Design Using PLDs	141	
3.14.1	PROM	142	
3.14.2	PLA	144	
3.14.3	PAL	146	
	Exercises	150	
	References	155	
4	Fundamentals of Synchronous Sequential Circuits		157
4.1	Introduction	157	
4.2	Synchronous and Asynchronous Operation	158	
4.3	Latches	159	
4.4	Flip-Flops	162	
4.4.1	<i>D</i> Flip-Flop	163	
4.4.2	<i>JK</i> Flip-Flop	165	
4.4.3	<i>T</i> Flip-Flop	167	
4.5	Timing in Synchronous Sequential Circuits	168	
4.6	State Tables and State Diagrams	170	
4.7	Mealy and Moore Models	172	
4.8	Analysis of Synchronous Sequential Circuits	175	
	Exercises	177	
	References	180	
5	VHDL in Digital Design		181
5.1	Introduction	181	
5.2	Entity and Architecture	182	
5.2.1	Entity	182	
5.2.2	Architecture	184	
5.3	Lexical Elements in VHDL	185	
5.4	Data Types	187	
5.5	Operators	189	
5.6	Concurrent and Sequential Statements	192	
5.7	Architecture Description	194	
5.8	Structural Description	196	
5.9	Behavioral Description	199	
5.10	RTL Description	200	
	Exercises	202	

6	Combinational Logic Design Using VHDL	205
6.1	Introduction	205
6.2	Concurrent Assignment Statements	206
6.2.1	Direct Signal Assignment	206
6.2.2	Conditional Signal Assignment	207
6.2.3	Selected Conditional Signal Assignment	211
6.3	Sequential Assignment Statements	214
6.3.1	Process	214
6.3.2	<i>If-Then</i> Statement	216
6.3.3	<i>Case</i> Statement	220
6.3.4	<i>If</i> Versus <i>Case</i> Statements	223
6.4	Loops	225
6.4.1	<i>For Loop</i>	225
6.4.2	<i>While Loop</i>	229
6.5	<i>For-Generate</i> statement	230
	Exercises	233
7	Synchronous Sequential Circuit Design	235
7.1	Introduction	235
7.2	Problem Specification	236
7.3	State Minimization	239
7.3.1	Partitioning Approach	239
7.3.2	Implication Table	242
7.4	Minimization of Incompletely Specified Sequential Circuits	244
7.5	Derivation of Flip-Flop Next State Expressions	249
7.6	State Assignment	257
7.6.1	State Assignment Based on Decomposition	261
7.6.2	Fan-out and Fan-in Oriented State Assignment Techniques	265
7.6.3	State Assignment Based on 1-Hot Code	271
7.6.4	State Assignment Using <i>m</i> -out-of- <i>n</i> Code	271
7.7	Sequential PAL Devices	273
	Exercises	286
	References	290
8	Counter Design	291
8.1	Introduction	291
8.2	Ripple (Asynchronous) Counters	291
8.3	Asynchronous Up-Down Counters	294
8.4	Synchronous Counters	295
8.5	Gray Code Counters	300
8.6	Shift Register Counters	302

8.7	Ring Counters	307
8.8	Johnson Counters	310
	Exercises	313
	References	313
9	Sequential Circuit Design Using VHDL	315
9.1	Introduction	315
9.2	<i>D</i> Latch	315
9.3	Flip-Flops and Registers	316
9.3.1	<i>D</i> Flip-Flop	316
9.3.2	<i>T</i> and <i>JK</i> Flip-Flops	318
9.3.3	Synchronous and Asynchronous Reset	320
9.3.4	Synchronous and Asynchronous Preset	322
9.3.5	Registers	322
9.4	Shift Registers	324
9.4.1	Bidirectional Shift Register	326
9.4.2	Universal Shift Register	327
9.4.3	Barrel Shifter	327
9.4.4	Linear Feedback Shift Registers	329
9.5	Counters	332
9.5.1	Decade Counter	334
9.5.2	Gray Code Counter	335
9.5.3	Ring Counter	336
9.5.4	Johnson Counter	337
9.6	State Machines	338
9.6.1	Moore-Type State Machines	338
9.6.2	Mealy-Type State Machines	341
9.6.3	VHDL Codes for State Machines Using Enumerated Types	342
9.6.4	Mealy Machine in VHDL	345
9.6.5	User-Defined State Encoding	351
9.6.6	1-Hot Encoding	355
9.7	Case Studies	356
	Exercises	368
	References	371
10	Asynchronous Sequential Circuits	373
10.1	Introduction	373
10.2	Flow Table	374
10.3	Reduction of Primitive Flow Tables	377
10.4	State Assignment	379

xii CONTENTS

10.4.1 Races and Cycles 379

10.4.2 Critical Race-Free State Assignment 381

10.5 Excitation and Output Functions 387

10.6 Hazards 390

10.6.1 Function Hazards 391

10.6.2 Logic Hazards 393

10.6.3 Essential Hazards 396

Exercises 398

References 401

Appendix: CMOS Logic **403**

A.1 Transmission Gates 405

A.2 Clocked CMOS Circuits 407

A.3 CMOS Domino Logic 408

Index **411**