

Digital Design Using Digilent FPGA Boards

-- Verilog / Active-HDL Edition

Table of Contents

1. Introduction to Digital Logic	1
1.1 Background	1
1.2 Digital Logic	5
1.3 Verilog	8
2. Basic Logic Gates	9
2.1 Truth Tables and Logic Equations	9
The Three Basic Gates	9
Four New Gates	11
2.2 Positive and Negative Logic: De Morgan's Theorem	13
2.3 Sum of Products Design	16
2.4 Product of Sums Design	15
Verilog Examples	18
Example 1 – 2-Input Gates	18
Example 2 – Multiple-Input Gates	21
Problems	24
3. Boolean Algebra and Logic Equations	28
3.1 Boolean Theorems	28
One-Variable Theorems	29
Two- and Three-Variable Theorems	29
3.2 Karnaugh Maps	34
Two-Variable K-Maps	34
Three-Variable K-Maps	36
Four-Variable K-Maps	38
3.3 Computer Minimization Techniques	40
Tabular Representations	40
Prime Implicants	41
Essential Prime Implicants	43
Verilog Examples	45
Example 3 – Majority Circuit	45
Example 4 – 2-Bit Comparator	47
Problems	50
4. Implementing Digital Circuits	52
4.1 Implementing Gates	52
4.2 Transistor-Transistor Logic (TTL)	54
4.3 Programmable Logic Devices (PLDs and CPLDs)	56
A 2-Input, 1-Output PLD	56

The GAL 16V8	58
CPLDs	60
4.4 Field Programmable Gate Arrays (FPGAs)	60
Verilog Examples	62
Example 5 – Map Report	62
Problems	63
5. Combinational Logic	64
5.1 Multiplexers	64
2-to-1 Multiplexer	64
4-to-1 Multiplexer	65
Quad 2-to-1 Multiplexer	66
Verilog Examples	67
Example 6 – 2-to-1 Multiplexer: <i>if</i> Statement	67
Example 7 – 4-to-1 Multiplexer: Module Instantiation	70
Example 8 – 4-to-1 Multiplexer: <i>case</i> Statement	74
Example 9 – A Quad 2-to-1 Multiplexer	75
Example 10 – Generic Multiplexer: Parameters	77
Example 11 – Glitches	79
5.2 7-Segment Displays	82
Verilog Examples	83
Example 12 – 7-Segment Decoder: Logic Equations	83
Example 13 – 7-Segment Decoder: <i>case</i> Statement	85
Example 14 – Multiplexing 7-Segment Displays	87
Example 15 – 7-Segment Displays: <i>x7seg</i> and <i>x7segb</i>	89
5.3 Comparators	94
Cascading Comparators	94
TTL Comparators	95
Verilog Examples	96
Example 16 – 4-Bit Comparator Using a Verilog Task	96
Example 17 – <i>N</i> -Bit Comparator Using Relational Operators	98
5.4 Decoders and Encoders	100
Decoders	100
TTL Decoders	101
Encoders	101
Priority Encoders	102
TTL Encoders	102
Verilog Examples	103
Example 18 – 3-to-8 Decoder: Logic Equations	103
Example 19 – 3-to-8 Decoder: <i>for</i> Loops	104
Example 20 – 8-to-3 Encoder: Logic Equations	105
Example 21 – 8-to-3 Encoder: <i>for</i> Loops	107
Example 22 – 8-to-3 Priority Encoder	107
5.5. Code Converters	109
Binary-to-BCD Converters	109
Shift and Add 3 Algorithm	110

Gray Code Converters	111
Verilog Examples	112
Example 23 – 4-Bit Binary-to-BCD Converter: Logic Equations	112
Example 24 – 8-Bit Binary-to-BCD Converter: <i>for</i> Loops	113
Example 25 – 4-Bit Binary to Gray Code Converter	115
Example 26 – 4-Bit Gray Code to Binary Converter	116
Problems	117
6. Arithmetic Circuits	120
6.1 Adders	120
Half Adder	120
Full Adder	120
Carry and Overflow	123
TTL Adder	125
Verilog Examples	125
Example 27 – 4-Bit Adder: Logic Equations	125
Example 28 – 4-Bit Adder: Behavioral Statements	128
Example 29 – <i>N</i> -Bit Adder: Behavioral Statements	129
6.2 Subtractors	129
Half Subtractor	129
Full Subtractor	130
An Adder/Subtractor Circuit	131
Verilog Examples	133
Example 30 – 4-Bit Adder/Subtractor: Logic Equations	133
Example 31 – <i>N</i> -Bit Subtractor: Behavioral Statements	134
6.3 Shifters	135
Verilog Examples	136
Example 32 – 4-Bit Shifter	136
6.4 Multiplication	137
Binary Multiplication	137
Signed Multiplication	139
Verilog Examples	140
Example 33 – Multiplying by a Constant	140
Example 34 – A 4-Bit Multiplier	141
6.5 Division	143
Binary Division	143
Verilog Examples	144
Example 35 – An 8-Bit Divider using a Task	144
6.6 Arithmetic Logic Unit (ALU)	146
Verilog Examples	147
Example 36 – 4-Bit ALU	147
Problems	149
7. Sequential Logic	151
7.1 Latches and Flip-Flops	151
SR Latch	151

Clocked SR Latch	153
D Latch	153
Edge-Triggered D Flip-Flop	154
Verilog Examples	156
Example 37 – Edge-Triggered D Flip-Flop	156
Example 38 – Edge-Triggered D Flip-Flop with Set and Clear	157
Example 39 – D Flip-Flops in Verilog	158
Example 40 – D Flip-Flop with Asynchronous Set and Clear	159
Example 41 – Divide-by-2 Counter	160
7.2 Registers	161
Verilog Examples	163
Example 42 – 1-Bit Register	163
Example 43 – 4-Bit Register	164
Example 44 – <i>N</i> -Bit Register	165
7.3 Shift Registers	166
4-Bit Ring Counter	167
Verilog Examples	167
Example 45 – Shift Registers	167
Example 46 – Ring Counter	168
Example 47 – Debounce Pushbuttons	169
Example 48 – Clock Pulse	171
7.4 Counters	173
Arbitrary Waveform	174
Verilog Examples	175
Example 49 – 3-Bit Counter	175
Example 50 – Modulo-5 Counter	177
Example 51 – <i>N</i> -Bit Counter	178
Example 52 – Clock Divider: Modulo-10K Counter	180
Example 53 – Arbitrary Waveform	184
7.5 Pulse-Width Modulation (PWM)	185
Controlling the Speed of a DC Motor using PWM	186
Controlling the Position of a Servo using PWM	187
Verilog Examples	188
Example 54 – Pulse-Width Modulation (PWM)	188
Example 55 – PWM Signal for Controlling Servos	190
7.6 BASYS/Nexys-2 Board Examples	191
Verilog Examples	191
Example 56 – Loading Switch Data into a Register	191
Example 57 – Shifting Data into a Shift Register	193
Example 58 – Scrolling the 7-Segment Display	195
Example 59 – Fibonacci Sequence	200
Problems	203
8. State Machines	206
8.1 Mealy and Moore State Machines	206
8.2 A Moore Machine Sequence Detector	207

8.3 Mealy Machine Sequence Detector	209
Verilog Examples	210
Example 60 – Sequence Detector	210
Example 61 – Door Lock Code	215
Example 62 – Traffic Lights	219
Problems	224
9. Datapaths and Control Units	225
9.1 Verilog <i>while</i> Statement	225
Example 63 – GCD Algorithm – Part 1	225
9.2 Datapaths and Control Units	227
Example 64 – GCD Algorithm – Part 2	229
Example 65 – An Integer Square Root Algorithm	237
10. Integrating the Datapath and Control Unit	247
Example 66 –GCD Algorithm – Part 3	249
Example 67 – Integer Square Root– Part 2	253
11. Memory	257
Example 68 – A Verilog ROM	257
Example 69 – Distributed RAM/ROM	262
Example 70 – Block RAM/ROM	267
12. VGA Controller	271
Example 71 – VGA-Stripes	275
Example 72 – VGA-PROM	281
Example 73 – Sprites in Block ROM	286
Example 74 – Screen Saver	292
13. PS/2 Port	297
Example 75 – Keyboard	300
Example 76 – Mouse	307
Appendix A – Aldec Active-HDL Tutorial	316
Part 1: Project Setup	316
Part 2: Design Entry	320
Part 3: Simulation	323
Part 4: Creating a Top-level Design	327
Part 5: Synthesis and Implementation	329
Part 6: Program FPGA Board	333
Appendix B – Number Systems	334
B.1 Counting in Binary and Hexadecimal	334
B.2 Positional Notation	338
B.3 Fractional Numbers	339
B.4 Number System Conversions	339

B.5 Negative Numbers	343
Appendix C – Making a Turnkey System	347
Appendix D – Digilent FPGA Boards Comparison Chart	349
Appendix E – Installing the Xilinx ISE/WebPACK, Aldec Active-HDL, and Digilent Adept2 Software	350
Appendix F – Verilog Quick Reference Guide	352