

Contents

Preface	xv
Acknowledgments	xvii
Chapter 1 Microcomputer Systems	1
1.1 Introduction	2
1.2 Microcontroller Systems	3
1.2.1 Random Access Memory	6
1.2.2 Read Only Memory	6
1.2.3 Programmable Read Only Memory	6
1.2.4 Erasable Programmable Read Only Memory	7
1.2.5 Electrically Erasable Programmable Read Only Memory	7
1.2.6 Flash EEPROM	7
1.3 Microcontroller Features	7
1.3.1 Supply Voltage	8
1.3.2 The Clock	8
1.3.3 Timers	8
1.3.4 Watchdog	9
1.3.5 Reset Input	9
1.3.6 Interrupts	9
1.3.7 Brown-out Detector	9
1.3.8 A/D Converter	10
1.3.9 Serial I/O	10
1.3.10 EEPROM Data Memory	10
1.3.11 LCD Drivers	11
1.3.12 Analog Comparator	11
1.3.13 Real-Time Clock	11
1.3.14 Sleep Mode	11
1.3.15 Power-on Reset	11
1.3.16 Low-Power Operation	11
1.3.17 Current Sink/Source Capability	12
1.3.18 USB Interface	12

1.3.19	Motor Control Interface	12
1.3.20	CAN Interface	12
1.3.21	Ethernet Interface	12
1.3.22	ZigBee Interface	12
1.3.23	Multiply and Divide Hardware	12
1.3.24	Operating Temperature	13
1.3.25	Pulse Width Modulated Outputs	13
1.3.26	JTAG Interface	13
1.3.27	Package Size	13
1.3.28	Direct Memory Access	13
1.4	Microcontroller Architectures	13
1.4.1	Reduced Instruction Set Computer and Complex Instruction Computer	14
1.5	8, 16, or 32 Bits?	14
1.6	Number Systems	15
1.6.1	Decimal Number System	15
1.6.2	Binary Number System	16
1.6.3	Octal Number System	16
1.6.4	Hexadecimal Number System	17
1.7	Converting Binary Numbers into Decimal	17
1.8	Converting Decimal Numbers into Binary	18
1.9	Converting Binary Numbers into Hexadecimal	19
1.10	Converting Hexadecimal Numbers into Binary	21
1.11	Converting Hexadecimal Numbers into Decimal	21
1.12	Converting Decimal Numbers into Hexadecimal	22
1.13	Converting Octal Numbers into Decimal	23
1.14	Converting Decimal Numbers into Octal	23
1.15	Converting Octal Numbers into Binary	24
1.16	Converting Binary Numbers into Octal	25
1.17	Negative Numbers	25
1.18	Adding Binary Numbers	26
1.19	Subtracting Binary Numbers	27
1.20	Multiplication of Binary Numbers	28
1.21	Division of Binary Numbers	29
1.22	Floating Point Numbers	29
1.22.1	The Largest Number	30
1.22.2	The Smallest Number	31
1.23	Converting a Floating Point Number into Decimal	31
1.23.1	Normalizing the Floating Point Numbers	31

1.23.2	Converting a Decimal Number into Floating Point	32
1.23.3	Multiplication and Division of Floating Point Numbers	33
1.23.4	Addition and Subtraction of Floating Point Numbers.	34
1.24	Binary Coded Decimal Numbers	35
1.25	The American Standard Code for Information Interchange Table.	36
1.26	Summary	37
1.27	Exercises	37
Chapter 2	PIC32 Microcontroller Series.	41
2.1	The PIC32MX360F512L Architecture	44
2.1.1	The Memory.	47
2.1.2	The Microcontroller Clock.	50
2.1.3	Resets.	56
2.1.4	The Input/Output Ports	57
2.1.5	The Parallel Master Port	61
2.1.6	Timers	64
2.1.7	Real-Time Clock and Calendar	69
2.1.8	Analog to Digital Converter.	71
2.1.9	Interrupts	81
2.2	Summary	89
2.3	Exercises	90
Chapter 3	C Programming for 32-Bit PIC Microcontrollers.	91
3.1	Structure of a Simple mikroC Pro for PIC32 Program.	93
3.1.1	Comments	94
3.1.2	White Spaces	95
3.1.3	Terminating Program Statements	95
3.1.4	Case Sensitivity.	96
3.1.5	Variable Names.	96
3.1.6	Reserved Names	96
3.1.7	Variable Types	96
3.1.8	Number Bases.	100
3.1.9	Constants	100
3.1.10	Escape Sequences	101
3.1.11	Static Variables	101
3.1.12	Volatile Variables	102
3.1.13	External Variables	103
3.1.14	Memory Type Specifiers	103
3.1.15	Arrays.	104
3.1.16	Pointers	106

3.1.17 Structures	108
3.1.18 Creating New Data Types	110
3.1.19 Unions	111
3.1.20 Operators in mikroC Pro for PIC32	112
3.1.21 Modifying the Flow of Control	119
3.2 Functions	130
3.2.1 mikroC Pro for PIC32 Functions	130
3.2.2 Passing Parameters to Functions.	135
3.2.3 Passing Variables by Reference to Functions.	141
3.2.4 Passing Variable Number of Arguments to Functions	143
3.2.5 Pointers to Functions.	144
3.2.6 Static Variables in Functions	146
3.2.7 Function Prototypes.	146
3.3 PIC32 Microcontroller Specific Features	149
3.3.1 SFR Registers	149
3.3.2 Linker Directives.	150
3.3.3 Built-in Utilities	150
3.3.4 Start-up Initialization.	151
3.3.5 Read—Modify—Write Cycles.	151
3.3.6 Interrupts	152
3.4 Summary	152
3.5 Exercises	153
Chapter 4 mikroC Pro for PIC32 Built-in Library Functions	157
4.1 ADC Library	159
4.2 LCD Library.	160
4.2.1 HD44780 LCD Controller	162
4.3 Software UART Library	166
4.4 Hardware UART Library.	171
4.5 Sound Library.	176
4.6 ANSI C Library	177
4.6.1 Ctype Library	178
4.6.2 Math Library.	178
4.6.3 Stdlib Library	180
4.6.4 String Library	182
4.7 Miscellaneous Library.	182
4.7.1 Button Library	183
4.7.2 Conversion Library	183
4.7.3 Time Library.	186
4.7.4 Trigonometry Library	189

4.8 Summary	190
4.9 Exercises	190
Chapter 5 PIC32 Microcontroller Development Tools.	193
5.1 Software Development Tools	195
5.1.1 Text Editors	195
5.1.2 Assemblers and Compilers.	196
5.1.3 Simulators	196
5.1.4 High-Level Language Simulators	197
5.1.5 Simulators with Hardware Simulation	197
5.1.6 Integrated Development Environment.	198
5.2 Hardware Development Tools	198
5.2.1 Development Boards	198
5.2.2 Device Programmers	212
5.2.3 In-Circuit Debuggers	213
5.2.4 In-Circuit Emulators	213
5.2.5 Breadboard	214
5.3 mikroC Pro for PIC32 IDE	215
5.3.1 mikroC Pro for PIC32 IDE Screen	216
5.3.2 Creating and Compiling a New File	223
5.3.3 Other Features of the mikroC Pro for PIC32 IDE	229
5.3.4 Using the Software Simulator	235
5.3.5 Using the mikroICD In-Circuit Debugger	241
5.3.6 Using a Development Board	244
5.4 Summary	256
5.5 Exercises	257
Chapter 6 Microcontroller Program Development	259
6.1 Using the Program Description Language and Flowcharts.	260
6.1.1 BEGIN–END	260
6.1.2 Sequencing	260
6.1.3 IF–THEN–ELSE–ENDIF	261
6.1.4 DO–ENDDO	261
6.1.5 REPEAT–UNTIL	263
6.1.6 Calling Subprograms	263
6.1.7 Subprogram Structure	264
6.2 Examples	264
6.3 Representing for Loops in Flowcharts	270
6.4 Summary	272
6.5 Exercises	272

Chapter 7 Simple PIC32 Microcontroller Projects	275
7.1 Project 7.1—LED DICE	277
7.1.1 Project Description	277
7.1.2 Current-Sinking.	278
7.1.3 Current-Sourcing.	279
7.1.4 Project Hardware	280
7.1.5 Project PDL	281
7.1.6 Project Program	282
7.1.7 Using a Random Number Generator.	282
7.2 Project 7.2—Liquid-Crystal Display Event Counting	285
7.2.1 Project Description	285
7.2.2 Project Hardware	285
7.2.3 Project PDL	287
7.2.4 Project Program	287
7.3 Project 7.3—Creating a Custom LCD Character.	290
7.3.1 Project Description	290
7.3.2 Project Hardware	290
7.3.3 Project PDL	290
7.3.4 Project Program	294
7.4 Project 7.4—LCD Progress Bar	295
7.4.1 Project Description	295
7.4.2 Project Hardware	295
7.4.3 Project PDL	295
7.4.4 Project Program	295
7.5 Project 7.5—Shifting Text on LCD	299
7.5.1 Project Description	299
7.5.2 Project Hardware	300
7.5.3 Project PDL	300
7.5.4 Project Program	300
7.6 Project 7.6—External Interrupt-Based Event Counting Using LCD	301
7.6.1 Project Description	301
7.6.2 Project Hardware	304
7.6.3 Project PDL	304
7.6.4 Project Program	306
7.7 Project 7.7—Switch Contact Debouncing.	310
7.7.1 Project Description	310
7.7.2 Project Hardware	314
7.7.3 Project PDL	315
7.7.4 Project Program	315

7.8 Project 7.8—Timer Interrupt-Based Counting	318
7.8.1 Project Description	318
7.8.2 Project Hardware	318
7.8.3 Project PDL	318
7.8.4 Project Program	320
7.9 Project 7.9—Temperature Measurement and Display on LCD	324
7.9.1 Project Description	324
7.9.2 Project Hardware	324
7.9.3 Project PDL	325
7.9.4 Project Program	326
7.10 Project 7.10—Playing a Melody	326
7.10.1 Project Description	326
7.10.2 Project Hardware	328
7.10.3 Project PDL	330
7.10.4 Project Program	331
7.11 Project 7.11—Playing a Melody Using Push-Button Switches	331
7.11.1 Project Description	331
7.11.2 Project Hardware	333
7.11.3 Project PDL	334
7.11.4 Project Program	335
7.12 Project 7.12—Generating Sine Wave Using D/A Converter	338
7.12.1 Project Description	338
7.12.2 Project Hardware	338
7.12.3 Project PDL	340
7.12.4 Project Program	341
7.13 Project 7.13—Communicating with a PC Using the RS232 PORT	345
7.13.1 Project Description	345
7.13.2 Project Hardware	346
7.13.3 Project PDL (Simple Project)	346
7.13.4 Project Program	346
7.13.5 Project PDL (Calculator Project)	349
7.13.6 Project Program	350
7.14 Project 7.14—Scrolling LCD Display	356
7.14.1 Project Description	356
7.14.2 Project Hardware	356
7.14.3 Project PDL	356
7.14.4 Project Program	357

Chapter 8 Advanced PIC32 Projects	359
8.1 Project 8.1—Generating High-Frequency Sine Waveform	361
8.1.1 Project Description	361
8.1.2 Method 1 in Detail	362
8.1.3 Method 2 in Detail	368
8.2 Project 8.2—Generating Pulse-Width Modulation Waveform	371
8.2.1 Project Description	371
8.2.2 Project Hardware	375
8.2.3 Project PDL	375
8.2.4 Project Program	378
8.3 Project 8.3—Changing the Brightness of an LED	378
8.3.1 Project Description	378
8.3.2 Project Hardware	380
8.3.3 Project PDL	380
8.3.4 Project Program	382
8.4 Project 8.4—Using a Thin Film Transistor Display	382
8.4.1 Project Description	382
8.4.2 Some mikroC PRO for PIC32 TFT Functions	382
8.4.3 Project Hardware	386
8.4.4 Project PDL	388
8.4.5 Project Program	389
8.5 Project 8.5—Plotting a Graph on the TFT Display	389
8.5.1 Project Description	389
8.5.2 Project Hardware	389
8.5.3 Project PDL	393
8.5.4 Project Program	393
8.6 Project 8.6—Using Secure Digital Cards	400
8.6.1 The SPI Bus	402
8.6.2 Operation of the SD Card in SPI Mode	404
8.6.3 Card Size Parameters	406
8.6.4 mikroC PRO for PIC32 Language SD Card Library Functions	407
8.6.5 Project Hardware	411
8.6.6 Project PDL	413
8.6.7 Program Listing	413
8.7 Project 8.7—Storing Temperature Readings in a File on the SD Card	415
8.7.1 Project Description	415
8.7.2 Project Hardware	416
8.7.3 Project PDL	418
8.7.4 Project Program	418

8.8 Project 8.8—Designing a Finite Impulse Response Filter	421
8.8.1 Project Description	421
8.8.2 FIR Filters	422
8.8.3 Using the Scope FIR Filter Design Program	423
8.8.4 Project Hardware	425
8.8.5 Implementing the FIR Filter	426
8.8.6 Program Listing	428
8.8.7 Program Listing	436
8.9 Project 8.9—Calculating Timing in Digital Signal Processing	436
8.9.1 Project Description	436
8.9.2 Project Hardware	439
8.9.3 Project PDL	441
8.9.4 Project Program	441
Appendix	443
Index	455