## CONTENTS

<table>
<thead>
<tr>
<th>Preface</th>
<th>XIII</th>
</tr>
</thead>
<tbody>
<tr>
<td>Credits</td>
<td>XVII</td>
</tr>
</tbody>
</table>

### 1. INTRODUCTION TO MICROCONTROLLERS

1.1 Explanation of Terms  
1.2 Microcontroller Data Types  
   1.2.1 Unsigned and Signed Binary Numbers  
   1.2.2 ASCII and EBCDIC Codes  
   1.2.3 Unpacked and Packed Binary-Coded-Decimal Numbers  
1.3 Evolution of the Microcontroller  
1.4 Embedded Controllers  

### 2. MICROCONTROLLER BASICS

2.1 Basic Blocks of a Microcomputer  
   2.1.1 System Bus  
   2.1.2 Clock Signals  
2.2 Microcontroller architectures  
2.3 Central Processing Unit (CPU)  
   2.3.1 Register Section  
   2.3.2 Control Unit  
   2.3.3 Arithmetic and Logic Unit (ALU)  
   2.3.4 Simplified Explanation of Control Unit design  
2.4 Basic concept of pipelining  
2.5 RISC vs. CISC  
2.6 Functional Representation of a Typical Microcontroller---- The PIC18F4321  

### 3. MICROCONTROLLER MEMORY AND INPUT/OUTPUT (I/O)

3.1 Introduction to Microcontroller Memory  
   3.1.1 Main memory  
   3.1.2 READ and WRITE Timing Diagrams  
   3.1.3 Main Memory Organization  
3.2 Microcontroller Input/Output (I/O)  
   3.2.1 Overview of digital output circuits  
   3.2.2 Simple I/O Devices  
   3.2.3 Programmed I/O  

Questions and Problems  
36  

vii
3.2.4 Unconditional and Conditional Programmed I/O 52
3.2.5 Interrupt I/O 53

QUESTIONS AND PROBLEMS 56

4. PROGRAMMING LANGUAGES 59
4.1 Computer Programming Languages 59
4.2 Machine Language 60
4.3 Assembly Language 60
4.3.1 Types of Assemblers 61
4.3.2 Assembler Delimiters 62
4.3.3 Specifying Numbers by Typical Assemblers 63
4.3.4 Assembler Directives or Pseudoinstructions 63
4.3.5 Assembly Language Instruction Formats 65
4.3.6 Typical Instruction Set 67
4.3.7 Typical Addressing Modes 73
4.3.8 Subroutine Calls in Assembly Language 74
4.4 High-Level Language 74
4.5 Introduction to C Language 76
4.5.1 Data types 78
4.5.2 Bit manipulation operators 79
4.5.3 Control structures 81
4.5.4 The if-else construct 81
4.5.5 The switch construct 82
4.5.6 The while construct 83
4.5.7 The for construct 84
4.5.8 The do-while construct 85
4.5.9 Structures, and Unions 85
4.5.10 Functions in C 86
4.5.11 Arrays 88
4.5.12 Macros 88
4.6 Choosing a programming language 88
4.7 Flowcharts 89

QUESTIONS AND PROBLEMS 90

5. PIC18F ARCHITECTURE AND ADDRESSING MODES 93
5.1 Basic features of the PIC18F family 93
5.2 PIC18F Register Architecture 96
5.3 PIC18F Memory Organization 100
5.3.1 PIC18F Program Memory 101
5.3.2 PIC18F Data Memory 101
5.4 PIC18F Addressing Modes 104
5.4.1 Literal or Immediate Addressing Mode 104
5.4.2 Inherent or Implied Addressing Mode 104
5.4.3 Direct or Absolute Addressing Mode 104
5.4.4 Indirect Addressing Mode 105
5.4.5 Relative Addressing Mode 110
5.4.6 Bit Addressing Mode 112

QUESTIONS AND PROBLEMS 113

6. ASSEMBLY LANGUAGE PROGRAMMING WITH THE PIC18F: PART 1 115
6.1 Introduction to the PIC18F MPLAB assembler 115
### Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2</td>
<td>PIC18F Instruction Format</td>
<td>120</td>
</tr>
<tr>
<td>6.3</td>
<td>PIC18F Instruction Set</td>
<td>121</td>
</tr>
<tr>
<td>6.3.1</td>
<td>Data Movement Instructions</td>
<td>124</td>
</tr>
<tr>
<td>6.3.2</td>
<td>Arithmetic Instructions</td>
<td>130</td>
</tr>
<tr>
<td>6.3.3</td>
<td>Logic Instructions</td>
<td>138</td>
</tr>
<tr>
<td>6.3.4</td>
<td>Rotate Instructions</td>
<td>141</td>
</tr>
<tr>
<td>6.3.5</td>
<td>Bit Manipulation Instructions</td>
<td>147</td>
</tr>
<tr>
<td>QUESTIONS AND PROBLEMS</td>
<td></td>
<td>151</td>
</tr>
</tbody>
</table>

#### 7. ASSEMBLY LANGUAGE PROGRAMMING WITH THE PIC18F: PART 2 155

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>PIC18F Jump/Branch instructions</td>
<td>155</td>
</tr>
<tr>
<td>7.2</td>
<td>PIC18F Test, Compare, and Skip instructions</td>
<td>157</td>
</tr>
<tr>
<td>7.3</td>
<td>PIC18F Table Read/Write instructions</td>
<td>163</td>
</tr>
<tr>
<td>7.4</td>
<td>PIC18F Subroutine instructions</td>
<td>168</td>
</tr>
<tr>
<td>7.5</td>
<td>PIC18F System Control instructions</td>
<td>170</td>
</tr>
<tr>
<td>7.6</td>
<td>PIC18F Hardware vs. Software stack</td>
<td>171</td>
</tr>
<tr>
<td>7.7</td>
<td>Multiplication and Division algorithms</td>
<td>178</td>
</tr>
<tr>
<td>7.7.1</td>
<td>Signed Multiplication algorithm</td>
<td>178</td>
</tr>
<tr>
<td>7.7.2</td>
<td>Unsigned Division algorithm</td>
<td>180</td>
</tr>
<tr>
<td>7.7.3</td>
<td>Signed Division algorithm</td>
<td>182</td>
</tr>
<tr>
<td>7.8</td>
<td>Advanced Programming Examples</td>
<td>184</td>
</tr>
<tr>
<td>7.9</td>
<td>PIC18F Delay Routine</td>
<td>188</td>
</tr>
<tr>
<td>QUESTIONS AND PROBLEMS</td>
<td></td>
<td>191</td>
</tr>
</tbody>
</table>

#### 8. PIC18F PROGRAMMED I/O USING ASSEMBLY & C 195

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>PIC18F Pins and Signals</td>
<td>195</td>
</tr>
<tr>
<td>8.1.1</td>
<td>Clock</td>
<td>196</td>
</tr>
<tr>
<td>8.1.2</td>
<td>PIC18F Reset</td>
<td>202</td>
</tr>
<tr>
<td>8.1.3</td>
<td>High Voltage and Low Voltage Programming (HVP and LVP)</td>
<td>205</td>
</tr>
<tr>
<td>8.1.4</td>
<td>“pragma config” and “config” directives</td>
<td>205</td>
</tr>
<tr>
<td>8.1.5</td>
<td>A simplified setup for the PIC18F4321</td>
<td>206</td>
</tr>
<tr>
<td>8.1.6</td>
<td>Downloading programs into the PIC18F4321 using the PICKit3 interface</td>
<td>206</td>
</tr>
<tr>
<td>8.2</td>
<td>PIC18F4321 Programmed I/O</td>
<td>208</td>
</tr>
<tr>
<td>8.2.1</td>
<td>I/O instructions in PIC18F assembly</td>
<td>211</td>
</tr>
<tr>
<td>8.2.2</td>
<td>Configuring PIC18F4321 I/O ports using PIC18F assembly</td>
<td>211</td>
</tr>
<tr>
<td>8.2.3</td>
<td>Configuring PIC18F4321 I/O ports using C</td>
<td>213</td>
</tr>
<tr>
<td>8.2.4</td>
<td>Interfacing LED’s (Light Emitting Diodes) and Seven-segment displays</td>
<td>215</td>
</tr>
<tr>
<td>8.2.5</td>
<td>Programmed I/O examples using PIC18F assembly</td>
<td>216</td>
</tr>
<tr>
<td>8.2.6</td>
<td>Programmed I/O examples using C Language</td>
<td>220</td>
</tr>
<tr>
<td>QUESTIONS AND PROBLEMS</td>
<td></td>
<td>228</td>
</tr>
</tbody>
</table>

#### 9. PIC18F INTERRUPT I/O, LCD, AND KEYBOARD INTERFACING 231

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1</td>
<td>Basics of Polled I/O vs. Interrupt I/O</td>
<td>231</td>
</tr>
<tr>
<td>9.2</td>
<td>PIC18F Interrupts</td>
<td>236</td>
</tr>
<tr>
<td>9.2.1</td>
<td>Interrupt Procedure</td>
<td>236</td>
</tr>
<tr>
<td>9.2.2</td>
<td>PIC18F Interrupt Types</td>
<td>238</td>
</tr>
<tr>
<td>9.2.3</td>
<td>Programming the PIC18F External Interrupts</td>
<td>238</td>
</tr>
<tr>
<td>9.2.4</td>
<td>Programming PIC18F external interrupts using assembly</td>
<td>243</td>
</tr>
</tbody>
</table>
Contents

9.2.5 Programming PIC18F external interrupts using C 243
9.2.6 Accessing PIC18F on-chip peripheral devices using Polled I/O vs. Interrupt I/O 252
9.3 PIC18F Interface to a typical LCD (Liquid Crystal Display) 252
9.4 Interfacing PIC18F4321 to a hexadecimal keyboard and a seven-segment display
   9.4.1 Basics of Keyboard and Display Interface to a Microcontroller 259
   9.4.2 PIC18F4321 Interface to a Hexadecimal Keyboard and a Seven-Segment Display 261
QUESTIONS AND PROBLEMS 270

10. PIC18F TIMERS AND ANALOG INTERFACE 273
10.1 PIC18F Timers 273
   10.1.1 Timer0 275
   10.1.2 Timer1 283
   10.1.3 Timer2 289
   10.1.4 Timer3 293
10.2 Analog Interface 301
   10.2.1 PIC18F on-chip ADC (A/D Converter) 302
   10.2.2 Interfacing an external D/A (Digital to Analog) Converter using C 315
QUESTIONS AND PROBLEMS 317

11. PIC18F CCP AND SERIAL I/O 321
11.1 PIC18F CCP (Capture/Compare/PWM (Pulse Width Modulation) Module 321
   11.1.1 CCP Registers 322
   11.1.2 CCP modules and associated timers 322
   11.1.3 PIC18F4321 Capture mode 322
   11.1.4 PIC18F4321 Compare mode 326
   11.1.5 PIC18F4321 PWM (Pulse Width Modulation) mode 329
11.2 DC Motor Control 332
11.3 Serial Interface 336
   11.3.1 Synchronous Serial Data Transmission 336
   11.3.2 Asynchronous Serial Data Transmission 337
   11.3.3 Basics of SPI and I2C 337
11.4 PIC18F Serial I/O 338
   11.4.1 PIC18F SPI mode 338
   11.4.2 PIC18F I2C (Inter-Integrated Circuit) mode 348
QUESTIONS AND PROBLEMS 359

APPENDIX A: ANSWERS TO SELECTED PROBLEMS 363
APPENDIX B: GLOSSARY 371
APPENDIX C: PIC18F INSTRUCTION SET (ALPHABETICAL ORDER) 383
APPENDIX D: PIC18F INSTRUCTION SET — DETAILS 389
APPENDIX E: PIC18F4321 SPECIAL FUNCTION REGISTERS 433
APPENDIX F: TUTORIAL FOR ASSEMBLING AND DEBUGGING A PIC18F ASSEMBLY LANGUAGE PROGRAM USING THE MPLAB 435
Contents

APPENDIX G: TUTORIAL FOR COMPILING AND DEBUGGING A C-PROGRAM USING THE MPLAB 465

APPENDIX H: INTERFACING THE PIC18F4321 TO A PERSONAL COMPUTER OR A LAPTOP USING PICKit™ 3 493

H.1 INITIAL HARDWARE SETUP FOR THE PIC18F4321 493
H.2 CONNECTING THE PERSONAL COMPUTER (PC) OR THE LAPTOP TO THE PIC18F4321 VIA PICkit3 494
H.3 PROGRAMMING THE PIC18F4321 FROM A PERSONAL COMPUTER OR A LAPTOP USING THE PICkit3 495

BIBLIOGRAPHY 499

INDEX 501