

PROGRAMMING AND CUSTOMIZING THE AVR MICROCONTROLLER

Dhananjay V. Gadre

McGraw-Hill

New York San Francisco Washington, D.C. Auckland Bogota
Caracas Lisbon London Madrid Mexico City Milan
Montreal New Delhi San Juan Singapore
Sydney Tokyo Toronto

CONTENTS

List of Figures	Xfff
List of Tables	xxi
Acknowledgments	xxiii
Chapter 1 Introduction	
1.1 Microcontroller, Microcomputer or Microprocessor?	2
1.2 Do you need a Microcontroller?	3
1.3 Why the Atmel's AVR Microcontroller?	5
1.4 Organization of This Book	6
1.5 Timing Diagram Conventions	6
Chapter 2 Microcontrollers	11
2.1 Microcontroller Architecture	14
2.2 Choosing a Microcontroller	16
2.3 Developing Applications with a Microcontroller	18
Chapter 3 The AVR RISC Microcontroller Architecture	21
3.1 Introduction	21
3.2 AVR Family Architecture	22
3.3 The Register File	25
3.4 The ALU	26
3.5 Memory Access and Instruction Execution	27
3.6 I/O Memory	27
3.6.1 SREG: Status Register	28
3.6.2 SP: Stack Pointer Register	29
3.6.3 GIMSK: General Interrupt Mask Register	29
3.6.4 GIFR: General Interrupt Flag Register	29
3.6.5 MCUCR: MCU General Control Register	30
3.6.6 MCUSR: MCU Status Register	30
3.6.7 TCCRO: Time/CounterO Control Register	31
3.6.8 TCNTO: Time/CounterO Register	31
3.6.9 TCCR1A: Timer/Counter1 Control Register A	32
3.6.10 TCCR1B: Timer/Counter1 Control Register B	33
3.6.11 TCNT1H, TCNT1L: Timer/Counter1 Count Registers	34
3.6.12 OCR1AH, OCR1AL: Timer/Counter1 Output Compare Registers	35
3.6.13 OCR1BH, OCR1BL: Timer/Counter1 Output Compare Registers	36

VIII CONTENTS

3.6.14 ICR1H, ICR1L: Timer/Counter Output Capture Registers	37
3.6.15 WDTCR: Watchdog Timer Control Register	37
3.6.16 EEAR: EEPROM Address Register	37
3.6.17 EEDR: EEPROM Data Register	38
3.6.18 EECR: EEPROM Control Register	38
3.6.19 PORTB: PortB Data Register	39
3.6.20 DDRB: PortB Data Direction Register	39
3.6.21 PINB: Input Pins on PortB	39
3.6.22 PORTD: PortD Data Register	39
3.6.23 DDRD: PortD Data Direction Register	39
3.6.24 PIND: Input Pins on PortD	39
3.6.25 SPI I/O Data Register	39
3.6.26 SPI Status Register	39
3.6.27 SPI Control Register	40
3.6.28 UART I/O Data Register	40
3.6.29 UART Status Register	40
3.6.30 UART Control Register	41
3.6.31 UART Baud Rate Register	42
3.6.32 ACSR: Analog Comparator Control and Status Register	42
3.7 The EEPROM	43
3.8 The I/O Ports	45
3.9 The SRAM	46
3.9.1 Interface to External SRAM	47
3.10 The Timer	47
3.11 The UART	49
3.12 The Interrupt Structure	53
3.13 The Internal Watchdog Timer	55
3.14 Power-Down Modes of Operation	56
3.15 Different Types of AVR Controllers	57

Chapter 4 The AVR Instruction Set

59

4.1 Program and Data Addressing Modes	59
4.1.1 Register Direct (Single Register)	59
4.1.2 Register Direct (Two Registers)	61
4.1.3 I/O Direct	61
4.1.4 Data Direct	61
4.1.5 Data Indirect	62
4.1.6 Indirect Program Addressing	62
4.1.7 Relative Program Addressing	62
4.2 Arithmetic and Logic Instructions	63
4.3 Program Control Instructions	67
4.4 Data Transfer Instructions	72
4.5 Bit and Bit-test Instructions	76

Chapter 5 AVR Hardware Design Issues

81

5.1 Power Source	81
5.1.1 Battery Power	82
5.1.2 Main Operating Supply	83
5.1.3 Power from Port Signal Lines	84
5.1.4 Voltage Regulators	85
5.2 Operating Clock Sources	86
5.2.1 Using a Crystal Clock IC	86

- 5.2.2 Using a Ceramic Resonator 87
- 5.2.3 Using a Quartz Crystal 88
- 5.2.4 Using a Quartz Clock Crystal 90
- 5.2.5 Using Internal RC Clock Oscillator 90
- 5.3 Reset Circuit 93

Chapter 6 Hardware and Software Interfacing with the AVR 97

- 6.1 A Beginner's Circuit 97
- 6.2 Lights and Switches 99
- 6.3 Stack Operation in AVR Processors 101
- 6.4 Implementing Combinational Logic 104
- 6.5 Connecting the AVR to the PC Serial Port 105
- 6.6 Expanding I/O 110
 - 6.6.1 I/O Expansion Using Shift Register 110
 - 6.6.2 IIC Expanders 111
- 6.7 Interfacing Analog to Digital Converters 112
 - 6.7.1 AD Conversion Using the On-Chip Comparator 113
 - 6.7.2 MAX186 117
 - 6.7.3 MAX186 Data Conversion and Readout 118
 - 6.7.4 MAX110/MAX111 121
- 6.8 Interfacing Digital-to-Analog Converters 124
 - 6.8.1 Using PWM for a DAC 124
 - 6.8.2 R-2R Ladder DAC 124
 - 6.8.3 MAX521 DAC 126
 - 6.8.4 Data Transfer to a MAX521 127
- 6.9 Interfacing LED Displays 732
 - 6.9.1 Seven-Segment Displays 132
 - 6.9.2 Dot Matrix Displays 133
- 6.10 Interfacing LCD Displays 135
- 6.11 Driving Relays with AVR 138
- 6.12 Stepper Motor Interface for the AVR 140
- 6.13 Interfacing to a Serial EEPROM 141
- 6.14 Interfacing to a Real Time Clock (RTC) 146
- 6.15 Accessing a Constants Table 149
- 6.16 Arbitrary Waveform Generation 150
- 6.17 A Switch-Case Implementation 150
- 6.18 Implementing a Finite State Machine 152
- 6.19 Generating Random Numbers 154

Chapter 7 Communication Links for the AVR Processor 157

- 7.1 Introduction 157
- 7.2 RS-232 Link 158
- 7.3 RS-422/423 Link 160
- 7.4 RS-485 Link 161
- 7.5 SPI and MICROWIRE Bus 163
- 7.6 IIC Bus 164
- 7.7 PC Parallel Port 166
- 7.8 ISA Bus 172
- 7.9 Universal Serial Bus 174
- 7.10 IrDA Data Link 178
- 7.11 CAN (Controller Area Network) Bus 182

Chapter 8 AVR System Development Tools	185
8.1 Code Assembler 185	
8.1.1 AVR Family Assembler 786	
8.1.2 IAR Assembler 187	
8.2 Code Simulator 187	
8.2.1 AVR Simulator 187	
8.2.2 AVR Studio 188	
8.3 Evaluation Boards 188	
8.3.1 Atmel AVR MCU00100 Development Board 189	
8.3.2 STK200 Board 189	
8.3.3 STK 300 Board 182	
8.4 ICE200 AVR Emulator 192	
8.5 The Device Programmer 193	
8.6 AVR System Design with Components Off the Shelf (COTS) 194	
8.6.1 The SimmStick Magic 194	
8.7 Code Development with a High Level Language 195	
8.7.1 C-AVR: A C Compiler for AVR 195	
8.7.2 DDS MICRO-C Developers Kit for the AVR 197	
8.7.3 BasicX: A BASIC Interpreter for the AVR 198	
8.7.4 BASCOM-AVR: A Basic Compiler for the AVR 198	
8.7.5 JAVRBasic: Jack's AVR Basic Compiler 198	
Chapter 9 Prototyping Techniques	199
9.1 Why Prototype? 199	
9.2 OK, So You Want to Prototype 200	
9.3 Tools of the Trade 202	
9.4 Steps for Prototyping 203	
Chapter 10 AVR Project 1	
Smart Dice: A Dice with an Attitude	207
10.1 At A Glance 207	
10.2 Introduction 207	
10.3 Design Issues: Specifying the Requirement 208	
10.4 Design Description 211	
10.5 Possible Alternatives 212	
10.6 Code Development 213	
10.7 Fabrication 217	
10.8 Testing 218	
10.9 Usage 219	
10.10 Power Consumption 279	
10.11 Adapting the Circuit to an AT90S2343 220	
Chapter 11 AVR Project 2	
A Morse Keyer	223
11.1 At a Glance 223	
11.2 Introduction 223	
11.3 Design Specification 225	
11.4 Design Description 225	
11.5 Possible Alternatives 228	
11.6 Fabrication 228	
11.7 Design Code 228	
11.8 Testing the System 229	

Chapter 12 AVR Project 3	
A Simple Dual-Channel Voltmeter	233
12.1 At a Glance	233
12.2 Introduction	233
12.3 Design Description	234
12.4 Usage	234
12.5 Fabrication	235
12.6 Design Code	235
Chapter 13 AVR Project 4	
The Ubiquitous Kitchen Timer	239
13.1 At a Glance	239
13.2 Introduction	240
13.3 Design Description	240
13.4 Possible Alternatives	241
13.5 Fabrication	247
13.6 Design Code	242
13.7 Testing	242
Chapter 14 AVR Project 5	
Radio Beacon Controller	245
14.1 At a Glance	245
14.2 Introduction	245
14.3 Design Specifications	246
14.4 Design Description	246
14.5 Fabrication	250
14.6 Design Code	250
14.7 Testing	252
Chapter 15 AVR Project 6	
AstroDat: A Stand-Alone Data Acquisition System	255
15.1 At A Glance	255
15.2 Introduction	255
15.3 Design Description for the SniffStick	257
15.4 Using the SniffStick	260
15.5 AstroDAT: A Complete DAS for Astronomical Application	267
15.6 AstroDAT User Interface	267
15.7 Design Description	263
15.8 System Development	267
15.9 Fabrication	268
15.10 Design Code	268
15.11 Data Readout	268
15.12 AstroDat User's Guide	270
Chapter 16 AVR Project 7	
Security Dongle	277
16.1 At a Glance	277
16.2 Introduction	278
16.2.1 What Are Security Locks?	278
16.2.2 Various Hardware Lock Schemes	278

16.3	How to Build an Electronic Lock	280
16.4	Design Description	284
16.5	Possible Alternatives	286
16.6	Fabrication	288
16.7	Design Code	288
16.8	Testing	289
Chapter 17	AVR Project 8	
	A Pulse Frequency Counter with an RS-232 Interface	291
17.1	At a Glance	297
17.2	Introduction	297
17.3	How Does a Frequency Counter Work?	292
17.4	How Does a Period Counter Work?	293
17.5	Design Description of an AVR-Processor-Based Frequency Counter	295
17.6	Usage	298
17.7	Fabrication	298
17.8	Design Code	298
17.9	Testing	299
Chapter 18	AVR Project 9	
	Sa-Re-Ga Follow Me: A Musical Toy	301
18.1	At a Glance	307
18.2	Introduction	307
18.3	Design Description	303
18.4	Fabrication	303
18.5	Design Code	305
Chapter 19	AVR Project 10	
	AVR ProtoBoard™ for Nuts™	309
19.1	At a Glance	309
19.2	Introduction	309
19.3	Design Description	370
Chapter 20	Ideas for Projects	317
20.1	AT90S2343 Controller Based Code Authenticator	377
20.2	A CCD Camera Controller	378
20.3	Personal Temperature Logger	378
20.3.1	Configuring the Temperature Logger	320
20.3.2	Extracting Data	320
20.4	Swipe Card Reader	320
20.5	IBM PC Keyboard Decoder	327
20.6	A Morse Code Tutor	327
Glossary		325
Internet Resources for the AVR		331
Index		333