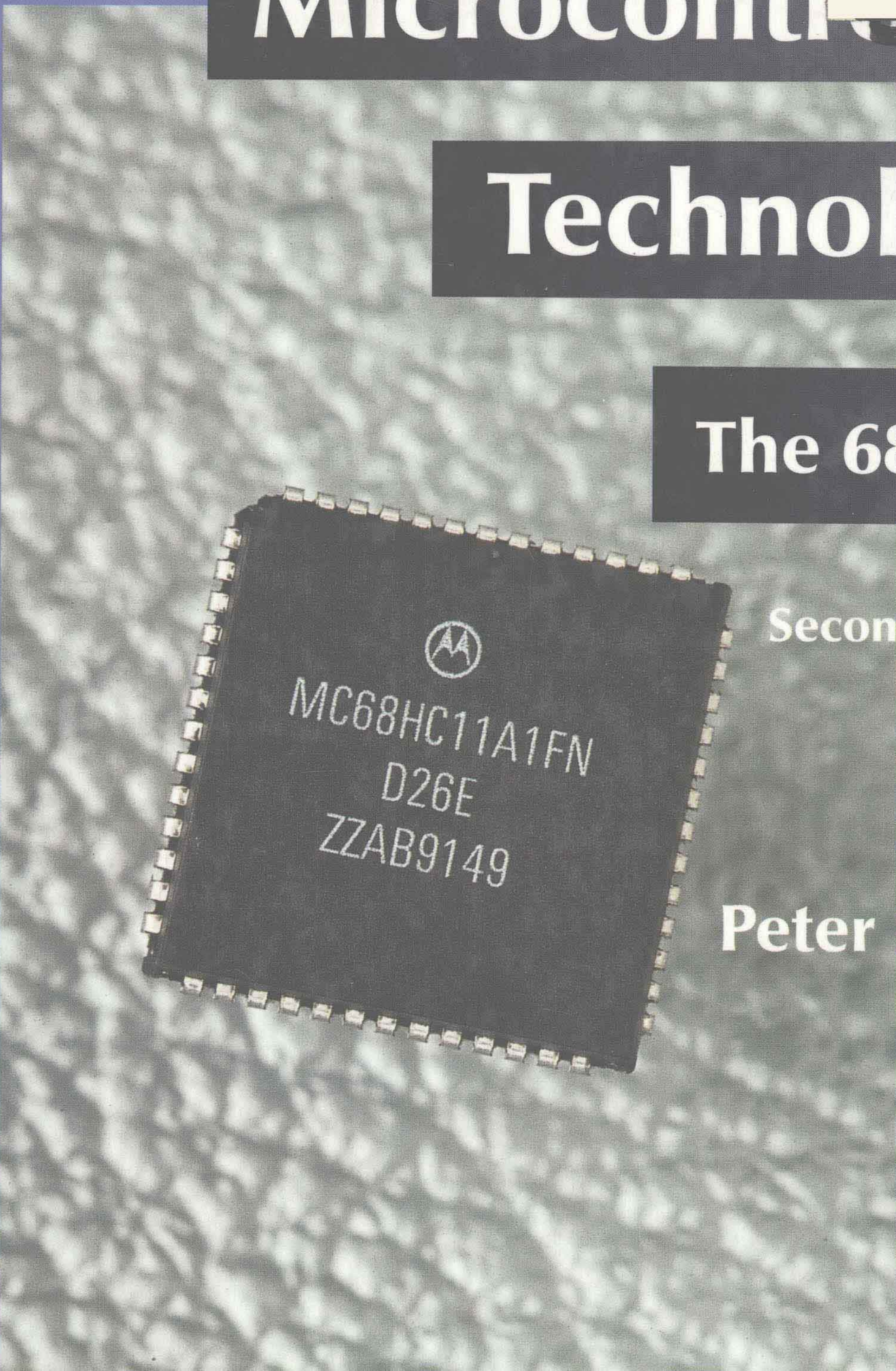
Microcontroller Technology

The 68HC11



Second Edition

Peter Spasov

SECOND EDITION

MICROCONTROLLER TECHNOLOGY THE 68HC11

Peter Spasov

Sir Sandford Fleming College

PRENTICE HALL
Englewood Cliffs, New Jersey Columbus, Ohio

To my wife Renate

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Preface

Microcontrollers are used in the industrial world to control many types of equipment, ranging from consumer to specialized devices. They have replaced older types of controllers, including microprocessors. Also, there is a growing need for off-line support of a computer's main processor. The demand will grow as more and more equipment uses more intelligence. Applications range from controlling engines in modern automobiles to controlling laser printers and other computer peripherals. One consumer application is a washing machine controller that adjusts the wash cycle based on load size, fabric type, and amount of dirt.

This book illustrates how to use a popular microcontroller, the Motorola 68HC11. The 68HC11 is relatively easy to work with, yet it has most of the features essential for a complete control system. Thus the student of control automation can use it to work with control systems at the component level. The interested layperson can also use it as a tool to understand and experiment with computer and data communications systems.

The goals of the second edition remain the same as those of the first edition. The book provides the background knowledge needed to understand and use microcontrollers in general as well as the 68HC11 specifically. It starts at an introductory level, explaining the applications and origins of microcontrollers. Next, a programmer's view of the machine is developed. Finally, we describe machine hardware and how to connect it to the outside world for control applications.

The reader will find the book useful in learning how to use the 68HC11. Original manufacturers' data books do not provide the background explanations that a novice needs. Experienced users will find the book to be a useful accompaniment to the manufacturer's original documentation.

The book can be used as a textbook in introductory, interfacing, and industrial control courses. To use the book, the reader should have a background understanding of digital logic and numbering systems. Some computer programming knowledge is useful but not absolutely essential. Although this book was written to be used in college courses, the interested hacker or hobbyist should find the material useful for self-study. Others with a formal education from the past should also find useful information. The book can accompany hands-on exercises using a microcontroller training kit or simulation software. Where possible, concepts are presented generically, to help the reader understand other microcontrollers and related devices.

To permit flexible use of the book, we have organized it into five parts:

Part 1. Microcontroller technology is introduced in Chapter 1: what it is, how it evolved, and how to use it. The chapter continues with explanations of terminology and parts of the microcontroller. Finally, essential memory concepts are reviewed.

Part 2. Chapters 2 to 4 cover programming concepts, the language used to instruct the microcontroller, and how to use registers and memory. Also covered is how to produce, use, and document programs.

Part 3. Chapters 5 to 7 cover operation of the chip itself. Topics include the system bus, operating modes, clocked operation, and memory technology.

Part 4. Chapters 8 to 12 deal with the subsystems for parallel, serial, programmable timer, and analog interfacing. The basic software techniques to use these systems are presented. Also introduced are some common hardware designs used to connect the microcontroller to sensors and actuators. An overview of all subsystems without the processor-specific details is presented in Chapter 8.

Part 5. Control methods are illustrated in Chapter 13, where it is shown how programs use the subsystems for control applications. Chapters 14 and 15 cover the industry to date, presenting a survey of typical applications, choices in choosing microcontrollers, and characteristics of other microcontrollers.

Typically, an introductory course would include Parts 1 and 2. We also recommend including Chapter 8. Advanced or more intensive courses would include Parts 3 and 4. Either type of course can use Part 5, provided that Chapter 8 is also covered.

Although the book contains some data sheets, it is not a complete reference. The readers should refer to the literature listed in Appendix D for complete data.

▶ SECOND EDITION CHANGES

Chapters 2 and 3 contain more illustrations and explanations about basic concepts. This makes the book more useful to the beginner. For similar reasons, Appendix G contains a section describing fractions and normalizing. Chapter 13 contains a new section about fuzzy logic. This logic technique has become very popular since the first edition. Chapter 13 also introduces a third-party C cross compiler since the one mentioned in the first edition is no longer supported. Since the Internet has grown phenomenally, the second edition lists Internet resources for the 68HC11 in a new appendix. Minor changes include new developments in the 68HC11 family, a brief introduction to Petri nets, and more information on how a C program uses the stack.

▶ HOW TO USE THIS BOOK

Most important to success using this book is an enthusiasm for computer and related technology. If you are already familiar with assembly language programming, you may wish to skim Chapters 1 and 2 for new information instead of reading them in detail. If you are not familiar with digital logic and binary numbers, you should also read Appendix G.

We use generic principles whenever possible. You should be able to work with any microcontroller after studying this book. But it is necessary to cover a specific microcontroller in depth in order to understand them all in general. In this book we have chosen the 68HC11. However there are many variations of the 68HC11. When explaining specific details, we generally refer to the 68HC11A8, unless we state otherwise.

To understand microcontrollers, you also have to know a lot of *jargon*. You cannot understand the concepts without knowing the jargon—but you cannot understand the jargon without knowing the concepts. We get around this dilemma by introducing details step by step.

The appendices provide references and further clarification of terms used in the book. Appendix A lists the details of the 68HC11 instructions used throughout the book. You will probably use it often. Appendix B is the quick reference section. Use it as a cross-reference to look up other 68HC11 details as needed. Appendix A and B are necessary if you do not have 68HC11 data sheets or a manual.

Appendix C is a glossary of terms. Most terms are explained in the text as required. New terms are indicated in italic type upon occurrence in the text. You may wish to reread earlier sections of the book to review terms when used in another context. The glossary provides an additional reference.

A lot of abbreviations are used in the technical literature. Unfortunately, these frustrate many readers. In practice, most technical data books use abbreviations, often without explanation. In this book each abbreviation is defined the first time it is used, and many are redefined upon subsequent appearances. You can also use Appendix C to look up an abbreviation.

Sources of further information on some topics are listed in Appendix D. Also listed are suppliers for some of the commercially available products mentioned in the book. We encourage you to use the bulletin board mentioned in Appendix D.

Some conventions are defined in Appendix E. Since there are many ways to do the same thing, we felt it necessary to define a *standard way*. The conventions are those used by many in the industry. For example, we use Motorola's dollar sign ($) convention to refer to a method of coding numbers (in this case the sign does not indicate dollars). This ensures that we all understand the sign to have the same meaning.

The *header files* used by some program examples are listed in Appendix F. Note that a header file is explained in Appendix F.

The basics of digital logic and number conversions are explained in Appendix G. You should read this section early if you are not already familiar with these topics.

If you need basic information about waveforms, refer to Appendix H.

Finally, we included a reference to Internet resources in Appendix I. It lists sources of free software and information that is available for the 68HC11 microcontroller.

Supplements

Prentice Hall also offers a lab manual, written by Robert John Dirkman and John Leonard of the University of Massachusetts, that can be used with this book. It is called the *Microprocessor Applications Laboratory Workbook*. Instructors can contact Prentice Hall for a copy of the "Instructor's Solutions Manual with Transparency Masters" to accompany this book.

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Finally, a very special thanks to my wife, Renate, who provided invaluable emotional support. I also thank my three-year-old daughter, Emilie, and recently-arrived Hannah, who both provide much joy.

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PART 1
Introducing Microcontroller Technology

1

Microcontroller Concepts

1.1 WHAT IS A MICROCONTROLLER? AND WHAT IS IT USED FOR?

The Swiss Army Knife. "Choose," the voice says. What do you choose? You may take only one tool for your journey. The journey will take you through forests, plains, mountains, and deserts. You need something small, light, and useful. You choose the Swiss Army knife and the voice "nods" respectfully. It is a good choice. Depending on the model, it has assorted blades, saw blade, scissors, can opener, corkscrew (most important!), tweezers, toothpick, and possibly more.

"What is a microcontroller?" the voice asks. You say: "It is a (computerized) Swiss Army knife." The voice is satisfied. Indeed, the microcontroller bears much resemblance to the Swiss Army knife. It is a single device, in this case a chip. The microcontroller follows instructions, reads information, stores information, communicates, measures time, and switches things on and off. It also does other things, depending on the model. Despite its power and versatility, you may not hear much about microcontrollers. Most computer literature describes the processor chips used in computers. But most single-chip programmable devices are microcontrollers.

If you are the type of person who likes to take things apart, you will find microcontrollers in all kinds of places. The most common place is under the hood of almost any car produced since 1985. Consumer items include televisions, compact disc players, washing machines, telephones, and microwave ovens. Office computers use microcontrollers in addition to their main processor to control peripherals such as keyboards and printers. Automated manufacturing systems use microcontrollers in production equipment such as robots and conveyor lines.

Now, we will take three views of microcontrollers: general, technical, and specific. After we consider the general view, we consider the technical and specific aspects of microcontrollers.

1.1.1 The General View

One could say that a microcontroller is a programmable single-chip integrated circuit (IC) that controls the operation of a system. Often, the system to be controlled is a machine. One of the most common applications is automotive control. This includes engine fuel injection control, transmission control, suspension and ride control, instrument displays, and braking systems. In fact, the 68HC11 microcontroller managed some engine control functions of first-place winners of Indianapolis 500 races for five years in a row.

Refer to Figure 1.1 for an application in controlling air/fuel mixture in an automobile engine. The amount of air and fuel and the timing of the ignition spark determine the fuel efficiency and amount of exhaust emission. The microcontroller unit uses the sensor inputs to control the ignition timing for maximum fuel efficiency and minimum exhaust emissions. It also looks at how fast the inputs change. The exhaust gas sensor measures the oxygen level so that the system can correct for any error. The microcontroller can be programmed to handle conditions when the engine is cold or warm, and accelerating or cruising. Also, the driver could instruct the unit to optimize speed and acceleration performance if necessary. With some extra inputs, the microcontroller unit could maintain constant speed, such as in a cruise control.

We went through this example in some detail to illustrate what could be involved in a control system using a microcontroller. For a more detailed understanding of air/fuel ratio control, refer to reference 1.

Automatic cameras also use microcontrollers. They control exposure and focus. Another application is the computer mouse. It typically uses a microcontroller to read the mouseball movement, sense the pushbutton positions, and handle communications with the computer.

1.1.2 Terminology and Conventions

We will be using words, abbreviations, and acronyms specifically used in the computer and microcontroller industry. Although we have minimized the use of technical jargon, its use is sometimes unavoidable. When we first use a term, we italicize it and you will generally find a definition in the glossary (Appendix C). You will have to understand some terms in context when you first encounter them. You may also check the index to locate other sections where a term is used.

In the technical description that follows (Section 1.1.3), we use a number of technical terms. Since the computer and microcontroller field is changing rapidly,