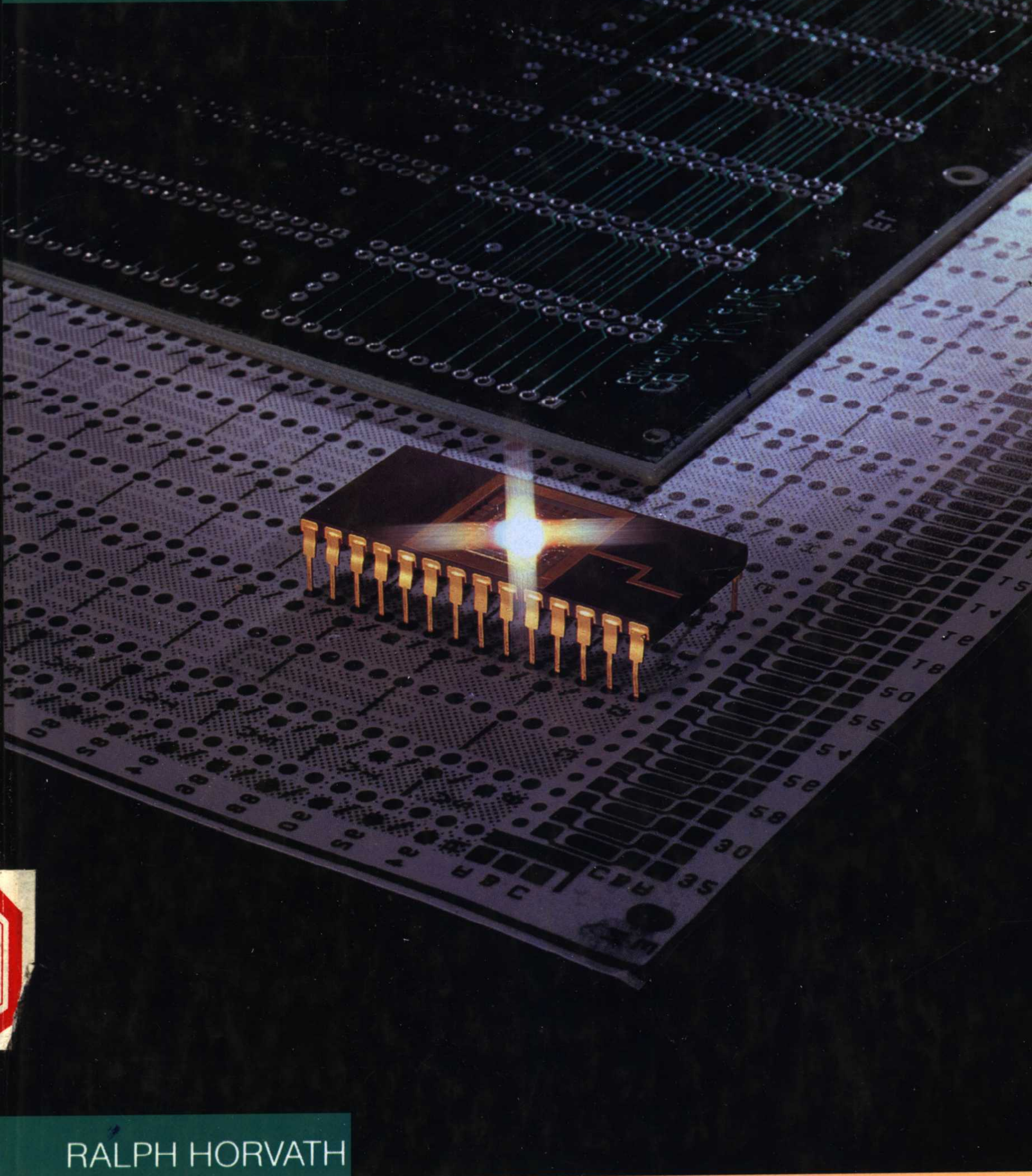
INTRODUCTION TO

MICROPROCESSORS

USING THE MC6809 OR THE MC68000



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McGraw-Hill, Inc.

New York St. Louis San Francisco Auckland Bogotá
Caracas Lisbon London Madrid Mexico Milan Montreal
New Delhi Paris San Juan Singapore Sydney Tokyo Toronto

This book was set in Times Roman by Publication Services, Inc.
The editors were Anne T. Brown and John M. Morriss.
The cover was designed by Carol Couch.
Project supervision was done by Publication Services, Inc.
R. R. Donnelley & Sons Company was printer and binder.

Cover photograph: © Srulik Haramaty/Phototake NYC.

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2 3 4 5 6 7 8 9 0 DOC DOC 9 0 9 8 7 6 5 4 3 2

ISBN 0-07-030507-2

Library of Congress Cataloging-in-Publication Data

Horvath, Ralph.
Introduction to microprocessors using the MC6809 or the MC68000/ Ralph Horvath.
p. cm. — (McGraw-Hill series in electrical and computer engineering. Computer engineering)
Includes index.
ISBN 0-07-030507-2
1. Motorola 6809 (Microprocessor) 2. Motorola 68000 (Microprocessor) I. Title. II. Series.
QA76.5.H72 1992
004.165—dc20 91-42488

PREFACE

INTENDED AUDIENCE

An *Introduction to Microprocessors Using the MC6809 or the MC68000* is intended for the typical sophomore engineering student who has had little formal electronic training and whose computer experience is probably limited to elementary programming in a higher level language such as FORTRAN or Pascal. In addition, it should be useful to engineers in the field as well as to managers who need an introduction to the area of microprocessors. It will provide any engineer with an adequate background so that he or she can intelligently use, program, modify, and maintain microprocessor systems or supervise people who do.

DEPTH OF COVERAGE

The approach emphasizes the point of view of the microprocessor system user. It introduces only those facts which will be of value to the engineer who must program, use, or maintain microprocessor systems or design hardware to couple with a microprocessor chip. It does not delve into the internal electronic aspects of the integrated circuits involved.

Many introductory books on microprocessors go into much more detail in logic design than is necessary for such a presentation, or they presume a strong background in logic design and relegate that subject to an appendix. These books are written primarily for electrical engineering (or computer engineering) students who are emphasizing the computer area and have a strong interest in understanding the internal workings of microprocessor chips. Not all electrical engineers and very few non-electrical engineers need this sort of preparation.

The coverage of logic circuits in this book is just sufficient to provide a satisfactory basis for an understanding of microprocessors. It is not intended to replace the traditional electrical engineering logic and switching course. In fact, it may serve to stimulate the reader to study this field in more depth.

The book introduces the reader to combinational circuits from a functional point of view with the emphasis on understanding the sorts of things they can accomplish. No design concepts are introduced other than to describe the minimization problem.

The discussion of sequential circuits is a descriptive one with enough detail to show the reader how simple registers can be constructed from flip-flops and gates. These topics have been included because I feel that at least a minimal coverage of both combinational and sequential logic circuits is a necessary prerequisite for a basic understanding of microprocessors.

TARGET PROCESSOR(S)

As is stated in the title, the book introduces two Motorola microprocessors as examples or targets, the MC6809 and the MC68000. The MC6809 is a very important processor from the pedagogical point of view. It is a simple enough machine to serve very well as an introductory vehicle to the world of microprocessors, yet it is complex enough to find extensive use in control applications in the real world. The MC68000 is the senior member of one of the major families of processors used in current personal computer systems and it too is used extensively in real time control applications.

For the first exposure to the material in the book, the reader should select one of the two processors and concentrate on it to the exclusion of the other. It would be a difficult and discouraging task to attempt to learn the details of both processors simultaneously. To support this approach, all processor specific sections, tables, figures, and problems are clearly labeled as such. When studying the details of one processor, those segments dealing with the other may be readily identified and omitted.

The choice of which processor to study initially will probably be determined by the availability of a laboratory system which may be used to prepare and run programs. It is very important that the student have such a system for the first (or only) processor to be studied.

After the initial exposure and after gaining an understanding of the details of the selected processor, the other may be studied for the purpose of contrast and comparison. However, such a comparison is not as important as the depth of coverage of the primary processor and the availability of a suitable laboratory platform.

ORGANIZATION OF MATERIAL

Following a brief presentation of the general aspects of computer systems, the book introduces the reader to the two primary digital areas of logic circuits and number systems. The basic aspects of microprocessors are then presented. As each new topic is introduced it is first discussed in a general way. The terms are defined, general examples are shown, and the fundamental concepts are established. Then, the specifics of the topic as related to the MC6809 are discussed followed by a similar presentation for the MC68000. The specifics are presented in such a way that either could stand alone; i.e., the coverage of each processor is independent of the other.

Following a brief historical overview, Chapter 1 introduces some very basic and important concepts and terminology. This chapter must be covered carefully and in detail, as it forms the basis for much of the material of the book.

Chapters 2 and 3 provide the introduction to logic circuits and number systems. These chapters include the minimum required exposure to these basic subjects which are so important to understanding the subsequent material. Unless the subjects have been covered in a prior course, these chapters must also be covered in detail.

Chapter 4 describes the architectural and functional structures of microprocessors in general, including such concepts as the programming model, accumulator and general register processors, condition codes, the fetch/execute cycle, basic memory types, and bus cycles. It ends with a presentation of the programming models and simple example programs for each of the target processors.

Chapter 5 discusses instruction sets and addressing modes in general and includes a detailed description of the modes available with the target processors. The emphasis is on describing the sorts of things which the individual machine language instructions may accomplish in order to support the discussion of the details of the addressing modes. Understanding the addressing modes in detail is of particular importance. The lack of such an understanding is often the major stumbling block to the student's grasp of the subsequent material on assembly language programming.

Chapter 6 introduces assembly language programming and presents a more detailed discussion of the instruction sets of the target processors, with the emphasis on their mnemonic forms and addressing mode limitations.

Chapters 5 and 6 are by far the longest chapters in the book. The material in them should be thoroughly understood by the student before going on to the subsequent material. Some instructors may prefer to cover the latter part of Chapter 6 before introducing assembly language programming. However, I recommend the order followed in the book.

Chapter 7 presents several examples of program segments which illustrate such things as double precision and BCD arithmetic, loop structures, relocatability, bit level manipulations, and BCD/binary number conversions.

Chapter 8 introduces stacks and their uses and includes extensive subroutine techniques, including parameter passing and dynamic memory allocation.

Structured modular programming is introduced in Chapter 9. This programming discipline is intentionally introduced late in the book. I feel that the student must have a thorough understanding of the capabilities of the processor before the material in this chapter can be of benefit. However, some instructors may prefer to present this material earlier, perhaps immediately after Chapter 6. It has been written in such a way as to support this approach.

Chapters 10 and 11 describe the general aspects of I/O and interrupt structures and present the details of these structures as implemented in the target processors. In addition, Chapter 10 introduces the three primary Motorola interface chips: the PIA, the PTM, and the ACIA. Chapter 12 presents some additional material on memory types and structures including address decoding and interfacing. The material in these three chapters is less detailed than earlier material. Some of it may be deferred to a follow-on interfacing course. Alternatively, the material may be supplemented with detailed manufacturer's specifications on specific chips and expanded to include some interfacing techniques.

Chapter 13 includes the pin-by-pin hardware descriptions of the target processors, including instruction timing and bus cycle timing. Chapter 14 introduces some of the more common development tools. Some or all of this material need not be covered formally and may be left for a reading assignment. The material in Chapter

13 should be covered in detail if the choice is made to expand the material to include interfacing.

LABORATORY WORK

When first learning about microprocessors it is important that the student be able to perform supporting experiments as new material is presented. Such experiments may be done on real hardware such as logic kits and microprocessor educational kits. On the other hand, they may be simulated quite well on a general purpose computer. Either approach seems to work satisfactorily, although many instructors and students do prefer to see the actual components.

Two simulator programs are available for use with this book, ASSYM000 for the MC68000 and ASSYM09 for the MC6809. Each program can assemble a source program into machine code and then simulate the execution of the program on its processor. They run in the DOS operating system on any IBM compatible personal computer. These programs accompany the instructor's problem-solution manual which may be obtained from McGraw-Hill when the book is adopted for classroom use.

The assembler/simulator programs were written at Michigan Technological University and rights to the programs are retained by the university. They may be loaded on only one computer with copies allowed only for back-up purposes. Additional copies may be obtained by contacting Michigan Technological University at (906) 487-2487.

ACKNOWLEDGMENTS

McGraw-Hill and I would like to thank the following reviewers for their many helpful comments and suggestions: Ashok Krishnamurthy, Ohio State University; Stephen Prigozy, United States Merchant Marine Academy; Barna Szabados, McMaster University; and William Trotter, Jr., University of Maryland.

Ralph Horvath

CONTENTS

CHAPTER 1

INTRODUCTION TO COMPUTERS

Welcome to the exciting and dynamic world of computers! The computing power which in the 1950s filled several entire rooms is now available on an electronic component small enough to fit on the tip of your finger. This tiny device, known as a *microprocessor,* is ushering in a new era of technological progress through its widespread application in every realm of human endeavor. In addition to their uses in computers, microprocessors are now used to control household appliances, automobile engines, laboratory equipment, factory machinery, robots, consumer electronic devices, chemical processing plants, steel mills, and medical diagnostic and treatment equipment; the list goes on and on. They have made it possible to capture a bit of the essence of human intelligence and apply it to the control of inanimate devices. Speaking facetiously, it is now possible to purchase a spark of human genius for $1.98! In this chapter we will look at some of the broader aspects of computers and microprocessors, including some historical developments, the evolution of the technology, and its division into hardware and software concerns.

1.1 HISTORICAL BACKGROUND

Most historians of technology agree that if any one person could be said to be the inventor or "father" of the computer it would be the English mathematician Charles Babbage. In the early part of the nineteenth century, Babbage first designed and attempted to build what he called an "Analytical Engine". This machine was intended to automatically compute values for mathematical tables. In those days before the invention of the calculator, mathematicians and engineers used tables to look up values of such things as logarithms, trigonometric functions, hyperbolic functions, factorials, and the like. The construction of these tables was a laborious and time-consuming task, and many people had attempted to devise machines to carry out the necessary calculations. Babbage's invention, however, was the first to attempt to automate the calculating process completely. It included the concept of a stored program and allowed the user to modify the program so as to alter the calculating behavior of the machine.

Unfortunately, with the limited technology of the nineteenth century, Babbage could not produce the mechanical components with sufficient accuracy to enable the machine to run properly. A machine built to his specifications in the early 1950s did perform as expected. By that time, however, the electronic computer had been developed and Babbage's invention was merely a historical curiosity.

During the early part of this century, much of the groundwork which led to the invention of the modern digital computer was accomplished by various telephone companies around the world, particularly by American Telephone and Telegraph's Bell Telephone Laboratories. Research in the design and development of the telephone switching network led to the invention of various components and design techniques that subsequently were implemented directly in the first successful computer. This computer was developed in the late 1930s to calculate ballistic information for use by the Allies during the Second World War. The computer used electromechanical devices known as *relays* to perform the various functions. Relays are electrically actuated mechanical switches that were used extensively in early telephone switching networks. (They are no longer used to perform logical functions of this type; now they are used simply to manipulate large electrical currents with small controlling currents.)

By the end of the Second World War several versions of the relay computer had been built, and their major shortcomings of speed and reliability were evident. In the early 1950s, however, a new generation of computers was conceived and built, using *vacuum tubes* rather than relays as its primary components. Vacuum tubes had been in use for many years in radio receivers and transmitters as well as in other electronic systems such as radar and sonar. In their new applications in computers they were used as electrically operated switches similar to relays in their behavior. In a relay, however, the switching action is enabled by the actual movement of a mechanical arm. In a vacuum tube switch, the switching action takes place through the movement of a stream of electrons flowing through a vacuum inside the device. As a consequence, the new computers were very much faster than their relay predecessors, performing hundreds of thousands of operations per second (as compared to tens of operations per second). They were also much more reliable because of their lack of mechanical motion. However, they eventually became so large that even with the best components available the mean time between failures was measured in hours!

Coincident with the development of the vacuum tube computer was the invention and subsequent development of the *transistor*. This device, which was destined to replace the vacuum tube in almost all of its applications, became the primary component in the next generation of computers, the transistorized solid-state computer.

When used as an electrically operated switch, the transistor has a significant advantage over the vacuum tube. In the transistor, the switching action takes place in streams of electric current flowing through the solid material of the device. This activity can take place at room temperature. In a vacuum tube, electrons must flow through a space between metal electrodes, and in order for an electrode to emit electrons into the space its temperature must be maintained at about 1000°C.

Because of its lower operating temperature and smaller size the transistor rapidly replaced the vacuum tube in the computers of the 1960s. The transistorized computer consisted of row upon row of printed circuit boards, each one containing as few as one or two or as many as 30 or 40 transistors together with associated components. A modest computer may have contained 5000 or so transistors, while a large one could contain as many as several hundred thousand transistors mounted on 20,000 or more printed circuit boards!

The next generation of computers had its roots in the space program of the 1960s, for which the United States expended enormous amounts of resources in order to put humans on the moon. Among the developments to come from this effort was the *integrated circuit*, which started as an attempt to assemble the equivalent of one printed circuit board's worth of components into a single component. The intent was to interconnect the components using the same process by which they were manufactured, with no manual intervention. This effort succeeded beyond imagination. The early integrated circuits contained the equivalent of one or two of the above-mentioned printed circuit boards, perhaps 10 transistors and about 100 other components. Modern integrated circuits can contain the equivalent of an entire computer, as many as several hundred thousand components.

The integrated circuit computer uses transistors that are similar to those of the earlier generation. The major difference is that the integrated circuit transistors are manufactured in integrated modules and interconnected with other components manufactured at the same time. Thus, a single component in this generation of computers may do the work of tens of thousands of components from the preceding generation. Yet this single integrated circuit component costs about the same and occupies about as much space as a dozen of the earlier components taken together. This is the basis of the computer revolution taking place today. The development cost of a modern computer may be comparable to that of one from an earlier generation, but the size and manufacturing cost are much lower. We are now manufacturing computers with the capabilities of the multi-million-dollar, multi-room-sized behemoths of the 1950s, but which cost only a few thousand dollars and fit on or under a (small) desk!

As a consequence of their reduced size and cost, modern integrated circuit computers are being used to do things that would never have been considered feasible in earlier generations. They are still used in the traditional applications of calculating mathematical results and performing various business support functions. But they are also used in the new area of computerized control, to monitor input signals from a system and to analyze these signals using traditional computation techniques. The results are then used by the computer to generate various signals which, in turn, control the system. The target system may be anything amenable to electrical monitoring and control.