# MICROPROCESSORS/ MICROCOMPUTERS

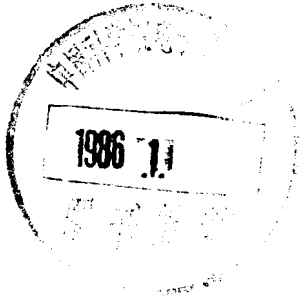
## ARCHITECTURE, SOFTWARE, AND SYSTEMS

ADI J. KHAMBATA

# MICROPROCESSORS/ MICROCOMPUTERS

## ARCHITECTURE, SOFTWARE, AND SYSTEMS

**DI J. KHAMBATA**
PAUL TECHNICAL-VOCATIONAL INSTITUTE





**JOHN WILEY & SONS**
NEW YORK CHICHESTER BRISBANE TORONTO SINGAPORE

***Library of Congress Cataloging in Publication Data:***
Khambata, Adi J.
Microprocessors/microcomputers.

Includes indexes.
1. Microprocessors. 2. Microcomputers.
I. Title.
QA76.5.K43 001.64'04 81-11360
AACR2

Printed in the United States of America

10 9 8 7 6 5 4 3 2

# PREFACE

Advances in semiconductor technology have revolutionized the computer field; this is impacting many aspects of American life and industrial activities. The availability of inexpensive computing capability permits applications that were not considered potential candidates for computerization a few years ago. Microprocessors/microcomputers appear in many consumer products, from computer games and kitchen appliances to automobiles. The advent of these low-cost computing systems has led to the development of still another field, until now completely unknown and foreign to the traditional computer industry: computer hobbyists and home computer use.

Understandably, this has created a voracious appetite for microcomputer education. Many segments of industry that were previously not concerned with computers are in the midst of a digital world, requiring personnel trained in the field of microcomputers. Several companies have set up specialized, in-house, microcomputer training courses. Others are relying on established educational institutions to supply them with trained graduates in this field. The major academic problem encountered by most educational institutions is the formation of the required curriculum and the availability of the appropriate teaching materials. The literature abounds with excellent books and other publications on microprocessors/microcomputers; however, most of them are not suitable for classroom use, nor can curriculum be developed around them. This book, based on microcomputer courses that I designed and taught at the St. Paul Technical-Vocational Institute, St. Paul, Minnesota, and at local industries over the past several years, will fill this need.

This book satisfies the requirements of four distinct user groups. First, it can be used in community colleges, vocational schools, and other two-year educational institutions. A group of microprocessor courses can be designed around the basic material in the book. Product supplements to the basic textbook provide sufficient background for the practical application of specific microcomputer systems in the laboratory. Second, each topic starts out at a very fundamental level; the presentations and discussions proceed to greater depth and higher levels, so it could also be used at institutions of higher learning such as four-year colleges and universities. Third, many persons working in industry need and desire to learn about and use microcomputers. Unfortunately, not all of these people can attend courses offered by educational institutions. Self-study may be their only option, and the reasonably detailed explanations and worked-out examples in this book will be helpful to these people. Finally, hobbyists will find this book useful because it is written so that they can scan a subject lightly or pursue it in greater depth, depending on desire and requirements.

It is assumed that students who use this book have some prior knowledge of digital logic and basic logic functions such as AND gates, OR gates, flip-flops, and logic

blocks (registers, counters, etc.). These items are not included here, since they are adequately covered in many other excellent publications. The book is divided into two sections. The first covers the hardware aspects of microcomputers, including the central processor (CPU) and the commonly used schemes for interfacing the CPU with the outside world. The second section covers the software aspects of microcomputers. This includes a chapter on BASIC, which is presently the most popular higher-level language used in microcomputer systems.

Chapter One is a fundamental review of digital computers. The architecture of the CPU and the sequence of basic operations are covered here. Number systems and binary data coding are discussed in Chapter Two. The pure binary system, the octal system, the binary-coded-decimal system (BCD), and the hexadecimal system are included. The CPU architecture is the topic of Chapter Three. Busses, which are an important feature of microprocessors, are covered along with machine and instruction cycles. The principal registers and counters of the CPU and their respective functions are then presented. Chapter Four deals with microprocessor instructions. The basic instruction formats for both the memory-reference and the nonmemory-reference instructions are treated. The various addressing modes are presented in Chapter Five. Special attention is given to the indirect addressing mode, which is troublesome to some students. Chapter Six discusses how instructions are executed by the CPU, the microsteps or microinstructions that comprise a macroinstruction are shown, and the basic concept of a microprogrammable microprocessor is introduced. Memory chips, which are used in microcomputer systems, are briefly presented in Chapter Seven. Programmed I/O transfers (both conditional and unconditional) are the subject of Chapter Eight. Chapter Nine describes the interrupt I/O. The vectored interrupt, the software-polled interrupt, and the popular daisy-chained interrupt are examined. Multilevel priority interrupts are also included. Direct Memory Access (DMA) is described in Chapter Ten. Serial I/O transfers are the subject of Chapter Eleven; conversion and synchronization logic and the problems of data identification in serial bit streams are studied in this chapter. Programmable I/O interfaces are described in Chapter Twelve; programmable interfaces for both serial and parallel transfers are included. Chapter Thirteen analyzes D/A and A/D converters. Many microprocessors are required to interface with equipments that have nondigital signals, and so appropriate D/A and A/D interfaces are required.

Chapter Fourteen (which begins the software section) introduces the microcomputer software development cycle. Problem definition and flowcharting are the subject of Chapter Fifteen. Chapter Sixteen shows how to organize the data for processing purposes; exponential notation, the sign convention, and floating-point operations are also presented. The data transformation process is the subject of Chapter Seventeen, which also describes the fundamental functional statements. Chapter Eighteen is entirely devoted to BASIC (Beginner's All-Purpose Symbolic Instruction Code), the higher-level language widely used in microcomputer systems today. Assemblers and interpreters are dealt with in Chapter Nineteen. Interpreters are used frequently in home computers, so this chapter is of special interest to hobbyists. Chapter Twenty briefly describes operating systems and systems software.

To aid readers in learning the material, several chapter elements have been incorporated into the text. These include numerous worked-out examples and figures, end-

of-chapter summaries, review questions, and problems. Three appendixes are also included. Appendix A gives the popular ASCII character set and the associated codes. The subject of system testing and checkout and the various testing approaches, commonly used with microcomputer systems, is examined in Appendix B. The logic analyzer, briefly treated in Appendix C, is the most powerful microcomputer troubleshooting tool available today. A glossary of important terms follows the appendixes.

In addition to offering theoretical descriptions and discussions, it is desirable to describe at least one real, existing microcomputer system. However, including a description of any one product in this book would immediately have dated the publication and also made it unacceptable to other users who may be committed to another product. This dilemma was resolved by adopting a unique approach. A series of separate, soft-cover, supplements, each covering a popular microcomputer system, will accompany the basic text. Four such supplements are presently planned. They will cover the Zilog Z-80, the popular Intel 8080 series, the Motorola MC6800, and the 6502 by MOS Technology. This approach will enable us to introduce additional supplements on future products that find acceptance in educational institutions as well as update existing supplements as needed. It also allows users of this book to purchase only the supplements that are of direct use for their specific needs. In addition to the paperback supplements, separate laboratory manuals—on the most popular microcomputers—will also be published.

When writing a book such as this, it often becomes necessary to borrow some material from prior publications of computer manufacturers and other publishers. I wish to express my appreciation and thanks to the following for giving me permission to use material from their respective publications in this textbook: McGraw-Hill Book Company, New York, Intel Corporation, Santa Clara, California, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, and John Wiley & Sons, Inc., Publishers, New York.

I would like to thank the many people who helped me during the writing and publication of this book. First, Irving L. Kosow, Series Editor at Wiley, meticulously edited the original manuscript and helped me transform it into a finished product. Judy Green, Engineering Technology Editor, and her staff were extremely helpful during the publication process. Their efforts and cooperation are most appreciated. Dr. George Richter, Technical Division Manager at St. Paul Technical-Vocational Institute, constantly encouraged and supported me. Several of my students and former engineering colleagues at Sperry Univac reviewed parts of the manuscript and offered many valuable comments and suggestions; special contributions were made by Philip Gaines, Walter Knights, and Richard Paske. I would also like to thank the following reviewers, whose comments and suggestions were invaluable in preparing the final version of the manuscript: Louis Gross, Columbus Technical Institute; James King, Joliet Junior College; Arthur Seidman, Pratt Institute; Dave Terrell, ITT Technical Institute; J.W. Toliver, University of Houston; and Charles Van Buren, DeVry Technical Institute.

This book is a Khambata family project: my wife Ruth and daughter Pixie typed the manuscript; my son Danny, assisted by his wife Renee, drew the diagrams; and my son Jim and his wife Shelly did all the proofreading. I thank all of them.

Adi J. Khambata

# CONTENTS