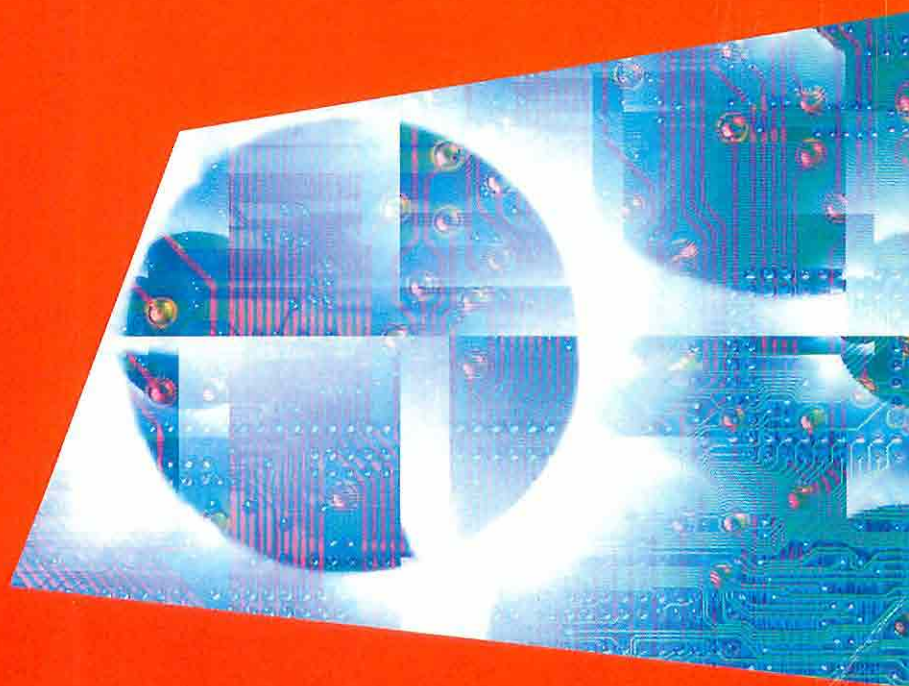




computer communications and networks



The Quintessential PIC Microcontroller



Springer

Sid Katzen

Sid Katzen

The Quintessential PIC Microcontroller



Springer

Sid Katzen, BSc, MSc, DPhil, MIEE, MIEEE, CEng
School of Electrical and Mechanical Engineering, University of Ulster,
Newtownabbey, County Antrim BT37 0QB, UK

Series editor

Professor A.J. Sammes, BSc, MPhil, PhD, FBCS, CEng
CISM Group, Cranfield University, RMCS, Shrivenham, Swindon SN6 8LA, UK

In memory of Eva Jones

ISBN 1-85233-309-X Springer-Verlag London Berlin Heidelberg

British Library Cataloguing in Publication Data

Katzen, Sid

The quintessential PIC microcontroller. – (Computer communications and networks)

1. Programmable controllers

I. Title

629.8'9

ISBN 185233309X

Library of Congress Cataloging-in-Publication Data

Katzen, Sid.

The quintessential PIC microcontroller. / Sid Katzen.

p. cm. -- (Computer communications and networks)

Includes index.

ISBN 1-85233-309-X (alk. paper)

1. Programmable controllers. I. Title. II. Series.

TJ223.P76 K38 2001

629.8'9—dc21

00-066153

Apart from any fair dealing for the purposes of research or private study, or criticism or review, as permitted under the Copyright, Designs and Patents Act 1988, this publication may only be reproduced, stored or transmitted, in any form or by any means, with the prior permission in writing of the publishers, or in the case of reprographic reproduction in accordance with the terms of licences issued by the Copyright Licensing Agency. Enquiries concerning reproduction outside those terms should be sent to the publishers.

© Springer-Verlag London Limited 2001

Printed in Great Britain

2nd printing, with corrections 2003

3rd printing, 2004

The use of registered names, trademarks etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant laws and regulations and therefore free for general use.

The publisher makes no representation, express or implied, with regard to the accuracy of the information contained in this book and cannot accept any legal responsibility or liability for any errors or omissions that may be made.

Typesetting: Camera-ready by author

Printed and bound at the Athenæum Press Ltd., Gateshead, Tyne and Wear

34/3830-5432 Printed on acid-free paper SPIN 10974797

Contents

Preface VII

Part I The Fundamentals

1. Digital Representation 3
2. Logic Circuitry 17
3. Stored Program Processing 41

Part II The Software

4. The PIC16F84 Microcontroller 77
5. The Instruction Set 105
6. Subroutines and Modules 135
7. Interrupt Handling 169
8. Assembly Language 195
9. High-Level Language 227

Part III The Outside World

10. The Real World 249
11. One Byte at a Time 267
12. One Bit at a Time 301
13. Time is of the Essence 357

VI Contents

14. Take the Rough with the Smooth	385
15. To Have and to Hold	425
16. A Case Study	449

Appendices

A. 14-bit Core Instruction Set	469
B. Special Purpose Register Structure for the PIC16F874/7	471
C. C Instruction Set	473
D. Acronyms and Abbreviations	475
Index	479

Preface

Microprocessors and their microcontroller derivatives are a ubiquitous, if rather invisible, part of the infrastructure of our 21st century electronic and communications society. In 1998 it was reckoned¹ that hidden in every home were about 100 microcontrollers and microprocessors; in the singing birthday card, washing machine, microwave oven, television controller, telephone, personal computer and so on. About 20 more lurked in the average family car. For example monitoring in-tire radio pressure sensors and displaying critical data through the car area network (CAN).

Around 4 billion such devices are sold each year to implement the intelligence of these smart electronic devices, ranging from smart egg timers through aircraft management systems. The evolution of the microprocessor from the first Intel device introduced 30 years ago in 1971 has revolutionised the structure of society, effectively creating the second smart industrial revolution coming to fruition at the beginning of the 21st century. Although the microprocessor is better known in its guise of powering the ubiquitous PC, in which raw computing power is the goal, sales of such microprocessors as the Intel Pentium, represent only around 2% of total volume. The vast majority of sales are of low-cost microcontrollers embedded into a dedicated-function digital electronic device, such as the smart card. Here the emphasis is the integration of the core processor with memory and input/output resources in the one chip. This integrated computing system is known as a microcontroller.

In seeking to write a book in this area the overall objective was to get the reader up to speed in designing small embedded microcontroller-based systems, rather than using microcontrollers as a vehicle to illustrate computer architecture in the traditional sense. This will hopefully give the reader the confidence that even at such an introductory level, he/she can design, construct and program a complete working embedded system.

Given the practical nature of this material, real-world hardware and software products are used throughout to illustrate the material. The microcontroller market is dominated by devices that operate on 8-bit data (although 4- and 16-bit instances are available) like early microprocessors and unlike the 64-bit Intel Pentium and Motorola Power PC 'heavy brigade'. In contrast the essence of the microcontroller lies in their high

¹New Scientist, vol. 59, no. 2141, 4th July 1998, pp. 139.

system integration/low cost profile. Power can be increased by distributing processors throughout the system. Thus, for example, a robot arm may have a microcontroller for each joint implementing simple local processes and communicating with a more powerful processor making over-all executive decisions.

In choosing a target architecture, both acceptance in the industrial market, easy availability and low cost development software has made the Microchip family one of the most popular choices as the pedagogic vehicle in learning microprocessor/microcontroller technology at all levels of electronic engineering from grade school to university. In particular the reduced instruction set together with the relatively simple innovative architecture reduces the learning curve. As well as its industrial and educational roles, the PIC families are the mainstay of hobbyist projects; as a leaf through any Electronic magazine will show.

Microchip inc. is a relatively recent entrant to the microcontroller market with its family of Harvard architecture PIC devices introduced in 1989. By 1999, Microchip was the second largest producer of 8-bit units – behind only Motorola.

The book is split into three parts. Part I covers sufficient digital, logic and computer architecture to act as a foundation for the microcontroller engineering topics presented in the rest of the text. Inclusion of this material makes the text suitable for stand-alone usage, as it does not require a prerequisite digital systems module.

Part II looks mainly at the software aspects of the mid-range PIC microcontroller family, its instruction set, how to program it at assembly and high-level C coding levels, and how the microcontroller handles sub-routines and interrupts. Although the 14-bit PIC family is the exemplar, both architecture and software are comparable to both the 12- and 16-bit ranges.

Part III moves on to the hardware aspects of interfacing and interrupt handling, with the integration of the hardware and software being a constant theme throughout. Parallel and serial input/output, timing, analog and EEPROM data handling techniques are covered. A practical build and program case study integrates the previous material into a working system, as well as illustrating simple testing strategies.

With the exception of the first two and last chapter, all chapters have both fully worked examples and self-assessment questions. As an extension to this, an associated Web site at

<http://www.engj.u1st.ac.uk/sidk/quintessential>

has the following facilities:

- Solutions to self-assessment questions.
- Further self-assessment questions.
- Additional material.

- Source code for all examples and questions in the text.
- Pointers to development software and data sheets for devices used in the book.
- Errata.

The manuscript was typeset on a Siemens Scenic D Pentium 133 PC by the author using a Y&Y implementation of $\text{\LaTeX} 2_{\epsilon}$ and the Lucida Bright font family. Camera-ready copy was produced in .pdf format and used to directly generate plates at 1270dpi resolution. Line drawings were created or modified with Autocad R13 and incorporated as encapsulated PostScript files. Photographs were taken by the author using a Olympus C-1400L 1.4 M pixel digital camera – absolutely full of microcontrollers!

S.J. Katzen
University of Ulster at Jordanstown
December 2000

A reprint has given me the opportunity of revisiting some typesetting issues; adding, updating and clarifying some material and upgrading a few of the diagrams. In particular I would like to thank correspondents from as far away as Hawaii, Canada and Switzerland who pointed out errors (fortunately mainly minor) and other gremlins. These are listed and acknowledged in the book's web site and have been corrected in this reprint. Hopefully the majority of such gremlins have been exorcised, but if you find any more or have any other suggestions, I will be happy to take these on board and acknowledge such communications via the Web site.

S.J. Katzen
University of Ulster at Jordanstown
October 2002

PART I

The Fundamentals

This book is about microcontrollers (MCUs). These are digital engines modeled after the architecture of a stored-program computer and integrated on to a single very large-scale integrated circuit together with support circuitry, memories and peripheral interface devices. Although the MCU is often confused with its better-known cousin the microprocessor in its role as the driving force of the ubiquitous personal computer, the vast majority of both microprocessors and microcontrollers are embedded into an assemblage of other digital components. The first microprocessors in the early 1970s were marketed as an alternative way of implementing digital circuitry. Here the task would be determined by a series of instructions encoded as binary code groups in read-only memory. This is more flexible than the alternative approach of wiring hardware integrated circuits in the appropriate manner. The microcontroller is simply the embodiment of this original role of the integrated computer.

We will look at embedded MCUs in a general digital processing context in Parts II and III. Here our objective is to lay the foundation for this material. We will be covering:

- *Digital code patterns.*
- *Binary arithmetic.*
- *Digital circuitry.*
- *Computer architecture and programming.*

This will by no means be a comprehensive review of the subject, but there are many other excellent texts in this area² which will launch you into greater depths.

²Such as S.J. Cahill's *Digital and Microprocessor Engineering*, 2nd edn., Prentice Hall, 1993.