Practical Microcontroller Engineering with ARM® Technology

Ying Bai



Practical Microcontroller Engineering with ARM® Technology

IEEE Press

445 Hoes Lane Piscataway, NJ 08854

IEEE Press Editorial Board

Tariq Samad, Editor in Chief

George W. Arnold	Vladimir Lumelsky	Linda Shafer
Dmitry Goldgof	Pui-In Mak	Zidong Wang
Ekram Hossain	Jeffrey Nanzer	MengChu Zhou
Mary Lanzerotti	Ray Perez	George Zobrist

Kenneth Moore, Director of IEEE Book and Information Services (BIS)

Practical Microcontroller Engineering with ARM® Technology

Ying Bai

Department of Computer Science and Engineering Johnson C. Smith University Charlotte, North Carolina



Copyright © 2016 by The Institute of Electrical and Electronics Engineers, Inc.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey. All rights reserved Published simultaneously in Canada

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 750-4470, or on the web at www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at http://www.wiley.com/go/permission.

Limit of Liability/Disclaimer of Warranty: While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Neither the publisher nor author shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

For general information on our other products and services or for technical support, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic formats. For more information about Wiley products, visit our web site at www.wiley.com.

Library of Congress Cataloging-in-Publication Data is available.

ISBN: 978-1-119-05237-1

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

This book is dedicated to my wife, Yan Wang, and to my daughter, Susan (Xue) Bai.

Contents

Preface xxix Acknowledgments xxxi Trademarks and Copyrights xxxiii							
							Copyright Permissions xxxv
							About the Companion Website xxxix
Chapter 1 Introduction to Microcontrollers and This Book							
1.1 Microcontroller Configuration and Structure 2 1.2 The ARM® Cortex®M4 Microcontroller System 3 1.3 The TM4C123GH6PM Microcontroller Development Tools and Kits 4 1.4 Outstanding Features About This Book 5 1.5 Who This Book Is For 5 1.6 What This Book Covers 6 1.7 How This Book Is Organized and How to Use This Book 8 1.8 How to Use the Source Code and Sample Projects 9 1.9 Instructors and Customers Supports 11							
Chapter 2 ARM® Microcontroller Architectures							
2.1 Overview and Introduction 13 2.2 Introduction to ARM® Cortex®-M4 MCU 15 2.2.1 The Architecture of ARM® Cortex®-M4 MCU 17 2.2.1.1 The ARM® MCU Architecture 17 2.2.1.2 The Architecture of the ARM® Cortex®-M4 Core (CPU) 20 2.2.1.2.1 The Register Bank in the Cortex®-M4 Core 21 2.2.1.2.2 The Special Registers in the Cortex®-M4 Core 22 2.2.1.3 The Architecture of the Floating-Point Registers 25 2.3 The Memory Architecture 27 2.3.1 The Memory Map 28							
2.3.2 The Stack Memory 29 2.3.3 The Program Models and States 32 2.3.4 The Memory Protection Unit (MPU) 33 2.4 The Nested Vectored Interrupt Controller (NVIC) Architecture 34 2.4.1 The Nested Vectored Interrupt Controller (NVIC) Features 35 2.4.2 Exception and Interrupt Sources 35 2.4.3 Exception Priority Levels and Mask Registers 35							

2 -	 2.4.4 Respond and Process Exceptions and Interrupts 2.4.5 Exception and Interrupt Vector Table 37 	
2.5	The Debug Architecture 37	
2.6		38
	2.6.1 TM4C123GH6PM Microcontroller Overview 39	
	2.6.2 TM4C123GH6PM Microcontroller On-Chip Memory Map 40	
	2.6.2.1 The System Peripherals 42	
	2.6.2.2 The On-Chip Peripherals 42	
	2.6.2.3 Interfaces to External Parallel Peripherals 44	
	2.6.2.4 Interfaces to External Serial Peripherals 44	
	2.6.3 TM4C123GH6PM Microcontroller General-Purpose Input-Output	
	(GPIO) Module 44	
	2.6.3.1 The System Clock 45	
	2.6.3.2 The General Configuration Procedures for GPIO Peripherals	47
	2.6.3.3 Tiva [™] TM4C123GH6PM GPIO Architecture 47	
	2.6.3.3.1 The Port Control Register (GPIOPCTL) 49	
	2.6.3.3.2 The Data Control Registers 49	
	2.6.3.3.3 The Mode Control Registers 49	
	2.6.3.3.4 The Commit Control Registers 51	
	2.6.3.3.5 The Interrupt Control Registers 51	
	2.6.3.3.6 The Pad Control Registers 52	
	2.6.3.3.7 The Identification Registers 55	
	2.6.3.4 The Initialization and Configuration of TM4C123GH6PM	
	GPIO Ports 55	
	2.6.4 TM4C123GH6PM Microcontroller System Controls 57	
	2.6.4.1 Device Identification 58	
	2.6.4.2 Reset Control 59	
	2.6.4.2.1 The Power-On Reset 60	
	2.6.4.2.2 The External Reset 61	
	2.6.4.2.3 The Brown-Out Reset (BOR) 61	
	2.6.4.2.4 The Software Reset 61	
	2.6.4.2.5 The Watchdog Timer Reset 62	
	2.6.4.3 Non-Maskable Interrupt Control 63	
	2.6.4.4 Clock Control 64	
	2.6.4.5 Other System Controls 67	
	2.6.4.5.1 The Run Mode 67	
	2.6.4.5.2 The Sleep Mode 68	
	2.6.4.5.3 The Deep-Sleep Mode 68	
	2.6.4.5.4 The Hibernate Mode 68	
	2.6.4.5.5 The System Timer (SysTick) 69	
	2.6.4.5.6 System Control Block (SCB) 70	
	2.6.4.6 System Clock Initialization and Configuration 71	
2.7	Introduction to Tiva [™] C Series LaunchPad [™] TM4C123GXL	
2.7	Evaluation Board 72	
2.8	Introduction to EduBASE ARM® Trainer 77	
2.9	Chapter Summary 77	
	mework 79	
1101	mework /9	

3.1		w and Introduction 83
3.2		tire Tiva™ TM4C123G-based Development System 84
3.3		ad and Install Development Suite and Specified Firmware 86
3.4		ction to the Integrated Development Environment—Keil® MDK
	μVersio	
		The Keil® MDK-ARM® for the MDK-Cortex-M Family 88
		General Development Flow with MDK-ARM® 89
		Warming Up Keil® MDK Cortex-M Kit with Example Projects 91
	3.4.4	The Functions of the Keil® MDK-ARM® µVersion®5 GUI 95
	3.4.4	.1 The File Menu 97
	3.4.4	.2 The Edit Menu 98
	3.4.4	.3 The Project Menu 101
	3.4.4	.4 The Flash Menu 121
	3.4.4	.5 The Debug Menu 121
	3.4.4	.6 The Peripherals Menu 123
	3.4.4	.7 The Tools Menu 124
	3.4.4	
	3.4.4	
	3.4.4	1
3.5		led Software Development Procedure 127
3.6		il® ARM®-MDK μVision5 Debugger and Debug Process 128
		The ARM [®] μVision5 Debug Architecture 129
		The ARM® Debug Adaptor and Debug Adaptor Driver 130
		Fiva™ C Series LaunchPad™ Debug Adaptor and Debug Adaptor Driver 132
		The ARM® μVersion5 Debug Process 133
		The ARM® Trace Feature 134
	3.6.5	•
		The ARM® Instruction Set Simulator 136
		The ARM® Programs Running from SRAM 137
		ARM® Optimizations 139
3.7		aWare [™] for C Series Software Suite 140
		The TivaWare™ C Series Software Package 142
	3.7.1	
	3.7.1	
	3.7.1	
		TivaWare™ C Series for TM4C123G LaunchPad™ Evaluation Kit 145
	3.7.2	
20	The Tim	Package 145
3.8		aWare [™] for C Series Utilities and Other Supports 147
		Additional Utilities Provided by TivaWare™ for C Series 148
	3.8.1	
	3.8.1	
	3.8.1	
	3.8.1 3.8.1	-
	3.0.1	.5 Tiva water for Coeffes Civioto support 150