# Microcontroller Programming and Interfacing with Texas Instruments MSP430FR2433 and MSP430FR5994

## Second Edition

# Synthesis Lectures on Digital Circuits and Systems

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Steven F. Barrett and Daniel J. Pack

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# Microcontroller Programming and Interfacing with Texas Instruments MSP430FR2433 and MSP430FR5994

## Second Edition

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*SYNTHESIS LECTURES ON DIGITAL CIRCUITS AND SYSTEMS #54*

## ABSTRACT

This book provides a thorough introduction to the Texas Instruments MSP430™ microcontroller. The MSP430 is a 16-bit reduced instruction set (RISC) processor that features ultra-low power consumption and integrated digital and analog hardware. Variants of the MSP430 microcontroller have been in production since 1993. This provides for a host of MSP430 products including evaluation boards, compilers, software examples, and documentation. A thorough introduction to the MSP430 line of microcontrollers, programming techniques, and interface concepts are provided along with considerable tutorial information with many illustrated examples. Each chapter provides laboratory exercises to apply what has been presented in the chapter. The book is intended for an upper level undergraduate course in microcontrollers or mechatronics but may also be used as a reference for capstone design projects. Also, practicing engineers already familiar with another microcontroller, who require a quick tutorial on the microcontroller, will find this book very useful. This second edition introduces the MSP–EXP430FR5994 and the MSP430–EXP430FR2433 LaunchPads. Both LaunchPads are equipped with a variety of peripherals and Ferroelectric Random Access Memory (FRAM). FRAM is a nonvolatile, low-power memory with functionality similar to flash memory.

## KEYWORDS

MSP430 microcontroller, microcontroller interfacing, embedded systems design, Texas Instruments

*To our families*

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# Preface

Texas Instruments is well known for its analog and digital devices, in particular, Digital Signal Processing (DSP) chips. Unknown to many, the company quietly developed its microcontroller division in the early 1990s and started producing a family of controllers aimed mainly for embedded meter applications, which require an extended operating time without intervention for power companies. It was not until the mid 2000s that the company began serious effort to present the MSP430 microcontroller family, its flagship microcontroller, to the academic community and future engineers. Their efforts have been quietly attracting many educators and students due to the MSP430's cost and the suitability of the controller for capstone design projects requiring microcontrollers. In addition, Texas Instruments offers many compatible analog and digital devices that can expand the range of the possible embedded applications of the microcontroller. Texas Instruments has continually added new innovation to the MSP430 microcontroller line. The second edition introduces the MSP–EXP430FR5994 and the MSP–EXP430FR2433 LaunchPads. Both LaunchPads are equipped with a variety of peripherals and Ferroelectric Random Access Memory (FRAM). FRAM is a nonvolatile, low-power memory with functionality similar to flash memory.

This book is about the MSP430 microcontroller family. We have three goals in writing this book. The first is to introduce readers to microcontroller programming. The MSP430 microcontrollers can be programmed either using assembly language or a high–level programming language such as C. The second goal of the book is to teach students how computers work. After all, a microcontroller is a computer within a single integrated circuit (chip). Finally, we present the microcontroller's input/output interface capabilities, one of the main reasons for developing embedded systems with microcontrollers.

**Background**

This book provides a thorough introduction to the Texas Instruments MSP430 microcontroller. The MSP430 is a 16-bit reduced instruction set (RISC) processor that features ultra-low power consumption and integrated digital and analog hardware. Variants of the MSP430 microcontroller have been in production since 1993 with a host of MSP430-related products including evaluation boards, compilers, software examples, and documentation.

This book is intentionally tutorial in nature with many worked examples, illustrations, and laboratory exercises. An emphasis is placed on real-world applications such as smart home concepts, mobile robots, an unmanned underwater vehicle, and a DC motor controller to name a few.

## Intended Readers

The book is intended for an upper level undergraduate course in microcontrollers or mechatronics but may also be used as a reference for capstone design projects. Also, practicing engineers who are already familiar with another line of microcontrollers, but require a quick tutorial on the MSP430 microcontroller, will find this book beneficial.

## Approach and Organization

This book provides a thorough introduction to the MSP430 line of microcontrollers, programming techniques, and interface concepts. Each chapter contains a list of objectives, background tutorial information, and detailed information on the operation of the MSP430 system under study. Furthermore, each chapter provides laboratory exercises to apply what has been presented in the chapter and how the concepts are employed in real applications. Each chapter concludes with a series of homework exercises divided into Fundamental, Advanced, and Challenging categories. The reader will get the most out of the book by also having the following references readily available:

- MSP430FR2433 Mixed–Signal Microcontroller, SLASE59B;
- MSP430FR4xx and MSP430FR2xx Family User's Guide, SLAU445G;
- MSP430FR599x, MSP430FR596x Mixed–Signal Microcontrollers, SLASE54B; and
- MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide, SLAU367O.

This documentation is available for download from the Texas Instruments website [www.ti.com].

Chapter 1 provides a brief review of microcontroller terminology and a short history followed by an overview of the MSP430 microcontroller. The overview surveys systems onboard the microcontroller and also various MSP430 families. The chapter concludes with an introduction to the hardware and software development tools that will be used for the remainder of the book. Our examples employ the MSP–EXP430FR5994 and the MSP430FR2433 LaunchPads, the Energia rapid prototyping platform, and the Texas Instruments' Code Composer Studio Integrated Development Environment (IDE). The information provided can be readily adapted to other MSP430 based experimenter boards.

Chapter 2 provides a brief introduction to programming in C. The chapter contains multiple examples for a new programmer. It also serves as a good review for seasoned programmers. Also, software programming tools including Energia, Code Composer Studio IDE, and debugging tools are explored. This chapter was adapted from material originally written for the Texas Instruments MSP432, a 32-bit processor that has close ties to the 16-bit MSP430.[1] Embed-

[1] This chapter was adapted with permission from *Arduino Microcontroller Processing for Everyone*, S. Barrett, 3rd ed., Morgan & Claypool Publishers, San Rafael, CA, 2013.

ded system developers will find a seamless transition between the MSP430 and MSP432 line of processors.

Chapter 3 introduces the MSP430 hardware architecture, software organization, and programming model. The chapter also presents an introduction to the MSP430 orthogonal instruction set, including its 27 instructions and 9 emulated instructions.

Chapter 4 describes a wide variety of input and output devices and how to properly interface them to the MSP430 microcontroller. We believe it is essential for the embedded system designer to understand the electrical characteristics of the processor so a proper interface to peripheral components may be designed. We have included a chapter on these concepts for the books we have written for the Synthesis Lecture Series. We continue to add material as new microcontroller peripherals are developed. The chapter begins with a review of the MSP430 electrical operating parameters followed by a discussion of the port system. The chapter includes a description of a wide variety of input device concepts including switches, interfacing, debouncing, and sensors. Output device concepts are then discussed including light-emitting diodes (LEDs), tri–state LED indicators, liquid crystal displays (LCDs), high-power DC and AC devices, motors, and annunciator devices.

Chapter 5 provides an in–depth discussion of the MSP430 power management system. The power management system provides for ultra-low power operation and practices.

Chapter 6 is dedicated to the different memory components onboard the MSP430 including the new FRAM nonvolatile memory, RAM, EEPROM and the associated memory controllers. The Direct Memory Access (DMA) controller is also discussed.

Chapter 7 discusses the clock and timer systems aboard the MSP430. The chapter begins with a detailed discussion of the flexible clock system, followed by a discussion of the timer system architecture. The timer architecture discussion includes the Watchdog timers, timers A and B, real-time clocks, and pulse width modulation (PWM).

Chapter 8 provides an introduction to the concepts of resets and interrupts. The various interrupt systems associated with the MSP430 are discussed, followed by detailed instructions on how to properly configure and program them.

Chapter 9 discusses the analog systems aboard the MSP430. The chapter discusses the analog–to–digital converters (ADCs), the digital–to–analog converters (DACs), and the comparators.

Chapter 10 is designed for a detailed review of the complement of serial communication systems resident onboard the MSP430, including the universal asynchronous receiver transmitter (UART), the serial peripheral interface (SPI), the I2C system, the radio frequency (RF) link, USB, and the IrDA infrared link. The systems are contained within the MSP430 universal serial communication interfaces eUSCI_A and eUSCI_B subsystems.

Chapter 11 provides a detailed introduction to the data integrity features aboard the MSP430 including a discussion of noise and its sources and suppression, an Advanced Encryption Standard (AES) 256 accelerator module, and a 16- or 32-bit cyclic redundancy check

(CRC) engine. This chapter was adapted from material originally written for the Texas Instruments MSP432, a 32-bit processor that has close ties to the 16-bit MSP430.[2] Embedded system developers will find a seamless transition between the MSP430 and MSP432 line of processors.

Chapter 12 discusses the system design process followed by system level examples. We view the microcontroller as the key component within the larger host system. It is essential the embedded system designer has development, design, and project management skills to successfully complete a project. This chapter provides an introduction some of the skills used for project development. We have included a chapter on these concepts for the books we have written for the Synthesis Lecture Series. The examples have been carefully chosen to employ a wide variety of MSP430 systems discussed throughout the book.

Table 1 provides a summary of chapter contents and related MSP430 subsystems.

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[2] *Embedded Systems Design with the Texas Instruments MSP432 32-bit Processor*, Dung Dang, Daniel J. Pack, and Steven F. Barrett, Morgan & Claypool Publishers, San Rafael, CA, 2017.

Table 1: MSP-EXP430FR5994 and the MSP-EXP430FR2433 LaunchPad subsystems.

| Chapter | MSP- EXP430FR2433 | MSP-EXP430FR5994 |
|---|---|---|
| Ch. 1: Introduction | | |
| Ch. 2: Programming | MSP430 port system | MSP430 port system |
| Ch. 3: HW and SW | Joint Test Action Group (JTAG) serial debug port, Enhanced Emulation Module (EEM) onboard debug tool, serial Spy-Bi-Wire (SBY) JTAG | Joint Test Action Group (JTAG) serial debug port, Enhanced Emulation Module (EEM) on-board debug tool, serial Spy-Bi-Wire (SBY) JTAG |
| Ch. 4: Interfacing | MSP430 port system | MSP430 port system |
| Ch. 5: Power Mgt | Power Mgt Module | Power Mgt: LDO, SVS, Brownout |
| Ch. 6: Memory | FRAM: 15KB + 512B<br>RAM: 4KB | FRAM: 256KB<br>RAM: 4 KB + 4 KB<br>DMA Controller<br>Memory Protection Unit (MPU)<br>IP Encapsulation Segment (IPE) |
| Ch. 7: Timer Systems<br>- Clock<br>- Timers | Clock system (CS), LFXT<br>Timer_A3(2), Timer_A2(2)<br>Watchdog, Real-Time Clock | Clock system (CS),<br>TB0: Timer_B, TA0: Timer_A,<br>TA1: Timer_A, TA4: Timer_A,<br>Watchdog, Real-Time Clock |
| Ch. 8: Resets and Interrupts | | |
| Ch. 9: Analog Peripherals | ADC: 8 ch, SE, 10-bit, 200 ksps | Comp_E: 16 ch, Ref_A<br>ADC 12_B: 16 ch SE/8 DE, 12-bit |
| Ch. 10: Comm Sys | eUSCI_A(2)<br>- UART, IrDA, SPI<br>eUSCI_B0<br>- SPI, I2C | eUSCI_A(4) (A0 to A3)<br>- UART, IrDA, SPI<br>eUSCI_B(4) (B0 to B3)<br>- SPI, I2C |
| Ch. 11: System Integrity | CRC16: 16-bit cyclic redundancy check | CRC16: CRC-16-CCITT<br>CRC32: CRC-32-ISO-3309<br>AES 256: security encryption/decryption |
| Ch. 12: System Design | | |

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