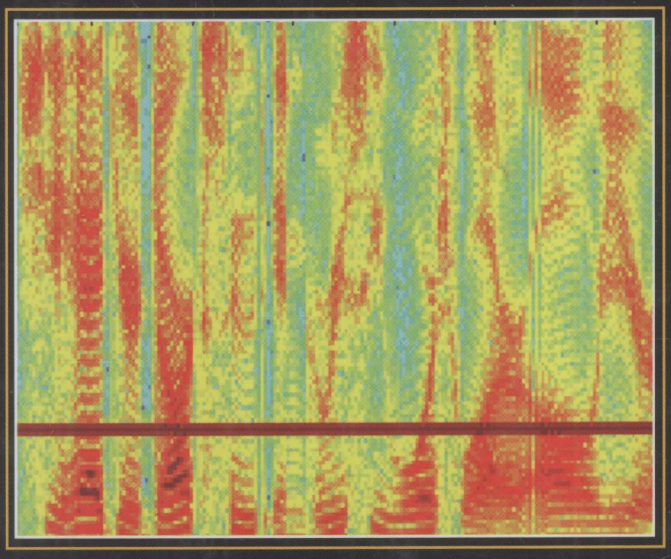
Embedded Signal Processing with the Micro Signal Architecture



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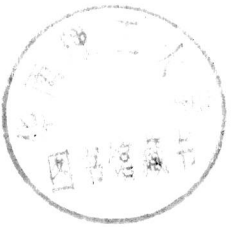
IEEE PRESS



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Embedded Signal Processing with the Micro Signal Architecture

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Preface

In this digital Internet age, information can be received, processed, stored, and transmitted in a fast, reliable, and efficient manner. This advancement is made possible by the latest fast, low-cost, and power-efficient embedded signal processors. Embedded signal processing is widely used in most digital devices and systems and has grown into a "must-have" category in embedded applications. There are many important topics related to embedded signal processing and control, and it is impossible to cover all of these subjects in a one- or two-semester course. However, the Internet is now becoming an effective platform in searching for new information, and this ubiquitous tool is enriching and speeding up the learning process in engineering education. Unfortunately, students have to cope with the problem of information overflow and be wise in extracting the right amount of material at the right time.

This book introduces just-in-time and just-enough information on embedded signal processing using the embedded processors based on the micro signal architecture (MSA). In particular, we examine the MSA-based processors called Blackfin processors from Analog Devices (ADI). We extract relevant and sufficient information from many resources, such as textbooks, electronic books, the ADI website, signal processing-related websites, and many journals and magazine articles related to these topics. The just-in-time organization of these selective topics provides a unique experience in learning digital signal processing (DSP). For example, students no longer need to learn advanced digital filter design theory before embarking on the actual design and implementation of filters for real-world applications. In this book, students learn just enough essential theory and start to use the latest tools to design, simulate, and implement the algorithms for a given application. If they need a more advanced algorithm to solve a more sophisticated problem, they are now more confident and ready to explore new techniques. This exploratory attitude is what we hope students will achieve through this book.

We use assembly programming to introduce the architecture of the embedded processor. This is because assembly code can give a more precise description of the processor's architecture and provide a better appreciation and control of the hardware. Without this understanding, it is difficult to program and optimize code using embedded signal processors for real-world applications. However, the use of C code as a main program that calls intrinsic and DSP library functions is still the preferred programming style for the Blackfin processor. It is important to think in low-level architecture but write in high-level code (C or graphical data flow). Therefore, we show how to balance high-level and low-level programming and introduce the techniques needed for optimization. In addition, we also introduce a very versatile

graphical tool jointly developed by ADI and National Instruments (NI) that allows users to design, simulate, implement, and verify an embedded system with a high-level graphical data flow approach.

The progressive arrangement makes this book suitable for engineers. They may skip some topics they are already familiar with and focus on the sections they are interested in. The following subsections introduce the essential parts of this book and how these parts are linked together.

PART A: USING SOFTWARE TOOLS TO LEARN DSP—A JUST-IN-TIME AND PROJECT-ORIENTED APPROACH

In Chapters 2, 3, and 4, we explore fundamental DSP concepts using a set of software tools from the MathWorks, ADI, and NI. Rather than introducing all theoretical concepts at the beginning and doing exercises at the end of each chapter, we provide just enough information on the required concepts for solving the given problems and supplement with many quizzes, interactive examples, and hands-on exercises along the way in a just-in-time manner. Students learn the concepts by doing the assignments for better understanding. This approach is especially suitable for studying these subjects at different paces and times, thus making self-learning possible.

In addition to these hands-on exercises, the end of each chapter also provides challenging pen-and-paper and computer problems for homework assignments. These problem sets build upon the previous knowledge learned and extend the thinking to more advanced concepts. These exercises will motivate students in looking for different solutions for a given problem. The goal is to cultivate a learning habit after going through the book.

The theory portion of these chapters may be skipped for those who have taken a fundamental course on DSP. Nonetheless, these examples and hands-on exercises serve as a handy reference on learning important tools available in MATLAB, the integrated development environment VisualDSP++, and the LabVIEW Embedded Module for Blackfin Processors. These tools provide a platform to convert theoretical concepts into software code before learning the Blackfin processor in detail. The introduction to the latest LabVIEW Embedded Module for Blackfin Processors shows the advancement in rapid prototyping and testing of embedded system designs for real-world applications. This new tool provides exciting opportunities for new users to explore embedded signal processing before learning the programming details. Therefore, instructors can make use of these graphical experiments at the end of each chapter to teach embedded signal processing concepts in foundation engineering courses.

PART B: LEARNING REAL-TIME SIGNAL PROCESSING WITH THE BLACKFIN PROCESSOR—A BITE-SIZE APPROACH TO SAMPLING REAL-TIME EXAMPLES AND EXERCISES

Part B consists of Chapters 5, 6, 7, and 8, which concentrate on the design and implementation of embedded systems based on the Blackfin processor. Unlike a conventional user's manual that covers the processor's architecture, instruction set, and peripherals in detail, we introduce just enough relevant materials to get started on Blackfin-based projects. Many hands-on examples and exercises are designed in a step-by-step manner to guide users toward this goal. We take an integrated approach, starting from algorithm design using MATLAB with floating-point simulations to the fixed-point implementation on the Blackfin processor, and interfacing with external peripherals for building a stand-alone or portable device. Along this journey to final realization, many design and development tools are introduced to accomplish different tasks. In addition, we provide many hints and references and supplement with many challenging problems for students to explore more advanced topics and applications.

Part B is in fact bridging the gap from DSP concepts to real-time implementations on embedded processors, and providing a starting point for students to embark on real-time signal processing programming with a fixed-point embedded processor.

PART C: DESIGNING AND IMPLEMENTING REAL-TIME DSP ALGORITHMS AND APPLICATIONS—AN INTEGRATED APPROACH

The final part (Chapters 9 and 10) motivates users to take on more challenging real-time applications in audio signal processing and image processing. Students can use the knowledge and tools learned in the preceding chapters to complete the applications introduced in Chapters 9 and 10. Some guides in the form of basic concepts, block diagrams, sample code, and suggestions are provided to solve these application problems. We use a module approach in Part C to build the embedded system part by part, and also provide many opportunities for users to explore new algorithms and applications that are not covered in Parts A and B. These application examples also serve as good mini-projects for a hands-on design course on embedded signal processing. As in many engineering problems, there are many possible solutions. There are also many opportunities to make mistakes and learn valuable lessons. Users can explore the references and find a possible solution for solving these projects. In other words, we want the users to explore, learn, and have fun!

A summary of these three parts of the book is illustrated in Figure 1. It shows three components: (A) DSP concepts, (B) embedded processor architecture and real-time DSP considerations, and (C) real-life applications: a simple A-B-C

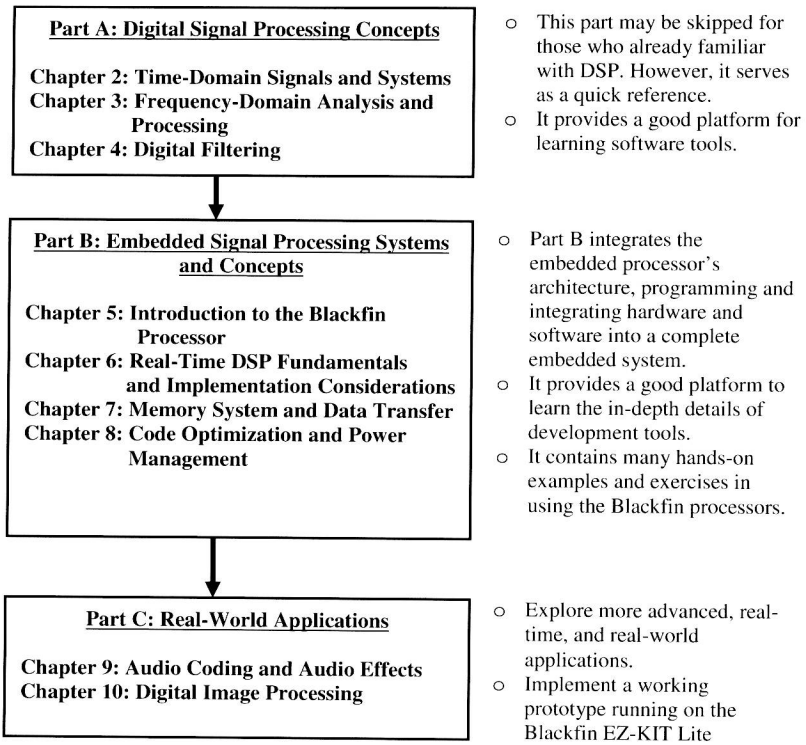

Figure 1 Summary of the book: contents and how to use them

approach to learning embedded signal processing with the micro signal architecture.

DESCRIPTION OF EXAMPLES, EXERCISES, EXPERIMENTS, PROBLEMS, AND APPLICATION PROJECTS

This book provides readers many opportunities to understand and explore the main contents of each chapter through examples, quizzes, exercises, hands-on experiments, exercise problems, and application projects. It also serves as a good hands-on workbook to learn different embedded software tools (MATLAB, VisualDSP++, and LabVIEW Embedded) and solve practical problems. These hands-on sections are classified under different types as follows.

1. **Examples** provide a just-in-time understanding of the concepts learned in the preceding sections. Examples contain working MATLAB problems to illustrate the concepts and how problems can be solved. The naming convention for software example files is

`example{chapter number}_{example number}.m`

They are normally found in the directory

`c:\adsp\chap{x}\MATLAB_ex{x}\`

where `{x}` is the chapter number.

2. **Quizzes** contain many short questions to challenge the readers for immediate feedback of understanding.
3. **Experiments** are mostly hands-on exercises to get familiar with the tools and solve more in-depth problems. These experiments usually use MATLAB, VisualDSP++, or LabVIEW Embedded. The naming convention for software experiment files is

   `exp{chapter number}_{example number}`

   These experiment files can be found in the directory

   `c:\adsp\chap{x}\exp{x}_{no.}_<option>`

   where `{no.}` indicates the experiment number and `<option>` indicates the BF533 or BF537 EZ-KIT.
4. **Exercises** further enhance the student's learning of the topics in the preceding sections, examples, and experiments. They also provide the opportunity to attempt more advanced problems to strengthen understanding.
5. **Exercise Problems** are located at the end of Chapters 1 to 8. These problem sets explore or extend more interesting and challenging problems and experiments.
6. **Application Projects** are provided at the end of Chapters 9 and 10 to serve as mini-projects. Students can work together as a team to solve these application-oriented projects and submit a report that indicates their approaches, algorithms, and simulations, and how they verify the projects with the Blackfin processor.

Most of the exercises and experiments require testing data. We provide two directories that contain audio and image data files. These files are located in the directories `c:\adsp\audio_files` and `c:\adsp\image_files`.

COMPANION WEBSITE

A website, www.ntu.edu.sg/home/ewsgan/esp_book.html, has been set up to support the book. This website contains many supplementary materials and useful reference links for each chapter. We also include a set of lecture slides with all the figures and tables in PowerPoint format. This website will also introduce new hands-on exercises and new design problems related to embedded signal processing. Because the fast-changing world of embedded processors, the software tools and the Blackfin

processor will also undergo many changes as time evolves. The versions of software tools used in this book are:

- MATLAB Version 7.0
- VisualDSP++ Version 4.0
- LabVIEW 8.0
- LabVIEW Embedded Edition 7.1

This website keeps track of the latest changes and new features of these tools. It also reports on any compatibility problems when running existing experiments with the newer version of software.

All the programs mentioned in the exercises and experiments are available for download in the Wiley ftp site: ftp://ftp.wiley.com/public/sci_tech_med/embedded_signal/.

We also include a feedback section to hear your comments and suggestions. Alternatively, readers are encouraged to email us at ewsgan@ntu.edu.sg and kuo@ceet.niu.edu.

Learning Objective:

We learn by example and by direct experience because there are real limits to the adequacy of verbal instruction.

Malcolm Gladwell, *Blink: The Power of Thinking Without Thinking, 2005*

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This book is also dedicated to many of our past and present students who have taken our DSP courses and have written M.S. theses and Ph.D. dissertations and completed senior design projects under our guidance at both NTU and NIU. Both institutions have provided us with a stimulating environment for research and teaching, and we appreciate the strong encouragement and support we have received. Finally, we are greatly indebted to our parents and families for their understanding, patience, and encouragement throughout this period.

WOON-SENG GAN AND SEN M. KUO

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