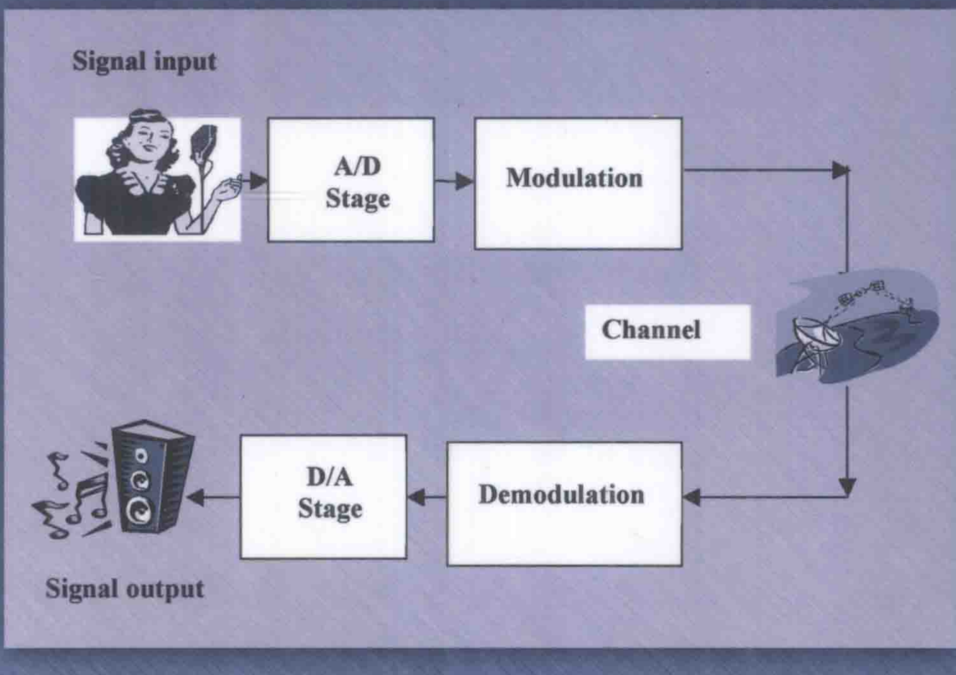
DIGITAL SIGNAL PROCESSING LABORATORY

SECOND EDITION



B. Preetham Kumar

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To Veena and Vasanth

and

In memory of my parents

Preface

The motivating factor in the preparation of this book was to develop a practical and readily understandable laboratory volume in Digital Signal Processing (DSP). The intended audience is primarily undergraduate and graduate students taking DSP for the first time as an elective course. The book is very relevant at the present time, when software and hardware developments in DSP are very rapid, and it is vital for the students to complement theory with practical software and hardware applications in their curriculum.

This book essentially evolved from the study material in two courses taught at the Department of Electrical and Electronic Engineering, California State University, Sacramento (CSUS). These courses, *Introduction to Digital Signal Processing,* and *Digital Signal Processing Laboratory,* have been offered at CSUS for the past several years. During these years of DSP theory and laboratory instruction for senior undergraduate and graduate students, often with varied subject backgrounds, we gained a great deal of experience and insight. Students who took these courses gave very useful feedback, such as their interest for an integrated approach to DSP teaching that would be comprised of side-by-side training in both theory and practical software/hardware aspects of DSP. In their opinion, the practical component of the DSP course curriculum greatly enhances the understanding of the basic theory and principles.

The factors above guided us to prepare each chapter of this book to include the following components: a ***brief theory*** to explain the underlying mathematics and principles, a ***problem solving*** section with a reasonable number of problems to be worked by the student, a ***computer laboratory*** with programming examples and exercises in MATLAB® and Simulink®,* and finally, in applicable chapters, a ***hardware laboratory*** with exercises using test and measurement equipment, and the Texas Instruments TMS320C6711 DSP Starter Kit.

In Chapter 1, we go into a brief theory of DSP applications and systems, with solved and unsolved examples, followed by a computer lab, which introduces the students to basic programming in MATLAB, and creation of system models in Simulink. This chapter concludes with a hardware section, which contains instructions and exercises on usage of basic signal sources, such as synthesized sweep generators, and measuring equipment, such as oscilloscopes and spectrum analyzers.

Chapter 2 is a more detailed description of LTI discrete-time signals and systems, and the mathematical tools used to describe these systems. Basic concepts such as z-transform, system function, discrete-time convolution,

* MATLAB® and Simulink® are registered trademarks of The Mathworks, Inc.

and difference equations are reviewed in the theory section. Practical types of LTI systems, such as *inverse systems* and *minimum phase* systems are also discussed, with example problems. This is followed by a computer lab, which has guidance and exercises in the creation and simulation of LTI system models.

Chapter 3 covers the practical time and frequency analysis of discrete-time signals, with emphasis on the evolution of the Discrete Fourier Transform (DFT) and the Fast Fourier Transform (FFT). The software lab includes spectral analysis, using the FFT, of practical periodic and nonperiodic signals such as noisy signal generators and Amplitude Modulation (AM) systems. The hardware lab involves actual measurement of harmonic distortion in signal generators, spectrum of AM signals, and the comparison of measured results with simulation from the computer lab section.

Chapter 4 is a practical discussion of the Analog-to Digital (A/D) process, with an initial brief review of sampling, quantization (uniform and nonuniform), and binary encoding in the Pulse Code Modulation (PCM) process. The software lab includes MATLAB/Simulink A/D process simulation of practical audio signals, and advanced systems such as Differential PCM. The hardware lab gives guidance of the construction and testing of a FET Sample and Hold circuit.

Chapters 5 and 6 are devoted to design and application of digital filters. Chapter 5 reviews the basic concepts of digital filters, and analytical design techniques for Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) digital filter design. The second edition also includes a section on FIR and IIR digital filter structures. The computer lab details Computer Aided Design (CAD) techniques for FIR and IIR digital filters, and has a series of rigorous exercises in usage of these techniques. Chapter 6 deals with the application of digital filters to one-dimensional (audio) and two-dimensional (video) signals. The computer lab has a set of practical exercises in the application of one- and two-dimensional digital filters for practical purposes, such as audio recovery from noise, and image deblurring.

Chapters 7 and 8 are focused on the application of practical DSP applications through the Digital Signal Processor (DSP) hardware. The hardware used in this book is the Texas Instruments TMS320C6711 Digital Signal Processor Starter Kit. Chapter 7 deals in detail with the organization and usage of the 6711 DSK, with a set of practical introductory exercises, such as signal generation and filtering. Chapter 8 is more applied and covers the hardware application and programming of the 6711 DSK for practical filtering applications of noise from audio signals.

There are six appendices. The first four appendices give detailed hardware description and user instructions of the equipment used in this book. The four equipment models covered are synthesized sweep generators, spectrum analyzers, dynamic signal analyzers, and digitizing oscilloscopes in Appendices A, B, C, and D, respectively. Appendix E gives detailed schematics, hardware description, and user instructions on the Texas Instruments 6711 DSK. Finally, Appendix F gives brief descriptions of alternate equipment and manufacturers, who produce equipment with similar capabilities as the ones described in Appendices A through D.

I would like to thank a number of people without whom this book could not have been completed. First, I greatly appreciate the help of Stan Wakefield, publishing consultant, who initiated my contact with CRC Press. I am very thankful to CRC acquisitions editor, Nora Konokpa, for her constant advice and encouragement throughout the manuscript preparation process. I would also like to thank Helena Redshaw and Jessica Vakili of CRC Press for guiding me in the preparation of the different chapters of the book. I would like to thank all the students at CSUS, who, over the years, gave important feedback on the DSP courses, which formed the basis of this book. I am particularly grateful to my student, Nilesh Lal, who tested and debugged all the experiments on the TI C6711 DSP starter kit, which constitutes the last, but most practical sections of the book.

Finally, I am indebted to my wife, Priya, who took time off from her already very busy schedule to proofread the chapters before submission to CRC Press. Above all, I am fortunate to have received her constant encouragement to whatever I have attempted, over all these years.

Note for the Second Edition

As in the first edition, the second edition has drawn upon some very useful feedback from students and faculty who used this book in their DSP courses. One addition was the inclusion of more worked examples in Chapters 1–6, to better demonstrate the mathematical techniques in every section. A new section on digital filter structures has also been added in Chapter 5 to complement the topics on digital filter design.

I would like to sincerely thank CRC publisher of engineering and environmental sciences, Nora Konokpa, for her constant help and encouragement to get going on this second edition. I would also like to thank CRC senior project coordinator Jill Jurgensen for guiding me in the preparation of the new edition.

As always, I am grateful to my family for their inspiration and support.

Note to Readers on Structure of Book and Exercises

This book is organized into *eight* chapters and *six* appendices, with each chapter typically having the following three sections: *brief theory, computer laboratory,* and *hardware laboratory.* All eight chapters have theory and computer laboratory sections; however Chapters 2, 5, and 6 do *not* have a hardware section. Generally, each chapter includes a brief theory section, followed by a MATLAB® and Simulink® simulation section and, finally, the hardware section, which includes experiments on generation and measurement of signals using signal generators, digital oscilloscopes and spectrum analyzers, and the Texas Instruments TMS320C6711 Digital Signal Processor Starter Kit.

This three-pronged approach is aimed at taking students from theory to simulation to experiment in a very effective way. Additionally, instructors have the option of selecting only the computer laboratory or hardware laboratory or both for their individual classes, based on availability of software or hardware.

Guidelines for Instructors

Please note that in each chapter, each of the three sections (theory, computer lab, and hardware lab) have *exercises* for students. However, these exercises are numbered starting from the theory section and proceeding sequentially until the hardware section. Hence each chapter typically has about *4 to 5 exercises,* and the instructor can assign any or all of the exercises for the student.

Guidelines for Students

Please attempt *all exercises* systematically, or as assigned by your instructor, after reviewing the theory material in each chapter. Clarify all doubts with the instructor before proceeding to the next section, since each section draws information from the previous material.

Author

B. Preetham Kumar received his B.E. (electronics) degree in 1982, his M.E. (communications systems) degree in 1984, both from the College of Engineering, Guindy, Chennai, India, and his Ph.D. in electrical engineering from the Indian Institute of Technology, Chennai, India in 1993. He worked as researcher/lecturer in the RF and Microwave Laboratory, University of California, Davis, and also as a part-time faculty member in the Department of Electrical and Electronic Engineering, California State University, Sacramento (CSUS) from 1993 to 1999. He joined CSUS on a full-time basis in August 1999, where he is currently professor and graduate coordinator in the Department of Electrical and Electronic Engineering.

Dr. Kumar is actively involved in the teaching and development of undergraduate and graduate courses in microwave engineering and wireless communications and digital signal processing. He has advised approximately 130 master's student projects, which has led to the publication of more than 60 papers in peer-refereed journals and international conferences in the areas of antenna design and RF and microwave circuits. He has recently completed a book *Digital Signal Processing Laboratory* (CRC Press) and has also coauthored two book chapters on power dividers and microwave/RF multipliers for the *John Wiley Encyclopedia of Electrical and Electronics Engineering.*

On the research side, he has worked on funded projects from Lockheed Martin, Agilent Technologies, National Semiconductor, Intel, and Antenna Wireless, Inc. Currently he is heading an effort to expand the use of hyperthermia, or microwave heating, as an adjuvant tool along with radiation and chemotherapy in the treatment of cancer. As part of this effort, he was awarded the Research and Creativity Award grant in 2006 to initiate a pilot clinical trial involving an improved radiation and hyperthermia treatment protocol at two cancer centers in India. He was recently awarded the International Cancer Technology Transfer (ICRETT) Fellowship from the International Union against Cancer (UICC) in Geneva, Switzerland, to complete the clinical trial in India.

Dr. Kumar has received many awards, including the Tau Beta Pi Outstanding Faculty Award in 1999, the Outstanding Teaching Award in 2000, and the Outstanding Scholar Award in 2005 from the College of Engineering and Computer Science, CSUS. His main areas of research are design of antenna array systems for near-field medical hyperthermia applications and miniaturized passive/active devices for wireless applications. He is a senior member of the Institute of Electrical and Electronics Engineers (IEEE), with service contribution as the chairman of the IEEE Sacramento Valley section and chairman of the Sacramento chapter of the IEEE Communications Society. He was elected in 2007 as overseas member in the Executive Council, Indian Association of Hyperthermic Oncology and Medicine.

Contents