Digital Signal Processing

K. Deergha Rao · M. N. S. Swamy

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## Theory and Practice

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असतोमा सदगमय
तमसोमा ज्योतिर्गमय
मृत्योर्मा अमृतं गमय

Lead me from the unreal to the real

Lead me from darkness to enlightenment

Lead me from death to immortality

*To*

*My parents Dalamma and Boddu,*

*My beloved wife Sarojini,*

*and my beloved teacher Prof. D. C. Reddy*

K. Deergha Rao

*To*

*My parents, teachers*

*and my beloved wife Leela.*

M. N. S. Swamy

# Preface

Digital signal processing (DSP) is now a core subject in electronics, communications, and computer engineering curricula. The motivation in writing this book is to include modern topics of increasing importance not included in the textbooks available on the subject of digital signal processing and also to provide a comprehensive exposition of all aspects of digital signal processing. The text is integrated with MATLAB-based programs to enhance the understanding of the underlying theories of the subject.

This book is written at a level suitable for undergraduate and master students as well as for self-study by researchers, practicing engineers, and scientists. Depending on the chapters chosen, this text can be used for teaching a one- or two-semester course, for example, introduction to digital signal processing, multirate digital signal processing, multirate and wavelet signal processing, digital filters design and implementation.

In this book, many illustrative examples are included in each chapter for easy understanding of the DSP concepts. An attractive feature of this book is the inclusion of MATLAB-based examples with codes to encourage readers to implement on their personal computers to become confident of the fundamentals and to gain more insight into digital signal processing. In addition to the problems that require analytical solutions, problems that require solutions using MATLAB are introduced to the reader at the end of each chapter. Another attractive feature of this book is that many real-life signal processing design problems are introduced to the reader by the use of MATLAB and programmable DSP processors. This book also introduces three chapters of growing interest not normally found in an upper division text on digital signal processing. In less than 20 years, wavelets have emerged as a powerful mathematical tool for signal and image processing. In this textbook, we have introduced a chapter on wavelets, wherein we have tried to make it easy for readers to understand the wavelets from basics to applications. Another chapter is introduced on adaptive digital filters used in the signal processing problems for faster and acceptable results in the presence of changing environments and changing system requirements. The last chapter included in this book is on DSP processors, which is a growing topic of interest in digital signal processing.

This book is divided into 13 chapters. Chapter 1 presents an introduction to digital signal processing with typical examples of digital signal processing applications. Chapter 2 discusses the time-domain representation of discrete-time signals and systems, linear time-invariant (LTI) discrete-time systems and their properties, characterization of discrete-time systems, representation of discrete-time signals and systems in frequency domain, representation of sampling in frequency domain, reconstruction of a bandlimited signal from its samples, correlation of discrete-time signals, and discrete-time random signals. Chapter 3 deals with z-transform and analysis of LTI discrete-time systems. In Chap. 4, discrete Fourier transform (DFT), its properties, and fast Fourier transform (FFT) are discussed. Chapter 5 deals with analog filter approximations and IIR filter design methodologies. Chapter 6 discusses FIR filter design methodologies. Chapter 7 covers various structures such as direct form I & II, cascade, parallel, and lattice structures for the realization of FIR and IIR digital filters. The finite word length effects on these structures are also analyzed. Chapters 8 and 9 provide an in-depth study of the multirate signal processing concepts and design of multirate filter banks. A deeper understanding of Chaps. 8 and 9 is required for a thorough understanding of the discrete wavelet transforms discussed in Chap. 10. The principle of adaptive digital filters and their applications are presented in Chap. 11. Chapter 12 deals with the estimation of spectra from finite duration observations of the signal using both parametric and nonparametric methods. Programmable DSP processors are discussed in Chap. 13.

The salient features of this book are as follows.

- Provides comprehensive exposure to all aspects of DSP with clarity and in an easy way to understand.
- Provides an understanding of the fundamentals, design, implementation, and applications of DSP.
- DSP techniques and concepts are illustrated with several fully worked numerical examples.
- Provides complete design examples and practical implementation details such as assembly language and C language programs for DSP processors.
- Provides MATLAB implementation of many concepts:
  - Digital FIR and IIR filter design
  - Finite word length effects analysis
  - Discrete Fourier transform
  - Fast Fourier transform
  - $z$-Transform
  - Multirate analysis
  - Filter banks
  - Discrete wavelet transform
  - Adaptive filters

- Power spectral estimation
- Design of digital filters using MATLAB graphical user interface (GUI) filter designer SPTOOL

- Provides examples of important concepts and to reinforce the knowledge gained.

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# Contents

# About the Authors

**K. Deergha Rao** is currently a Professor in the Department of Electronics and Communication Engineering, Vasavi College of Engineering, affiliated to Osmania University, Hyderabad, India, and is Former Director and Professor at the Research and Training Unit for Navigational Electronics (NERTU), Osmania University. He was a Postdoctoral Fellow and Part-Time Professor in the Department of Electrical and Computer Engineering, Concordia University, Montreal, Canada, for 4 years. He has conducted several research projects for leading Indian organizations. His teaching areas include digital signal processing, channel coding, signals and systems, and MIMO wireless communications, and his current research focuses on wireless channel coding, OFDM wireless communication channel estimation, compressive sensing, and VLSI for communications. He has presented papers at several IEEE international conferences in the USA, Switzerland, Thailand, and Russia. He has more than 100 publications to his credit, including more than 60 in IEEE journals and conference proceedings. He is a senior member of IEEE. He was awarded the IETE K. S. Krishnan Memorial Award in 2013 for the best system-oriented paper. He has authored two books, *Channel Coding Techniques for Wireless Communications* and *Signals and Systems* (both with Springer), and co-authored the book *Digital Signal Processing*.

**M. N. S. Swamy** is a Research Professor and holds the Concordia Chair in Signal Processing in the Department of Electrical and Computer Engineering at Concordia University, Montreal, Canada, where he served as the Founding chair of the Department of Electrical Engineering from 1970 to 1977 and the Dean of Engineering and Computer Science from 1977 to 1993. He received his M.Sc. and Ph.D. degrees in Electrical Engineering from the University of Saskatchewan, Saskatoon, Canada. He was made an Honorary Professor by the National Chiao Tung University, Taiwan, in 2009, which is equivalent to an honorary doctorate at the institute. He has also been associated with the Department of Electrical Engineering, Technical University of Nova Scotia, Halifax, NS, Canada; the University of Calgary, Calgary, AB, Canada; and the Department of Mathematics, University of Saskatchewan. He has published extensively in the areas of circuits, systems, and signal processing and holds six patents. He is a coauthor of eight books and several book chapters. He is a recipient of numerous IEEE Circuits and Systems Society Awards, including the Education Award in 2000, the Golden Jubilee Medal in 2000, and Guillemin–Cauer Best Paper Award. He is a Fellow of several professional societies including IEEE. The Indian Institute of Science (IISc) in Bengaluru, a premier research institution of India, has established a gold medal and a scholarship in his name. In 1993, he was awarded the commemorative medal for the 125th Anniversary of Canada, issued by the Governor General of Canada, in recognition of his significant contributions to Canada and the community. Recently, the journal *Circuits, Systems and Signal Processing* (CSSP) has instituted a Best Paper Award in his name.