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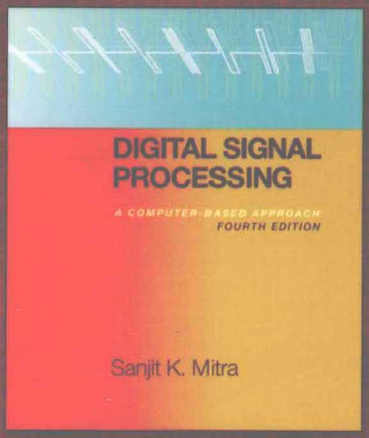

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基于计算机的方法（第4版）

Digital Signal Processing

A Computer-Based Approach

Sanjit K. Mitra 著

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前　言

在过去的半个世纪里，数字信号处理（DSP），无论是研究还是应用，都得到爆发式的增长。推动这种增长的，是计算机技术和软件开发的巨大进步。国内外几乎所有的电子工程和计算机工程系，都开出了一门或多门有关数字信号处理的课程，而第一门课程往往向高年级的本科生开出。本书是为高年级本科生和一年级研究生所准备的两学期课程的教材。本书也可以作为从事实际工作的工程师和科学家自学之用。

本书的第3版是五年前出版的，从收到的读者反馈来看，显然已经需要出一个新的修订版了。这个新的版本做了三种改变：增加了一些新的内容，压缩了一些已有的内容，对有些材料作了重新安排。我们相信，新版本里每章材料的安排更加符合逻辑。新增加的一些例题，有助于说明新的困难的概念。

第4版的一个主要改变在于，第2、3、4章的内容，安排到新的三章里：一章涉及离散时间信号的时域表达；一章是离散时间信号的频域表达；一章是离散系统的时域和频域表达。第3版第4章中关于模拟低通滤波器的设计，模拟高通、带通、带阻滤波器的设计，模拟防混叠滤波器的设计以及模拟重构滤波器的设计等内容，本版移到附录里。此外，删去了有关连续信号数字处理接口器件的讨论，包括采样/保持电路、A/D变换器以及D/A变换器。

本版的第二个主要改变在于，删去了有关应用的一章，以及本书所附的CD中本章的相关材料。有关短时傅里叶变换的讨论移到了第5章（有限长度的离散变换）。

第4版新增加的内容包括循环前缀（5.10.2节）、数字积分器（7.4.3节）、数字微分器（7.4.4节）、DC阻断器（7.4.5节）、一种新的以级联格形结构的形式实现一对FIR传输函数的方法（8.9节）、IIR数字滤波器计算机辅助设计的扩展讨论（9.7节）、高效内插FIR滤波器设计中决定稀疏因子优化值的方法（10.6.2节）、使用转置的快速DFT算法（11.3.3节）等。删去了第8章中有关数字正弦-余弦发生器的内容及其相关的习题。将第11章中有关可调数字滤波器的内容移到数字滤波器的实现（8.7节）。最后，从第11章里删去算术运算和函数逼近的内容。有关函数逼近的若干习题，保留在该章后面的习题里。

本书很重要的一个特点是，深度使用MATLAB，通过说明该程序的强大功能的例题，来解决信号处理的问题。本书使用一种三段式的教学方法结构，充分利用MATLAB的优越性，力求避免用“照猫画虎”的方法来求解问题的缺憾。首先，每章的开始，都提出基本的理论和算法。其次，有关的材料都用手工计算的例题来说明。第三，用MATLAB来求解。一开始，尽可能仔细地提供MATLAB的程序代码，使学生可以在自己的计算机上重复这些例题。对于

要求解析解的传统问题，每章也都包含了大量的要求使用 MATLAB 来解的习题。本书只要求具有最低限度的 MATLAB 知识。我们相信，通过使用经过测试的、完整的程序，然后再自己编写简单的程序来求解第 2～14 章的习题，学生都可以很快地掌握如何用 MATLAB 来求解复杂的问题。

通过计算机的验证，可以强化对理论的理解，就像在前三版里一样，新的第 4 版也包含了一个大的 MATLAB 程序库。第 3 版里原有的 MATLAB 程序，已经升级为适应新的 MATLAB 版本和 Signal Processing Toolbox 版本。此外，还增加了新的 MATLAB 程序和代码段。所有的程序都收到本书所附的 CD 里[①]。读者可以运行这些程序，来验证书中所得出的结果。所有的程序及代码段，都在 MATLAB 7.10.0.499 版（R2010a）和 Signal Processing Toolbox 6.13 版（R2010a）下作了测试。书中的某些程序，从执行速度来说，并不一定是最快的，也不一定是最短的，主要是希望写得最清楚，用不着更多的解释。

本书再一个值得关注的特点是，包含了大量简单而实用的例子，使读者得以接触实际生活中的信号处理问题，从而可以用计算机来解决所涉及的设计问题。本书还包含一些当前所关注的问题，但没有写在正文里，而是在各章后面的习题里。

本书所附的 CD 里，有一些重要的、很实际的数字信号处理的应用。这些应用很容易理解，并不要求更高层次课程的知识。CD 里还有其他的一些有用的材料，包括实际信号的文件、复习材料、附加的例题、经常遇到的问题（FAQ）、大量数字信号处理的典型应用、简短的 MATLAB 指南等。教材正文里的 CD 符号，向读者提示 CD 里的相关材料。我们会根据读者的反馈，在以后的版本里，继续改善 CD 的内容。

使用本书的先修课程是三年级的线性连续时间和离散时间系统，通常，多数大学都会这样要求。本书简短地回顾了线性系统和变换，以及线性系统理论的基本材料。这样做，既包含了必要的材料，又没有显著地增加本书的篇幅。

本书包含 14 章和 3 个附录。

第 1 章是信号处理领域的引论，概述信号及信号处理的方法。

第 2 章讨论离散时间信号的时域表达、数字序列。介绍了若干基本的离散时间信号，它们在任意离散时间信号的描述中起着重要作用，还介绍了离散时间系统。接下来，由一个或多个这样的序列，通过若干种基本运算，来建立其他的序列。这些基本运算的组合，也用来组成离散时间系统。用一个简单的例子来说明用一个离散时间序列来表达一个连续时间信号的问题。

第 3 章是离散时间信号的频域表达。一开始回顾连续时间信号连续傅里叶变换（CTFT）表达。离散时间傅里叶变换（DTFT）用于在频域表示离散时间信号，接下来是用其反变换来恢复原来的离散时间信号。由于 DTFT 是无限项求和，所以要讨论其收敛问题。接下来讨论

① 本书所配 CD 中的内容已放在清华大学出版社网站上，请到网站上该书链接处下载。网址是 http://www.tup.com.cn。

DTFT 的限制，以及相位函数的不连续问题。之后是带限连续时间信号通过理想采样，达到离散时间表达，以及从其采样版本准确恢复原信号的条件。

第 4 章的开始，回顾若干种离散时间系统的时域表达及其应用。其后是讨论离散时间系统的各种分类、因果、线性以及时不变（LTI）。且在这里证明，一个因果的 LTI 离散时间系统的时域表达，就是其单位冲激响应，并由此而得到该系统的输入输出关系。讨论了通过连接简单的 LTI 系统，来建立复杂的 LTI 系统。一个 LTI 离散时间系统的频域表达，就是其频率响应，即单位冲激响应的 DTFT。由此而引入频率响应的概念，并仔细考察了相位延时和群延时之间的差别。

第 5 章的主要部分，关注离散傅里叶变换（DFT），它在一些数字信号处理应用中扮演非常重要的角色，因为可以利用其快速算法来实现线性卷积。讨论 DFT、IDFT 及其性质。本章还讨论了离散余弦变换（DCT）以及哈尔（Haar）变换。本章所讨论的三种变换，是有限长度序列正交变换的例子。本章还简要介绍了短时傅里叶变换，它往往作为非确定离散时间信号的频域表达。

第 6 章讨论 z-变换。首先是 z-变换、反 z-变换的定义及其性质。仔细讨论了 z-变换的收敛问题。还讨论了 LTI 离散时间系统的传输函数的概念及其和系统的频率响应的关系。

本书只关心 LTI 离散时间系统，第 7 章则讨论其变换域的表达。考察了这些变换域表达的特殊性质，以及若干种简单应用。

LTI 数字滤波器硬件或软件实现的第一步，是使用基本的构建模块相连接的结构表达，提供与输入及输出相关的中间变量之间的关系，以便结构的实现。

第 8 章讨论数字滤波器各种形式的结构表达，然后讨论现实的因果 IIR 及 FIR 数字滤波器的常用方案。

第 9 章讨论 IIR 滤波器的设计。首先讨论该滤波器设计所涉及的若干问题，然后是设计 IIR 滤波器最常用的方法，从原型模拟传输函数到数字传输函数的变换，从一种类型的 IIR 传输函数到另一种类型传输函数的转换。还讨论了在 IIR 数字滤波器设计中使用 MATLAB。

第 10 章关注 FIR 数字滤波器的设计。首先介绍一种非常简单的方法，接着讨论一种常用的等纹波线性相位 FIR 数字滤波器的计算机辅助设计，以及在 FIR 数字滤波器设计中使用 MATLAB。

第 11 章关注数字信号处理算法的实现。首先讨论两个主要的实现问题，数字滤波器和 DFT 在计算机上的软件实现。接下来讨论计算机里数字和信号变量的各种表示方法，这是在第 12 章里分析有限字长效应的基础。还简要地介绍了经常用于处理溢出的方法。

第 12 章分析各种量化误差源的影响，介绍对这些影响不那么敏感的结构。还讨论了系数量化的影响。

第 13 章和第 14 章讨论多采样率离散时间系统、采样率变化的基本概念和性质、抽取和插入数字滤波器的设计，以及多滤波器组的设计。

附录 A 简要介绍模拟低通滤波器的设计方法，包括模拟防混叠滤波器和模拟重构滤波器设计的要求。附录 B 讨论模拟高通、带通、带阻滤波器的设计方法。附录 C 回顾随机变量和随机过程的重要统计特性。

本书的材料在加利福尼亚大学圣巴巴拉分校使用了 20 多年，用于两学期的数字信号处理课程。大概来说，第 2 章到第 8 章是前半课程的基础，第 8 章到第 14 章，以及若干应用的例子，构成研究生课程的基础。在过去的若干年里，南加利福尼亚大学也使用了本书。

本书包含 324 个例题、146 个 MATLAB 程序和代码段、845 个习题和 158 个 MATLAB 练习题。

我们作了很大的努力，力图保证本书中所有材料的准确性，包括所有的 MATLAB 程序。但是，我还是希望读者能将所发现的错误告知我，尽管印刷版中的有些错误非本人或出版社能够控制的。这些错误和别的评论，请用 E-mail 发给 mitra@ece.ucsb.edu。

本书的网站，www.mhhe.com/mitra，还包含一些对教师和学生都有用的资源。教授们可以从 McGraw-Hill's COSMOS 得到电子版的习题解答。COSMOS 为教师提供大量的材料来生成习题、布置作业以及将他们自己的习题转换和集成为软件。请和你的 McGraw-Hill 销售代表联系，以便得到更多的信息。

最后，我非常庆幸，在 40 多年的教学生涯中，有幸和很多杰出的学生一起工作。我一直收获颇丰，无论是业务还是个人生活，无论是他们的友谊还是协作。我把这本书献给他们。

Sanjit K. Mitra

本书各章选译部分的内容放在书末。

About the Author

Sanjit K. Mitra is the Stephen and Etta Varra Professor in the Ming Hsieh Department of Electrical Engineering, University of Southern California, Los Angeles and a Research Professor in the Department of Electrical & Computer Engineering, University of California, Santa Barbara, He received the M.S. and Ph.D. degrees in Electrical Engineering from the University of California, Berkeley, in 1960 and 1962, respectively. He has served IEEE in various capacities, including service as the President of the IEEE Circuits & Systems Society in 1986 and as a Member-at-Large of the Board of Governors of the IEEE Signal Processing Society from 1996 to 1999. He has published over 660 papers in the areas of analog and digital signal processing, and image processing, twelve books, and holds five patents. Dr. Mitra has received many distinguished industry and academic awards, including the 1973 F. E. Terman Award and the 1985 AT&T Foundation Award of the American Society of Engineering Education; the 1989 Education Award, the 1999 Mac Van Valkenburg Society Award and the CAS Golden Jubilee Medal of the IEEE Circuits & Systems Society; the 1989 Distinguished Senior U.S. Scientist Award from the Alexander von Humboldt Foundation of Germany; the 1995 Technical Achievement Award, the 2001 Society Award, and the 2006 Education Award of the IEEE Signal Processing Society; the Millennium Medal in 2000 and the 2006 James H. Mulligan, Jr. Education Medal of the IEEE; the 2002 Technical Achievement Award and the 2009 Athanasios Papoulis Award of the European Association for Signal Processing (EURASIP); the 2005 SPIE Technical Achievement Award of the International Society for Optical Engineering; and the University Medal of the Slovak Technical University, Bratislava, Slovakia in 2005. He is the co-recipient of the 2000 Blumlein-Browne-Willans Premium of the the Institution of Electrical Engineers (London) and the 2001 IEEE Transactions on Circuits & Systems for Video Technology Best Paper Award. He is a member of the U.S. National Academy of Engineering, an Academician of the Academy of Finland, a member of the Norwegian Academy of Technological Sciences, a foreign member of the Croatian Academy of Sciences and Arts, and a foreign member of the Academy of Engineering of Mexico, a Foreign Fellow of the Indian National Academy of Engineering and the National Academy of Sciences, India. He has been awarded Honorary Doctorate degrees from the Tampere University of Technology, Finland, the "Politehnica" University of Bucharest, Romania, and the Technical University of Iasi, Romania. Dr. Mitra is a Fellow of the IEEE, AAAS, and SPIE, and a member of EURASIP.

Preface

The field of digital signal processing (DSP) has seen explosive growth during the past five decades, as phenomenal advances both in research and application have been made. Fueling this growth have been the advances in digital computer technology and software development. Almost every electrical and computer engineering department in this country and abroad now offers one or more courses in digital signal processing, with the first course usually being offered at the senior level. This book is intended for a two-semester course on digital signal processing for seniors or first-year graduate students. It is also written at a level suitable for self-study by the practicing engineer or scientist.

The third edition of this book was published five years ago, and the user feedback we have received since then made it evident that a new edition was needed to incorporate the suggested changes. Three types of changes were made to the manuscript: inclusion of a number of new topics, elimination of some topics, and a major reorganization of the materials. We believe the materials in each chapter are now organized more logically. A few additional worked-out examples have been included to explain new and difficult concepts.

One major change occurring in the fourth edition is reorganizing the contents of Chapters 2, 3, and 4 into three new chapters: a chapter dealing with the time-domain representation of discrete-time signals, a chapter on the frequency-domain representation of discrete-time signals, and a chapter on the time-domain and frequency-domain representations of a class of discrete-time systems. The sections on design of analog lowpass filters, design of analog highpass, bandpass, and bandstop filters, analog anti-aliasing filter design, and analog reconstruction filter design in Chapter 4 of the third edition have been moved into two appendices in this edition. In addition, the discussion of the interface devices needed for the digital processing of continuous-time signals in practice have been eliminated. These devices are the sample-and-hold circuit, analog-to-digital converter, and digital-to-analog converter.

The second major change implemented in this edition is the removal of the chapter on applications and the inclusion of most of the materials of this chapter in the CD accompanying this book. The discussion on short-time Fourier transform from this chapter has also been moved to Chapter 5 on finite-length discrete transforms.

The new topics included in the fourth edition are the cyclic prefix (Section 5.10.2), digital integrators (Section 7.4.3), digital differentiators (Section 7.4.4), DC blockers (Section 7.4.5), a new method of the realization of a pair of FIR transfer functions in the form of a cascaded lattice structure (Section 8.9), expanded discussion of computer-aided design of IIR digital filters (Section 9.7), a method for the determination of the optimal value of the sparsity factor for the design of computationally efficient interpolated FIR filters (Section 10.6.2), and the development of fast DFT computation algorithm using the transpose operation (Section 11.3.3). The section on the design of digital sine-cosine generators has been removed from Chapter 8 and included as problems at the end of the chapter. The section on the design of tunable digital filters has been moved from Chapter 11 to the chapter on digital filter implementation (Section 8.7). Finally, the sections on arithmetic operations and function approximation have been removed from Chapter 11. A few problems on certain function approximations have been included as problems at the end of the chapter.

A key feature of this book is the extensive use of MATLAB® -based[1] examples that illustrate the program's powerful capability to solve signal processing problems. The book uses a three-stage pedagogical structure designed to take full advantage of MATLAB and to avoid the pitfalls of a "cookbook" approach to problem solving. First, each chapter begins by developing the essential theory and algorithms. Second, the material is illustrated with examples solved by hand calculation. And third, solutions are derived using MATLAB. From the beginning, MATLAB codes are provided with enough details to permit the students to repeat the examples on their computers. In addition to conventional theoretical problems requiring analytical solutions, each chapter also includes a large number of problems requiring solution via MATLAB. This book requires a minimal knowledge of MATLAB. We believe students learn the intricacies of problem solving with MATLAB faster by using tested, complete programs and then writing simple programs to solve specific problems that are included at the ends of Chapters 2 to 14.

Because computer verification enhances the understanding of the underlying theories, as in the first three editions, a large library of worked-out MATLAB programs are included in the fourth edition. The original MATLAB programs of the third edition have been updated to run on the newer versions of MATLAB and the *Signal Processing Toolbox*. In addition, new MATLAB programs and code fragments have been added in this edition. All MATLAB programs are included in the CD accompanying this text. The reader can run these programs to verify the results included in the book. All MATLAB programs and code fragments in the text have been tested under version 7.10.0.499 (R2010a) of MATLAB and version 6.13 (R2010a) of the *Signal Processing Toolbox*. Some of the programs listed in this book are not necessarily the fastest with regard to their execution speeds, nor are they the shortest. They have been written for maximum clarity without detailed explanations.

A second attractive feature of this book is the inclusion of extensive simple, but practical, examples that expose the reader to real-life signal processing problems, which has been made possible by the use of computers in solving practical design problems. This book also covers many topics of current interest not normally found in an upper-division text. Additional topics are also introduced to the reader through problems at the end of Chapters 2 through 14.

The CD accompanying the book includes several important, practical applications of digital signal processing. These applications are easy to follow and do not require knowledge of other advanced-level courses. It also contains several other useful materials, such as files of real signals, review materials, additional examples, frequently asked questions (FAQs), a large number of typical applications of digital signal processing, and a short tutorial on MATLAB. Where possible, pointers in the text with CD symbols have been used to direct the reader to relevant materials in the CD. From the reader's feedback, we hope to improve the contents in the CD for future editions.

The prerequisite for this book is a junior-level course in linear continuous-time and discrete-time systems, which is usually required in most universities. A minimal review of linear systems and transforms is provided in the text, and basic materials from linear system theory are included, with important materials summarized in tables. This approach permits the inclusion of more advanced materials without significantly increasing the length of the book.

The book is divided into 14 chapters and three appendices. Chapter 1 presents an introduction to the field of signal processing and provides an overview of signals and signal processing methods.

Chapter 2 discusses the time-domain representations of discrete-time signals as sequences of numbers. Several basic discrete-time signals that play important roles in the time-domain characterization of arbitrary discrete-time signals and discrete-time systems are introduced here. Next, a number of basic operations to generate other sequences from one or more sequences are described. A combination

[1] MATLAB is a registered trademark of The MathWorks, Inc., 3 Apple Hill Dr., Natick, MA 01760, Phone: 508-647-7000, **http://www.mathworks.com**.

of these operations is also used in developing a discrete-time system. The problem of representing a continuous-time signal by a discrete-time sequence is examined for a simple case.

Chapter 3 is devoted to the frequency-domain representation of discrete-time signals. It starts with a short review of the continuous-time Fourier transform (CTFT) representations of continuous-time signals. The discrete-time Fourier transform (DTFT) that is used to represent the discrete-time signal in the frequency domain is then introduced followed by the inverse discrete-time Fourier transform to recover the original discrete-time signal from its DTFT representation. As the DTFT representation involves an infinite sum, a discussion of the convergence of the DTFT is included. Properties of the DTFT are next reviewed, and the unwrapping of the phase function to remove certain discontinuities in the DTFT is discussed. The conditions for discrete-time representation of a band-limited continuous-time signal under ideal sampling and its exact recovery from the sampled version are next derived.

Chapter 4 begins with a review of the time-domain representations of a few simple discrete-time systems and their applications. This is followed by a discussion of various classes of discrete-time systems of which the class of causal, linear, and time-invariant (LTI) systems is of major interest in this book. It is shown here that the time-domain representation of a causal LTI discrete-time system is in terms of its impulse response which leads to the input-output relation of the system. Generation of more complicated LTI system by interconnecting simple LTI systems is then discussed. The frequency-domain representation of an LTI discrete-time system is given by its frequency response, which is the DTFT of its impulse response. The concept of the frequency response is then introduced, followed by a careful examination of the difference between phase and group delays associated with the frequency response.

The major part of Chapter 5 is concerned with the discrete Fourier transform (DFT), which plays an important role in some digital signal processing applications as it can be used to implement linear convolution efficiently using fast algorithm for its computation. The DFT and its inverse are introduced, along with a discussion of their properties. This chapter also includes a review of the discrete cosine transform (DCT) and the Haar transform. All three transforms discussed in this chapter are examples of orthogonal transforms of a finite-length sequence. The chapter also includes a brief review of the short-time Fourier transform, which is often used to provide a frequency-domain representation of nondeterministic discrete-time signals.

Chapter 6 is devoted to a discussion of the z-transform. The transform and its inverse are introduced, along with a discussion of their properties. The convergence condition of the z-transform is examined in detail. It also includes a discussion of the concept of the transfer function of an LTI discrete-time system and its relation to the frequency response of the system.

As mentioned earlier, this book concentrates almost exclusively on the LTI discrete-time systems, and Chapter 7 discusses their transform-domain representations. Specific properties of such transform-domain representations are investigated, and several simple applications are considered.

A structural representation using interconnected basic building blocks is the first step in the hardware or software implementation of an LTI digital filter. The structural representation provides the relations between some pertinent internal variables with the input and the output, which, in turn, provides the keys to the implementation. There are various forms of the structural representation of a digital filter, and two such representations are reviewed in Chapter 8, followed by a discussion of some popular schemes for the realization of real causal IIR and FIR digital filters.

Chapter 9 considers the IIR digital filter design problem. First, it discusses the issues associated with the filter design problem. Then, it describes the most popular approach to IIR filter design, based on the conversion of a prototype analog transfer function to a digital transfer function. The spectral transformation of one type of IIR transfer function into another type is discussed. The use of MATLAB in IIR digital filter design is illustrated.

Chapter 10 is concerned with the FIR digital filter design problem. A very simple approach to FIR filter design is described, followed by a discussion of a popular algorithm for the computer-aided design of equiripple linear-phase FIR digital filters. The use of MATLAB in FIR digital filter design is illustrated.

Chapter 11 is concerned with the implementation aspects of DSP algorithms. Two major issues concerning implementation are discussed first. The software implementations of digital filtering and DFT algorithms on a computer are reviewed to illustrate the main points. This is followed by a discussion of various schemes for the representation of number and signal variables on digital machines, which is basic to the development of methods for the analysis of finite wordlength effects considered in Chapter 12. A brief review of operations often used to handle overflow is included here.

Chapter 12 is devoted to analysis of the effects of the various sources of quantization errors; it describes structures that are less sensitive to these effects. Included here are discussions on the effect of coefficient quantization.

Chapters 13 and 14 discuss multirate discrete-time systems with unequal sampling rates at various parts. The chapter includes a review of the basic concepts and properties of sampling rate alteration, design of decimation and interpolation digital filters, and multirate filter bank design.

Appendix A provides a brief review of analog lowpass filter design methods along with the requirements for the design of analog anti-aliasing filter and analog reconstruction filter. Appendix B discusses the methods for the design of analog highpass, bandpass and bandstop filters. Appendix C reviews the important statistical properties of the random variable and the random process.

The materials in this book have been used in a two-quarter course sequence on digital signal processing at the University of California, Santa Barbara, and have been extensively tested in the classroom for over 20 years. Basically, Chapters 2 through 8 formed the basis of an upper-division course, while Chapters 8 through 14 along with a few examples of applications formed the basis of a graduate-level course. In addition, a major part of this book has been used in an upper-division course at the University of Southern California for the last several years.

This text contains 324 examples, 146 MATLAB programs and code fragments, 845 problems, and 158 MATLAB exercises.

Every attempt has been made to ensure the accuracy of all materials in this book, including the MATLAB programs. I would, however, appreciate readers bringing to my attention any errors that may appear in the printed version for reasons beyond my control and that of the publisher. These errors and any other comments can be communicated to me by e-mail addressed to **mitra@ece.ucsb.edu**.

The book's website, **www.mhhe.com/mitra**, contains additional resources for both instructors and students. Professors can benefit from McGraw-Hill's COSMOS electronic solutions manual. COSMOS enables instructors to generate a limitless supply of problem material for assignment, as well as transfer and integrate their own problems into the software. Please contact your McGraw-Hill sales representative for additional information.

Finally, I have been particularly fortunate to have had the opportunity to work with outstanding students who were in my research group during my teaching career, which spans over 40 years. I have benefited immensely, and continue to do so, both professionally and personally, from my friendship and association with them, and to them I dedicate this book.

Sanjit K. Mitra

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Supplements

All MATLAB programs included in this book are in the CD accompanying this book and are also available from the Internet site **www.ece.ucsb.edu/Faculty/Mitra/Book4e**.

A solutions manual prepared by Hsin-Han Ho, Travis Smith, and Martin Gawecki and containing the solutions to all problems and MATLAB exercises is available to instructors from the publisher. PowerPoint slides of most materials of this book are available to instructors from the author.

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