# DIGITAL SIGNAL PROCESSING

## Principles, Algorithms, and Applications

Second Edition

John G. Proakis
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**John G. Proakis**

Northeastern University

**Dimitris G. Manolakis**

Worcester Polytechnic Institute



Macmillan Publishing Company
NEW YORK

Maxwell Macmillan Canada
TORONTO

Maxwell Macmillan International
NEW YORK OXFORD SINGAPORE SYDNEY

Editor(s): John Griffin
Production Supervisor: Ron Harris
Production Manager: Sandra E. Moore
Text Designer: Eileen Burke

This book was set in 10/12 Times Roman by Waldman Graphics, Inc., printed by Hamilton Printing, Inc., and bound by Hamilton Printing, Inc. The cover was printed by Hamilton Printing, Inc.



Printed in the United States of America



Earlier edition entitled *Introduction to Digital Signal Processing*, copyright © 1988 by Macmillan Publishing Company.

Macmillan Publishing Company is part of the Maxwell Communication Group of Companies.

Macmillan Publishing Company
866 Third Avenue, New York, New York 10022

Maxwell Macmillan Canada, Inc.
1200 Eglinton Avenue East
Suite 200
Don Mills, Ontario M3C 3N1

Library of Congress Cataloging in Publication Data

Proakis, John G.
Digital signal processing : principles, algorithms, and applications / John G. Proakis, Dimitris G. Manolakis. — 2nd ed.
p. cm.
Rev. ed. of: Introduction to digital signal processing. © 1988.
Includes bibliographical references and index.
ISBN 0-02-396815-X
1. Signal processing—Digital techniques. I. Manolakis, Dimitris G. II. Proakis, John G. Introduction to digital signal processing. III. Title.
TK5102.5.P6773 1992
621.382'2—dc20
91-15536
CIP

Printing: 1 2 3 4 5 6 7 8 Year: 2 3 4 5 6 7 8 9 0 1

# PREFACE

This book has resulted from our teaching of undergraduate and graduate-level courses in digital signal processing over the past several years. In this book we present the fundamentals of discrete-time signals, systems, and modern digital processing algorithms and applications for students in electrical engineering, computer engineering, and computer science. As written, the book is suitable for either a one-semester or a two-semester undergraduate-level course in discrete systems and digital signal processing. It is also intended for use in a one-semester first-year graduate-level course in digital signal processing.

A balanced coverage is provided of both theory and practical applications. Included are software implementations of digital filters and digital signal processing algorithms. Appropriately designed programs in FORTRAN are provided to aid the student in implementing and exercising each algorithm immediately after exposition. A large number of well-designed problems and a number of computer experiments are also provided to help the student in mastering the subject matter. A solutions manual is available for the benefit of the instructor and can be obtained from the publisher.

It is assumed that the student in electrical and computer engineering has had undergraduate courses in advanced calculus (including ordinary differential equations), and linear systems for continuous-time signals, including an introduction to the Laplace transform. Although the Fourier series and Fourier transforms of periodic and aperiodic signals are described in Chapter 3, we expect that many students may have had this material in a prior course.

In Chapter 1 we describe the operations involved in the analog-to-digital conversion of an analog signal. The process of sampling a sinusoid is described in some detail and the problem of aliasing is explained. Signal quantization and digital-to-analog conversion are also described in general terms in Chapter 1, but the analysis is presented in subsequent chapters.

Chapter 2 is devoted entirely to the characterization and analysis of liner time-invariant (shift-invariant) discrete-time systems and discrete-time signals in the time domain. The convolution sum is derived and systems are categorized according to the duration of their impulse response as finite-duration impulse response (FIR) and infinite-duration impulse response (IIR). Linear time-invariant systems characterized by difference equations are presented and the solution of difference equations with initial conditions is obtained. The chapter concludes with a treatment of discrete-time correlation.

Chapter 3 treats the analysis of signals and systems in the frequency domain. Fourier series and the Fourier transform are presented for both continuous-time and discrete-time signals. Linear time-invariant (LTI) discrete systems are characterized in the

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