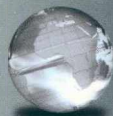


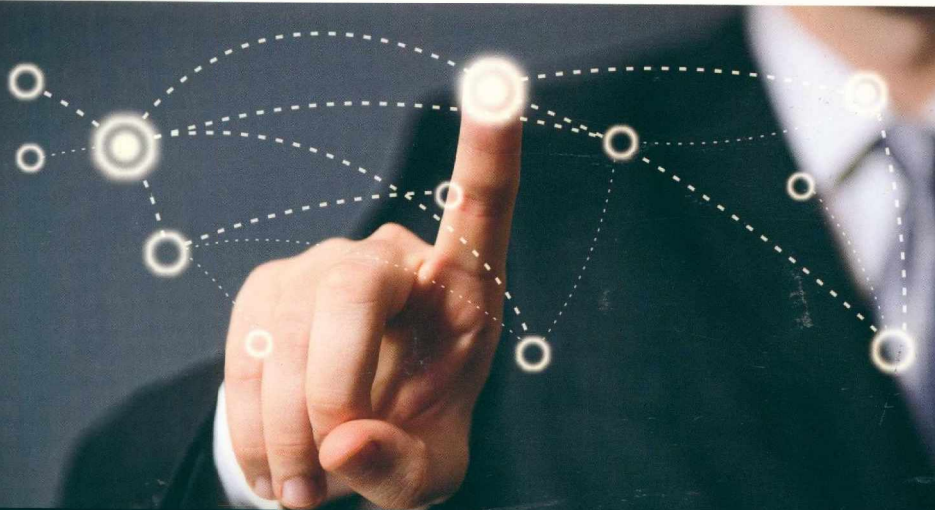
GLOBAL
EDITION



Signals, Systems, and Transforms

FIFTH EDITION

Charles L. Phillips • John M. Parr • Eve A. Riskin



ALWAYS LEARNING

PEARSON

SIGNALS, SYSTEMS, AND TRANSFORMS

FIFTH EDITION

CHARLES L. PHILLIPS
Emeritus
Auburn University
Auburn, Alabama

JOHN M. PARR
University of Evansville
Evansville, Indiana

EVE A. RISKIN
University of Washington
Seattle, Washington

Global Edition contributions by

T. PRABHAKAR
GMR Institute of Technology,
Rajam, Andhra Pradesh

PEARSON

Boston Columbus Indianapolis New York San Francisco Upper Saddle River
Amsterdam Cape Town Dubai London Madrid Milan Munich Paris Montréal Toronto
Delhi Mexico City São Paulo Sydney Hong Kong Seoul Singapore Taipei Tokyo

Vice President and Editorial
Director, ECS: *Marcia J. Horton*
Executive Editor: *Andrew Gilfillan*
Associate Editor: *Alice Dworkin*
Editorial Assistant: *William Opaluch*
Marketing Manager: *Tim Galligan*
Publishing Operations Director, Global Edition:
Angshuman Chakraborty
Publisher, Global Edition: *Laura Dent*
Manager-Publishing Operations, Global Edition:
Shokhi Shah Khandelwal

Associate Print and Media Editor, Global Edition:
Anuprova Dey Chowdhuri
Acquisitions Editor, Global Edition: *Sandhya Ghoshal*
Publishing Administrator, Global Edition: *Hema Mehta*
Project Editor, Global Edition: *Karthik Subramanian*
Art Director: *Jayne Conte*
Cover Designer: *Bruce Kenselaar*
Full-Service Project Management:
Integra Software Services Pvt. Ltd.
Cover Printer: *Courier Westford*
Cover Photo: *Shutterstock/TijanaM*

Pearson Education Limited
Edinburgh Gate
Harlow
Essex CM20 2JE
England

and Associated Companies throughout the world

Visit us on the World Wide Web at: www.pearsonglobaleditions.com

© Pearson Education Limited 2014

The rights of Charles L. Phillips, John M. Parr, and Eve A. Riskin to be identified as the authors of this work have been asserted by him in accordance with the Copyright, Designs and Patents Act 1988.

Authorized adaptation from the United States edition, entitled Signals, Systems, and Transforms, Fifth Edition, ISBN 978-0-13-350647-1 by Charles L. Phillips, John M. Parr, and Eve A. Riskin, published by Pearson Education © 2014.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without either the prior written permission of the publisher or a license permitting restricted copying in the United Kingdom issued by the Copyright Licensing Agency Ltd, Saffron House, 6–10 Kirby Street, London EC1N 8TS.

All trademarks used herein are the property of their respective owners. The use of any trademark in this text does not vest in the author or publisher any trademark ownership rights in such trademarks, nor does the use of such trademarks imply any affiliation with or endorsement of this book by such owners.

Microsoft and/or its respective suppliers make no representations about the suitability of the information contained in the document and related graphics published as part of the services for any purpose. All such documents and related graphics are provided “as is” without warranty of any kind. Microsoft and/or its respective suppliers hereby disclaim all warranties and conditions with regard to this information, including all warranties and conditions of merchantability, whether express, implied or statutory, fitness for a particular purpose, title and non-infringement. In no event shall Microsoft and/or its respective suppliers be liable for any special, indirect or consequential damages or any damages whatsoever resulting from loss of use, data or profits, whether in an action of contract, negligence or other tortious action, arising out of or in connection with the use or performance of information available from the services.

The documents and related graphics contained herein could include technical inaccuracies or typographical errors. Changes are periodically added to the information herein. Microsoft and/or its respective suppliers may make improvements and/or changes in the product(s) and/or the program(s) described herein at any time. Partial screen shots may be viewed in full within the software version specified.

Microsoft® and Windows® are registered trademarks of the Microsoft Corporation in the U.S.A. and other countries. This book is not sponsored or endorsed by or affiliated with the Microsoft Corporation.

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

10 9 8 7 6 5 4 3 2 1
19 18 17 16 15 14

Typeset in Times Ten LT Std Roman by Integra Software Services Pvt. Ltd.

Printed and bound by Courier Westford in the United States of America

To

*Taylor, Justin, Jackson, Rebecca, and Alex
Michaela, Cadence, Miriam, and Connor Duncan,
Gary, Noah, and Aden*

BRIEF CONTENTS

PREFACE	19
1 INTRODUCTION	25
2 CONTINUOUS-TIME SIGNALS AND SYSTEMS	47
3 CONTINUOUS-TIME LINEAR TIME-INVARIANT SYSTEMS	114
4 FOURIER SERIES	178
5 THE FOURIER TRANSFORM	225
6 APPLICATIONS OF THE FOURIER TRANSFORM	296
7 THE LAPLACE TRANSFORM	360
8 STATE VARIABLES FOR CONTINUOUS-TIME SYSTEMS	425
9 DISCRETE-TIME SIGNALS AND SYSTEMS	470
10 DISCRETE-TIME LINEAR TIME-INVARIANT SYSTEMS	519
11 THE z -TRANSFORM	576
12 FOURIER TRANSFORMS OF DISCRETE-TIME SIGNALS	633
13 STATE VARIABLES FOR DISCRETE-TIME SYSTEMS	716
APPENDICES	755
INDEX	805

CONTENTS

PREFACE	19
1 INTRODUCTION	25
1.1 Modeling	25
1.2 Continuous-Time Physical Systems	28
Electric Circuits,	28
Operational Amplifier Circuits,	30
Simple Pendulum,	33
DC Power Supplies,	34
Analogous Systems,	36
1.3 Samplers and Discrete-Time Physical Systems	38
Analog-to-Digital Converter,	38
Numerical Integration,	40
Picture in a Picture,	41
Compact Discs,	42
Sampling in Telephone Systems,	43
Data-Acquisition System,	45
1.4 MATLAB and SIMULINK	46
2 CONTINUOUS-TIME SIGNALS AND SYSTEMS	47
2.1 Transformations of Continuous-Time Signals	48
Time Transformations,	48
Amplitude Transformations,	54
2.2 Signal Characteristics	56
Even and Odd Signals,	56
Periodic Signals,	58

- 2.3 Common Signals in Engineering 63
- 2.4 Singularity Functions 69
 - Unit Step Function, 69
 - Unit Impulse Function, 73
- 2.5 Mathematical Functions for Signals 78
- 2.6 Continuous-Time Systems 83
 - Interconnecting Systems, 85
 - Feedback System, 88
- 2.7 Properties of Continuous-Time Systems 89
 - Stability, 93
 - Linearity, 98

 - Summary 100
 - Problems 102

3 CONTINUOUS-TIME LINEAR TIME-INVARIANT SYSTEMS

114

- 3.1 Impulse Representation of Continuous-Time Signals 115
- 3.2 Convolution for Continuous-Time LTI Systems 116
- 3.3 Properties of Convolution 129
- 3.4 Properties of Continuous-Time LTI Systems 132
 - Memoryless Systems, 133
 - Invertibility, 133
 - Causality, 134
 - Stability, 135
 - Unit Step Response, 136
- 3.5 Differential-Equation Models 137
 - Solution of Differential Equations, 139
 - General Case, 141
 - Relation to Physical Systems, 143
- 3.6 Terms in the Natural Response 144
 - Stability, 145
- 3.7 System Response for Complex-Exponential Inputs 148
 - Linearity, 148
 - Complex Inputs for LTI Systems, 149
 - Impulse Response, 153
- 3.8 Block Diagrams 154
 - Direct Form I, 158
 - Direct Form II, 158