Second Edition

Signals and Systems Simplified

***for* Anna University** ECE Course

adheres to the latest syllabus of Anna University ECE course. An easy-to-understand text with crisp but complete explanation of topics will enable the students to understand the basic concepts easily.

This book is organized into 5 chapters. The fundamental concepts, modeling and analysis of signals and systems are presented in an easy and elaborative manner. Considering the highly mathematical nature of this subject, more emphasis has been given to problem-solving methodology. Throughout the book, carefully chosen examples are presented so that the reader will have a clear understanding of the concepts discussed. This book, with its lucid writing style and useful pedagogical features, will prove to be a master text for engineering students.

Salient Features

- Solution to university questions will enable students to score better in examinations.
- Clear explanation of concepts with appropriate diagrams.
- Different types of fonts for text, proof and solved problems for better understanding.
- Step-by-step presentation of proofs and solved problems.
- MATLAB programming will be useful for laboratory and other projects.

A Nagoor Kani BE, MS

is a multifaceted personality with an efficient technical expertise and management skills. He obtained his BE in EEE from Thiagarajar College of Engineering, Madurai, and MS (Electronics and Control) through Distance Learning Program from BITS, Pilani.

He started his career as a self-employed industrialist (1986–1989) and then changed his career to teaching in 1989. He worked as Lecturer in Dr MGR Engineering College (1989–1990) and as Assistant Professor in Satyabhama Engineering College (1990–1997). He started his own coaching center for BE students named Institute of Electrical Engineering which was renamed as RBA Tutorials in 2005. The well-known companies currently run by him are RBA Engineering (manufacturing laboratory equipment and microprocessor trainer kits), RBA Innovations (involved in developing projects for engineering students and industries), RBA Tutorials (conducting coaching classes for engineering and GATE students) and RBA Publications (publishing of engineering books). He is an eminent writer and has written 13 engineering books.

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CBS Publishers & Distributors Pvt Ltd
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ISBN: 978-93-54661-01-3

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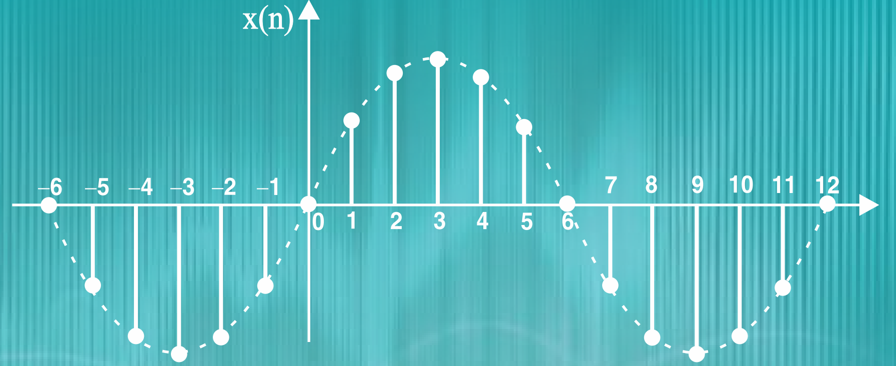

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A Nagoor Kani
Founder, RBA Educational Group
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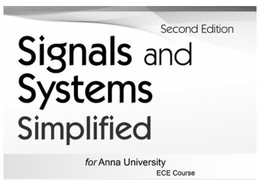

ISBN: 978–93-5466-101-3

Second Edition: 2022
First Edition: 2018

Published by Satish Kumar Jain and produced by Varun Jain for
CBS Publishers & Distributors Pvt Ltd
4819/XI Prahlad Street, 24 Ansari Road, Daryaganj, New Delhi 110 002, India
Ph: 011–23289259, 23266861, 23266867 Fax: 011–23243014
Website: www.cbspd.com e-mail: delhi@cbspd.com; cbspubs@airtelmail.in

Corporate Office: 204 FIE, Industrial Area, Patparganj, Delhi 110 092, India
Ph: 011–49344934 Fax: 011–49344935 e-mail: publishing@cbspd.com; publicity@cbspd.com

Branches

- **Bengaluru:** Seema House 2975, 17th Cross, K.R. Road, Banasankari 2nd Stage, Bengaluru 560 070, Karnataka, India
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  Ph: +91–484-4059061–67 Fax: +91–484-4059065 e-mail: kochi@cbspd.com
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Printed at: Mudrak, Noida, UP, India.

to

Er T A Benazir

PREFACE

The main objective of this book is to explore the basic concepts of signals and systems in a simple and easy-to-understand manner.

This text on signals and systems has been crafted and designed to meet students' requirements. Considering the highly mathematical nature of this subject, more emphasis has been given on the problem-solving methodology. Considerable effort has been made to elucidate mathematical derivations in a step-by-step manner. Exercise problems with varied difficulty levels are given in the text to help students get an intuitive grasp on the subject.

This book with its lucid writing style and germane pedagogical features will prove to be a master text for engineering students and practitioners.

Salient Features

- Proof of important concepts and theorems are clearly highlighted by shaded boxes
- Wherever required, problems are solved in multiple methods
- Additional explanations for solutions and proofs are provided in separate boxes
- Different types of fonts are used for text, proof and solved problems for better clarity
- Keywords are highlighted by bold, italic fonts
- Easy, concise and accurate study material
- Extremely precise edition where concepts are reinforced by pedagogy
- Demonstration of multiple techniques in problem solving, additional explanations and proofs highlighted
- Ample figures and examples to enhance students' understanding
- Practice through MCQ's

Pedagogy

- Solved Numerical Examples: 44 + 46 + 35 + 38 + 59 = 222 (excluding a, b, c, d,…)
- Short-Answer Questions: 27 + 32 + 18 + 20 + 35 = 132
- Figures: 58 + 33 + 18 + 13 + 22 = 144 (numbered figures excluding figures in problems and QA)
- Exercise Numerical Problems: 21 + 21 + 22 + 12 + 20 = 96 (exercise problems excluding a, b, c, d,…)
- Review Questions: 40 + 35 + 18 + 15 + 32 = 140
- MCQs: 35 + 48 + 13 + 18 + 18 = 132
- Fill in the blanks and True/False: 55 + 46 + 21 + 20 + 31 = 173

Organization

In this book, the concepts of signals and systems are organized in five chapters. Each chapter provides the foundations and practical implications of their own topic with large number of solved numerical examples and illustrative figures for better understanding. The important concepts are summarized at the end of each chapter which can help in quick reference. Another significant aspect of this book is that, it contains MATLAB based computer exercises for each chapter with complete explanation, which will be of great assistance to both instructor and student.

Chapter 1 starts with a general introduction about various types of signals, systems and their importance in real life. Basic definitions of signals, their mathematical representation, significance of their frequency domain analysis and usage of MATLAB in this course are presented in brief manner.

Chapter 1 explores various standard continuous time and discrete time signals, classifications of continuous time and discrete time signals and possible mathematical operations on signals such as amplitude and time scaling, folding, time shifting, addition, multiplication, etc. The concept of generation of discrete time signals is also presented in this chapter. The classification and properties of continuous time and discrete time systems are also presented in chapter 1 with appropriate examples.

Chapter 2 deals with analysis of continuous time signals using Fourier series, Fourier transform and Laplace transform. Chapter 2 starts with Fourier analysis of continuous time signals which forms the basics for frequency domain analysis. Fourier series in both trigonometric and exponential forms, Fourier coefficients of various signals with symmetry, properties of Fourier series, frequency spectrum using Fourier series and Gibbs phenomenon have been discussed. Then the Chapter 2 explains the development of Fourier transform from Fourier series, Fourier transform of some standard signals, various properties of Fourier transform and frequency spectrum via Fourier transform. The proof of properties of Fourier transform of continuous time signal are also presented with clear steps.

Also, Chapter 2 discusses about analysis of continuous time signals using Laplace transform. The properties of Laplace transform and proof with clear steps are presented. The rational functions of 's' and their representation in terms of poles and zeros, region of convergence of Laplace transform and its properties are presented in a crisp and clear manner. Further, chapter 2 discusses about the inverse Laplace transform using partial fraction method and convolution theorem. The relation between Fourier transform and Laplace transform of continuous time signals is also discussed in chapter 2.

Chapter 3 deals with analysis of Linear Time Invariant (LTI) continuous time systems in time domain, frequency domain and s-domain. The differential equation governing the LTI continuous time system in time domain and their direct solutions in time domain are discussed with examples. The time domain convolution operation that can be used to find the response of LTI system from its impulse response is explained with clear numerical examples. Another important thing in chapter 3 is that the graphical convolution operation of continuous time signals is discussed by clearly separating the shift index and time index that will aid in clear understanding.

Also, the Chapter 3 deals with detailed analysis of continuous time systems in s-domain using Laplace transform. The transfer function in s-domain, impulse response, response for specific inputs, convolution and deconvolution operations using Laplace transform are presented with appropriate numerical examples. The stability of the LTI systems in s-domain via Laplace transform is dealt clearly.

In addition, the Chapter 3 deals with analysis of continuous time systems in frequency domain using Fourier transform. The transfer function of continuous time system in frequency domain, impulse response, response for specific inputs and convolution using Fourier transform are presented with appropriate numerical examples. The computation of frequency response of continuous time LTI systems using Fourier transform is also explained.

The standard realization structures for the continuous time systems characterized by differential equations are also presented in chapter 3.

Chapter 4 deals with analysis of discrete time signals using discrete time fourier transform (DTFT) and Ƶ-transform. Chapter 4 starts with Fourier transform analysis of discrete time signals which forms the basics for frequency domain analysis. The frequency spectrum, various properties of Fourier transform and Fourier transform of some standard signals are presented. The proof of properties of DTFT are presented with clear steps. The concept of sampling and aliasing in frequency spectrum are also discussed.

Also, Chapter 4 discusses about analysis of discrete time signals using Ƶ-transform. The properties of Ƶ-transform and proof with clear steps are presented. The rational functions of 'z' and their representation in terms of poles and zeros, region of convergence of Ƶ-transform and its properties are presented in detail with appropriate examples. Further, chapter 4 discusses about the various methods of inverse Ƶ-transform. The relation between Fourier transform and Ƶ-transform of discrete time signals is also discussed in chapter 4.

Chapter 5 deals with analysis of discrete time systems in time domain, frequency domain and z-domain. The difference equation governing the LTI discrete time system in time domain and their direct solutions in time domain are discussed with examples. The time domain discrete convolution operation that can be used to find the response of LTI discrete time system from its impulse response is explained with clear numerical examples. The graphical convolution operation of discrete time signals is illustrated with figures for each step that will aid in clear understanding.

Also, Chapter 5 deals with analysis of discrete time systems in frequency domain using Fourier transform. The transfer function of discrete time system in frequency domain, impulse response, response for specific inputs and convolution using Fourier transform are presented with appropriate numerical examples The computation of frequency response of discrete time LTI systems using Fourier transform is also explained with examples.

In addition, Chapter 5 deals with detailed analysis of discrete time systems in z-domain using Ƶ-transform. The transfer function in z-domain, impulse response, response for specific inputs, convolution and deconvolution operations using Ƶ-transform are presented with appropriate numerical examples. The stability of the LTI systems in z-domain via Ƶ-transform is dealt clearly.

Also, Chapter 5 focuses on structures for realization of discrete time systems with special attention to IIR and FIR systems.

A Nagoor Kani

ACKNOWLEDGEMENTS

I express my heartfelt thanks to my wife Ms C Gnanaparanjothi Nagoor Kani and my sons N Bharath Raj alias Chandrakani Allaudeen and N Vikram Raj for the support, encouragement and cooperation they have extended to me throughout my career.

I thank Ms T A Benazir for the affection and care on my day-to-day activities.

It's my pleasure to acknowledge the contributions of our technical editors, Ms. E R Suhasini, Ms M A Aswathy, Ms C Mohana Priya, Ms Devi Asokan and Ms L Sharmila for editing, proof-reading and type-setting of the manuscript and preparing the layout of the book.

I thank all my office staff for their support and help in carrying my office work.

My sincere thanks to all reviewers for their valuable suggestions and comments which helps me to explore the subject to greater depth.

I am also grateful to Mr Satish K Jain, CMD, CBS Publishers & Distributors, for his keen interest in publishing this work in CBS banner. My sincere thanks to all team members of CBS Publishers & Distributors, for their concern and care in publishing this work.

Finally, a special note of appreciation is due to my sisters, brothers, relatives, friends, students and the entire teaching community for their overwhelming support and encouragement to my writing.

A Nagoor Kani

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

Symbols

a_o, a_n, b_n	Fourier coefficients of trignometric form of Fourier series of x(t)
B	Bandwidth in Hz
c_n	Fourier coefficients of exponential form of Fourier series of x(t)
E	Energy of a signal
f	Frequency of discrete time signal in Hz/sample
F	Frequency of continuous time signal in Hz
F_o	Fundamental frequency of continuous time signal in Hz
F_m	Maximum frequency of continuous time signal
F_s	Sampling frequency of continuous time signal in Hz
$\mathcal{H}$	System operator
j	Complex operator, $\sqrt{-1}$
L	Inductance
$n\Omega_o$	Harmonic angular frequency, where n = 1,2,3,...
P	Power of a signal
p	Pole
R	Resistor
s	Complex frequency ($s = \sigma + j\Omega$)
t	Time in seconds
T	Time period in seconds
W	Phase factor or twiddle factor
z	Complex variable ($z = u + jv$)
z	Unit advance operator or zero
z^{-1}	Unit delay operator
Ω	Angular frequency of continuous time signal in rad/sec
Ω_o	Fundamental angular frequency
Ω_{max}	Maximum angular frequency in rad/sec
ω	Angular frequency of discrete time signal
ω_k	Sampling frequency point
σ	Neper frequency (Real part of s)
*	Convolution operator
$\oint$	Integration operator
$\frac{d}{dt}$	Differentiation operator

Standard/Input/Output Signals

h(n)	Impulse response of discrete time system
h(t)	Impulse response of continuous time system
sgn(t)	Signum signal
sinc (t)	Sinc signal
u(n)	Discrete time unit step signal
u(t)	Continuous time unit step signal
x(n)	Discrete time signal
x(n)	Input of discrete time system
$x_o(n)$	Odd part of discrete time signal x(n)
$x_e(n)$	Even part of discrete time signal x(n)
x(n–m)	Delayed or linearly shifted x(n) by m units
x(t)	Continuous time signal or Input of continuous time system
$x_o(t)$	Odd part of continuous time signal x(t)

$x_e(t)$	Even part of continuous time signal x(t)
x(t–m)	Delayed or linearly shifted x(t) by m units
y(n)	Output/Response of discrete time system
$y_{zs}(n)$	Zero state response of discrete time system
$y_{zi}(n)$	Zero input response of discrete time time system
y(t)	Output /Response of continuous time system
$y_{zs}(t)$	Zero state response of continuous time system
$y_{zi}(t)$	Zero input response of continuous time system
δ(t)	Continuous time impulse signal
δ(n)	Discrete time impulse signal
Π(t)	Unit pulse signal

Transform Operators and Functions

$\mathcal{F}$	Fourier transform
$\mathcal{F}^{-1}$	Inverse Fourier transform
H(s)	Laplace transform of h(t)
$\mathcal{L}$	Laplace transform
$\mathcal{L}^{-1}$	Inverse Laplace transform
$X(e^{j\omega})$	Discrete time fourier transform of x(n)
$X_r(e^{j\omega})$	Real part of $X(e^{j\omega})$
$X_i(e^{j\omega})$	Imaginary part of $X(e^{j\omega})$
X(jΩ)	Fourier transform of x(t)
X(s)	Laplace transform of x(t)
X(z)	$\mathcal{Z}$-transform of x(n)
$\mathcal{Z}$	$\mathcal{Z}$-transform
$\mathcal{Z}^{-1}$	Inverse $\mathcal{Z}$-transform

Abbreviations

BIBO	**B**ounded **I**nput **B**ounded **O**utput
CT	**C**ontinuous **T**ime
CTFS	**C**ontinuous **T**ime **F**ourier **S**eries
CTFT	**C**ontinuous **T**ime **F**ourier **T**ransform
DT	**D**iscrete **T**ime
DTFT	**D**iscrete **T**ime **F**ourier **T**ransform
FIR	**F**inite **I**mpulse **R**esponse
IIR	**I**nfinite **I**mpulse **R**esponse
LHP	**L**eft **H**alf **P**lane
LTI	**L**inear **T**ime **I**nvariant
RHP	**R**ight **H**alf **P**lane
ROC	**R**egion of **C**onvergence