SIGNALS AND SYSTEMS USING MATLAB®

SECOND EDITION

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Second Edition

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Dedication

'To my grandchildren, the future is theirs'

Preface

... in this book I have only made up a bunch of other men's flowers, providing of my own only the string that ties them together.
M. De Montaigne (1533–1592)
French Essayist

This is the second edition of *Signals and Systems Using MATLAB*. Keeping with the outlook of the first edition, the content of this second edition is the result of rewriting, adding, and reorganizing the first edition material. Many of these changes resulted from helpful comments from students and faculty who have used the book in their courses, and we thankfully acknowledge them.

As indicated in the first edition, it is hardly possible to keep up with advances in technology but reassuring to know that in science and engineering development and innovation are possible through a solid understanding of basic principles. The theory of signals and systems is one of those fundamentals, and it will be the foundation of much research and development in engineering for years to come. In the near future, not only engineers will need to know about signals and systems—to some degree everybody will. The pervasiveness of computers, cell phones, digital recordings, and digital communications, among others, will require it.

Learning as well as teaching signals and systems is complicated by the combination of mathematical abstraction and concrete engineering applications in the subject. Thus a course in signals and systems needs to be designed to nurture the students' interest in applications, but also to make them appreciate the significance of the concepts and of the mathematical tools. The aim of this textbook is to serve the students' needs in learning the theory of signals and systems as well as to facilitate the teaching of the material for faculty by proposing an approach that the author has found effective in his own teaching. To enhance the learning experience, we consider the use of MATLAB, an essential tool in the practice of engineering. MATLAB not only helps to illustrate the theoretical results but to make students aware of the computational issues that engineers face in implementing them.

LEVEL

Although the material in this textbook is intended for junior-level courses in signals and systems in electrical and computer engineering, it could also be used in teaching similar courses to mechanical engineering and bioengineering students and it might be of interest to students in applied mathematics. Moreover, the "student-friendly" nature of the text also makes it useful to practicing engineers interested in learning or in reviewing the basic principles of signals and systems on their own. The material is organized so that students not only get a solid understanding of the theory—enhanced by analytic examples and software examples using MATLAB, learn about applications, but also develop confidence and proficiency in the material by working on analytic and computational problems.

The organization of the material in the book follows the assumption that the student has been exposed to the theory of linear circuits, differential equations, and linear algebra and that this material will be followed by courses in control, communications, or digital signal processing. The content is guided by the goal of nurturing the interest of students in applications, and of assisting them in becoming more mathematically sophisticated.

APPROACH

In writing this text, we have taken the following approach:

1. The material is divided into three parts: introduction, theory, and applications of continuous-time signals and systems, and theory and applications of discrete-time signals and systems.

   Material in the first part is intended to help students understand the connection between continuous- and discrete-time signals and systems, infinitesimal and finite calculus, and why complex numbers and functions are used in the study of signals and systems. MATLAB is introduced here as a tool for numeric as well as symbolic computations. An overview of the rest of the chapters is weaved throughout this chapter, and motivational practical applications are provided. Significantly, the introductory chapter is named Chapter 0, to serve as an analogy to the ground floor of the building formed by the other chapters.

   The treatment of continuous- and discrete-time signals and systems is then done separately—combining them has been found to be confusing to students. An effort is made in the second and third parts of the book to show students not only the connections and relevance of each of the transformations used in the analysis of signals and systems, but that these transformations should be seen as a progression rather than as disconnected methods.

2. A great deal of effort has been put into making the text *"student friendly"* as much as possible. To make sure that the student does not miss some of the important issues presented in a section, we have inserted well-thought out remarks intended to minimize common misunderstandings we have observed from our students in the past. Plenty of analytic examples, with different levels of complexity, are given to illustrate issues. Each chapter has a set of examples using MATLAB, illustrating topics presented in the text or special issues that the student should know. The MATLAB code is given so that students can learn by example from it. To help students follow the mathematical derivations, we provide extra steps whenever necessary and do not skip steps that are basic in the understanding of a derivation. Summaries of important issues are boxed and concepts and terms are bolded to help students grasp the main points and terminology.
3. Without any doubt, learning the material in signals and systems requires working analytical as well as computational problems. Thus we considered it important to provide problems of different levels of complexity to exercise not only basic problem-solving skills, but to achieve a level of proficiency in the subject and mathematical sophistication. With respect to the first edition, the number of problems at the end of the chapters has been significantly increased and analytic and computational problems have been separated. The basic problems were designed to provide a way for students to achieve mastery of conceptual issues, while the MATLAB problems were designed to deepen the conceptual understanding as they are applied. To encourage students to work on their own, partial or complete answers are provided for most of the problems at the end of each chapter.
4. Two additional features should be beneficial to students. One is the inclusion of quotations and footnotes to present interesting ideas, remarks, or historical comments, and the other is the inclusion of sidebars that attempt to teach historical facts that students should be aware of. The theory of signal and systems clearly connects with mathematics and a great number of mathematicians have contributed to it. Likewise, there is a large number of engineers who have contributed significantly to the development and application of signals and systems. All of them need to be recognized for their contributions, and we should learn from their experiences.
5. Finally, other features are: (i) the design of the index of the book so that it can be used by the student to find definitions, symbols, and MATLAB functions used in the text; (ii) a list of references to the material.

CONTENT

The core of the material is presented in the second and third parts of the book. In the second part we cover the basics of continuous-time signals and systems and illustrate their applications, while in the third part we do similarly for discrete-time signals and system.

Because the concepts of signals and systems are relatively new to students, we provide an extensive and complete presentation of these topics in Chapters 1 and 2. In Chapter 1, we consider basic characteristics and processing of continuous-time signals, and provide the representation of signals using basic signals. Chapter 2 introduces the concept of systems, in particular of continuous-time systems. Linearity, time-invariance, causality, and stability are introduced in this chapter. Using linearity and time-invariance, the computation of the output of a continuous-time system using the convolution integral is introduced and illustrated.

Chapter 3 covers the basics of the Laplace transform and its application in the analysis of continuous-time signals and systems. It introduces the student to the concept of poles and zeros, damping and frequency, and their connection with signals as functions of time. This chapter emphasizes the solution of ordinary differential equations representing linear time-invariant (LTI) systems, paying special attention to transient solutions due to their importance in control, as well as to steady-state solutions due to their importance in filtering and in communications. The computation of the convolution integral is compared using time-domain methods and using the Laplace transform to emphasize the operational power of the transform. The important concept of transfer function for LTI systems and the significance of its poles and zeros are studied in detail. Different approaches are considered in computing the inverse Laplace transform.

Fourier analysis of continuous-time signals and systems is covered in detail in Chapters 4 and 5. The Fourier series analysis of periodic signals, covered in Chapter 4, is extended to the analysis of aperiodic signals resulting in the Fourier transform of Chapter 5. The Fourier transform is useful in representing both periodic and aperiodic signals and for the frequency response of systems. Special attention is given to the connection of these methods with the Laplace transform so that, whenever possible, known Laplace transforms can be used to compute the Fourier series coefficients and the Fourier transform—thus avoiding integration but using the concept of the region of convergence. The concept of frequency, the response of the system (connected to the location of poles/zeros of the transfer function), and the steady-state response are emphasized in these chapters.

The ordering of the presentation of the Laplace and the Fourier transformations (similarly for the Z-transform and the Fourier representation of discrete-time signals) is significant for the learning and for the teaching of the material. Our approach of presenting first the Laplace transform and then the Fourier series and Fourier transform is justified for several reasons. For one, students coming into a signals and systems course typically have been familiarized with the Laplace transform in their previous circuits or differential equations courses, and will continue using it in control courses. So expertise in this topic is important and the learned material will stay with them longer. Another is that a common difficulty students have in applying the Fourier series and the Fourier transform is connected with the required integration. Thus the Laplace transform can be used not only to side-step the integration but to provide a more comprehensive understanding of the frequency representation. By asking students to consider the two-sided Laplace transform and the significance of its region of convergence, they will appreciate better the Fourier representation as a special case of Laplace's in many cases. More importantly, these transforms can be seen as a continuum rather than as independent methods. It also makes theoretical sense to deal with the Laplace representation of systems first to justify the existence of the steady-state solution considered in the Fourier representations—which would not exist unless stability of the system is guaranteed, and stability can only be tested using the Laplace transform. The paradigm of interest is the connection of transient and steady-state responses that must be understood by students before they can understand the connections between Fourier and the Laplace analysis and their application in control, communications, and filtering.

Chapters 6 and 7 present applications of the Laplace transform to control and of the Fourier transform to communications, and filtering. The intent of these chapters is to motivate interest in these areas. Chapter 6 illustrates the significance of the concepts of transfer function, response of systems, and stability in classical control. Relative to the first edition, we have added a section on the state-variable representation of systems—of great interest in modern control-and its connection to the Laplace transform. Chapter 7 illustrates the application of the Fourier analysis in communications and in analog filtering. Analytic as well as MATLAB examples illustrate different applications to control, communications, and filter design.

Using the sampling theory as a bridge, the third part of the book covers the theory and illustrates the application of discrete-time signals and systems. Chapter 8 presents the theory of sampling: the conditions under which the signal does not lose information in the sampling process and the recovery of the analog signal from the sampled signal as well as its application in digital communications.