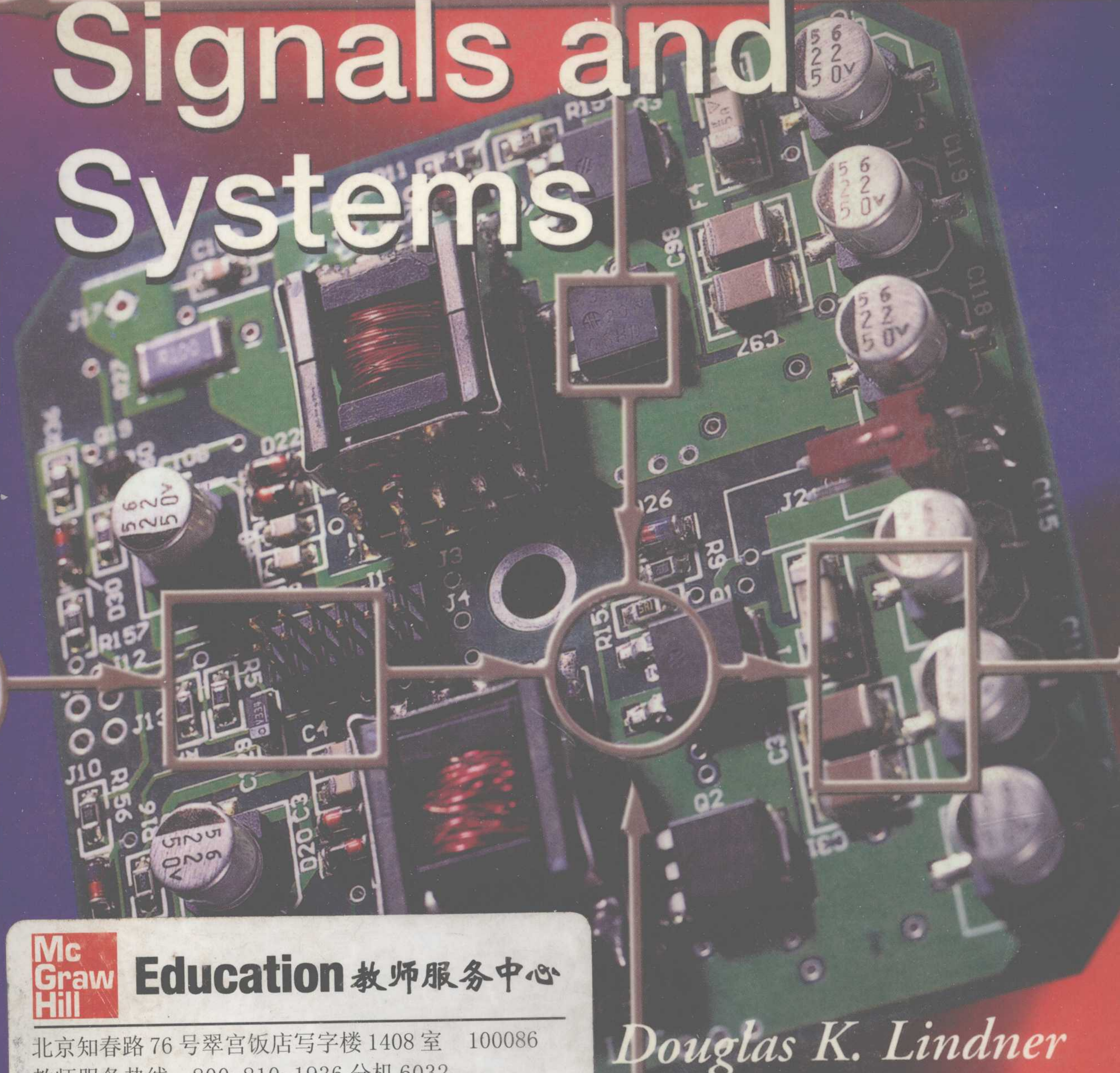
Introduction to Signals and Systems



Douglas K. Lindner

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Introduction
to
Signals and Systems

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Preface

Introduction This textbook is designed for a one- or two- semester, sophomore-junior level core course on signals and systems. A typical background of a student would include a course on network analysis, an introduction to physics, and differential equations. The proposed text, however, only assumes a sophomore level maturity.

It is widely recognized that there many common elements in the modeling, analysis, and design in many diverse engineering systems. These elements have been collected under the heading of *system theory*, formalized, and given a systematic treatment. It is the purpose of this book to discuss the most fundamental concepts associated with this theory while stressing their relationship to the engineering problems from which system theory evolved. The mathematical background for the concepts discussed here is also contained in this book.

Structure of the Material The two most basic concepts in this theory are a *signal* and a *system*. The intention of the organization of the text is to present the core signals and systems material in terms of a few well-drawn, tightly interconnected concepts. The development starts from the definition of a signal and a system. The results related to signals are grouped together and the results related to systems are grouped together. One of the major benefits of this organization is that the concepts related to system models (or representations) can now be grouped together. The interrelationships between convolution integrals, transfer functions, and state space equations can be emphasized. These relationships are particularly important in view of modern computational tools which implement these interrelationships. In the same way the concepts related to signals can be grouped together to emphasize their continuity. The frequency domain concepts of the spectral content of a signal and the frequency response of a system then provide a link between the signals material and the systems material. This presentation has the effect of focusing the reader on the engineering aspects of the material instead of emphasizing the transform mathematics.

System theory rests on mathematical transform theory: Fourier, Laplace, and z-transforms. In this text, however, we have chosen to relegate the transform theory to background chapters rather than present it as interwoven with the system theory results.

This book covers both continuous-time and discrete-time signals and systems. It has been noted that continuous-time and discrete-time theory share many mathematical properties. On the other hand, the physical processes that are modeled by continuous-time systems are very different than physical processes that are modeled by discrete-time systems. Because this book emphasizes the connections between physical processes and their models, we have separated the continuous-time theory from the discrete-time theory. Both presentations, however, are structured in a parallel fashion to emphasize the mathematical similarities of the material. In fact, the discrete-time material can be covered before the continuous-time material.

Integration of the Computer Computer aided design has been and continues to be an important component of industrial engineering. In recent years professionally written CAD packages have become available for classroom use. The computer tools reflect the way the practicing engineer organizes the underlying signals and systems concepts to solve everyday engineering problems. The conceptual framework employed by the practicing engineer is embodied in the conceptual framework of the text. In this way classroom discussion is integrated with professional practice and the structure of CAD packages. The signals material as it is presented in existing texts conforms to this standard. The conceptual framework of the text is structured to also integrate the systems material smoothly with the various computer tools currently available for classroom use.

The purpose of the introduction of the computer into a signals and systems course is to give the student the tools and ability to use these tools to analyze complex, realistic examples. We have chosen MATLAB®[1] for integration into this material. MATLAB, however, requires a familiarity with a core set of concepts and terminology in signals and systems. Since this course is the introductory course into the area of signals and systems, the essential issue is to give the students these concepts and terminology to understand the manuals and use MATLAB in a way that also advances their understanding of signal and systems material. Here we are concerned with the compatibility of the computational tool with the concepts that are being taught in the course. The organization of the proposed text is motivated, in part, by the relationship between the students' understanding of the basic concepts, the commands available in the computer package, and the students' ability to use the data structure of the CAD package. MATLAB has been integrated into the text in a structured and systematic way as described in Section 1.7, How to Use MATLAB with This Book.

Continuity with the Network Analysis Course The courses which are prerequisites for a signals and systems course are generally a networks course, a differential equations course, and a course which includes an introduction to dynamics. All of these topics are quite closely related to signals and systems, but the students frequently don't make the connection between these two blocks of material, particularly in the beginning. This loss of continuity between the networks course and the signals and systems course can be traced to the sequence of topics that are found in many introductory treatments of signals and systems. Typically, after signals and systems are defined, the abstract properties of systems are defined followed by the derivation of the convolution integral as a system representation. This discussion is followed by a discussion of Fourier series and transforms. These topics are abstract and mathematically challenging. Furthermore, these topics are not always covered in the preceding networks course. This initial block of mathematically oriented material leaves the students disoriented.

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[1] MATLAB is a registered trademark of The MathWorks, Inc. 24 Prime Park Way, Natick, MA 01760-1500. Phone: 508-647-7000, http://www.mathworks.com

To make the material more accessible to the students, several changes have been introduced into the organization of the topics in this text. First, the sequencing of the topics on systems has been reversed. Starting with transfer functions, state space equations are developed, followed by the convolution integral. (State space equations can be skipped, if desired.) Then system properties are introduced. The reason for this sequencing is that the transfer functions are most naturally related to impedances in network analysis. So it is very easy to tie this material back to networks at the beginning. This sequencing of the systems material is from "the concrete to the abstract." By first studying many examples of systems, students readily assimilate the more abstract system concepts.

The second way to transition the students gradually to a more abstract (and powerful) way of thinking is to place systems before signals. The motivation is that the students have essentially been exposed to many systems in networks, while their exposure to signals concepts is more limited. Typically, Fourier series, the first important signal concept, occur at the end of the networks. Most students don't really absorb this abstract concept. By covering systems first the students gain maturity in abstract thinking through the systems analysis, which in turn helps them master the signals material. Furthermore, many signals concepts only become clear in their relationship to systems, particularly frequency domain concepts. The modularity of this text allows the chapters on systems to be covered before the chapters on signals, if desired.

Web Site More information about this text including supplements can be found on the web at: http://www.mhhe.com/engcs/electrical/lindner.

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Chapter 1

Introduction to Signals and Systems

Chapter Outline

The purpose of this chapter is to explain the basic philosophical concepts that form the basis for the technical concepts presented in the rest of the text. We discuss how these philosophical ideas are evident in the organization of the text. This philosophy also helps to explain how the material in this text is related to the engineering literature as a whole. To readers wholly unfamiliar with the contents of this book, the following discussion may seem a little abstract. Readers are urged to return to this chapter as they progress through the text to develop the big picture as well as the details.

Summary of Sections

Section 1.1: We discuss the philosophy on which this book is based.

Section 1.2: We introduce the two most fundamental concepts used in the text: signals and systems.

Section 1.3: We discuss the principle of mathematical modeling.

Section 1.4: We discuss more on the concepts of signals and systems.

Section 1.5: We discuss continuous-time and discrete-time.

Section 1.6: We discuss the basic organization of the text.

Section 1.7: We explain how to use MATLAB with this book.

1.1 A LITTLE PHILOSOPHY

As engineers and scientists we are interested in understanding the phenomena in the physical world around us. This knowledge can be used to improve the way we interact with our environment, show us how to improve upon the mechanisms we find in it, and show us how to design and fabricate entirely new devices. There are some underlying principles in the methodologies used for the acquisition of this knowledge for extending our understanding of known concepts. The acquisition of knowledge begins with the observation of a physical process. We use "observation" in a rather general sense meaning not only a direct sensory perception of the physical process, but also indirect perception through a sensor. It is crucial, however, that the process be *observed* in some way.

Once the process has been observed (implying repeatability) the acquisition of a deeper knowledge of the process proceeds in two modes of inquiry. The first mode of inquiry continues with direct observation of the process - experimentation. The physical process is observed in a variety of settings. Its action on other physical processes is documented. Various techniques can be developed to act on the physical process to alter its characteristics. This approach is highly developed, and a vast array of laboratory instrumentation is available for investigation of every type of physical process.

The second mode of inquiry involves developing an abstract description of the physical process. Then this abstract description is used to indirectly investigate the properties of the physical process. The simplest abstract description is a verbal description of the physical process. The statement of Newton's laws gives us a verbal description of these fundamental laws of physics. Verbal descriptions, however, are limited in their ability to accurately describe the physical process. A much more powerful language for the description of a physical process is a mathematical description. Mathematics, in its broadest interpretation, contains a wealth of knowledge that can be brought to bear in the investigation of the properties of the physical process by analyzing its abstract representation. In this mode of inquiry, our understanding of the physical process is developed indirectly by studying the properties of the mathematical description using the tools of mathematics. For example, differential calculus is very useful for understanding and applying Newton's laws.

In recent years the computer has evolved as a new tool for understanding abstract descriptions of physical processes. Our observations of the physical process must be translated into numbers, a mathematical description of the physical process. By processing these numbers possibly in conjunction with a mathematical description of the physical process such as a differential equation, we are able to greatly expand our understanding of the physical process through automated computation. The extension of abstract descriptions of physical processes into the computer environment is having an enormous impact on the way engineering is done today.

Consider, for example, an oil painting. An oil painting is a physical process in that it persists through time. The painting is experimentally created by the artist with paints and a brush. The artist's understanding of the painting is, in part, through the act of painting, an experimental mode of inquiry. It is also possible to develop an abstract description of the painting. At the simplest level such an abstract description may be a verbal description of the color and geometry of the painting. With persistence, a more sophisticated description can be developed using the laws of physics along with a mathematical description of the colors and geometry. This more abstract, sophisticated description is useful in that it allows us to reproduce the painting on our computer screen. We can also use the computer model of the painting to gain insight into its historical origins.

At this early point in our discussion we emphasize that we are primarily interested in developing tools that can be used in the understanding of physical processes. Furthermore, there are two separate, but complementary approaches for understanding the physical process: experimentation and abstraction. Neither one of these approaches is satisfactory by itself, but depends on the other to guide it. This basic fact provides the foundation and orientation for the material in this book.

1.2 BASIC CONCEPTS

1.2.1 Introduction

In this book we will discuss the abstract description of a physical process. It turns out that diverse physical processes have mathematical descriptions that are similar in their mathematical properties. Furthermore, the same analytical tools can be used for the analysis of the mathematical descriptions of many of these processes. Therefore, the organization of the material in the book tends to emphasize the mathematical aspects of the subject. While this organization underscores the power and usefulness of this material, it should be remembered that the ultimate goal is to use these concepts to further our understanding of the physical processes. Some attempt has been made in the text to keep the readers tuned in to this objective. The fact that we don't discuss the experimental aspects of the analysis of physical processes doesn't imply that this knowledge is less useful than the concepts contained in this text. Its just that space is limited.

This book is concerned with the mathematical descriptions of a physical process and the analytical tools used to analyze these descriptions. To a lesser extent we will address the problem of design: synthesizing a mathematical description with the ultimate goal of constructing a physical device that matches the abstract description. The readers are undoubtedly familiar with this approach, it being the way of science. One of the primary goals of a first networks course is to introduce the mathematical tools used to describe the operation of a electric network composed of a resistor, capacitor, and inductor along with a voltage or current source. The voltages and currents in a network are represented by functions. The relationship between these voltages and currents is shown to be given by differential equations. Later it is shown how these mathematical objects can be analyzed using Laplace and Fourier