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Mark Wickert, PhD

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Signals & Systems For Dummies

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by Mark Wickert, PhD

For Dummies
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About the Author

Mark Wickert is a professor of electrical and computer engineering at the University of Colorado, Colorado Springs, Colorado. His teaching focus is signals and systems with an emphasis in communications and signal processing. Mark was previously a board-level designer at Motorola Government Electronics, now a division of General Dynamics.

Mark also works as an industry consultant in digital communications and signal processing for Amergint Technologies LLC. He's worked with Real Time Logic and developed algorithms for a ZIGBEE radio chip at Atmel Corporation as well.

Mark earned BS and MS degrees in electrical engineering from Michigan Technological University and PhD from Missouri University of Science and Technology (then UMR). He is a member of the Institute of Electrical and Electronics Engineers.

Dedication

To Becki, David, and Paul — my family.

To God be the glory!

Author's Acknowledgments

This project started with an invitation from my agent, Matt, and a strong dose of encouragement from my wife, Becki, who endured a lot of changes that came with my focus on developing material for this book. My sons, David and Paul, had to accept seeing less of me, too, especially during our summer vacation. Thank you all for your support and encouragement throughout this process.

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Finally, to my dad. Thanks for encouraging my middle-school interest in building electronic gadgets. You spurred my lifelong love for building hardware, software, and countless other things — I'll always be grateful.

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We're proud of this book; please send us your comments at http://dummies.custhelp.com. For other comments, please contact our Customer Care Department within the U.S. at 877-762-2974, outside the U.S. at 317-572-3993, or fax 317-572-4002.

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Contents at a Glance

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Introduction

Signals and systems is one of the toughest classes you'll take as an engineering student. But struggling to figure out this material doesn't necessarily mean you need to sprout early-onset gray hairs and resign yourself to frown lines in your college years. And you definitely don't want to give up on engineering over this stuff because becoming an engineer is, in my opinion, one of the best career choices you can make. See, you're no dummy!

This book can help you make sense of the fundamental concepts of signals and systems that may be giving you some static — or even frying your brain. Even better, you can apply the tips and tricks I provide in this book to the courses you'll take down the line — and right into the real world of computer and electrical engineering!

About This Book

Like all other *For Dummies* books, *Signals & Systems For Dummies* isn't a tutorial. It's a reference book that you can use as you need it. You don't need to read each chapter cover to cover (but you may find all the material utterly mesmerizing). You can jump right to the topics or concepts that are giving you trouble, get the help you need, and be on your way with helpful insight to real-world examples of electrical concepts that may be tough to imagine in your textbook of equations.

Conventions Used in This Book

I use the following conventions throughout the text to make things consistent and easy to follow:

- New terms appear in *italic* and are closely followed by an easy-to-understand definition. Variables also appear in italic.
- **Bold** highlights keywords in bulleted lists and the action parts of numbered steps.
- Lowercase variables indicate signals that change with time, and uppercase variables indicate signals that are constant. For example, $v(t)$ and $i(t)$ denote voltage and current signals that change with time. If, however, V and I are capitalized, these signals don't vary in time.

What You're Not to Read

Although I'm sure you want to read every word of this book, I realize you have other reading material to get through. When you're short on time and need to just get through the basics, you can skip the sidebars (the shaded boxes sprinkled throughout the book) and paragraphs flagged with a Technical Stuff icon.

Foolish Assumptions

I know you're a unique kind of brilliant and have one-of-a-kind skills and attributes, but as I wrote this book, I had to make some assumptions about my readers. Here's what I assume about you:

- You're currently taking an introductory signals and systems course as part of your computer or electrical engineering major, and you need help with certain concepts and techniques. Or you're planning to take a signals and systems course next semester, and you want to prepare by checking out some supplementary material.
- You have a solid handle on algebra and calculus.
- You've taken an introductory physics class, which exposed you to the concepts of voltage, current, and power in circuits.
- You're familiar with linear differential equations with constant coefficients.

How This Book Is Organized

The study of signals and systems integrates a handful of specific topics from your math and physics courses, and it introduces new techniques to design and manage electrical systems. To help you grasp the core concepts of this electrifying field (sorry, I couldn't resist) in manageable bites, I've split the book into several parts, each consisting of chapters on related topics. Chapters are laid out in an alternation of continuous- and discrete-time topics, starting with the time domain, moving to the frequency domain, and then covering the *s*- and *z*-domains.

Additional content, including case studies, is available online at `www.dummies.com/extras/signalsandsystems`.

Part I: Getting Started with Signals and Systems

This part gives you the signals and systems lingo and an overview of the basic concepts and techniques necessary for tackling your signals and systems course. If you're already familiar with the fundamentals of how signals and systems operate in the continuous- and discrete-time domains, you can use this part as a refresher.

Part II: Exploring the Time Domain

The focus of these chapters narrows to more closely examine the time domain of signals and systems. In Chapter 7, I introduce differential and difference equation system models, which are used to represent electronic circuits, the audio equalizer on your MP3 music player, filters that separate signals from one another, hybrid systems composed of electrical and mechanical components, and more. I also describe signal and system classifications and properties in these chapters.

Part III: Picking Up the Frequency Domain

The chapters in this part drill down on the frequency domain and the world of system design, particularly wireless systems. Bridging the gap between the continuous- and discrete-time worlds is sampling theory, which is covered in Chapter 10.

Part IV: Entering the s- and z-Domains

This part gets tougher because you're dealing with the *s*- and *z*-domains — a third domain system that engineers use to view the world. *Poles* and *zeros* rule here. Signal processing and control systems designers are fond of the *s*- and *z*-domains because, for starters, they reduce the mathematics of passing a signal through a system to rather simple algebraic manipulation. From the poles and zeros, you can easily discern system stability and the impact they have on the frequency domain. Great stuff.

Part V: The Part of Tens

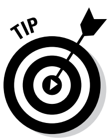
Here, get hip to more than ten common mistakes people make when solving problems for signals and systems. Also find a list of ten properties you never want to forget. You may want to print these lists and keep 'em within view.

Icons Used in This Book

To make this book easier to read and simpler to use, I include some icons to help you find key information.

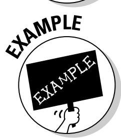
Anytime you see this icon, you know the information that follows is so important that it's worth recalling after you close this book — even if you don't remember anything else you read.

This icon appears next to information that's interesting but not essential. Don't be afraid to skip these paragraphs.



This bull's-eye points out advice that can save you time when managing signals and systems.

This icon tries to prevent you from making fatal mistakes in your analysis.



This icon flags worked-through examples in the content so you can find the most practical stuff fast if you're especially pressed for time.

Where to Go from Here

This book isn't a novel — although it just may be as intriguing as one. You can start at the beginning and read through to the end, or you can jump in at any chapter to get the information you need on a specific topic. If you need help with calculus and other math basics before dishing out the heartier fare of signals and systems, then pick through Chapter 2 for a quick review. If you just can't wait another second to find out how the Fourier transform works with different types of signals, then by all means flip to Chapters 9 and 11 right away.

If you're not sure where to start, or you don't know enough about signals and systems yet to even wonder about specific topics, no problem — that's exactly what this book is for. I recommend starting with the chapters in Part I and moving forward from there if you really are a newbie. Then, keep on reading; you'll be charged up with nitty-gritty details of signals and systems in no time.

Part I

Getting Started with Signals and Systems

web extras

Visit www.dummies.com for valuable Dummies content online.

In this part . . .

- Find out why computer and electrical engineers need to understand signals and systems analysis.
- See how signals and systems function in the worlds of continuous- and discrete-time.
- Discover alternative domains used for modeling signals and systems.
- Refresh your mathematical know-how and see how algebra, calculus, and trig apply to signals and systems work.
- Explore the basic means for assessing the performance of technology-based solutions.

Chapter 1

Introducing Signals and Systems

In This Chapter

- Figuring out the math you need for signals and systems work
- Determining the different types of signals and systems
- Understanding signal classifications and domains
- Checking out possible products with behavioral level modeling
- Looking at real products as signals and systems
- Using open-source computer tools to check your work

Which came first: the signal or the system? Before you answer, you may want to know that by *system,* I mean a structure or design that operates on signals. You live and breathe in a sea of signals, and systems harness signals and put them to work. So which came first, you think? It may not really matter, but I'm guessing — as I smooth out a long imaginary philosopher-type beard — that signals came first and then began passing through systems.

But I digress. The study of signals and systems as portrayed in this book centers on the *mathematical modeling* of both signals and systems. Mathematical modeling allows an engineer to explore a variety of product design approaches without committing to costly prototype hardware and software development. After you tune your model to produce satisfactory results, you can implement your design as a prototype. And at some point, real signals (and sometimes math-based simulations) test the system design before full implementation.

When studying signals and systems, it's easy to get mired in mathematical details and lose sight of the big picture — the functional systems of your end result. So try to remember that, at its best, signals and systems is all about designing and working with products through applied math. Math is the means, not the star of the show.

Two broad classes of signals are those that are *continuous* functions of time t and those that are *discrete* functions of time index n. Throughout this book, I separate information on continuous- and discrete-time signals and systems. In this chapter, I introduce simple continuous and discrete signals and the corresponding systems. I also point out some of the distinguishing characteristics of signal types.

Before getting started, I want to mention that signals as functions of time are how most people experience the real world of computer and electronic engineering, yet transforming signals and systems to other domains — specifically, the frequency, s-, and z-domains — and back again is quite beneficial in some situations. I touch on the transformation of signals and systems in this chapter and dig into the details in Parts III and IV.

In this chapter, I also cover the important role of computer tools in signals and systems problem solving and tell you how to use a few specific open-source programs. If you want to set up these freely available tools on your computer, you can follow along when I describe specific functions that enable you to check your work or work more efficiently — after you get a handle on core concepts and techniques.

Applying Mathematics

Anyone aspiring to a working knowledge of signals and systems needs a solid background in math, including these specific concepts:

- Calculus of one variable
- Integration and differentiation
- Differential equations

To actually implement designs that center on signals and systems, you also need a background in these subjects:

- Electrical/electronic circuits
- Computer programming fundamentals, such as C/C++ and Java
- Analysis, design, and development software tools
- Programmable devices

Many signals and systems designers rely on modeling tools that use a matrix/vector language or class library for numerics and a graphics visualization capability to allow for rapid prototyping. I use numerical Python for examples in this book; other languages with similar syntax include MATLAB and NI LabVIEW MathScript.

Finding perspective on analog processing

Once upon a time, the implementation path for signals and systems was purely analog circuit design. As technology has advanced, solutions based on digital signal processing (discrete-time signals and systems) through powerful low-cost and low-power digital hardware has become the mainstay. Digital hardware solutions are programmable and can be reconfigured through software updates after products ship.

The signals you're likely to work with in the real world are analog in nature, but you'll almost always process them digitally. Knowing programming languages is important in this environment. Yet analog signal processing is alive and well — it's vital to your working knowledge of signals and systems — but the overall role of analog processing in current design is less formidable than it's been in the past.

With so many electrical engineering solutions being software-based today — versus a matter of analog circuitry (see nearby sidebar "Finding perspective on analog processing") — a system designer can also be the implementer. This leap requires only simulation code to be transformed into the implementation language, such as Verilog or C/C++.

TIP: Working pencil-and-paper solutions for signals and systems coursework requires a good scientific calculator. I recommend a calculator that supports complex arithmetic operations, using the minimum number of keystrokes. At minimum, your calculator needs to have trig, log, and exponential functions for signals and systems work.

Getting Mixed Signals . . . and Systems

Signals come in two flavors: continuous and discrete. It's the same story with systems. In other words, some signals — and some systems — are active all the time; others aren't. In this section, I describe continuous and discrete signals along with the corresponding systems. I also tell you how to classify certain signals and systems based on their most basic properties.

Going on and on and on

Continuous-time signals and systems never take a break. When a circuit is wired up, a signal is there for the taking, and the system begins working — and doesn't stop. Keep in mind that I use the term *signal* here loosely; any one specific signal may come and go, but a signal is always present at each and every time instant imaginable in a continuous-time system.

Continuous-time signals

Continuous signals function according to time *t*. A sinusoidal function of time is one of the most basic signals. The mathematical model for a sinusoid signal is $x(t) = A\cos(2\pi f_0 t - \phi)$, $-\infty < t < \infty$, where A is the signal amplitude, f_0 is the signal frequency, and ϕ is the signal phase shift. The independent variable is time *t*. If you're curious about the first peak of $x(t)$ occuring at 3/16, notice that this occurs when the argument of the cosine is 0 — the is, $2\pi \cdot 2 \cdot t - 3\pi/4 = 0$ or $t = 3\pi/4 \cdot 1/(4\pi) = 3/16$.

I cover this signal in detail in Chapter 3, but to help you get acquainted, check out the plot of a sinusoid signal in Figure 1-1.

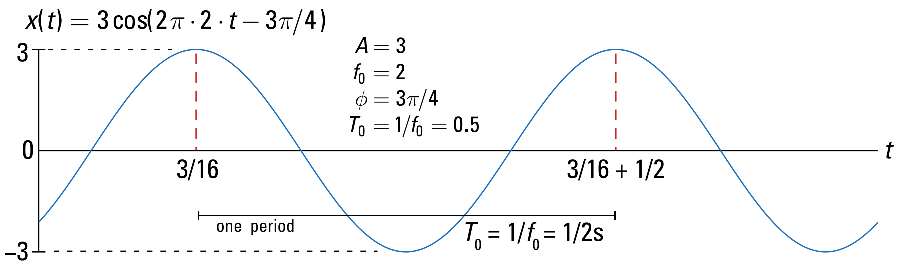


Figure 1-1: The plot of a sinusoidal signal.

The amplitude of this signal is 3, the frequency is 2 Hz, and the phase shift is $3\pi/4$ rad.

Continuous-time systems

Systems operate on signals. In mathematical terms, a *system* is a function or *operator*, $T\{\}$, that maps the input signal $x(t)$ to output signal $y(t) = T\{x(t)\}$.

An example of a continuous-time system is the electronic circuits in an amplifier, which has gain 5 and level shift 2: $y(t) = T\{x[n]\} = 5x(t) + 2$.

See a block diagram representation of this simple system in Figure 1-2.

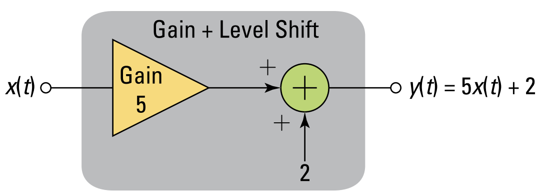


Figure 1-2: A simple continuous-time system model.

Building an amplifier that corresponds to this mathematical model is another matter entirely. You can create a simple electronic circuit, but it will have limitations that the math model doesn't have. It's up to you, as an electronic