国外电子与通信教材系列

英文版

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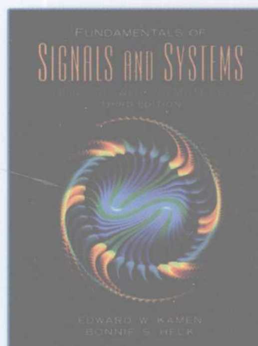
信号与系统基础教程

（第三版）

（MATLAB版）

Fundamentals of Signals and Systems Using the Web and MATLAB

Third Edition



[美] Edward W. Kamen
Bonnie S. Heck 著

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Fundamentals of Signals and Systems Using the Web and MATLAB

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内容简介

本书讨论了信号与系统的基本理论和基本分析方法及其应用，从输入输出描述到状态描述，从连续到离散，从时域到变换域，共包括11章的内容。第1章至第7章，是信号与系统的基本内容，分别讨论了时域中信号与系统各种的特性以及连续和离散时间系统的各种模型；从频域的观点分析了信号与系统，讨论了离散时间傅里叶变换（DTFT）和离散傅里叶变换（DFT），系统的傅里叶分析，拉普拉斯变换，z变换和线性时不变系统的传输函数表示法等内容；从第8章开始讨论扩展内容，包括利用传输函数表示法对线性时不变连续时间系统进行了分析，将传输函数思想用于控制问题；将拉普拉斯和z变换的思想用于数字滤波器和控制器的设计；对线性时不变连续时间和离散时间系统的状态描述的基本理论进行了阐述。另外，本书还给出了大量的MATLAB软件仿真实例，提供了MATLAB实用程序及网上在线演示。

本书可作为电类各专业信号与系统课程的双语教材或参考书，也可供工程技术人员参考。

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序

2001年7月间，电子工业出版社的领导同志邀请各高校十几位通信领域方面的老师，商量引进国外教材问题。与会同志对出版社提出的计划十分赞同，大家认为，这对我国通信事业、特别是对高等院校通信学科的教学工作会很有好处。

教材建设是高校教学建设的主要内容之一。编写、出版一本好的教材，意味着开设了一门好的课程，甚至可能预示着一个崭新学科的诞生。20世纪40年代MIT林肯实验室出版的一套28本雷达丛书，对近代电子学科、特别是对雷达技术的推动作用，就是一个很好的例子。

我国领导部门对教材建设一直非常重视。20世纪80年代，在原教委教材编审委员会的领导下，汇集了高等院校几百位富有教学经验的专家，编写、出版了一大批教材；很多院校还根据学校的特点和需要，陆续编写了大量的讲义和参考书。这些教材对高校的教学工作发挥了极好的作用。近年来，随着教学改革不断深入和科学技术的飞速进步，有的教材内容已比较陈旧、落后，难以适应教学的要求，特别是在电子学和通信技术发展神速、可以讲是日新月异的今天，如何适应这种情况，更是一个必须认真考虑的问题。解决这个问题，除了依靠高校的老师和专家撰写新的符合要求的教科书外，引进和出版一些国外优秀电子与通信教材，尤其是有选择地引进一批英文原版教材，是会有好处的。

一年多来，电子工业出版社为此做了很多工作。他们成立了一个“国外电子与通信教材系列”项目组，选派了富有经验的业务骨干负责有关工作，收集了230余种通信教材和参考书的详细资料，调来了100余种原版教材样书，依靠由20余位专家组成的出版委员会，从中精选了40多种，内容丰富，覆盖了电路理论与应用、信号与系统、数字信号处理、微电子、通信系统、电磁场与微波等方面，既可作为通信专业本科生和研究生的教学用书，也可作为有关专业人员的参考材料。此外，这批教材，有的翻译为中文，还有部分教材直接影印出版，以供教师用英语直接授课。希望这些教材的引进和出版对高校通信教学和教材改革能起一定作用。

在这里，我还要感谢参加工作的各位教授、专家、老师与参加翻译、编辑和出版的同志们。各位专家认真负责、严谨细致、不辞辛劳、不怕琐碎和精益求精的态度，充分体现了中国教育工作者和出版工作者的良好美德。

随着我国经济建设的发展和科学技术的不断进步，对高校教学工作会不断提出新的要求和希望。我想，无论如何，要做好引进国外教材的工作，一定要联系我国的实际。教材和学术专著不同，既要注意科学性、学术性，也要重视可读性，要深入浅出，便于读者自学；引进的教材要适应高校教学改革的需要，针对目前一些教材内容较为陈旧的问题，有目的地引进一些先进的和正在发展中的交叉学科的参考书；要与国内出版的教材相配套，安排好出版英文原版教材和翻译教材的比例。我们努力使这套教材能尽量满足上述要求，希望它们能放在学生们的课桌上，发挥一定的作用。

最后，预祝“国外电子与通信教材系列”项目取得成功，为我国电子与通信教学和通信产业的发展培土施肥。也恳切希望读者能对这些书籍的不足之处、特别是翻译中存在的问题，提出意见和建议，以便再版时更正。

吴佑寿
中国工程院院士、清华大学教授
“国外电子与通信教材系列”出版委员会主任

出 版 说 明

进入21世纪以来，我国信息产业在生产和科研方面都大大加快了发展速度，并已成为国民经济发展的支柱产业之一。但是，与世界上其他信息产业发达的国家相比，我国在技术开发、教育培训等方面都还存在着较大的差距。特别是在加入WTO后的今天，我国信息产业面临着国外竞争对手的严峻挑战。

作为我国信息产业的专业科技出版社，我们始终关注着全球电子信息技术的发展方向，始终把引进国外优秀电子与通信信息技术教材和专业书籍放在我们工作的重要位置上。在2000年至2001年间，我社先后从世界著名出版公司引进出版了40余种教材，形成了一套“国外计算机科学教材系列”，在全国高校以及科研部门中受到了欢迎和好评，得到了计算机领域的广大教师与科研工作者的充分肯定。

引进和出版一些国外优秀电子与通信教材，尤其是有选择地引进一批英文原版教材，将有助于我国信息产业培养具有国际竞争能力的技术人才，也将有助于我国国内在电子与通信教学工作中掌握和跟踪国际发展水平。根据国内信息产业的现状、教育部《关于“十五”期间普通高等教育教材建设与改革的意见》的指示精神以及高等院校老师们反映的各种意见，我们决定引进“国外电子与通信教材系列”，并随后开展了大量准备工作。此次引进的国外电子与通信教材均来自国际著名出版商，其中影印教材约占一半。教材内容涉及的学科方向包括电路理论与应用、信号与系统、数字信号处理、微电子、通信系统、电磁场与微波等，其中既有本科专业课程教材，也有研究生课程教材，以适应不同院系、不同专业、不同层次的师生对教材的需求，广大师生可自由选择和自由组合使用。我们还将与国外出版商一起，陆续推出一些教材的教学支持资料，为授课教师提供帮助。

此外，“国外电子与通信教材系列”的引进和出版工作得到了教育部高等教育司的大力支持和帮助，其中的部分引进教材已通过“教育部高等学校电子信息科学与工程类专业教学指导委员会”的审核，并得到教育部高等教育司的批准，纳入了“教育部高等教育司推荐——国外优秀信息科学与技术系列教学用书”。

为做好该系列教材的翻译工作，我们聘请了清华大学、北京大学、北京邮电大学、南京邮电大学、东南大学、西安交通大学、天津大学、西安电子科技大学、电子科技大学、中山大学、哈尔滨工业大学、西南交通大学等著名高校的教授和骨干教师参与教材的翻译和审校工作。许多教授在国内电子与通信专业领域享有较高的声望，具有丰富的教学经验，他们的渊博学识从根本上保证了教材的翻译质量和专业学术方面的严格与准确。我们在此对他们的辛勤工作与贡献表示衷心的感谢。此外，对于编辑的选择，我们达到了专业对口；对于从英文原书中发现的错误，我们通过与作者联络、从网上下载勘误表等方式，逐一进行了修订；同时，我们对审校、排版、印制质量进行了严格把关。

今后，我们将进一步加强同各高校教师的密切关系，努力引进更多的国外优秀教材和教学参考书，为我国电子与通信教材达到世界先进水平而努力。由于我们对国内外电子与通信教育的发展仍存在一些认识上的不足，在选题、翻译、出版等方面的工作中还有许多需要改进的地方，恳请广大师生和读者提出批评及建议。

电子工业出版社

教材出版委员会

Preface

With the presentation at an introductory level, this book contains a comprehensive treatment of continuous-time and discrete-time signals and systems, with demos on the textbook website, data downloaded from the Web, and illustrations of numerous MATLAB® commands for the solution of a wide range of problems arising in engineering and in other fields such as financial data analysis. The third edition is a major revision of the previous edition in that the degree of mathematical complexity has been reduced, practical applications involving downloaded data and other illustrations have been added, and the material has been reorganized in a significant way so that the flexibility in using the book in a one-quarter or one-semester course should be greatly enhanced. Highlights of the revised content of the third edition include the following:

1. The presentation has been simplified by deletion or rewrite of various mathematical parts of the previous edition, and by inclusion of new illustrations that should give additional insight into the meaning and significance of the mathematical formulations covered in the text. Summaries have been added at the end of the chapters to highlight the material covered in the chapters.
2. The core of the new edition consists of Chapters 1–7, most of which an instructor should be able to cover in a one-quarter course. For a one-semester course, an instructor should be able to cover the material in Chapters 1–7 and then select material on filtering, controls, and/or the state representation that can be found in Chapters 8–11.
3. The new edition contains practical applications that use actual data downloaded from the Web. It is shown how the data can be downloaded and then imported into MATLAB for analysis by techniques covered in the text. The focus is on the problem of data analysis in the presence of noise, which often arises in engineering, business and finance, and other fields. Details are given on the analysis of stock price data with the objective of determining if the trend in the stock price is up or down.
4. The new edition contains a major enhancement of the MATLAB component. In particular, the MATLAB Symbolic Math Toolbox that is available in the Student Version (7.0.1) of MATLAB is used throughout *the text to complement* and simplify various computational aspects of the theory and examples given in

the book. Many examples are given that illustrate how this tool can be used to solve differential equations and to evaluate integrals for computing system responses and Fourier and Laplace transforms and inverse transforms, including inverse z-transforms. Simulink is also used to build system models and simulate system behavior.

5. The textbook website (http://users.ece.gatech.edu/~bonnie/book3) developed by Bonnie Heck has been updated with the inclusion of additional worked problems, all the data files and M-files for the third edition, and other new materials. Also on the website are the online demos previously mentioned and a tutorial on MATLAB.
6. The material on control systems has been enhanced and includes the addition of the description of a digital control lab project based on a LEGO® MINDSTORMS® kit. The lab project provides students with a "hands-on" experience in designing and implementing digital controllers for a dc motor.

The background required for reading the book consists of the usual freshman/sophomore courses in calculus and elementary differential equations. It is also helpful, but not necessary, to have had some exposure to physics. The book is also intended to be used for self-study. Both authors have been teaching the material in the book to electrical engineering juniors for many years, and Bonnie Heck has been actively involved in the use of the Web for enhancing education in the fields of signals, systems, and controls.

As noted, key features of the text include the use of online demos on the textbook website and the downloading of data from the Web in order to carry out data analysis. In many of the demos, students may change various values to see what results. For example, the frequencies making up a signal can be changed with the resulting effect on the signal displayed, and the parameters of a system's frequency response function (or transfer function) can be changed with the effect on system performance displayed. In some of the demos, the students can hear the sounds that correspond to the signals being considered. There is also a demo on a mass–spring–damper system that provides an animation of the output response resulting from the application of various inputs. Via this demo, students can actually see the characteristics of the response to an impulsive input, step input, and sinusoidal input. The reference to a demo in the text is given by an icon in the left-hand margin, as illustrated here.

Another key feature of the book is the use of MATLAB (Version 7.0) to generate computer implementations of the techniques for signal and system analysis and design covered in this work. Along with the online demos, the MATLAB implementations provide the reader with the opportunity to verify that the theory does work and allow the reader to experiment with the application of the techniques studied. Use of the various MATLAB commands is illustrated in numerous examples throughout the text. This includes a discussion in Chapter 1 on the use of MATLAB to plot signals and on how data can be downloaded from the Web and imported into MATLAB. A large number of the homework problems also involve MATLAB. All of the MATLAB programs and M-files that are used in the examples are available from the website that accompanies the text. The M-files in Chapters 1–9 require either the Student Version of MATLAB, version 7.0 or the full version of MATLAB version 7.0 along with the Control System Toolbox version 6.1, the Signal Processing Toolbox version 6.2, and Simulink version 6.1. Chapter 10 requires the Signal Processing Toolbox for digital filter design.

The book includes a wide range of examples and problems on different areas in engineering, including electrical circuits, mechanical systems, and electromechanical devices (such as a dc motor). Examples are also given on data analysis, with part of the emphasis on the filtering or smoothing of noisy data (such as stock price data) for the purpose of revealing the trend of the data. It is also shown how the dominant cyclic components can be determined and extracted from time series data by use of the discrete Fourier transform (DFT). Other features of the book are a parallel treatment of continuous-time and discrete-time signals and systems, and three chapters on feedback control, digital filtering, and the state representation that prepare students for senior electives in these topics.

The book begins with the time-domain aspects of signals and systems in Chapters 1 and 2. These include the basic properties of signals and systems, the discrete-time convolution model, the input/output difference equation model, the input/output differential equation model, and the continuous-time convolution model. Chapter 3 begins the treatment of signals and systems from the frequency-domain standpoint. Starting with signals that are a sum of sinusoids, the presentation then goes into the Fourier series representation of periodic signals and on to the Fourier transform of nonperiodic signals. The use of the Fourier transform in the study of signal modulation is also considered in Chapter 3. Chapter 4 deals with the Fourier analysis of discrete-time signals with the focus on the discrete-time Fourier transform (DTFT) and the discrete Fourier transform (DFT). The DFT is used to determine the dominant sinusoidal components of a discrete-time signal in the presence of noise, with applications given in terms of data downloaded from the Web. Then in Chapter 5, the Fourier theory is applied to the study of both continuous-time and discrete-time systems. Applications to ideal analog filtering, sampling, signal reconstruction, and digital filtering are pursued in Chapter 5.

After the Fourier theory, the study of the Laplace transform begins in Chapter 6 with the definition and properties of the Laplace transform and the transfer function representation of linear time-invariant continuous-time systems. In Chapter 7, the z-transform is introduced, and the transfer function representation of linear time-invariant discrete-time systems is pursued. This leads to the notion of the frequency response function, which is first considered in Chapter 5. In Chapter 8, the analysis of linear time-invariant continuous-time systems is carried out by the use of the transfer function representation. The transfer function framework is then applied to the problem of control in Chapter 9; and in Chapter 10, the Laplace and z-transform frameworks are applied to the design of digital filters and controllers. In Chapter 11, the fundamentals of the state description of linear time-invariant continuous-time and discrete-time systems are presented.

As noted, the book can be used in a one-quarter or one-semester course in signals and systems, with Chapters 1–7 (or parts of these chapters) covered in a one-quarter course and parts of Chapters 1–11 covered in a one-semester course. By selecting appropriate sections and chapters from the book, an instructor could cover the continuous-time case in one course and the discrete-time case in a second course.

The authors wish to thank the faculty who have used the previous editions of the book in a course, and the students who have taken a course with the book designated as the course text, for their numerous helpful comments. We also appreciate the written comments made by the following reviewers: Professor Charles W. Brice, University of South

Carolina; Professor Ravi Warrier, Kettering University; Professor Jeffrey G. Andrews, University of Texas at Austin; Professor Stanley Lawrence Marple, Jr., Oregon State University; and Professor Uvais Qidwai, Tulane University.

We would also like to thank Tom Robbins (formerly Editor at Prentice Hall) for his comments on the previous editions of the book, Prentice Hall Editor Michael McDonald for his suggestions regarding the third edition, and Alice Dworkin and Scott Disanno of Prentice Hall for their efforts regarding editorial aspects and production of the third edition. Thanks go to Courtney Esposito at The Mathworks for providing us with information on the latest versions of the MATLAB and Simulink software programs. Bonnie Heck wishes to thank her former students John Finney and James Moan, who wrote preliminary versions of the MATLAB tutorial that is available on the website; and Darren Garner, James Ho, Jason Meeks, Johnny Wang, and Brian Wilson for their efforts in generating the demos that are on the website.

EDWARD W. KAMEN
BONNIE S. HECK

PROPERTIES OF THE FOURIER TRANSFORM

Property	Transform Pair/Property
Linearity	$ax(t) + bv(t) \leftrightarrow aX(\omega) + bV(\omega)$
Right or left shift in time	$x(t - c) \leftrightarrow X(\omega)e^{-j\omega c}$
Time scaling	$x(at) \leftrightarrow \frac{1}{a}X\left(\frac{\omega}{a}\right) \quad a > 0$
Time reversal	$x(-t) \leftrightarrow X(-\omega) = \overline{X(\omega)}$
Multiplication by a power of t	$t^n x(t) \leftrightarrow j^n \frac{d^n}{d\omega^n} X(\omega) \quad n = 1, 2, \ldots$
Multiplication by a complex exponential	$x(t)e^{j\omega_0 t} \leftrightarrow X(\omega - \omega_0) \quad \omega_0$ real
Multiplication by sin $\omega_0 t$	$x(t) \sin \omega_0 t \leftrightarrow \frac{j}{2}[X(\omega + \omega_0) - X(\omega - \omega_0)]$
Multiplication by cos $\omega_0 t$	$x(t) \cos \omega_0 t \leftrightarrow \frac{1}{2}[X(\omega + \omega_0) + X(\omega - \omega_0)]$
Differentiation in the time domain	$\frac{d^n}{dt^n} x(t) \leftrightarrow (j\omega)^n X(\omega) \quad n = 1, 2, \ldots$
Integration	$\int_{-\infty}^{t} x(\lambda)\, d\lambda \leftrightarrow \frac{1}{j\omega} X(\omega) + \pi X(0)\delta(\omega)$
Convolution in the time domain	$x(t) * v(t) \leftrightarrow X(\omega)V(\omega)$
Multiplication in the time domain	$x(t)v(t) \leftrightarrow \frac{1}{2\pi} X(\omega) * V(\omega)$
Parseval's theorem	$\int_{-\infty}^{\infty} x(t)v(t)\, dt = \frac{1}{2\pi} \int_{-\infty}^{\infty} \overline{X(\omega)} V(\omega)\, d\omega$
Special case of Parseval's theorem	$\int_{-\infty}^{\infty} x^2(t)\, dt = \frac{1}{2\pi} \int_{-\infty}^{\infty} \lvert X(\omega) \rvert^2\, d\omega$
Duality	$X(t) \leftrightarrow 2\pi x(-\omega)$

COMMON FOURIER TRANSFORM PAIRS

$1, \quad -\infty < t < \infty \leftrightarrow 2\pi\delta(\omega)$

$-0.5 + u(t) \leftrightarrow \dfrac{1}{j\omega}$

$u(t) \leftrightarrow \pi\delta(\omega) + \dfrac{1}{j\omega}$

$\delta(t) \leftrightarrow 1$

$\delta(t - c) \leftrightarrow e^{-j\omega c}, \quad c$ any real number

$e^{-bt}u(t) \leftrightarrow \dfrac{1}{j\omega + b}, \quad b > 0$

$e^{j\omega_0 t} \leftrightarrow 2\pi\delta(\omega - \omega_0)$, ω_0 any real number

$p_\tau(t) \leftrightarrow \tau \operatorname{sinc} \dfrac{\tau\omega}{2\pi}$

$\tau \operatorname{sinc} \dfrac{\tau t}{2\pi} \leftrightarrow 2\pi p_\tau(\omega)$

$\left(1 - \dfrac{2|t|}{\tau}\right)p_\tau(t) \leftrightarrow \dfrac{\tau}{2} \operatorname{sinc}^2\left(\dfrac{\tau\omega}{4\pi}\right)$

$\dfrac{\tau}{2} \operatorname{sinc}^2\left(\dfrac{\tau t}{4\pi}\right) \leftrightarrow 2\pi\left(1 - \dfrac{2|\omega|}{\tau}\right)p_\tau(\omega)$

$\cos \omega_0 t \leftrightarrow \pi[\delta(\omega + \omega_0) + \delta(\omega - \omega_0)]$

$\cos(\omega_0 t + \theta) \leftrightarrow \pi[e^{-j\theta}\delta(\omega + \omega_0) + e^{j\theta}\delta(\omega - \omega_0)]$

$\sin \omega_0 t \leftrightarrow j\pi[\delta(\omega + \omega_0) - \delta(\omega - \omega_0)]$

$\sin(\omega_0 t + \theta) \leftrightarrow j\pi[e^{-j\theta}\delta(\omega + \omega_0) - e^{j\theta}\delta(\omega - \omega_0)]$

COMMON LAPLACE TRANSFORM PAIRS

$u(t) \leftrightarrow \frac{1}{s}$

$u(t) - u(t-c) \leftrightarrow \frac{1 - e^{-cs}}{s}, \quad c > 0$

$t^N u(t) \leftrightarrow \frac{N!}{s^{N+1}}, \quad N = 1, 2, 3, \ldots$

$\delta(t) \leftrightarrow 1$

$\delta(t - c) \leftrightarrow e^{-cs}, \quad c > 0$

$e^{-bt}u(t) \leftrightarrow \frac{1}{s+b}, \quad b$ real or complex

$t^N e^{-bt} u(t) \leftrightarrow \frac{N!}{(s+b)^{N+1}}, \quad N = 1, 2, 3, \ldots$

$(\cos \omega t)u(t) \leftrightarrow \frac{s}{s^2 + \omega^2}$

$(\sin \omega t)u(t) \leftrightarrow \frac{\omega}{s^2 + \omega^2}$

$(\cos^2 \omega t)u(t) \leftrightarrow \frac{s^2 + 2\omega^2}{s(s^2 + 4\omega^2)}$

$(\sin^2 \omega t)u(t) \leftrightarrow \frac{2\omega^2}{s(s^2 + 4\omega^2)}$

$(e^{-bt} \cos \omega t)u(t) \leftrightarrow \frac{s + b}{(s+b)^2 + \omega^2}$

$(e^{-bt} \sin \omega t)u(t) \leftrightarrow \frac{\omega}{(s+b)^2 + \omega^2}$

$(t \cos \omega t)u(t) \leftrightarrow \frac{s^2 - \omega^2}{(s^2 + \omega^2)^2}$

$(t \sin \omega t)u(t) \leftrightarrow \frac{2\omega s}{(s^2 + \omega^2)^2}$

$(te^{-bt} \cos \omega t)u(t) \leftrightarrow \frac{(s+b)^2 - \omega^2}{[(s+b)^2 + \omega^2]^2}$

$(te^{-bt} \sin \omega t)u(t) \leftrightarrow \frac{2\omega(s+b)}{[(s+b)^2 + \omega^2]^2}$

PROPERTIES OF THE LAPLACE TRANSFORM

Property	Transform Pair/Property
Linearity	$ax(t) + bv(t) \leftrightarrow aX(s) + bV(s)$
Right shift in time	$x(t-c)u(t-c) \leftrightarrow e^{-cs}X(s), \quad c > 0$
Time scaling	$x(at) \leftrightarrow \frac{1}{a}X\left(\frac{s}{a}\right), \quad a > 0$
Multiplication by a power of t	$t^N x(t) \leftrightarrow (-1)^N \frac{d^N}{ds^N} X(s), \quad N = 1, 2, \ldots$
Multiplication by an exponential	$e^{at}x(t) \leftrightarrow X(s-a)$, a real or complex
Multiplication by $\sin \omega t$	$x(t) \sin \omega t \leftrightarrow \frac{j}{2}[X(s+j\omega) - X(s-j\omega)]$
Multiplication by $\cos \omega t$	$x(t) \cos \omega t \leftrightarrow \frac{1}{2}[X(s+j\omega) + X(s-j\omega)]$
Differentiation in the time domain	$\dot{x}(t) \leftrightarrow sX(s) - x(0)$
Second derivative	$\ddot{x}(t) \leftrightarrow s^2X(s) - sx(0) - \dot{x}(0)$
nth derivative	$x^{(N)}(t) \leftrightarrow s^N X(s) - s^{N-1}x(0) - s^{N-2}\dot{x}(0) - \cdots - sx^{(N-2)}(0) - x^{(N-1)}(0)$
Integration	$\int_0^t x(\lambda)\, d\lambda \leftrightarrow \frac{1}{s}X(s)$
Convolution	$x(t) * v(t) \leftrightarrow X(s)V(s)$
Initial-value theorem	$x(0) = \lim_{s\to\infty} sX(s)$
	$\dot{x}(0) = \lim_{s\to\infty} [s^2X(s) - sx(0)]$
	$x^{(N)}(0) = \lim_{s\to\infty} [s^{N+1}X(s) - s^N x(0) - s^{N-1}\dot{x}(0) - \cdots - sx^{(N-1)}(0)]$
Final-value theorem	If $\lim_{t\to\infty} x(t)$ exists, then $\lim_{t\to\infty} x(t) = \lim_{s\to 0} sX(s)$

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