国外电子与通信教材系列

数字集成电路设计

Digital Integrated Circuit Design

英文版

[加] Ken Martin 著

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内 容 简 介

本书是数字集成电路设计课程的经典教材。全书分 13 章，从 NMOS、CMOS 逻辑门等基础知识开始，依次讲述处理、布线及相关论题，数字集成器件和建模，传统的 MOS 设计，CMOS 定时和输入/输出电路，锁存器、触发器和同步系统设计，双极型和双 CMOS 逻辑门，高级 CMOS 逻辑门设计，数字集成系统积木式组件，集成存储器，砷化镓数字电路，数字系统测试等主要内容。涵盖了半导体物理、集成电路处理、晶体管级设计、逻辑级设计、系统级设计、测试等知识。

本书是电子和通信等专业高年级本科生的理想教科书，也可作为研究生和在职工程师的参考用书。

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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。

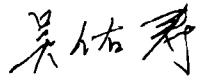
我国领导部门对教材建设一直非常重视。20世纪80年代，在原教委教材编审委员会的领导下，汇集了高等院校几百位富有教学经验的专家，编写、出版了一大批教材；很多院校还根据学校的特点和需要，陆续编写了大量的讲义和参考书。这些教材对高校的教学工作发挥了极好的作用。近年来，随着教学改革不断深入和科学技术的飞速进步，有的教材内容已比较陈旧、落后，难以适应教学的要求，特别是在电子学和通信技术发展神速、可以讲是日新月异的今天，如何适应这种情况，更是一个必须认真考虑的问题。解决这个问题，除了依靠高校的老师和专家撰写新的符合要求的教科书外，引进和出版一些国外优秀电子与通信教材，尤其是有选择地引进一批英文原版教材，是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

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。



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、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

The impact of digital integrated circuits on our modern society has been pervasive. Without them, the current computer and information-technology revolution would not exist. Digital integrated circuits represent the most important enabling technology in this revolution. This is largely true because of the immense amount of signal and computer processing that can be realized in a single integrated circuit; modern integrated circuits may contain millions of logic gates. This textbook is intended to take readers having only a minimal background and knowledge in electronics to the point at which they can design state-of-the-art digital integrated circuits.

Designing high-performance digital integrated circuits requires expertise in many different areas; these include semiconductor physics, integrated circuit processing, transistor-level design, logic-level design, system-level design, testing, etc. All of these topics are covered in this text, although the emphasis is on transistor-level design of digital integrated circuits and systems. This contrasts with many other texts in which more of a system-level or very large-scale integration approach is emphasized with transistor-level details minimized. It is the author's belief that before system-level considerations can be properly evaluated, an in-depth understanding of transistor-level design must first be obtained. This is not to suggest that important system-level considerations are not covered; indeed important system-level concepts such as timing, pipelining, clock distribution, and system building blocks are dealt with in detail, but the emphasis is on transistors. Throughout the book, we have attempted to provide physical and intuitive explanations, and although mathematical quantitative analyses of many circuits have necessarily been presented, we have attempted not to "miss seeing the forest because of the trees." In other words, this book attempts to present the critical underlying concepts without becoming entangled in tedious and overcomplicated circuit analyses.

INTENDED AUDIENCE

This book is primarily intended for use as a junior- and senior-level undergraduate textbook, first, as a first-level graduate textbook, second, and as a reference for practicing engineers, third. To understand the material in this book, it is expected that the reader will have had at least one basic introductory course in electronic circuits. Specifically, it helps if the reader is familiar with the concept of basic one- and two-transistor circuits, although this is not essential.

With regard to how this book might be used in an undergraduate course, there are many options. The chapters of this book have intentionally been made mostly independent such that some chapters can be covered and others can be skipped. Also, the organization and writing make it relatively easy to change the order of presentation. If the course is intended to cover

digital circuits and integrated circuit processing is covered in other courses, Chapter 2 can be skipped. If readers have a good device modeling background, Chapter 3 might be skipped except for assigning the first section only as review. Some instructors may prefer covering latches and flip-flops before timing issues are discussed; indeed, some instructors may prefer discussing timing issues only in a graduate-level course. Some instructors may prefer covering bipolar logic gates immediately after covering MOS logic gates, whereas other instructors may not cover bipolar logic gates at all in a first-level digital integrated circuit course. All of these alternatives are easily accommodated with the present text. We believe that such flexibility is essential in presenting textbooks for study in junior- and senior-level undergraduate courses.

Here at the University of Toronto, we cover the material in Chapters 1–4 and selected material from Chapters 5–8 in our undergraduate courses. The course comes in at the junior level for computer engineering students who have little device modeling background, whereas electrical engineering students who take the course in their fourth year have extensive modeling background. The former students spend more time studying Chapter 2 but in less detail, whereas for the latter students it is assumed the material is already understood and Chapter 2 is used only as a reference. Individual instructors will often vary the order and extent of coverage between Chapters 5 and 8. Some instructors will emphasize transistor-level design of gates, whereas others will emphasize higher level circuits (flip-flops, adders, multipliers, decoders, etc.). Indeed, some instructors prefer to cover some aspects of memories (Chapter 11) even in an undergraduate course. The first section in Chapter 11 covers the fundamentals of integrated circuit memories that is suitable for an undergraduate course; the latter sections in Chapter 11 cover more advanced topics that might be covered only in a graduate-level course.

A secondary audience for this book includes recently graduated electrical engineers who wish to rapidly increase their knowledge of modern digital circuit-design techniques. For this audience, we have put much effort into highlighting the most important considerations when designing the various circuits, and we have also tried to include modern (at the time of writing), and well-designed, examples and references to sources for further study.

ACKNOWLEDGMENTS

The author would like to especially acknowledge Thomas Szkopek who did most of the Spice simulations in the text and helped correct many grammatical and technical errors. Dan Vranesic and Martha Oka helped draft many of the figures. Other students who also helped on the text include Ruth Milman and Catherine Lacavera. The author would also like to acknowledge John Wiley for giving permission to copy much of the material that was previously contained in Chapters 1 and 2 of *Analog Integrated Circuit Design*, Wiley, 1997. Much of this material has been included in Chapters 2 and 3 of this text. As much as possible, appropriate references for original concepts are cited in the text, but the author has been working in the area of integrated circuits for so many years that often the original sources of popular and important concepts have been forgotten. For any reference errors or omissions, he sincerely apologizes.

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