国外电子与通信教材系列

英文改编版

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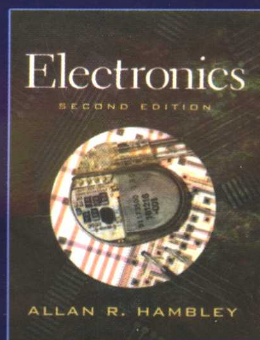
电子技术基础

Electronics, Second Edition

[美] Allan R. Hambley 著
李春茂 改编



電子工業出版社
Publishing House of Electronics Industry
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北京 · BEIJING

内容简介

本书改编自 Allan R. Hambley 所著的《电子学（第二版）》一书。编者结合多年的教学经验以及当前的教学大纲，对其做了较大的改动，目的在于使其更适合作为高校电气与计算机工程专业本科生的英文教材。全书从设计人员的观点出发、通过列举大量的示例，介绍了电子学的基本知识，探讨了设计电路的方法。涉及的内容包括基本元件和电路、电压和电流定律、节点分析和网孔分析法、常用电路分析方法、电容与电感、基本*RL*和*RC*电路、正弦稳态电路分析、交流电路功率分析、多相电路、磁耦合电路、二端口网络、傅里叶电路分析等。本书的特色是语言浅显易懂，示例丰富，教辅资源齐全。

本书可作为高等院校电气工程、计算机工程等相关专业本科生的双语教学教材或专业英语教学参考书，也可供相关人员自学或参考。

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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。

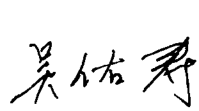
我国领导部门对教材建设一直非常重视。20世纪80年代，在原教委教材编审委员会的领导下，汇集了高等院校几百位富有教学经验的专家，编写、出版了一大批教材；很多院校还根据学校的特点和需要，陆续编写了大量的讲义和参考书。这些教材对高校的教学工作发挥了极好的作用。近年来，随着教学改革不断深入和科学技术的飞速进步，有的教材内容已比较陈旧、落后，难以适应教学的要求，特别是在电子学和通信技术发展神速、可以讲是日新月异的今天，如何适应这种情况，更是一个必须认真考虑的问题。解决这个问题，除了依靠高校的老师和专家撰写新的符合要求的教科书外，引进和出版一些国外优秀电子与通信教材，尤其是有选择地引进一批英文原版教材，是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

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。



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

前　　言

2001年12月11日，中国正式加入世贸组织（WTO）。这标志着中国融入了世界多边贸易体制，对中国的改革开放和世界经济贸易的发展都将产生积极而深远的影响。为适应经济全球化和科技革命的挑战，中国教育部（教高[2001]4号文件第8条）明确规定：本科教育要创造条件使用外语进行公共课和专业课教学，暂不具备直接用外语授课的学校、专业，可以先对部分课程用外语教材、中文授课的方式分步到位。目前，我国各个院校先后在不同专业对相关课程试行"双语教学"，并取得了一定的经验，值得借鉴和推广，同时还存在一些问题有待研究与探讨。

1. 什么是"双语教学"

顾名思义，"双语教学"就是采用外文原版教材、以中外文两种语言进行授课的教学形式。从教学层次上"双语教学"可以分为：第一层次，穿插式双语教学，即有意识地把第二语言（比如英语）作为教学语言穿插于课堂教学中，并逐步培养学生用英语思考问题的意识和能力；第二层次，完全式双语教学，即熟练运用英语作为教学语言，并且英语占总学时的三分之二以上。对"双语教学"的理解决不是在课堂上讲几句英语，或写几个英语专业词汇；也不能简单地等同于强化英语。必须将"双语教学"和"育人为本"密切联系起来，通过双语教学模式培养的学生应当是全面发展的复合型、国际型人才，而不是只会参加外语考试的尖子。在教学过程中，一方面尽量给学生创造语言环境，为学生提供用外语读、说、写的机会，训练学生运用英语思考问题和解决问题的能力；另一方面通过"双语教学"来促进语言能力的发展，培养学生同时使用两种语言进行思维，并能在两种语言之间根据交际对象和工作环境进行灵活切换，最终形成一种"双语型"思维。经过长时间的教学语言的感染，使学生能达到"外语突出，各科领先，综合发展"，这也就是"双语教学"所追求的目标。

2. 开展"双语教学"的必要性、重要性和可行性

开展"双语教学"有助于促进师生外语能力的提高。改革开放以来，中国政府对教育的投入越来越大，特别是对外语教学更加重视，在各行各业以及各种层次的文化考试中，外语是必不可少的考试科目，这对国民外语水平的提高起到了极大的推动作用。但由于应试教育下的中国学生，对外语学习的理解只是机械的背单词、做习题，而不是在实践中应用，更谈不上作为一种社会文化去理解和体会外语本身，多数学生掌握的是"中国式"的 "哑巴外语"、"聋子外语"。为了培养学生的外语实践能力，在有条件的高等院校应当开展"双语教学"，以"双语教学"的形式和手段，结合相关课程的学习来培养学生的阅读能力、计算能力、写作能力、电脑处理信息能力以及必要的生存能力。同时通过"双语教学"的实践还可以提高任课教师的外语水平，在教与学的过程中形成良性循环。

"双语教学"有利于促进学生深入学习、准确掌握学科知识。"双语教学"最根本的目的还是为了使学生获得先进的学科知识。现代计算机技术和网络技术的发展使得各种信息的传播速度大大提高，英语成为现代信息技术传播的重要语言工具。我们必须承认，在某些学科领域，中国和西方发达国家还存在着较大差距。因此，我们国内很多教材、参考资料等都是翻译版本，但由于翻译者不同的文化背景、不同的理解方式与不同的处理方法，加之译文在时间上相对滞后等原因，使得学生在获取信息方面不够及时准确。因此，通过"双语教学"可以使学生直接使用本学科的专业外语资料，同时在报刊、杂志、网络上获取更多本学科领域最前沿、代表最新动态的相关知识，这有助于学生对相关学科知识的深入学习与掌握。

目前在有条件的高校进行“双语教学”是可行的。大学生四、六级外语考试促进了学生学习外语的积极性，在校学生的外语成绩有了明显的提高；中国加入WTO以后，与世界各国的文化交流日益频繁，东西方文化在碰撞中交融，西方先进的科学技术、文化教育体系与我国传统的文化精髓融为一体，成为推动社会进步的强大动力；进入21世纪以来，国内各出版社相继引进了一批优秀的国外原版教材，影印、翻译后在全国发行。所有这些都为中国高等学校开设双语课程提供了必要条件，使得“双语教学”成为可能。理工科各专业在大学二年级中选择一两门专业基础课进行“双语教学”比较合适，因为大学二年级学生基本达到了三级或四级（少数达到六级）外语水平，在原版教材中专业词汇又以极高的重复率出现，加上他们具有较系统的数学、物理基础作为中外文教材共同的逻辑思维工具，可以促进学生对所学内容的深刻理解，同时又为他们学习专业词汇搭建了平台，为培养学生的外语阅读和思维能力提供了良好机会，也为他们后续专业课程的学习奠定了基础。

3. 怎样搞好“双语教学”

在试行“双语教学”的过程中，可以采取学期淘汰制，通过考试对学习吃力或不用心学习的学生进行淘汰，让他们回到同年级中文班学习，这从另一个角度促进了他们学习的积极性。为了在有限的时间内讲授较多的内容，最好把要讲的内容做成英文多媒体教学课件，图文并茂，有针对性地举例分析，细心讲解，并辅之以粉笔加黑板的传统教学模式及必要的形体语言，这样有利于提高课堂“双语教学”的效果。特别强调，实践教学是必不可少的重要环节。为了搞好“双语教学”，还有两个特别重要的因素值得重视：教材和师资。

(1) 教材是根本。由于国外的教育教学体制与我们国家存在很大差异，我们在教材的选择方面有一定困难。比如，“电路与电子技术”这门课在国外很难选得到，只能选择“电路分析”与“电子学”两门课程，但由于书价过高以及学时的限制，这样对学生来说显然是一种“浪费”。针对这种实际情况，电子工业出版社积极配合，并征得了原出版商和原版作者的同意，我们自己动手对引进的原版教材改编压缩，并配备多媒体教学课件和辅助教学软件包，使其既接近我们的教学计划和学时要求，又“原汁原味”地吸收了国外先进的学科内容，真正做到“洋为中用”，有效地解决了教材难题（国内尚无先例）。

(2) 师资是关键。教育应当以人为本。在多年的教学实践和教育体制改革中，我们总结出了适合国情的“以教师为主导、以学生为主体”的办学思路，那么，提高教学质量的关键是教师。即使条件再优越，设备再先进，没有好的师资也不可能办好学校。古今中外皆如此。“双语教学”更不例外。我们的教师长期工作在教学第一线，讲授课程内容一般是没有问题的，但接受双语教学任务还存在一些比较客观的困难因素，主要是语言障碍。在双语授课过程中，正确的发音和专业词汇的准确释意是必需的。为此，建议有条件的学校最好组织有关教师到英语比较纯正的国家进行半年至一年或更长时间的语言环境训练。

教学实践表明，在有条件的学校实行“双语教学”有利于提高教学质量，也有助于提高学生的专业外语水平以及直接用外语获取知识的能力，从而提高他们的综合素质；有利于中西文化的交流和先进科学技术的推广；有利于中国全方位地进行改革开放。当然，“双语教学”还有很多工作要做：师资需要加强培训，教材和配套教学辅导材料需要建设，教学手段需要改进，等等。

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2005-7-18 于华南理工大学

Contents

Chapter 1

Introduction

The goal of this book is to give the reader a good understanding of the basic principles of digital and analog electronic circuits. The book emphasizes the application and design of integrated circuits; however, circuit design is most effective when it is carried out with a view toward the overall design process–as well as the particular system of which the circuit is to be a part. Therefore, this first chapter presents an overview of electronic systems, a general discussion of the steps in their design, and basic concepts related to digital systems and electronic amplifiers.

Electronic-circuit design is fun. You can earn a good living from it and impress many people to whom electronics seems like magic. Learning the material in this book is an important step toward a rewarding career as a designer of electronic systems.

1.1 Electronic Systems

Some electronic systems are familiar from everyday life. For example, we encounter radios, televisions, telephones, and computers on a daily basis. Other electronic systems are present in daily life, but are less obvious. Electronic systems control fuel mixture and ignition timing to maximize performance and minimize undesirable emissions from automobile engines. Electronics in weather satellites provide us with a continuous detailed picture of our planet.

Still other systems are even less familiar. For example, a system of satellites known as the **Global Positioning System (GPS)** has been developed by the United States to provide three-dimensional positional information for ships and aircraft anywhere on earth to an accuracy of several tens of meters. This is possible because signals emitted by several satellites can be received by the vehicle. By comparing the time of arrival of the signals and by using certain information contained in the received signals concerning the orbits of the satellites, the position of the vehicle can be determined. In addition, the received signals can be processed to set a local clock to an accuracy of about 100 ns.

Other electronic systems include the air-traffic control system, various radars, compact-disc recording equipment and players, two-way radios for police and marine communication, satellites that relay television and other signals from geosynchronous orbit, electronic instrumentation, manufacturing control systems, computerized monitors for patients in intensive care units, and navigation systems.

Electronic-System Block Diagrams

Electronic systems are composed of subsystems or functional blocks. These functional blocks can be categorized as **amplifiers**, **filters**, **signal sources**, **wave-shaping circuits**, **digital logic functions**, **digital memories**, **power supplies**, and **converters**. Briefly, we can say that amplifiers increase the power level of weak signals, filters separate desired signals from undesired signals and noise, signal sources generate waveforms such as sinusoids or square waves, wave-shaping circuits change one waveform into another (sinusoid to square wave, for example), digital logic functions process digital signals, memories store information in digital form, power supplies provide necessary dc power to the other functional blocks, and converters change signals from analog form to digital form or vice versa. Later in this chapter, we consider the external characteristics of amplifiers in some detail.

The block diagram of an AM radio is shown in Figure 1.1. Notice that there are three amplifiers and two filters. The local oscillator is an example of a signal source, and the peak detector is a special type of wave-shaping circuit. Digital circuits appear in the user interface (keypad and display) and in the frequency synthesizer. The digital circuits control channel selection and other functions, such as loudness. The complete system description would include detailed specifications for each block. For example, the gain, input impedance, and bandwidth of each amplifier would be given. (We will carefully define these terms later.) Each functional block in turn consists of a circuit composed of resistors, capacitors, inductors, transistors, integrated circuits, and other devices.

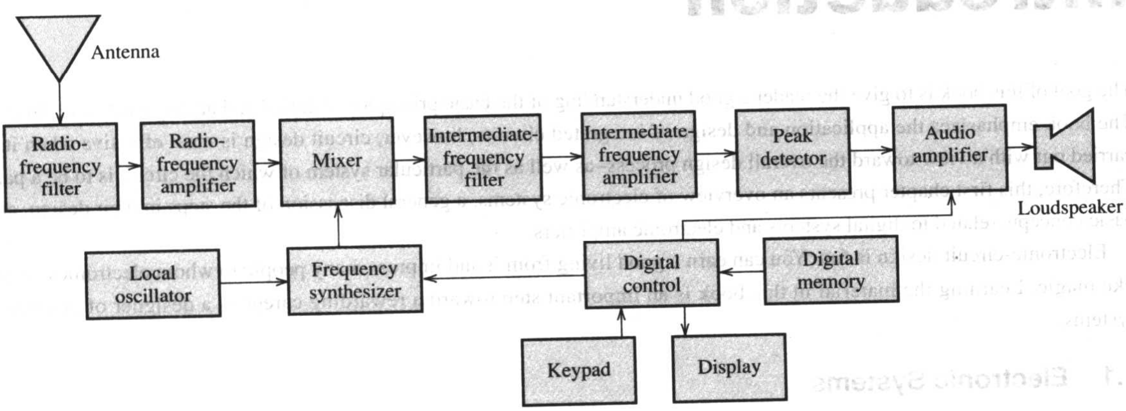

Figure 1.1 Block diagram of a simple electronic system: an AM radio.

The main goal of this book is to give you the basic skills needed to start from the external specifications of a block, such as an amplifier, and to design a practical circuit that meets the desired specifications. The selection of appropriate block diagrams for complex electronic systems is covered in other courses, such as control systems, computer architecture, digital signal processing, or communication systems.

Information Processing Versus Power Electronics

Many electronic systems fall into one or more of these categories: digital signal-processing systems, communication systems, medical electronics, instrumentation, control systems, and computer systems. A unifying aspect of these categories is that they all involve the collection and processing of information-bearing signals. Thus, the primary concern of many electronic systems is to extract, store, transport, or process the information in a signal.

Often, systems are also required to deliver substantial power to an output device. Certainly, this is true in an audio system, for which power must be delivered to loudspeakers to produce the desired sound level. In a control system for automatic positioning of a communication satellite, information extracted from various sources is used to control small rocket motors that maintain the satellite in its proper position and orientation. A cardiac pacemaker uses information extracted from the electrical signals produced by the heart to determine when to apply a stimulus in the form of a minute pulse of electricity to ensure proper pumping action. Although the output power of a pacemaker is very small, it is very important to consider the efficiency of its circuits to ensure a long life for the battery.

Some electronic systems are concerned mainly with the power content of signals, rather than information. For example, we might want a system to deliver ac electrical power (converted from dc supplied by batteries) to a computer, even when the ac line power fails.

Analog Versus Digital Systems

Information-bearing signals can be either **analog** or **digital**. An analog signal takes on a continuous range of amplitude values. The amplitude of a typical analog signal is plotted against time in Figure 1.2(a). Notice that as time increases, the amplitude of the signal varies over a continuous range. On the other hand, a digital signal takes on a finite number of amplitudes. Often, digital signals are binary (i.e., there are only two possible amplitudes); however, more levels are sometimes useful. Frequently, digital signals change amplitude only at uniformly spaced points in time. An example of a digital signal is shown in Figure 1.2(b).

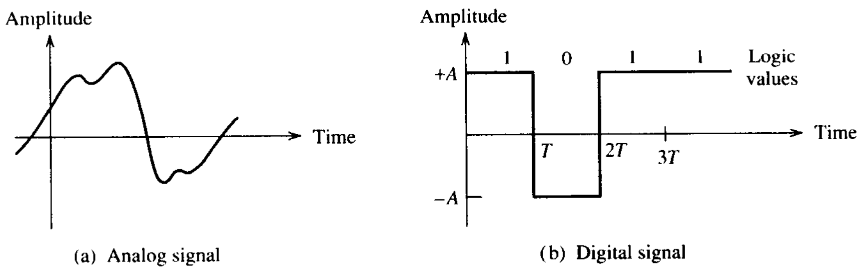

Figure 1.2 Analog signals take a continuum of amplitude values. Digital signals take a few discrete amplitudes.

The signals originally presented to the input of an electronic system by a **transducer** are usually in analog form. (A transducer is a device that converts energy to, or from, electrical form.) Examples of analog signals are sounds converted to electrical signals by a microphone, television signals, seismic vibrations, the output of a temperature transducer in a steam turbine, and so on. Other signals, such as the output of a computer keyboard, originate in digital form.

Conversion of Signals from Analog to Digital Form

Analog signals can be converted to digital form by a two-step process. First, the analog signal is sampled (i.e., measured) at periodic points in time. Then, a code word is assigned to represent the approximate value of each sample. Usually, the code words consist of binary symbols. This process is illustrated in Figure 1.3. Each sample value is represented by a 3-bit code word corresponding to the amplitude zone into which the sample falls. Thus, each sample value is converted into a code word, which in turn can be represented by a digital waveform, as shown in the figure. A circuit for the conversion of signals in this manner is called an **analog-to-digital converter** (ADC). Conversely, a **digital-to-analog converter** (DAC) converts digital signals back to analog form. (Later in the book, we discuss the design of both types of converters.)

The rate at which a signal must be sampled depends on the frequency content of the signal. (Signals can be considered to consist of sinusoidal components having various frequencies, amplitudes, and phases. Fourier analysis is a branch of mathematics that deals with this representation of signals. No doubt, you have had, or will have, other courses dealing with Fourier theory. We consider the frequency content of signals later in this chapter, but not on a rigorous mathematical basis.) If a signal contains no components with frequencies higher than f_H, the signal can be exactly reconstructed from its samples, provided that the sampling rate is selected to be more than twice f_H. For example, audio signals have a highest frequency of about 15 kHz. Therefore, the minimum sampling rate that should be used for audio signals is 30 kHz. Practical considerations dictate a sampling frequency somewhat higher than the theoretical minimum. For instance, audio compact-disc technology converts audio signals to digital form with a sampling rate of 44.1 kHz. Naturally, it is desirable to use the lowest practical sampling rate to minimize the amount of data (in the form of code words) that must be stored or manipulated.

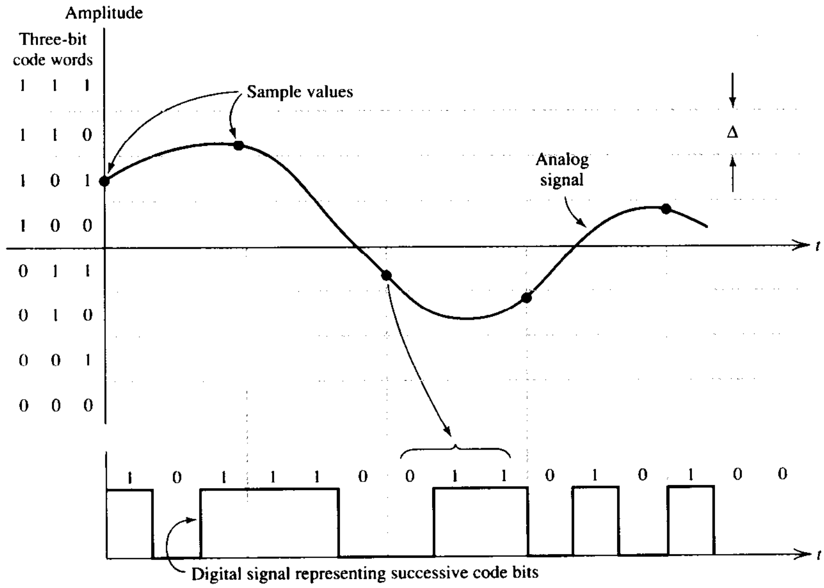

Figure 1.3 An analog signal is converted to an approximate digital equivalent by sampling. Each sample value is represented by a 3-bit code word.

Another consideration that is important in converting analog signals to digital form is the number of amplitude zones to be used. Exact signal amplitudes cannot be represented, because all amplitudes falling into a given zone have the same code word. Thus, when a DAC converts the code words to form the original analog waveform, it is possible to reconstruct only an approximation to the original signal — the reconstructed voltage is in the middle of each zone. This is illustrated in Figure 1.4. Consequently, some **quantization error** exists between the original signal and the reconstruction. This error can be reduced by using a larger number of zones, which requires a longer code word for each sample. The number N of amplitude zones is related to the number k of bits in a code word by

$$N = 2^k \tag{1.1}$$

Thus, if we are using an 8-bit ($k = 8$) ADC, there are $N = 2^8 = 256$ amplitude zones. In compact-disc technology, 16-bit words are used to represent sample values. With this number of bits, it is very difficult for a listener to detect the effects of quantization error on the reconstructed audio signal.

An electronic system that processes signals in analog form is called an analog system. Similarly, a digital system processes digital signals. Many modern systems contain both digital and analog elements, with converters to allow signals to pass from one side to the other.

Relative Advantages of Analog and Digital Systems

Noise is any undesired disturbance added to the desired signal. It can arise from the thermal agitation of electrons in a resistor, from inductive or capacitive coupling of signals from other circuits, or from a number of other sources. Often these noise signals are random in occurrence and (to some degree) outside the control of the circuit designer. One of the most significant advantages that digital systems have, compared with analog systems, is in the way that noise affects the signals.

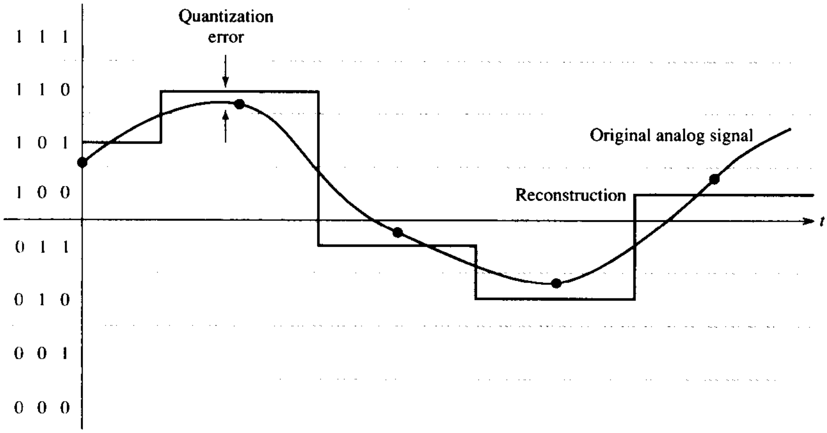

Figure 1.4 Quantization error occurs when an analog signal is reconstructed from its digital form.

Figure 1.5 shows typical analog and digital signals before and after the addition of noise. Notice that the original levels (high or low) of the digital signal can be discerned even after the noise has been added, provided that the peak amplitude of the noise is less than half of the distance between the levels of the digital signal. This is possible because the digital signal takes only specific amplitudes that can still be recognized after some noise is added. Thus, noise can be completely removed from digital signals, provided that the noise amplitude is not too large.

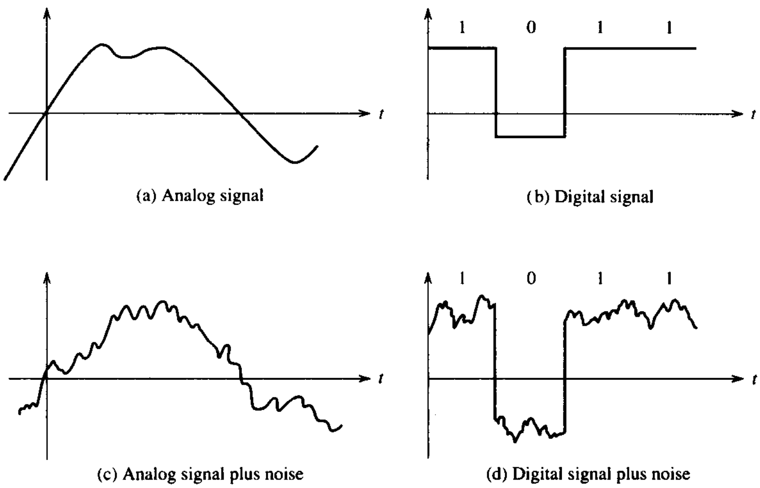

Figure 1.5 After noise is added, the original amplitudes of a digital signal can be determined. This is not true for an analog signal.

On the other hand, when noise is added to the analog signal, it is not possible to determine the original amplitude of the signal exactly, because all amplitude values are valid. For example, a scratch on an analog phonograph record creates noise that cannot be removed. If we transfer the signal to analog tape, even more noise is added. Thus, noise tends to accumulate in analog signals each time they are processed.

In general, analog systems require fewer individual circuit components than do digital systems. In the early years of electronics, individual circuit components were manufactured separately and then connected together by a manual process. Such circuits are called **discrete circuits**. Most early systems were designed as analog systems (to minimize the parts count), because the cost of a discrete circuit is nearly proportional to the number of circuit elements.

Modern technology has made it possible to manufacture thousands of circuit components and their interconnections all at one time by a small number of processing steps. Circuits produced in this manner are called **integrated circuits** (ICs). It is now possible to manufacture a circuit with 100 000 components nearly as economically as a circuit with only 10 similar components. Thus, the cost of a circuit does not increase proportionately with the number of components—provided that all the components are amenable to integrated-circuit construction.

It turns out that digital circuits tend to be easier than analog circuits to implement with integrated-circuit techniques. Analog circuits often require large resistances, capacitances, or inductances that cannot be readily manufactured by such techniques. Thus, although digital systems are often more complex than analog systems, the digital approach to a design usually results in an affordable system with much higher performance. As integrated-circuit technology has developed, the trend of the electronics industry has been toward high-performance digital systems. A comparison of a digital compact disc with the older analog phonograph or tape player reveals this trend clearly, as well as the improved performance of the digital approach.

Furthermore, digital systems are more adaptable than analog systems to a variety of uses. For example, digital computers can be used for a wide range of tasks. An analog communication system designed to carry a number of voice signals is not easily adaped to a television signal or to computer data. On the other hand, when digital techniques are used, a system that can communicate digitized signals from a variety of sources is possible.

Many of the input and output signals of electronic systems are analog. Furthermore, many functions — particularly those that deal with low signal amplitudes or very high frequencies—require an analog approach. The availability of complex digital circuits has actually increased the amount of analog electronics in existence because many modern systems contain both digital and analog portions, but would not be feasible as either totally digital or totally analog systems. Thus, we can expect that future systems will contain both analog and digital elements. In any case, at the circuit level, which is our main concern in this book, design considerations for both types of systems are similar.

1.2 The Design Process

In this section, we give a general description of the steps that take place in the creation of complex electronic systems. Often, a large team of engineers — hundreds of thousands — is required to complete the steps from the statement of a problem to a working system. Usually, only part of the system consists of electronic circuits, and many other types of expertise are required. In this book, our main interest is circuit design, but it is always important for circuit designers to consider how their work fits into the total system-design process.

System Design

A flowchart of the design process for electronic systems is shown in Figure 1.6. The process starts with the statement of a problem to be solved. For example, we might want a system that can provide positional information to ships and aircraft.

The first step is to develop detailed system specifications. These include generally applicable items such as size, weight, shape, power consumption, what type of power sources are to be used, and the acceptable system cost. Other specifications pertain to a particular class of systems. For example, in a communication system, we need to know the type of signals to be transmitted, the overall bandwidth required for analog signals, the data rate for the digital signals, the minimum signal-to-noise ratio acceptable at the destination for the analog signals, the maximum acceptable error probability for data transmission, the number and location of transmitters and receivers, and so on.

Design is an iterative process. As a design progresses, we may need to return to the system specification step to refine the specifications. Issues often come up during the design that were not anticipated at the outset. Sometimes the options must be presented to the user of the final system for guidance in setting additional specifications. On the other hand, the design engineers may be able to determine appropriate additional specifications from their knowledge of the purpose of the system.