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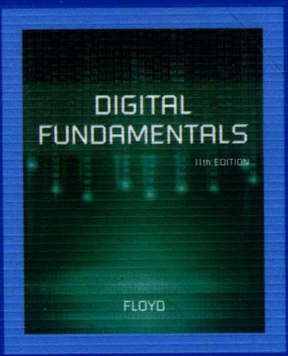

数字电子技术
（第十一版）（英文版）

［美］ Thomas L. Floyd 著

余 璆　熊 洁　改编

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内容简介

本书是一本关于数字电子技术的经典教材，并专门针对国内教学的实际情况进行了缩减。全书主要介绍了数字电子技术的基本概念、数制、逻辑门、布尔代数和逻辑化简、组合逻辑分析、组合逻辑的作用、计数器、移位寄存器、存储器、可编程逻辑与软件、数据传输、集成电路技术等。全书的特色在于示例与习题丰富、图解清晰、语言流畅、写作风格简约。

本书可作为高等院校电子信息类相关专业本科生的数字电子技术课程的双语教材，也可供相关技术、科研人员使用，或作为继续教育的参考用书。

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前　言

Digital Fundamentals（即改编后的《数字电子技术》）的第十一版继续秉承长期以来的传统，侧重于数字技术核心的基础内容。本书通过丰富的插图、举例、练习和若干应用帮助读深入理解相关的基本概念。除此以外，本书也涉及了应用逻辑功能、功能的实现、集成电路技术，还涉及了信号转换和处理、数据传输、处理和控制等一些特定主题。第十一版增加了一些新的内容和特点，许多原有的内容也得到了扩展。

书中涉及的知识旨在让学生进一步学习更高层次或选修内容之前，掌握所有重要的基础概念。涉及的内容范围具有灵活性，以便适应各种课程的需求。例如，对于某些课程并不太适合的设计性课题或者应用性课题，忽略或减少相关的内容不会影响书中基本概念的学习。半导体电路的背景知识并非本书必需的先修内容，集成电路技术（芯片内部电路）的知识则有选择地提及一些。

第十一版的新内容

- 全新的页面布局和设计，视觉效果更好，容易使用，修改和改进了一些内容。
- 删除了过时的设备。
- 新增了布尔简化的Q-M（Quine-McCluskey）方法。
- 新增了Moore和Mealy状态机的内容。
- 新增了有关数据传输的一章，包括标准总线的全面介绍。
- 突出了D触发器的使用。

本书的特性

- 基本核心内容和高层次的或外围的内容不相混合。
- *InfoNotes*（计算机小知识）以侧边栏的版面形式给出精炼的趣味短文。
- 每章都提示学生如何找到各种练习的答案。
- 每章中的各个小节都有检查题，答案列在每章的最后。
- 给出的每个例题都带有相关的练习，答案列在每章的最后。
- 分散在各处的*Hands-On Tips*（实践技巧）提供有用的实践知识。
- 网站上的MultiSim文件提供书中选做的仿真参考电路。
- 每章最后的是非判断题。
- 每章最后的单选自测题。
- 每章最后的分节习题在本书的最后给出奇数题目的答案。

学生资源[1]

- 可选择购买的实验手册（*Experiments in Digital Fundamentals, Eleventh Edition*），由Dave Buchla 和 Doug Joksch 撰写。
- *MultiSim*电路。网站（www.pearsonhighered.com/careersresources.com）上的MultiSim文件，包含了书中选做的仿真参考电路，由图P-1表示。

图 P-1

- 在线章节，“Intergrated Circuit Technologies”
- VHDL教程
- Verilog教程
- MultiSim教程
- Altera Quartus II教程
- Xilinx ISE教程
- 变量卡诺图教程
- 汉明码教程
- Q-M方法教程，等等

教师资源[2]

- 教师资源手册，包含相关章节的习题解答，应用逻辑习题的解答，MultiSim仿真结果的总结，由Dave Buchla 和 Doug Joksch 撰写的实验手册的实验结果。
- 书中插图的幻灯片文件。

一些专题的说明

检查题　每个小节的结尾都有习题组成的复习部分，以加强这一小节主要概念的理解。这个特点如图P-2所示。

SECTION 5–1 CHECKUP

Answers are at the end of the chapter.

1. Determine the output (1 or 0) of a 4-variable AND-OR-Invert circuit for each of the following input conditions:
   (a) $A = 1, B = 0, C = 1, D = 0$　(b) $A = 1, B = 1, C = 0, D = 1$
   (c) $A = 0, B = 1, C = 1, D = 1$
2. Determine the output (1 or 0) of an exclusive-OR gate for each of the following input conditions:
   (a) $A = 1, B = 0$　(b) $A = 1, B = 1$
   (c) $A = 0, B = 1$　(d) $A = 0, B = 0$
3. Develop the truth table for a certain 3-input logic circuit with the output expression $X = A\overline{B}C + \overline{A}BC + \overline{A}\overline{B}\overline{C} + AB\overline{C} + ABC$.
4. Draw the logic diagram for an exclusive-NOR circuit.

图 P-2

检查题的答案列在本章的结尾。

① 相关的一些资源也可登录华信教育资源网 www.hxedu.com.cn 注册下载。

② 教师资源申请方式请参见书后的“教辅申请表”。

例题和相关的问题　书中给出了丰富的例题，用以帮助对基本概念进行解释。每个例题都配有相关的问题，通过让学生解答和例题相似的题目来加强和拓宽所学知识。典型的例题和相关问题如图P-3所示。

EXAMPLE 5–15

Determine the output waveform X for the circuit in Example 5–14, Figure 5–34(a), directly from the output expression.

Solution

The output expression for the circuit is developed in Figure 5–35. The SOP form indicates that the output is HIGH when A is LOW and C is HIGH or when B is LOW and C is HIGH or when C is LOW and D is HIGH.

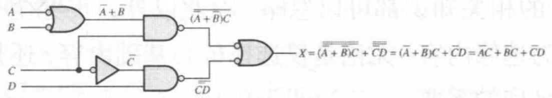

FIGURE 5–35

The result is shown in Figure 5–36 and is the same as the one obtained by the intermediate-waveform method in Example 5–14. The corresponding product terms for each waveform condition that results in a HIGH output are indicated.

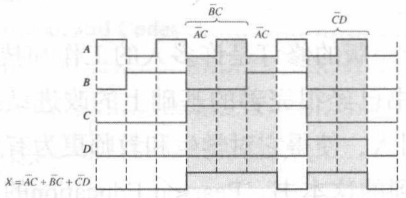

FIGURE 5–36

Related Problem

Repeat this example if all the input waveforms are inverted.

图 P-3

献给学生

数字技术遍布于我们生活的方方面面。例如手机和其他类型的无线通信，包括电视、收音机、过程控制、汽车电子、消费电子、飞机导航等，本书仅仅给出了为数不多的依赖于数字电子的应用。具有坚实的数字技术基础知识，会使您在将来得到技术含量很高的工作。最重要的事情，就是理解数字基础的核心内容，这样就可以深入到其他内容的学习。

献给教师

通常，时间的限制或课程的侧重点确定了本课程涉及的内容。为了满足特定课程的特定内容，忽略或强调一些知识及改变某些内容的学习顺序是很常见的。本教材为授课内容的选取提供了很大的灵活性。某些相关主题分散在不同的章节，如果忽略了某些知识点，则其他的内容不会受到影响。同样，如果增加了某些知识点，它们和其余的内容则可以无缝衔接。本书围绕数字基础的核心内容编写，大部分内容对于数字课程来说都是必不可少的。围绕本课程，可以增加或减少书中的内容，取决于课程的侧重点和/或其他因素。即使是核心内容，也可以忽略一些选修的章节。

- **核心基础内容**。有关数字技术基础的内容贯穿全书。对于围绕核心内容的一些其他主题，依据课程的需要可以增加或删除。本书涉及的内容在数字技术中是很重要的，但是围绕核心内容的每块主题可以根据特定的需要删除，这不会影响核心的基础内容的学习。

◆ **集成电路技术**。本书提供一章在线章节“Intergrated Circuit Technologies”。如果想讨论电路的详细特性，可以选读这一章的部分或全部内容，以补充数字基础电路的知识。忽略这一章不会影响本书其他内容的学习。

◆ **特殊主题**。这些内容包括信号接口和处理、数据传输、数据处理和控制，分散在第11章、第12章和其他章节的选读内容中。这些内容对于课程也许是必需的，或者也可以在其他课程里讲授。例如，在基础核心内容中，Q-M方法、循环冗余码、超前进位加法器或时序逻辑设计的相关知识都可以忽略。除此以外，贯穿全书的MultiSim（计算机仿真）内容可以作为选修内容。无论是仅选择核心基础内容，还是全部保留或介于两者之间，本书都将满足您的需要。

致谢

*Digital Fundamentals*第十一版的修订是许多人的工作和技术的成果。我认为我们已经完成了预期的工作，那是在本书已经很完善的基础上的改进结果。这不仅仅是基础内容的改善，还是最新和前沿技术的引入，使得它对学生和教师更为有用。

为了编写读者现在所看到的这本书，Pearson Education的人员进行了多个阶段的工作，倾注了大量的时间、智慧和努力，才使得本书得以完成，他们是Rex Davidson、Lindsey Gill和Vern Anthony，还有其他的许多人。Lois Porter还对手稿的编辑做出了卓越的贡献。Doug Joksch给出了VHDL编程（参阅在线资源）的相关内容。Gary Snyder修订和升级了MultiSim电路文件（参阅在线资源）。对于所有这些人和其他间接参与本书编辑的人，在此表示我的感谢和感激之情。

在修订本书和所有其他版本中，依靠了许多读者和专家的帮助。在此衷心感谢如下的审稿人，他们提出了许多有价值的建议和建设性的意见：

Dr. Cuiling Gong，Texas Christian大学

Jonathan White，Harding大学

Zane Gastineau，Harding大学

Dr. Eric Bothur，Midlands技术学院

同样感谢Pearson Education所有销售人员的努力，是他们的帮助使得本书得以和广大读者见面。此外，感谢所有选用本书作为教材的教师和个人读者。我希望您会发现*Digital Fundamentals*的第十一版比以前的版本更好，它将继续是学生学习的有价值的教材和参考资料。

Tom Floyd

目　录

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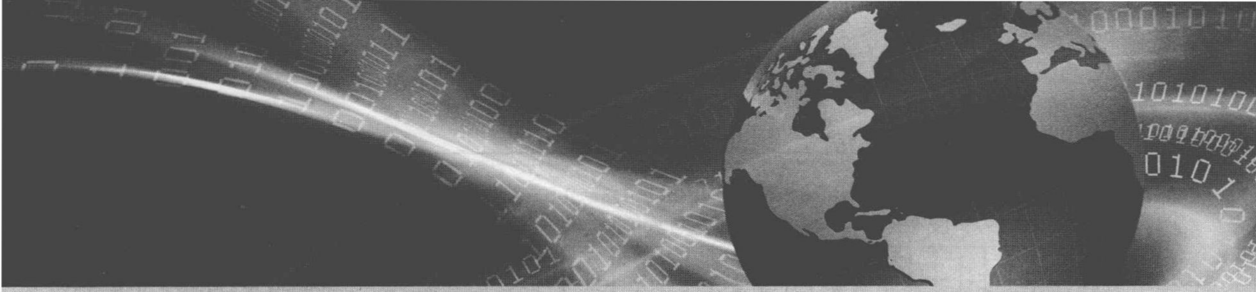


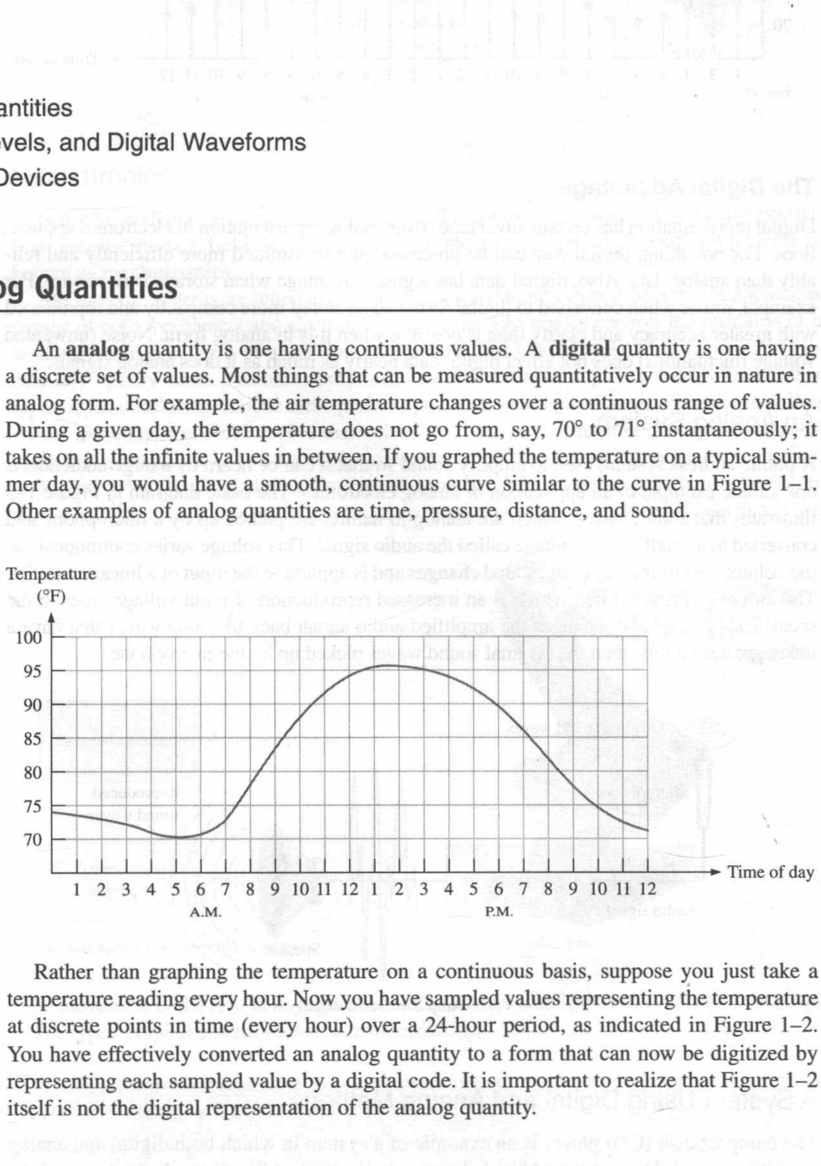
Chapter 1 Introductory Concepts

CHAPTER OUTLINE

1–1 Digital and Analog Quantities

An **analog** quantity is one having continuous values. A **digital** quantity is one having a discrete set of values. Most things that can be measured quantitatively occur in nature in analog form. For example, the air temperature changes over a continuous range of values. During a given day, the temperature does not go from, say, 70° to 71° instantaneously; it takes on all the infinite values in between. If you graphed the temperature on a typical summer day, you would have a smooth, continuous curve similar to the curve in Figure 1–1. Other examples of analog quantities are time, pressure, distance, and sound.

FIGURE 1–1
Graph of an analog quantity (temperature versus time).



Rather than graphing the temperature on a continuous basis, suppose you just take a temperature reading every hour. Now you have sampled values representing the temperature at discrete points in time (every hour) over a 24-hour period, as indicated in Figure 1–2. You have effectively converted an analog quantity to a form that can now be digitized by representing each sampled value by a digital code. It is important to realize that Figure 1–2 itself is not the digital representation of the analog quantity.

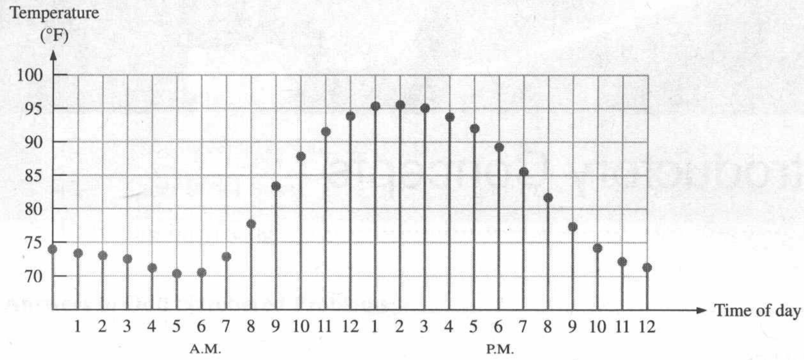


FIGURE 1–2 Sampled-value representation (quantization) of the analog quantity in Figure 1–1. Each value represented by a dot can be digitized by representing it as a digital code that consists of a series of 1s and 0s.

The Digital Advantage

Digital representation has certain advantages over analog representation in electronics applications. For one thing, digital data can be processed and transmitted more efficiently and reliably than analog data. Also, digital data has a great advantage when storage is necessary. For example, music when converted to digital form can be stored more compactly and reproduced with greater accuracy and clarity than is possible when it is in analog form. Noise (unwanted voltage fluctuations) does not affect digital data nearly as much as it does analog signals.

An Analog System

A public address system, used to amplify sound so that it can be heard by a large audience, is one simple example of an application of analog electronics. The basic diagram in Figure 1–3 illustrates that sound waves, which are analog in nature, are picked up by a microphone and converted to a small analog voltage called the audio signal. This voltage varies continuously as the volume and frequency of the sound changes and is applied to the input of a linear amplifier. The output of the amplifier, which is an increased reproduction of input voltage, goes to the speaker(s). The speaker changes the amplified audio signal back to sound waves that have a much greater volume than the original sound waves picked up by the microphone.

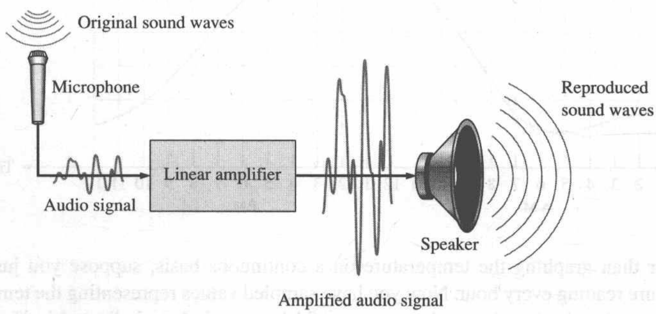


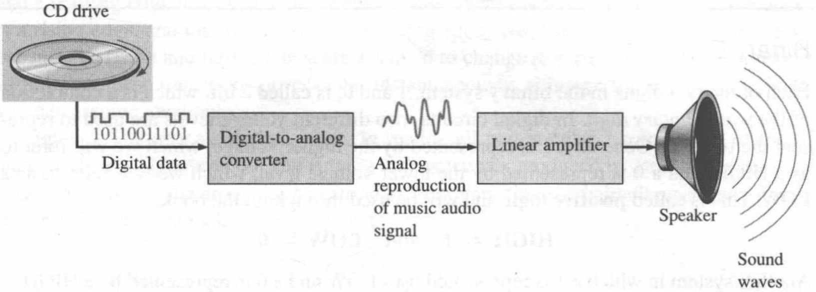
FIGURE 1–3 A basic audio public address system.

A System Using Digital and Analog Methods

The compact disk (CD) player is an example of a system in which both digital and analog circuits are used. The simplified block diagram in Figure 1–4 illustrates the basic principle. Music in digital form is stored on the compact disk. A laser diode optical system picks up the digital data from the rotating disk and transfers it to the **digital-to-analog converter (DAC)**. The DAC changes the digital data into an analog signal that is an electrical reproduction of the original music. This signal is amplified and sent to the speaker for you to enjoy. When the music was originally recorded on the CD, a process, essentially the reverse of the one described here, using an **analog-to-digital converter (ADC)** was used.

FIGURE 1–4

Basic block diagram of a CD player. Only one channel is shown.



Mechatronics

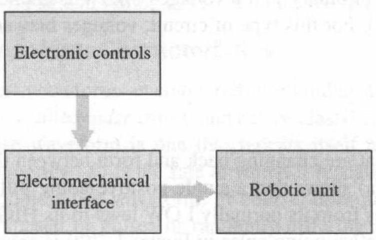
Both digital and analog electronics are used in the control of various mechanical systems. The interdisciplinary field that comprises both mechanical and electronic components is known as **mechatronics**.

Mechatronic systems are found in homes, industry, and transportation. Most home appliances consist of both mechanical and electronic components. Electronics controls the operation of a washing machine in terms of water flow, temperature, and type of cycle. Manufacturing industries rely heavily on mechatronics for process control and assembly. In automotive and other types of manufacturing, robotic arms perform precision welding, painting, and other functions on the assembly line. Automobiles themselves are mechatronic machines; a digital computer controls functions such as braking, engine parameters, fuel flow, safety features, and monitoring.

Figure 1–5(a) is a basic block diagram of a mechatronic system. A simple robotic arm is shown in Figure 1–5(b), and robotic arms on an automotive assembly line are shown in part (c).

FIGURE 1–5

Example of a mechatronic system and application.



(a) Mechatronic system block diagram

(b) Robotic arm

The movement of the arm in any quadrant and to any specified position is accomplished with some type of digital control such as a microcontroller.

SECTION 1-1 CHECKUP

Answers are at the end of the chapter.

1. Define *analog.*
2. Define *digital.*
3. Explain the difference between a digital quantity and an analog quantity.
4. Give an example of a system that is analog and one that is a combination of both digital and analog. Name a system that is entirely digital.
5. What does a mechatronic system consist of?

1–2 Binary Digits, Logic Levels, and Digital Waveforms

Binary Digits

Each of the two digits in the **binary** system, 1 and 0, is called a **bit**, which is a contraction of the words *binary digit.* In digital circuits, two different voltage levels are used to represent the two bits. Generally, 1 is represented by the higher voltage, which we will refer to as a HIGH, and a 0 is represented by the lower voltage level, which we will refer to as a LOW. This is called **positive logic** and will be used throughout the book.

HIGH = 1 and LOW = 0

Another system in which a 1 is represented by a LOW and a 0 is represented by a HIGH is called *negative logic.*

Groups of bits (combinations of 1s and 0s), called *codes,* are used to represent numbers, letters, symbols, instructions, and anything else required in a given application.

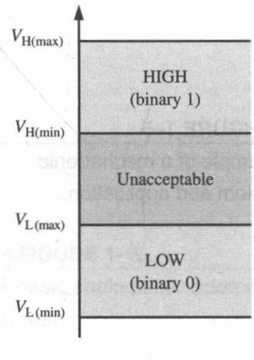
InfoNote

The concept of a digital computer can be traced back to Charles Babbage, who developed a crude mechanical computation device in the 1830s. John Atanasoff was the first to apply electronic processing to digital computing in 1939. In 1946, an electronic digital computer called ENIAC was implemented with vacuum-tube circuits. Even though it took up an entire room, ENIAC didn't have the computing power of your handheld calculator.

Logic Levels

The voltages used to represent a 1 and a 0 are called *logic levels.* Ideally, one voltage level represents a HIGH and another voltage level represents a LOW. In a practical digital circuit, however, a HIGH can be any voltage between a specified minimum value and a specified maximum value. Likewise, a LOW can be any voltage between a specified minimum and a specified maximum. There can be no overlap between the accepted range of HIGH levels and the accepted range of LOW levels.

Figure 1–6 illustrates the general range of LOWs and HIGHs for a digital circuit. The variable $V_{H(max)}$ represents the maximum HIGH voltage value, and $V_{H(min)}$ represents the minimum HIGH voltage value. The maximum LOW voltage value is represented by $V_{L(max)}$, and the minimum LOW voltage value is represented by $V_{L(min)}$. The voltage values between $V_{L(max)}$ and $V_{H(min)}$ are unacceptable for proper operation. A voltage in the unacceptable range can appear as either a HIGH or a LOW to a given circuit. For example, the HIGH input values for a certain type of digital circuit technology called CMOS may range from 2 V to 3.3 V and the LOW input values may range from 0 V to 0.8 V. If a voltage of 2.5 V is applied, the circuit will accept it as a HIGH or binary 1. If a voltage of 0.5 V is applied, the circuit will accept it as a LOW or binary 0. For this type of circuit, voltages between 0.8 V and 2 V are unacceptable.

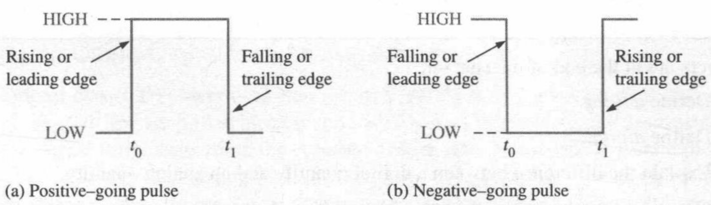


▲ **FIGURE 1–6**

Logic level ranges of voltage for a digital circuit.

Digital Waveforms

Digital waveforms consist of voltage levels that are changing back and forth between the HIGH and LOW levels or states. Figure 1–7(a) shows that a single positive-going **pulse** is generated when the voltage (or current) goes from its normally LOW level to its HIGH level and then back to its LOW level. The negative-going pulse in Figure 1–7(b) is generated when the voltage goes from its normally HIGH level to its LOW level and back to its HIGH level. A digital waveform is made up of a series of pulses.



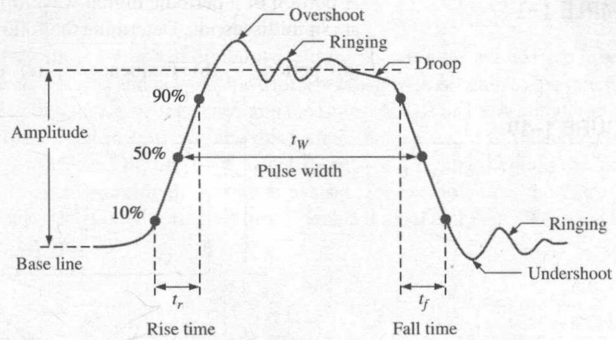
◀ **FIGURE 1–7**

Ideal pulses.

The Pulse

As indicated in Figure 1–7, a pulse has two edges: a **leading edge** that occurs first at time t_0 and a **trailing edge** that occurs last at time t_1. For a positive-going pulse, the leading edge is a rising edge, and the trailing edge is a falling edge. The pulses in Figure 1–7 are ideal because the rising and falling edges are assumed to change in zero time (instantaneously). In practice, these transitions never occur instantaneously, although for most digital work you can assume ideal pulses.

Figure 1–8 shows a nonideal pulse. In reality, all pulses exhibit some or all of these characteristics. The overshoot and ringing are sometimes produced by stray inductive and capacitive effects. The droop can be caused by stray capacitive and circuit resistance, forming an *RC* circuit with a low time constant.

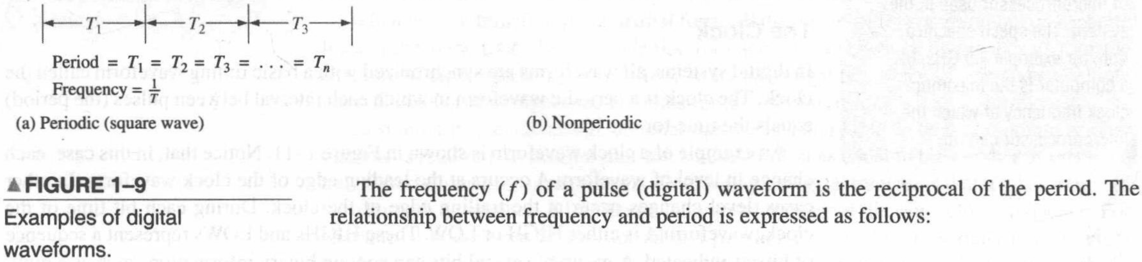


▶ **FIGURE 1–8**
Nonideal pulse characteristics.

The time required for a pulse to go from its LOW level to its HIGH level is called the **rise time (t_r)**, and the time required for the transition from the HIGH level to the LOW level is called the **fall time (t_f)**. In practice, it is common to measure rise time from 10% of the pulse **amplitude** (height from baseline) to 90% of the pulse amplitude and to measure the fall time from 90% to 10% of the pulse amplitude, as indicated in Figure 1–8. The bottom 10% and the top 10% of the pulse are not included in the rise and fall times because of the nonlinearities in the waveform in these areas. The **pulse width (t_W)** is a measure of the duration of the pulse and is often defined as the time interval between the 50% points on the rising and falling edges, as indicated in Figure 1–8.

Waveform Characteristics

Most waveforms encountered in digital systems are composed of series of pulses, sometimes called *pulse trains,* and can be classified as either periodic or nonperiodic. A **periodic** pulse waveform is one that repeats itself at a fixed interval, called a **period (T)**. The **frequency (f)** is the rate at which it repeats itself and is measured in hertz (Hz). A nonperiodic pulse waveform, of course, does not repeat itself at fixed intervals and may be composed of pulses of randomly differing pulse widths and/or randomly differing time intervals between the pulses. An example of each type is shown in Figure 1–9.



▲ **FIGURE 1–9**
Examples of digital waveforms.

The frequency (f) of a pulse (digital) waveform is the reciprocal of the period. The relationship between frequency and period is expressed as follows:

$$f = \frac{1}{T}$$ Equation 1–1

$$T = \frac{1}{f}$$ Equation 1–2

An important characteristic of a periodic digital waveform is its **duty cycle**, which is the ratio of the pulse width (t_W) to the period (T). It can be expressed as a percentage.

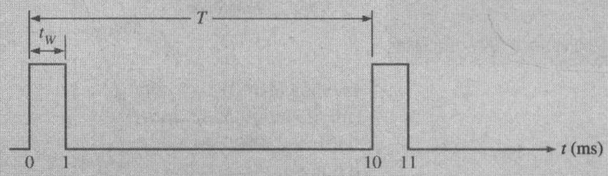
$$\textbf{Duty cycle} = \left(\frac{t_W}{T}\right)100\%$$ Equation 1–3

EXAMPLE 1-1

A portion of a periodic digital waveform is shown in Figure 1–10. The measurements are in milliseconds. Determine the following:

(a) period (b) frequency (c) duty cycle

▶ FIGURE 1–10



Solution

(a) The period (T) is measured from the edge of one pulse to the corresponding edge of the next pulse. In this case T is measured from leading edge to leading edge, as indicated. T equals **10 ms**.

(b) $f = \frac{1}{T} = \frac{1}{10\text{ ms}} = \mathbf{100\ Hz}$

(c) $\text{Duty cycle} = \left(\frac{t_W}{T}\right)100\% = \left(\frac{1\text{ ms}}{10\text{ ms}}\right)100\% = \mathbf{10\%}$

Related Problem*

A periodic digital waveform has a pulse width of 25 μs and a period of 150 μs. Determine the frequency and the duty cycle.

*Answers are at the end of the chapter.

A Digital Waveform Carries Binary Information

InfoNote

The speed at which a computer can operate depends on the type of microprocessor used in the system. The speed specification, for example 3.5 GHz, of a computer is the maximum clock frequency at which the microprocessor can run.

Binary information that is handled by digital systems appears as waveforms that represent sequences of bits. When the waveform is HIGH, a binary 1 is present; when the waveform is LOW, a binary 0 is present. Each bit in a sequence occupies a defined time interval called a **bit time**.

The Clock

In digital systems, all waveforms are synchronized with a basic timing waveform called the **clock.** The clock is a periodic waveform in which each interval between pulses (the period) equals the time for one bit.

An example of a clock waveform is shown in Figure 1–11. Notice that, in this case, each change in level of waveform A occurs at the leading edge of the clock waveform. In other cases, level changes occur at the trailing edge of the clock. During each bit time of the clock, waveform A is either HIGH or LOW. These HIGHs and LOWs represent a sequence of bits as indicated. A group of several bits can contain binary information, such as a number or a letter. The clock waveform itself does not carry information.