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FUNDAMENTAL OF DIGITAL ELE CTRONIC TECHNOLOGY

数字电子技术基础（上）

Feng Yu & Qiang Liu

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Fundamental of Digital Electronic Technology

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PREFACE

This book is written in English to help students whose first language is not English, while they learn technical knowledge, to familiarize with technical English expressions and to learn reading and writing for academic English. From our teaching experience it is realized that learning a technical topic with the text book in English, the students will gradually master the fast reading and comprehensive understanding skills, and also build up confidence for academic discussion, presentation and writing in English. These skills are essential for students going abroad to study and enable them to get quickly accustomed with the English study environment, such as lecturing, seminars and tutorials in English. Moreover, after leaving university, as an electronic or control engineer one will often exchange ideas or work collaboratively with western engineers or academics. The experience of using English text book will be realized more and more important.

In organizing the contents and writing this book several aspects have been considered, including the requirements by pursuing a higher degree in both national and overseas high quality universities. To achieve this purpose, several world-widely popular text and reference books in this subject have been refereed, including " Digital Fundamentals" by Thomas L. Floyd in USA and " Fundamentals of Digital Electronic Technology" by Shi Yan in China. In line with the trend in today's world in the Digital Electronics field and closely following the new techniques is one of the unique features of the book.

About using of the book, I recommend that the book is used as a major text book for college students in majors of electrical and electronics engineering, control engineering, or communication engineering, etc. I do not recommend using one or two chapters of the book separately, such as CPLD, FPGA or Microprocessors, as the book is written with chapters systematically related and it is not effective to select a single chapter to learn.

Finally, I would be grateful if readers could generously let me know any mistakes or inappropriate use of technical content or English in the book, which must exist inevitably due to our limited knowledge in using English. The author would like to express my gratitude to professor Ding_ Li Yu of Liverpool John Moores University for compiling and checking on the book.

Electrical & Information college of Changchun Architecture and Civil Engineering College
Feng Yu

08/03/2013

CONTENTS

Chapter 1 INTRODUCTION TO DIGITAL PRINCIPLES

1-1 DIGITAL AND ANALOG QUANTITIES

Analog quantity is one having continuous values with continuous time. A digital quantity is one having a discrete set of values at a series of instants. Most things that can be measured quantitatively appear 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, 20℃ to 21℃ instantaneously; it takes on all the infinite values in between. If you graphed the temperature on the day, you would have a smooth, continuous curve similar to the curve in Fig. 1-1.

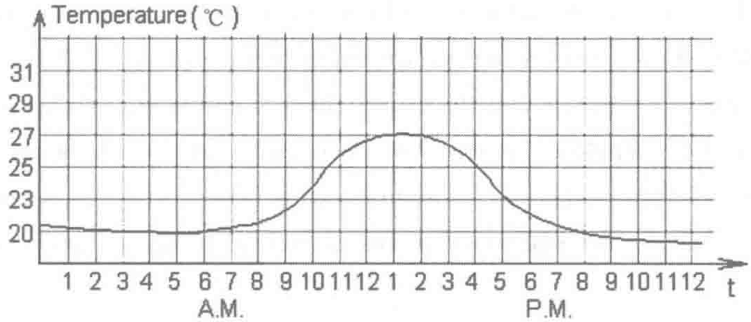


Fig. 1-1 Temperature versus time

Other examples of analog quantities are time, pressure, distance, and sound.

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 Fig. 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. (Each value represented by a dot can be digitized by representing it as a digital code.) It is important to realize that Fig. 1-2 itself is not the digital representation of the analog quantity.

The digital Advantage

Digital has certain advantages over analog 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.

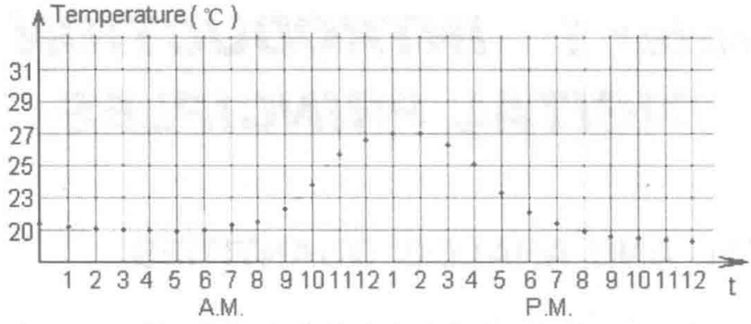


Fig. 1 – 2 Sampled value representation of the analog in Fig. 1 – 1

An Analog Electronic System

An audio frequency power amplifier system, used to amplify voice and music so that it can be heard by a large audience, is one example of an application of analog electronics. The basic diagram in Fig. 1 – 3 illustrates that sound waves, which are analog in nature, are. Picked up by a microphone and convinced 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 having a much greater volume than the original sound waves picked up by the microphone.

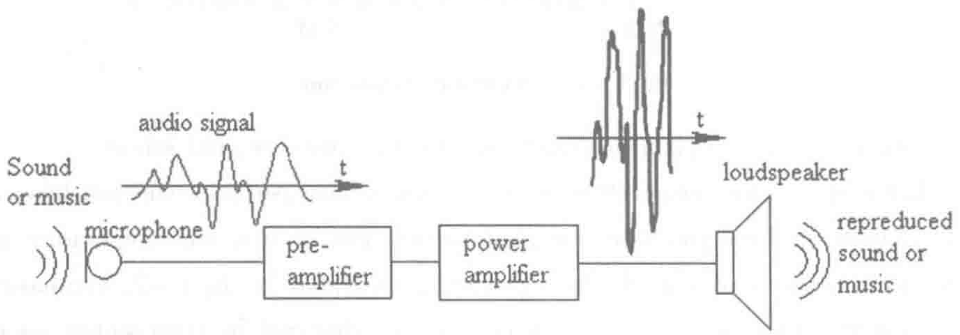


Fig. 1 – 3 An audio power amplifier system

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 diagram in Fig. 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.

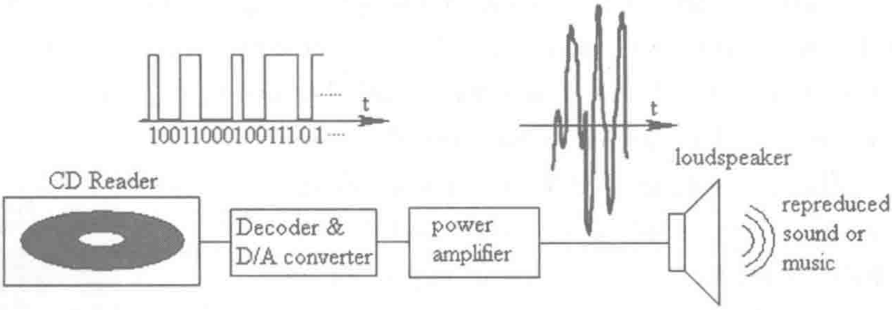


Fig. 1 - 4 Basic principle of a CD player

1 - 2 BINARY DIGITS, LOGIC LEVELS AND DIGITAL WAVEFORMS

Binary Digits

Digital electronics involves circuits and systems in which there are only two possible states. These states are represented by two different voltage levels: A HIGH and a LOW.

We can represent every types of information, such as numbers, symbols, alphabetic characters etc., with combinations of the two states. Those combinations are called codes.

The two-state number system is called binary, and its two digits are 0 and 1. The two digits in the binary system, 1 and 0, are called bits, which is a contraction of the words binary digit. In digital circuits, two different voltage levels are used to represent the two bits. A 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

A less common 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 and0s), called codes, are used to represent numbers, letters, symbols, instructions, and anything else required in a given application.

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 distal 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 HIGH levels and the accepted LOW levels.

Fig. 1 – 5 illustrates the general range of LOWs and HIGHs for a digital circuit. The variable $U_{H(max)}$ represents the maximum HIGH voltage value, and $U_{H(min)}$ represents the minimum HIGH voltage value. The maximum LOW voltage value is represented by $U_{L(max)}$, and the minimum LOW voltage value is represented by $U_{L(min)}$. The voltage values between $U_{L(max)}$ and $U_{H(min)}$ are unacceptable for proper operation. A voltage in the un-acceptable range can appear as either a HIGH or a LOW to a given circuit. Therefore, these unacceptable values are never used. For example, the HIGH values for a certain type of digital circuit called TTL may range from 2 V to 5 V and the LOW values may range from 0 V to 0.8 V. So, for example, if a voltage of 3.5 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 and are never used.

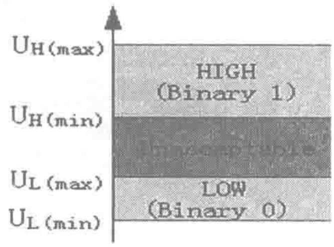


Fig. 1 – 5 Logic level ranges of voltage for a digital circuit

Digital Waveforms

Digital waveforms consist of voltage levels that are changing back and forth between the HIGH and LOW levels or states. Fig. 1 – 6(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 Fig. 1 – 6(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.

The Pulse As indicated in Fig. 1 – 6, the 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 Fig. 1 – 6 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.

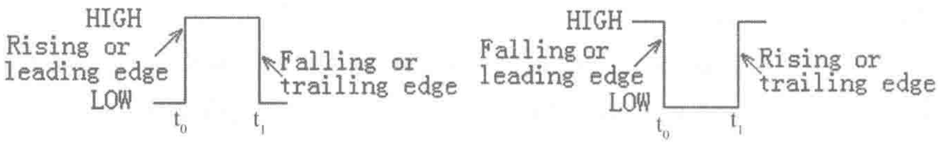
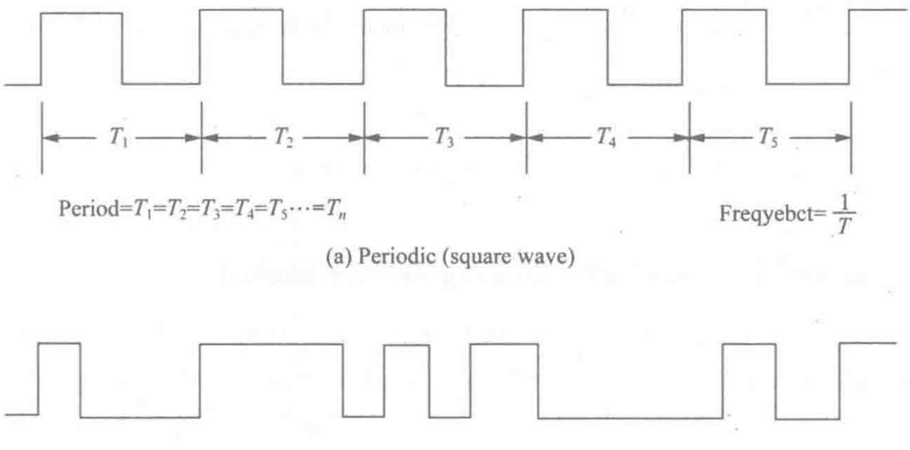


Fig. 1 – 6 Ideal pulses

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 Fig. 1 – 7.



(a) Periodic (square wave)

(b) Nonperiodic

Fig. 1 – 7 Example of digital waveforms

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

$$f = \frac{1}{T} \quad (1-1)$$

$$T = \frac{1}{f} \quad (1-2)$$

An important characteristic of a periodic digital waveform is its duty cycle. The duty cycle is defined as the ratio of the pulse width (t_w) to the period (T) and can be expressed as a percentage.

$$\text{Duty} \quad \text{cycle} = (\frac{t_w}{T})100\% \quad (1-3)$$

EXAMPLE 1 – 1

A portion of a periodic digital waveform is shown in Fig. 1 – 8.

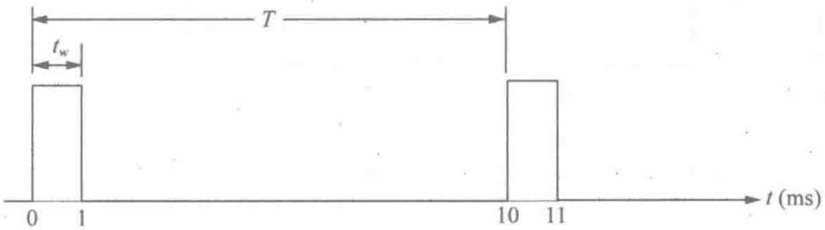


Fig. 1 – 8

The measurements are in milliseconds. Determine the following:
period; (b) frequency; (c) duty cycle.

SOLUTION

(a) The period 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 equals10 ms.

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

(c) Duty cycle $= (\frac{t_w}{T})100\% = (\frac{1ms}{10ms})100\% = 10\%$

A Digital Waveform Carries Binary Information

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 Fig. 1 -9. 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 be used as a piece of binary information, such as a number or a letter. The clock waveform itself does not carry information.

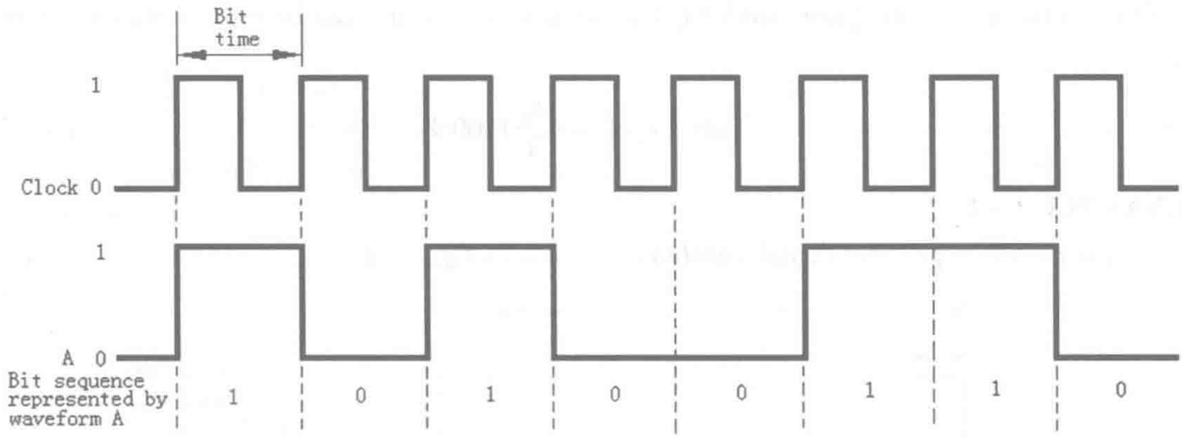


Fig. 1 -9 a clock waveform synchronized with a waveform representation of a sequence of bits

Timing Diagrams

A timing diagram is a graph of digital waveforms showing the actual time relationship of two or more waveforms and how each waveform changes in relation to the others. Fig. 1 -9 is an example of a simple timing diagram that shows how the clock waveform and waveform A are related on a time base.

By looking at a timing diagram, you can determine the states (HIGH or LOW) of all the waveforms at any specified point in time and the exact time that a waveform changes state relative to the other waveforms. Fig. 1 – 10 is an example of a timing diagram made up of four waveforms. From this timing diagram you can see, for example, that all three waveforms (A, B, and C) are HIGH only during bit time 7 and they all change back LOW at the end of bit time 7.

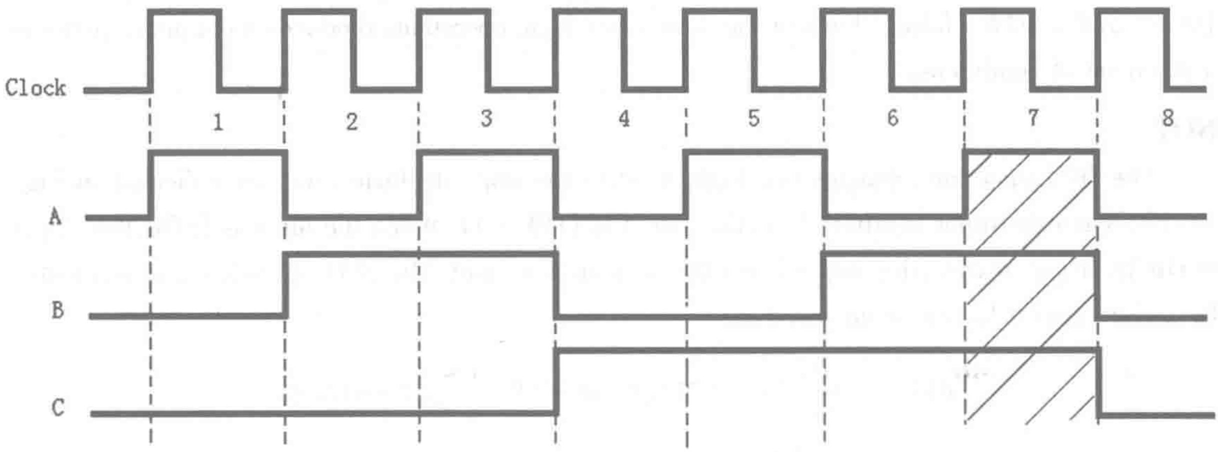


Fig. 1 – 10 Example of a timing diagram

1 – 3 BASIC LOGIC OPERATIONS

Several propositions, when combined, formprepositional, or logic, functions. For example, the prepositional statement "The light is on" will be true if "The bulb is not burned out" is true and " the switch is on" is true. Therefore, this logical statement can be made: The light is on only if the bulb is not burned out and the switch is on. In this example the first statement is true only if the last two statements are true. The first statement ("The light is on") is then the basic proposition, and the other two statements are the conditions on which the proposition depends.

In the 1850s, the Irish logician and mathematician George Boole developed a mathematical system for formulating logic statements with symbols so that problems can be written and solved in a manner similar to ordinary algebra. Boolean algebra, as it is known today, is applied in the design and analysis of digital systems and will be covered in detail in Chapter 3.

The term logic is applied to digital circuits used to implement logic functions. Several kinds of digital logic circuits are the basic elements that form the building blocks for such complex digital systems as the computer. We will now look at these elements and discuss their functions in a very general way. Later chapters will cover these circuits in detail.

Three basic logic operations are indicated by standard distinctive shape symbols in Fig. 1 – 11. The lines connected to each symbol are the inputs and outputs. The inputs are on the left of each symbol and the output is on the right. A circuit that performs a specified logic operation (AND, OR) is called a logic gate. AND and OR gates can have any number of inputs, as indicated by the dashes in the figure.