Unit 1 Fundamentals of Electronic Circuits

1.1 Introduction to Circuit Theory

(1) Nodes, Branches and Loops

Since the elements of an electric circuit can be interconnected in several ways, we need to understand some basic concepts of network topology. **To differentiate between a circuit and a network, we may regard a network as an interconnection of elements or devices, whereas a circuit is a network providing one or more closed paths.**① In network topology, we study the properties relating to the placement of elements in the network and the geometric configuration of the network. Such elements include branches, nodes, and loops.

A branch represents a single element such as a voltage source or a resistor. In other words, a branch represents any two-terminal element. The circuit in Fig.1.1 has five branches, namely, the 10V voltage source, the 2A current source, and the three resistors.

A node is the point of connection between two or more branches.

A node is usually indicated by a dot in a circuit. **If a short circuit (a connecting wire) connects two nodes, the two nodes constitute a single node.**② The circuit in Fig.1.1 has three nodes *a*, *b*, and *c*. Notice that the three points that form node *b* are connected by perfectly conducting wires and therefore constitute a single point. The same is true of the four points forming node *c*. We demonstrate that the circuit in Fig.1.1 has only three nodes by redrawing the circuit in Fig.1.2. The two circuits in Fig.1.1 and Fig.1.2 are identical. However, for the sake of clarity, nodes *b* and *c* are spread out with perfect conductors as in Fig.1.2.

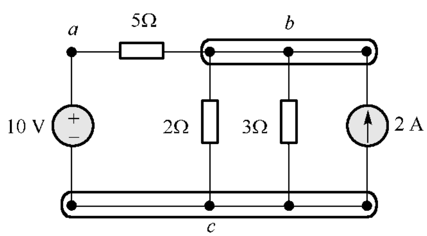


Fig.1.1 A circuit

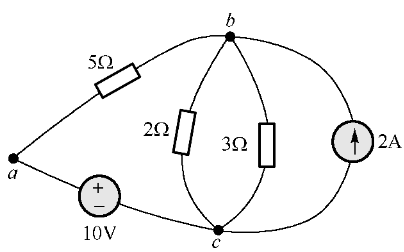


Fig.1.2 The circuit redrawed

A loop is any closed path in a circuit. A loop is a closed path formed by starting at a node, passing through a set of nodes, and returning to the starting node without passing through any node more than once. A loop is said to be independent if it contains a branch which is not in any other loop. Independent loops or paths result in independent sets of equations.

For example, the closed path *abca* containing the 2Ω resistor in Fig.1.2 is a loop. Another loop is the closed path *bcb* containing the 3Ω resistor and the current source. Although one can identify six loops in Fig.1.2, only three of them are independent.

A network with b branches, n nodes, and l independent loops will satisfy the fundamental theorem of network topology:

$$b = l + n - 1 \tag{1.1}$$

As the next two definitions show, circuit topology is of great value to the study of voltages and currents in an electric circuit.

Two or more elements are in series if they are cascaded or connected sequentially and consequently carry the same current.

Two or more elements are in parallel if they are connected to the same two nodes and consequently have the same voltage across them.

Elements may be connected in a way that they are neither in series nor in parallel. In the circuit shown in Fig.1.1, the voltage source and the 5Ω resistor are in series because the same current will flow through them. **The 2Ω resistor, the 3Ω resistor, and the current source are in parallel because they are connected to the same two nodes (*b* and *c*) and consequently have the same voltage across them.**[3] The 5Ω and 2Ω resistors are neither in series nor in parallel with each other.

(2) Ohm's Law，Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL)

Ohm's Law states the voltage across a resistor, R (or impedance, Z) is directly proportional to the current passing through it (the resistance/impedance is the proportionality constant).

$$\begin{aligned} &\text{DC}: v = iR \\ &\text{AC}: V = IZ \end{aligned} \tag{1.2}$$

Ohm's Law by itself is not sufficient to analyze circuits. However, when it is coupled with Kirchhoff's two laws, we have a sufficient, powerful set of tools for analyzing a large variety of electric circuits. Kirchhoff's laws were first introduced in 1847 by the German physicist Gustav Robert Kirchhoff (1824–1887). These laws are formally known as Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL).

Kirchhoff's First Law is based on the law of conservation of charge, which requires that the algebraic sum of charges within a system cannot change.

Kirchhoff's Current Law (KCL) states that the algebraic sum of currents entering a node (or a closed boundary) is zero.

Mathematically, KCL implies that:

$$\sum_{n=1}^{N} i_n = 0 \tag{1.3}$$

where N is the number of branches connected to the node and i_n is the nth current entering (or leaving) the node. By this law, currents entering a node may be regarded as positive, while currents leaving the node may be taken as negative or vice versa.

Consider the node in Fig.1.3. Applying KCL gives:

$$i_1 - i_2 + i_3 + i_4 - i_5 = 0 \tag{1.4}$$

since currents i_1, i_3, and i_4 are entering the node, while currents i_2 and i_5 are leaving it. By rearranging the terms, we get:

$$i_1 + i_3 + i_4 = i_2 + i_5 \tag{1.5}$$

Eq.(1.5) is an alternative form of KCL. The sum of the currents entering a node is equal to the sum of the currents leaving the node.

Note that KCL also applies to a closed boundary. This may be regarded as a generalized case, because a node may be regarded as a closed surface shrunk to a point. In two dimensions, a closed boundary is the same as a closed path. As typically illustrated in the circuit of Fig.1.4, the total current entering the closed surface is equal to the total current leaving the surface.

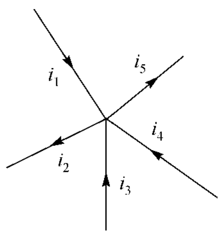


Fig.1.3 A node

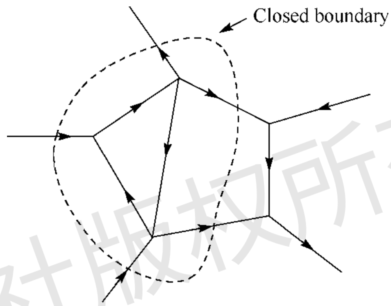


Fig.1.4 A closed boundary

Kirchhoff's voltage law (KVL) states that the algebraic sum of all voltages around a closed path (or loop) is zero.

Expressed mathematically, KVL states that:

$$\sum_{m=1}^{M} v_m = 0 \tag{1.6}$$

where M is the number of voltages in the loop (or the number of branches in the loop) and v_m is the mth voltage.

To illustrate KVL, consider the circuit in Fig.1.5.

The sign on each voltage is the polarity of the terminal encountered first as we travel around the loop. We can start with any branch and go around the loop either clockwise or counterclockwise. Suppose we start with the voltage source and go clockwise around the loop as shown; then voltages would be $-v_1$,$+v_2$,$+v_3$,$-v_4$, and $+v_5$, in that order. ④

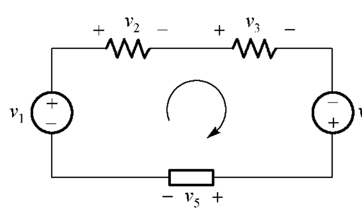


Fig.1.5 The circuit

For example, as we reach branch 3, the positive terminal is met first; hence we have $+v_3$. For branch 4, we reach the negative terminal first; hence, $-v_4$. Thus, KVL yields:

$$-v_1 + v_2 + v_3 - v_4 + v_5 = 0 \tag{1.7}$$

Rearranging terms gives:

$$v_2 + v_3 + v_5 = v_1 + v_4 \tag{1.8}$$

which may be interpreted as:

$$\text{Sum of voltage drops} = \text{Sum of voltage rises} \tag{1.9}$$

This is an alternative form of KVL. Notice that if we had traveled counterclockwise, the result would have been $+v_1$, $-v_5$, $+v_4$, $-v_3$, and $-v_2$, which is the same as before except that the signs are reversed. Hence, Eqs.(1.7) and (1.8) remain the same.

When voltage sources are connected in series, KVL can be applied to obtain the total voltage. The combined voltage is the algebraic sum of the voltages of the individual sources.

New Words and Expressions

element	*n*. 成分；元件
interconnect	*vt*. 使互相连接
node	*n*. 节点
branch	*n*. 树枝；分枝；分部；支流；支脉　*v*. 出现分歧
loop	*n*. 环，循环，线（绳）圈，弯曲部分，回路，回线 *vt*. 使成环；使成圈；以环连接　*vi*. 打环；翻筋斗
topology	*n*. 拓扑；布局；拓扑学
configuration	*n*. 构造；结构；配置；外形
terminal	*n*. 终点站；终端；接线端
resistor	*n*. [电]电阻器
independent	*n*. 独立自主者；无党派者　*adj*. 独立自主的；不受约束的
series	*n*. 连续；系列；级数；串联
parallel	*adj*. 平行的；相同的；类似的；并联的　*n*. 平行线；平行面；相似物　*v*. 相应；平行
impedance	*n*. [电]阻抗；全电阻；[物]阻抗
theorem	*n*. [数]定理；法则

Notes

① To differentiate between a circuit and a network, we may regard a network as an interconnection of elements or devices, whereas a circuit is a network providing one or more closed paths.

译文：为了区别网络和电路，可以认为网络是若干元件或装置的相互连接，而电路则是指具有一个或多个闭合路径的网络。

解析：differentiate 在此处为动词，differentiate between A and B 表示区分 A 和 B；To differentiate between a circuit and a network 是目的状语从句，意思是“为了区别网络和电路”，主句为 we may regard a network as an interconnection of elements or devices；regard … as 表示“把……认为”，providing one or more closed paths 为 network 的后置定语。

② If a short circuit (a connecting wire) connects two nodes, the two nodes constitute a single node.

译文：如果 2 个节点间用一根短路线连接，则此 2 个节点构成 1 个单节点。

解析：由 if 引导的条件状语从句，表示“如果”，从句中的主语是 a short circuit (a connecting wire)，谓语动词是 connects，宾语是 two nodes。主句中，主语是 the two nodes，谓语动词是 constitute，宾语是 a single node。

③ The 2Ω resistor, the 3Ω resistor, and the current source are in parallel because they are connected to the same two nodes (b and c) and consequently have the same voltage across them.

译文：2Ω电阻、3Ω电阻和电流源是接在相同的两个节点（*b* 和 *c*）上，即这 3 个元件是并联连接的，因此各元件上的电压相同。

解析：in parallel 表示“并联的”, The 2Ω resistor, the 3Ω resistor, and the current source are in parallel 为主句, because they are connected to the same two nodes (*b* and *c*)为原因状语从句, consequently 引导结果状语从句，但此从句省略了主语 they。

④ The sign on each voltage is the polarity of the terminal encountered first as we travel around the loop. We can start with any branch and go around the loop either clockwise or counterclockwise. Suppose we start with the voltage source and go clockwise around the loop as shown; then voltages would be $-v_1, +v_2, +v_3, -v_4$, and $+v_5$, in that order.

译文：顺着环路来看，每个电压的符号就是首先遇到的端子的极性。绕行回路可以从任一支路开始，绕行方向可以是顺时针，也可以是逆时针。假设我们从电压源开始，顺时针绕环路一圈，那么按顺序的电压取值分别为$-v_1$、$+v_2$、$+v_3$、$-v_4$、$+v_5$。

解析：第一个句子是主系表结构，主语是 The sign on each voltage；系动词是 is；表语是 the polarity of the terminal，同时也是 encountered first 的先行词，此处用过去分词表示被动意义；as we travel around the loop 为状语。第二个句子中，start with 表示“从……开始”；either clockwise or counterclockwise 为方式状语；第三个句子中，suppose 为“假想”，后面可以接一个句子，也可以 suppose that 接句子；as shown 译为“正如以下显示的一样”；then 表示承接，后接句子，主语是 voltages；in that order 为方式状语。

1.2 Analog and Digital Circuits

(1) Analog

Analog quantities vary continuously, and analog systems represent the analog information using electrical signals that vary smoothly and continuously over a range. A good example of an analog system is the recording thermometer, the actual equipment is shown in Fig. 1.6.

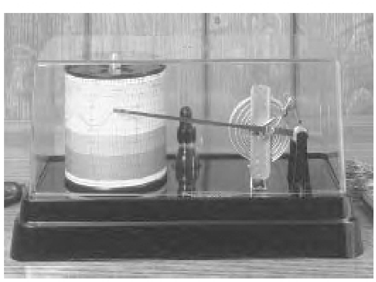


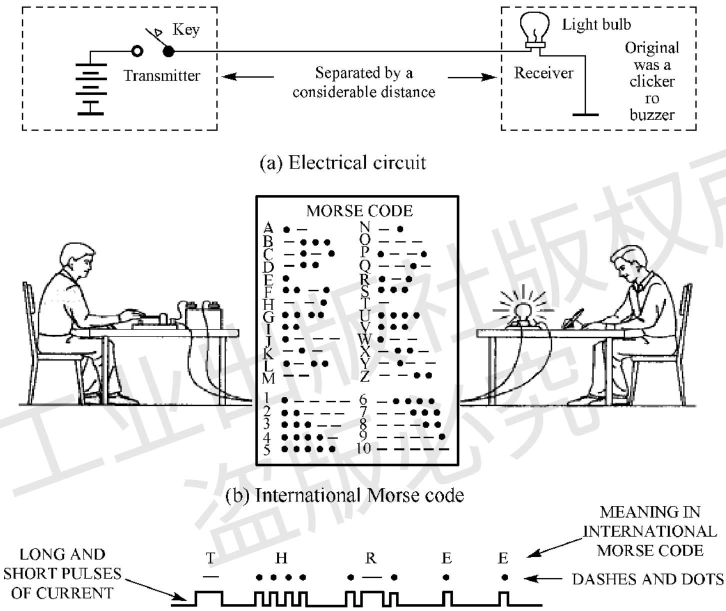
Fig.1.6 An example of an analog system — a recording thermometer

An ink pen records the temperature in degrees Fahrenheit (ºF) and plots it continuously against time on a special graph paper attached to a drum as the drum rotates. Note that the temperature changes smoothly and continuously. There are no abrupt steps or breaks in the data.

(2) Digital

Digital quantities vary in discrete levels. In most cases, the discrete levels are just two values—ON and OFF. Digital systems carry information using combinations of ON-OFF electrical signals that are usually in the form of codes that represent the information.① The telegraph system is an example of a digital system.

The system shown in Fig.1.7 is a simplified version of the original telegraph system, but it will demonstrate the principle and help to define a digital system.



(a) Electrical circuit
(b) International Morse code
(c) Digital information

Fig.1.7 A digital telegraph system

The electrical circuit (as shown in Fig.1.7(a)) is a battery with a switch in the line at one end and a light bulb at the other. The person at the switch position is remotely located from the person at the light bulb. The information is transmitted from the person at the switch position to the person at the light bulb by coding the information to be sent using the international Morse telegraph code.

Morse code uses short pulses (dots) and long pulses (dashes) of current to form the code for letters or numbers as shown in Fig.1.7(b). As shown in Fig.1.7(c), combining the codes of dots and dashes for the letters and numbers into words sends the information. **The sender keeps the same shorter time interval between letters but a longer time interval between words. This allows the receiver to identify that the code sent is a character in a word or the end of a word itself. The T is one dash (one long current pulse). The H is four short dots (four short current pulses). The R is a dot-dash-dot, and the two Es are a dot each. The two states are ON and OFF—current or**

no current.[2] The person at the light bulb position identifies the code by watching the glow of the light bulb. In the original telegraph, this person listened to a buzzer or "sounder" to identify the code.

Coded patterns of changes from one state to another as time passes carry the information. At any instant of time the signal is either one of two levels. The variations in the signal are always between set discrete levels, but, in addition, a very important component of digital systems is the timing of signals. **In many cases, digital signals, either at discrete levels, or changing between discrete levels, must occur precisely at the proper time or the digital system will not work. Timing is maintained in digital systems by circuits called system clocks. This is what identifies a digital signal and the information being processed in a digital system.** [3]

(3) Quantities

The temperature, pressure, humidity and wind velocity in our environment all change smoothly and continuously, and in many cases, slowly. Instruments that measure analog quantities usually have slow response and less than high accuracy. **To maintain an accuracy of 0.1% or 1 part in 1000 is difficult with an analog instrument.**[4]

Digital quantities, on the other hand, can be maintained at very high accuracy and measured and manipulated at very high speed. The accuracy of the digital signal is in direct relationship to the number of bits used to represent the digital quantity. For example, using 10 bits, an accuracy of 1 part in 1024 is assured. **Using 12 bits gives four times the accuracy (1 part in 4096), and using 16 bits gives an accuracy of 0.0015%, or 1 part in 65 536.**[5] This accuracy can be maintained as digital quantities are manipulated and processed very rapidly, millions of times faster than analog signals.

As a result, if analog quantities are required to be processed and manipulated, the new design technique is to first convert the analog quantities to digital quantities, process them in digital form, reconvert the result to analog signals and output them to their destination to accomplish a required task. The complete procedure is indicated in Fig.1.8, and the need for analog circuits, digital circuits and the conversion circuits between them is immediately apparent.

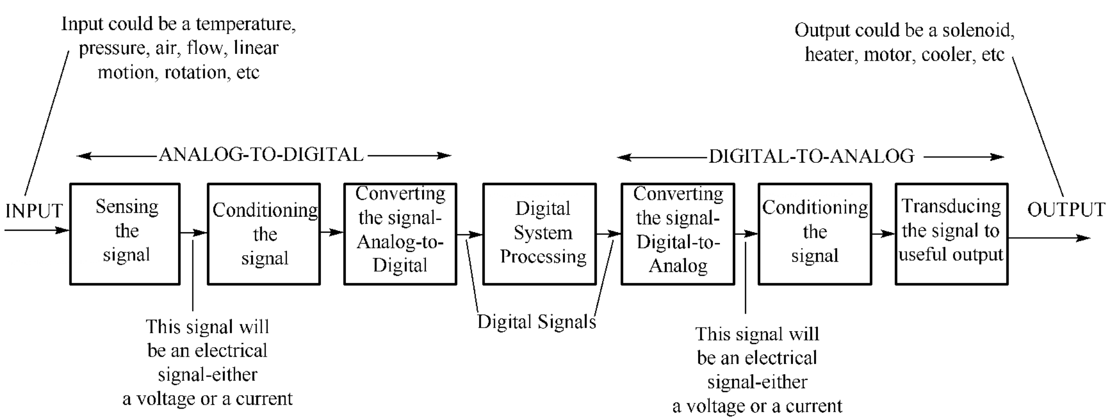


Fig.1.8 A typical system describing the functions in the analog-to-digital and digital-to-analog chain

(4) Analog-to-Digital Conversion (A/D)

Fig.1.9 separates out the analog-to-digital portion of the Fig.1.8 chain to expand the basic functions in the chain. Most of nature's inputs such as temperature, pressure, humidity, wind velocity, speed, flow rate, linear motion or position are not in a form to input them directly to electronic systems. They must be changed to an electrical quantity—a voltage or a current—in order to interface to electronic circuits.

The basic function of the first block is called sensing. The components that sense physical quantities and output electrical signals are called sensors.

The sensor illustrated in Fig.1.9 measures pressure. The output is in millivolts and is an analog of the pressure sensed. An example of output plotted against time is shown.

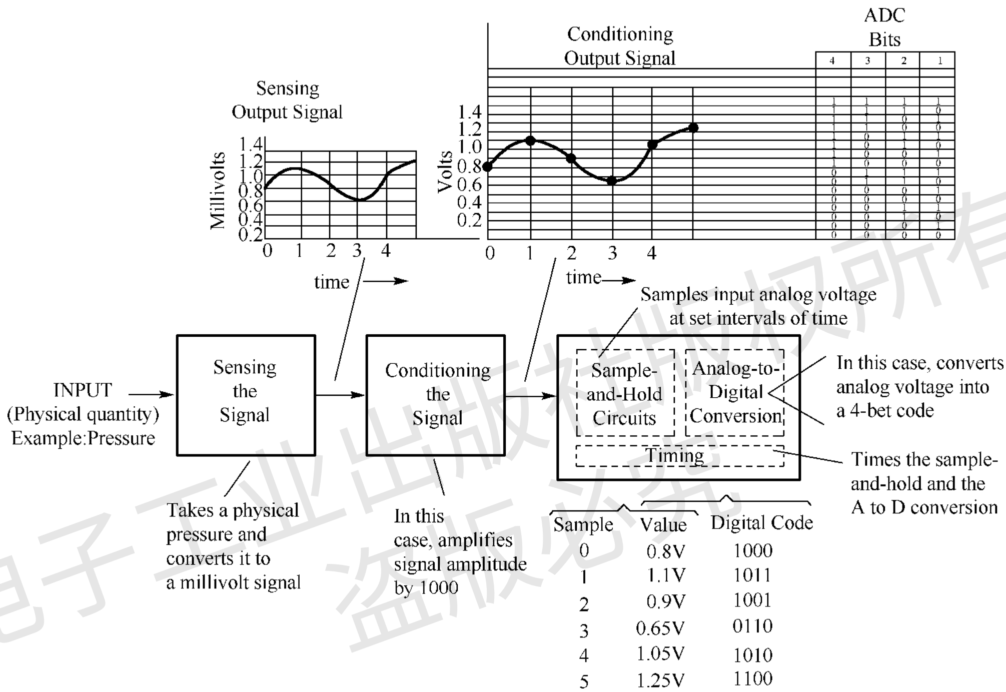


Fig.1.9 The basic functions for analog-to-digital conversion

One of the earliest analog-to-digital converters (ADCs) was the counting ADC shown in Fig.1.10. It is made up of a binary counter that counts pulses from a central clock. The counters binary output is fed to two units—a digital-to-analog converter (DAC) and a latch. Each unit has the number of input or output bit lines to cover the number of bits required from the ADC. Notice the DAC in the loop. This is the reason that the discussion of the DAC came first. The binary code input to the DAC produces an analog voltage that feeds one input of a comparator. The analog input voltage to be converted to a digital output is the other comparator input. When the input from the DAC is lower than the analog input, the comparator will be a high voltage (a digital 1); when the input from the DAC is equal to or greater than the analog input, the comparator output is a low voltage (a digital 0). **When the comparator output changes from a high voltage to a low voltage, it triggers the latch to latch in the binary values from the bit lines of the counter. Thus, the output of the latch is the binary code matching the value of the input analog voltage.** ⑥

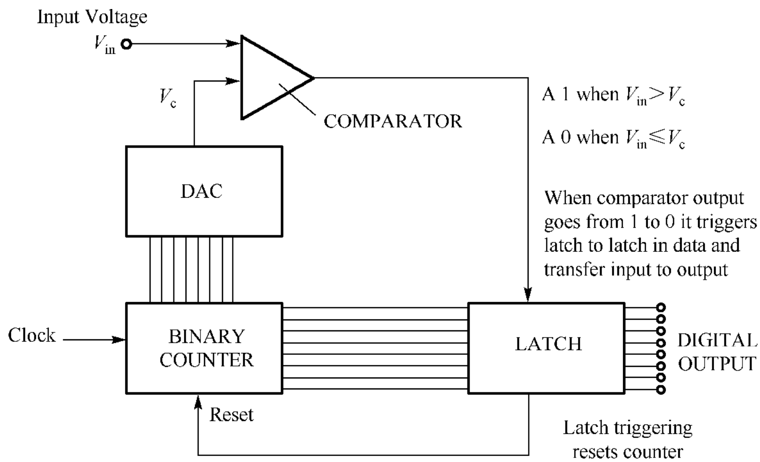


Fig.1.10 A 8-bit counting ADC

(5) Digital-to-Analog Conversion (D/A)

Fig.1.11 illustrates the basic digital-to-analog function. The digital processing system outputs digital information in the form of digital codes, and as shown, the digital codes are usually presented to the input of the digital-to-analog converter in one of two ways.

The first way—parallel bit transfer—means that all bits of the digital code are outputted at the same time.

In Fig.1.11, a 4-bit code is used as an example. The 4-bit codes are coupled out in sequence as they are processed by the digital processor. They arrive at a preset data interval. In Fig.1.11, the 4-bit code 1000 is outputted first, followed by 1011, 1001, 0110, 1010, and 1100, respectively.

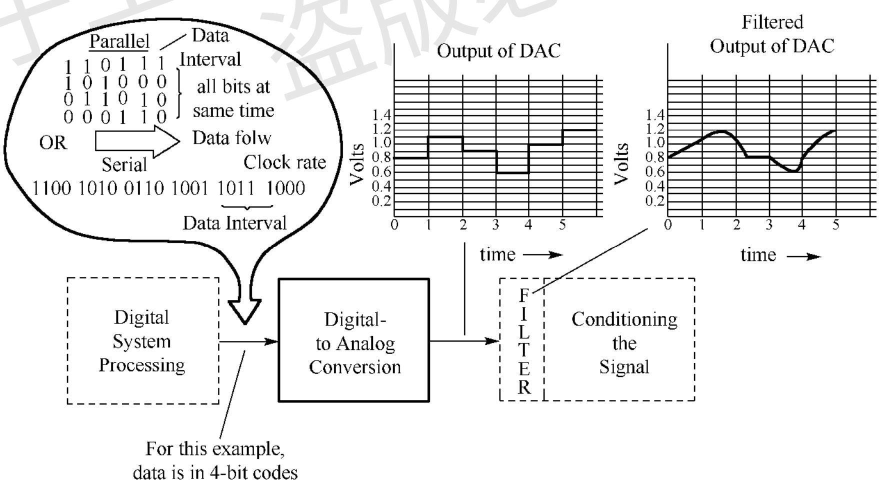


Fig.1.11 The basic function of digital-to-analog conversion

The digital-to-analog converter accepts all bits at the same time. It must have four input lines, the same number of input lines as the 4-bit codes. In most modern day digital-to-analog converters the 4-bit codes of Fig.1.11 are really 8-bit, or most likely 16-bit codes.

The second way is serial transfer of data. As shown in Fig.1.11, the 4-bit codes are outputted one bit at a time, each following the other in sequence, and each group of four bits following each other in sequence. A clock rate determines the rate at which the bits are transferred. The digital-to-analog converter accepts the bits in sequence and reassembles them into the respective bit groups and then acts on them.

One of the simplest DACs, from a circuit standpoint, is the resistor- string DAC. $2n-1$ resistors of equal value are interconnected from a reference voltage, V_{REF} to ground. The outputs from the resistor string are fed to a decoder. The decoder closes the appropriate switch dictated by the input digital code. A resistor-string for a 4-bit DAC is shown in Fig.1.12.

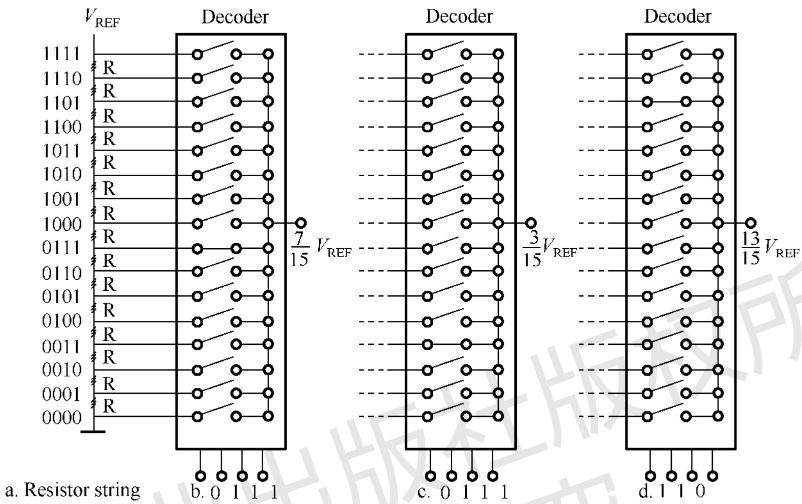


Fig.1.12 Decoder for resistor string

The first position of the string is for zero volts. The next position has a voltage:

$$V=\frac{R}{15R}\times V_{REF} \quad \text{or} \quad V=\frac{V_{REF}}{15} \tag{1.10}$$

or for any string, since it is the number 1 position:

$$V_1=\frac{1}{2^n-1}\times V_{REF} \tag{1.11}$$

where n = bits in digital code.

The next position, position 2, has a voltage:

$$V_2=\frac{2R}{15R}\times V_{REF} \quad \text{or} \quad V_2=\frac{2}{15}\times V_{REF} \tag{1.12}$$

or for position 2 for any string:

$$V_2=\frac{2}{2^n-1}\times V_{REF} \tag{1.13}$$

The position one removed from V_{REF} has a voltage:

$$V_{14}=\frac{14}{2^n-1}\times V_{REF} \tag{1.14}$$

New Words and Expressions

analog	*n*. 类似物；模拟
digital	*adj*. 数字的；数位的 *n*. 数字；数字式
thermometer	*n*. 温度计；体温计
Fahrenheit	*adj*. 华氏温度计的 *n*. 华氏温度计
drum	*n*. 鼓；鼓声；鼓形圆桶 *vi*. 击鼓；作鼓声 *vt*. 打鼓奏
discrete	*adj*. 不连续的；离散的
original	*adj*. 最初的；原始的；独创的；新颖的 *n*. 原物；原作
remote	*adj*. 遥远的；偏僻的；细微的
bulb	*n*. 鳞茎；球形物
Morse code	莫尔斯电码
pulse	*n*. 脉搏；脉冲
buzzer	*n*. 嗡嗡作声的东西；蜂鸣器；信号手
manipulate	*vt*.（熟练地）操作；使用（机器等）；操纵（人或市价、市场）；利用；应付
destination	*n*. 目的地；[计]目的文件；目的单元格
humidity	*n*. 湿气；潮湿；湿度
interface	*n*. 接触面；界面
comparator	*n*. 比较仪
trigger	*vt*. 引发；引起；触发 *vi*. 转移；换车 *n*. 扳机
sequence	*n*. 次序；顺序；序列
parallel	*adj*. 平行的；相同的；并联的 *n*. 平行线；平行面；类似 *v*. 相应；平行
serial	*adj*. 连续的；串行的；顺次
decoder	*n*. 解码器
reassemble	*vt*. 重新召集 *vi*. 重新集合

Notes

① Digital quantities vary in discrete levels. In most cases, the discrete levels are just two values—ON and OFF. Digital systems carry information using combinations of ON-OFF electrical signals that are usually in the form of codes that represent the information.

译文：数字量是离散变化的。在大多数情况下，离散信号只有两种状态：导通和截止。数字系统通过导通和截止的电信号组合来表示信息，通常以编码的形式反映出来。

解析：第一句中，主语是 Digital quantities，指“数字量”，谓语是 vary，状语部分是 in discrete levels。第二句中，the discrete levels 是主语，just two values—ON and OFF 是表语。第三句中，Digital systems 是主语，in the form of codes 是表语，that represent the information…是由 that 引导的定语从句。

② The sender keeps the same shorter time interval between letters but a longer time interval between words. This allows the receiver to identify that the code sent is a character in a word or the end of a word itself. The T is one dash (one long current pulse). The H is four short dots (four short current pulses). The R is a dot-dash-dot. And the two Es are a dot each. The two states are ON and OFF—current or no current.

译文：发送者在字母之间保持着相同的较短时间间隔，而在词之间保持较长时间间隔。这就使接收者能分辨出传送码是一个词中的字符，还是一个单词本身的结束。T 是一个破折号（一个长电流脉冲）。H 是 4 个短点（4 个短电流脉冲）。R 是点-破折号-点的组合。两个 E 时，则一个点代表一个 E。高低两种状态表示导通和截止，即有电流和无电流。

解析：第一句的主语是 The sender，谓语是 keeps，宾语是 the same shorter time interval between letters but a longer time interval between words；第二句中的主语是 This，指代首句内容，谓语是 allows，宾语是 the receiver，指“接收者”，to identify that the code sent is a character in a word or the end of a word itself 为宾语补足语。

③ In many cases, digital signals, either at discrete levels, or changing between discrete levels, must occur precisely at the proper time or the digital system will not work. Timing is maintained in digital systems by circuits called system clocks. This is what identifies a digital signal and the information being processed in a digital system.

译文：在许多情况下，数字信号，无论是在离散电平，还是在离散电平间变化，都必须准确地发生在合适的时间，否则数字系统将无法正常工作。通过被称为系统时钟的电路来维持数字系统的计时。这就是在数字系统中识别数字信号和处理数字信息。

解析：第一句的主语是 digital signals, 指数字信号，either at discrete levels, or changing between discrete levels 为插入语，must occur precisely 为谓语，at the proper time 为状语；or 表示否则，后接另外一个句子，其主语是 the digital system，谓语部分是 will not work；第二句的主语是 Timing，指时钟，谓语部分是 is maintained，为被动语态，状语是 digital systems，by circuits；called system clocks 为主语补足语；在第三句中，what 指代的是 this，而 this 指代的是前面的一句话内容。

④ To maintain an accuracy of 0.1% or 1 part in 1000 is difficult with an analog instrument.

译文：在使用模拟量仪器进行测量时，要维持 0.1%或 1‰的误差是很困难的。

解析：主语是 To maintain an accuracy of 0.1% or 1 part in 1000，指维持 0.1%或 1‰的误差；is difficult 为系表结构，with an analog instrument 为方式状语。

⑤ Using 12 bits gives four times the accuracy (1 part in 4096), and using 16 bits gives an accuracy of 0.0015%, or 1 part in 65 536.

译文：使用 12 进位时，精度是其 4 倍（1/4096），而使用 16 进位的精度则是 0.0015%（或 1/65 536）。

解析：主语是 Using 12 bits，谓语是 gives，宾语是 four times the accuracy；and 连接一个并列的句子，主语是 using 16 bits，谓语是 gives，宾语是 an accuracy of 0.0015%, or 1 part in 65 536。

⑥ When the comparator output changes from a high voltage to a low voltage, it triggers the latch to latch in the binary values from the bit lines of the counter. Thus, the output of the latch is the binary code matching the value of the input analog voltage.

译文：当比较器的输出从高电压到低电压变化时，它触发锁存器锁存从该计数器位线来的二进制数值。因此，锁存器的输出是与输入模拟电压值相匹配的二进制代码。

解析：第一句中，when 引导时间状语从句，从句的主语是 the comparator output，谓语是 changes，状语是 from a high voltage to a low voltage；主句中，it 代替的是前面的 the comparator output，谓语是 triggers，宾语是 the latch，不定式动词词组 to latch in the binary values 作宾语补足语，from the bit lines of the counter 作状语；第二句中，Thus 为连接词，the output of the latch 是主语，matching the value of the input analog voltage 作定语，修饰前面的宾语 the binary code。

1.3 Three-Phase Circuits

Most of the electrical power generated in the world today is three-phase. Three-phase power was first conceived by Nikola Tesla. **In the early days of electric power generation, Tesla not only led the battle concerning whether the nation should be powered with low-voltage direct current or high-voltage alternating current, but he also proved that three-phase power was the most efficient way that electricity could be produced, transmitted, and consumed.** [1]

There are several reasons why three-phase power is superior to single-phase power.

1) **The horsepower rating of three-phase motors or the kVA (kilo-voltamp) rating of three-phase transformers is about 150% greater than for single-phase motors or transformers with a similar frame size.** [2]

2) The power delivered by a single-phase system pulsates, as shown in Fig.1.13. The power falls to zero three times during each cycle. The power delivered by a three-phase circuit pulsates also, but it never falls to zero, as shown in Fig.1.14. In a three-phase system, the power delivered to the load is the same at any instant. This produces superior operating characteristics for three-phase motors.

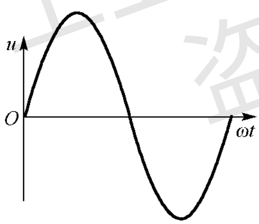


Fig.1.13 Single-phase power falls to zero three times each cycle

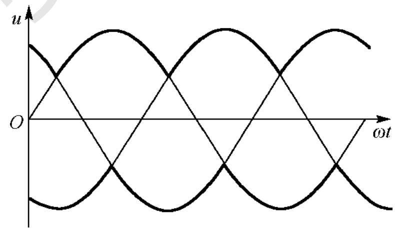


Fig.1.14 Three-phase power never falls to zero

3) In a balanced three-phase system, the conductors need be only about 75% the size of conductors for a single-phase two-wire system of the same kVA rating. This helps offset the cost of supplying the third conductor required by three-phase systems.

A single-phase alternating voltage can be produced by rotating a magnetic field through the conductors of a stationary coil, as shown in Fig.1.15.

Since alternate polarities of the magnetic field cut through the conductors of the stationary coil, the induced voltage will change polarity at the same speed as the rotation of the magnetic field. The alternator shown in Fig.1.15 is single phase because it produces only one AC voltage.

If three separate coils are spaced 120° apart, as shown in Fig.1.16, three voltages 120° out of phase with each other will be produced when the magnetic field cuts through the coils. This is the manner in which a three-phase voltage is produced. There are two basic three-phase connections, the wye-or star-connection and the delta connection.

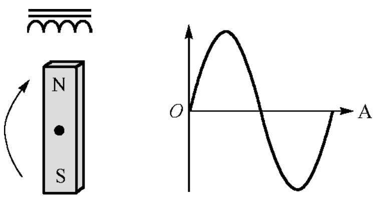


Fig.1.15 Producing a single-phase voltage

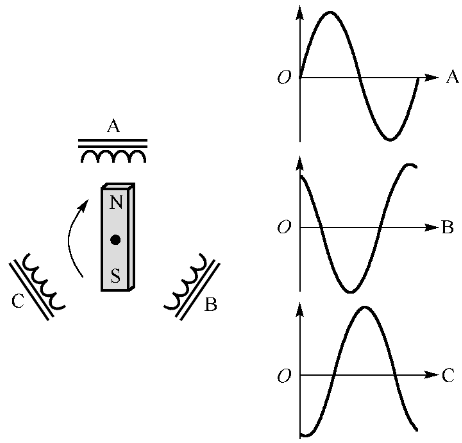


Fig.1.16 The voltages of a three-phase system are 120 ° out of phase with each other

(1) Wye-Connection

The wye-connection is made by connecting one end of each of the three-phase windings together as shown in Fig.1.17. The voltage measured across a single winding or phase is known as the phase voltage. The voltage measured between the lines is known as the line-to-line voltage or simply as the line voltage, as shown in Fig.1.18.

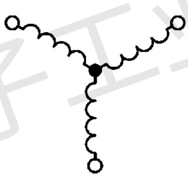


Fig.1.17 A wye-connection

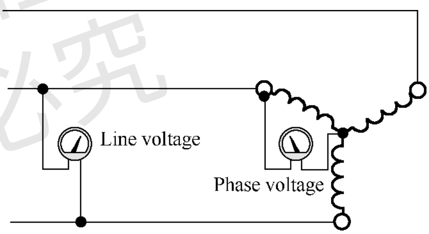


Fig.1.18 Line and phase voltages are different in a wye connection

In Fig.1.19, ammeters have been placed in the phase winding of a wye-connected load and in the line supplying power to the load. Voltmeters have been connected across the input to the load and across the phase. A line voltage of 208V has been applied to the load. Notice that the voltmeter connected across the lines indicates a value of 208V, but the voltmeter connected across the phase indicates a value of 120V.

In a wye-connected system, the line voltage is higher than the phase voltage by a factor of the square root of 3 (1.732). ③ Two formulas used to compute the voltage in a wye-connected system are:

$$E_{\text{Line}} = E_{\text{Phase}} \cdot \sqrt{3} \tag{1.15}$$

or

$$E_{\text{Phase}} = -\frac{E_{\text{Line}}}{\sqrt{3}} \tag{1.16}$$

Notice in Fig.1.19 that 10A of current flow in both the phase and the line. In a wye-connected system, phase current and line current are the same.

$$I_{\text{Line}} = I_{\text{Phase}} \tag{1.17}$$

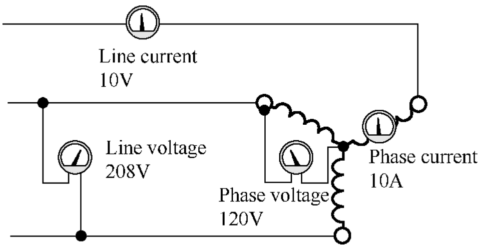


Fig.1.19 Line current and phase current are the same in a wye connection

(2) Voltage Relationships in A Wye-Connection

Many students of electricity have difficulty at first understanding why the line voltage of the wye-connection used in this illustration is 208V instead of 240V. Since line voltage is measured across two phases that have a value of 120V each, it would appear that the sum of the two voltages should be 240V. One cause of this misconception is that many students are familiar with the 240V/120V connection supplied to most homes. If voltage is measured across the two incoming lines, a voltage of 240V will be seen. If voltage is measured from either of the two lines to the neutral, a voltage of 120V will be seen. The reason for this is that this is a single-phase connection derived from the center tap of a transformer, as shown in Fig.1.20. If the center tap is used as a common point, the two line voltages on either side of it will be 180° apart and opposite in polarity, as shown in Fig.1.21. The vector sum of these two voltages would be 240V.

Three-phase voltages are 120° apart, not 180°. If the three voltages are drawn 120° apart, it will be seen that the vector sum of these voltages is 208V, as shown in Fig.1.22.

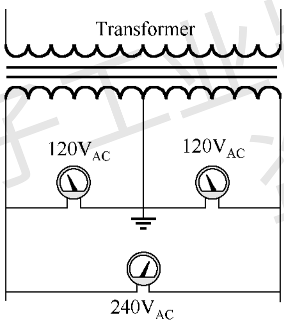


Fig.1.20 Single-phase transformer with grounded center tap

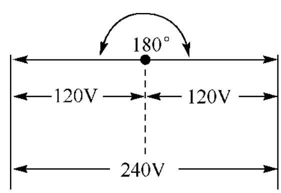


Fig.1.21 The voltages of a single-phase system are 180 ° out of phase with each other

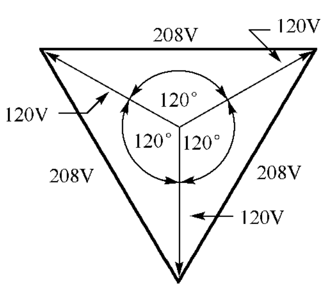


Fig.1.22 Vector sum of the voltages in a three-phase wye-connection

Another illustration of vector addition is shown in Fig.1.23. In this illustration, two-phase voltage vectors are added and the resultant is drawn from the starting point of one vector to the end point of the other. **The parallelogram method of vector addition for the voltages in a wye-connected three-phase system is shown in Fig.1.24.** [4]

(3) Delta Connection

In Fig.1.25, three separate inductive loads have been connected to form a delta connection. This connection receives its name from the fact that a schematic diagram of this connection resembles the Greek letter delta (Δ).

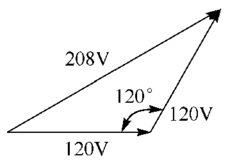


Fig.1.23 Adding voltage vectors of two-phase voltage values

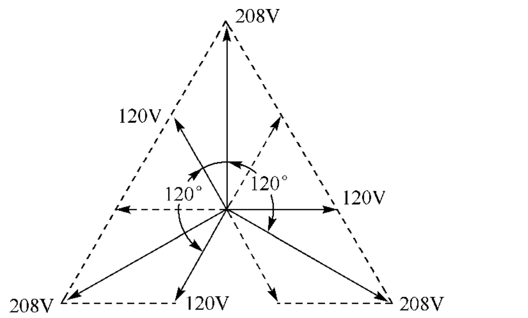


Fig.1.24 The parallelogram method of adding three-phase vectors

In Fig.1.26, voltmeters have been connected across the lines and across the phase. Ammeters have been connected in the line and in the phase. In the delta connection, line voltage and phase voltage are the same. Notice that both voltmeters indicate a value of 480V.

$$E_{\text{Line}} = E_{\text{Phase}} \tag{1.18}$$

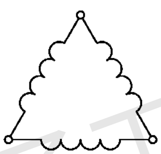


Fig.1.25 Three-phase delta connection

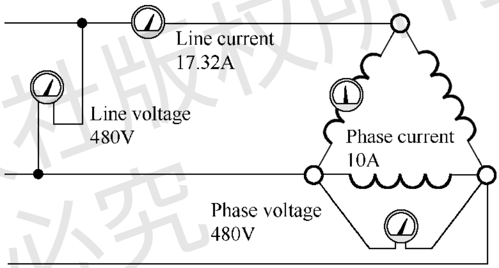


Fig.1.26 Voltage and current relationships in a delta connection

Notice that the line current and phase current are different, however. The line current of a delta connection is higher than the phase current by a factor of the square root of 3 (1.732). In the example shown, it is assumed that each of the phase windings has a current flow of 10A. The current in each of the lines, however, is 17.32A. The reason for this difference in current is that current flows through different windings at different times in a three-phase circuit. During some periods of time, current will flow between two lines only. At other times, current will flow from two lines to the third, as shown in Fig.1.27.

The delta connection is similar to a parallel connection because there is always more than one path for current flow. Since these currents are 120° out of phase with each other, vector addition must be used when finding the sum of the currents, as shown in Fig.1.28.

Formulas for determining the current in a delta connection are:

$$I_{\text{Line}} = I_{\text{Phase}} \cdot \sqrt{3} \tag{1.19}$$

or

$$I_{\text{Phase}} = \frac{I_{\text{Line}}}{\sqrt{3}} \tag{1.20}$$

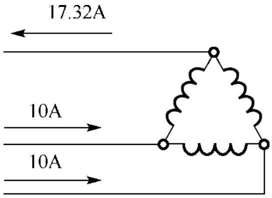


Fig.1.27 Division of currents in a delta connection

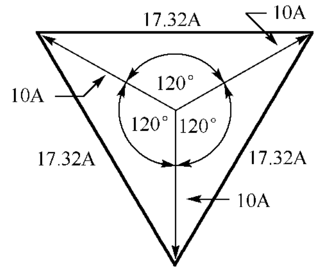


Fig.1.28 Vector addition is used to compute the sum of the currents in a delta connection

(4) Three-Phase Power

Students sometimes become confused when computing power in three-phase circuits. One reason for this confusion is that there are actually two formulas that can be used. If line values of voltage and current are known, the power (watts) of a pure resistive load can be computed using the formula:

$$VA = \sqrt{3} \cdot I_{\text{Line}} \cdot E_{\text{Line}} \tag{1.21}$$

If the phase values of voltage and current are known, the apparent power can be computed using the formula:

$$VA = 3 \cdot I_{\text{Phase}} \cdot E_{\text{Phase}} \tag{1.22}$$

Notice that in the first formula, the line values of voltage and current are multiplied by the square root of 3. In the second formula, the phase values of voltage and current are multiplied by 3. The first formula is used more often because it is generally more convenient to obtain line values of voltage and current, which can be measured with a voltmeter and clamp-on ammeter.

New Words and Expressions

transformer *n.* 变压器
single-phase 单相
pulsate *vi.* 脉动
three-phase power 三相电源
three-phase circuit 三相电路
the parallelogram method 平行四边形法
wye connection 星形连接
delta connection 三角形连接
phase voltage 相电压
line voltage 线电压
confuse *vt.* 使混乱；使更难于理解；使困窘；使困惑 *vi.* 使糊涂
voltmeter *n.* 电压表
ammeter *n.* 电流表
clamp-on ammeter 钳式安培计

Notes

① In the early days of electric power generation, Tesla not only led the battle concerning whether the nation should be powered with low-voltage direct current or high-voltage alternating current, but he also proved that three-phase power was the most efficient way that electricity could be produced, transmitted, and consumed.

译文：在出现电力发电早期，特斯拉不仅领导着决策其国家是否应该使用低压直流电或高压交流电的争论，而且他还证明了三相电源是电力生产、传输和消费最有效的方式。

解析：not only…but also…意为“不仅……而且……”, that electricity could be produced, transmitted, and consumed 为定语从句，修饰 the most efficient way。

② The horsepower rating of three-phase motors or the kVA (kilo-voltamp) rating of three-phase transformers is about 150% greater than for single-phase motors or transformers with a similar frame size.

译文：三相电动机的功率额定值和三相变压器的千伏安等级，比具有相似结构大小的单相电动机或变压器要大 150%左右。

解析：about 150% greater than 为比较级，意为“比……大 150%左右”。

③ In a wye-connected system, the line voltage is higher than the phase voltage by a factor of the square root of 3 (1.732).

译文：在一个星形连接系统中, 线电压比较高，它等于相电压乘以 3 的平方根（1.732)。

解析：本句中 the line voltage 为主语，is higher than the phase voltage 为系表结构作谓语，by a factor of the square root of 3 (1.732)为方式状语。

④ The parallelogram method of vector addition for the voltages in a wye-connected three-phase system is shown in Fig.1.24.

译文：如图 1.24 所示，在星形连接的三相系统中，电压的矢量和遵循平行四边形求矢量和法。

解析：本句中 The parallelogram method of vector addition 为主语，is shown 是被动语态作谓语。

1.4 Further Reading

Reading Amplifiers and Their Applications

(1) Operational Amplifiers

Integrated circuit manufacturers have provided an excellent product—the operational amplifier (op amp) — to designers of electronic circuits for signal conditioning sensor signals. Many types and varieties are available for a wide spectrum of applications. System designers that need amplification in their design need not design an individual amplifier circuit but can use an op amp instead.

The term “op amp” refers to a direct-coupled amplifier that was used initially in analog computers to perform mathematical computations, while solving real-time control system problems. Op amps are DC amplifiers that have high gain, high input impedance, low output impedance, and wide bandwidth. Another significant advantage is that the amplifier's characteristics can be varied using external components. Fig.1.29 describes a general-purpose op amp.

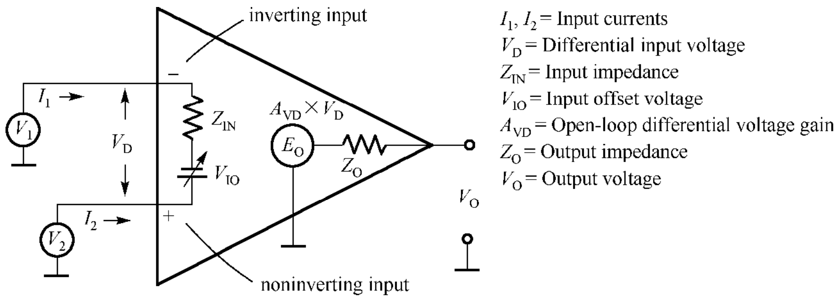


Fig.1.29 General-purpose operational amplifier

The amplifier has two inputs and one output. The amplifier output is normally a linear output voltage, V_o, that is proportional to the difference of the voltage between the two inputs. Thus, it is classified as a differential amplifier. The two inputs are identified with a minus and a plus sign. The input with the minus sign is called the inverting input; the input with the plus sign is the noninverting input. If the noninverting input is more positive than the inverting input, the output voltage, V_o, is positive with respect to ground. Conversely, if the inverting input is more positive than the noninverting input, V_o will be negative with respect to ground. When both inputs are referenced to ground, and the inverting input is more positive, V_o swings negative; when the non-inverting input is more positive, V_o swings positive.

In Fig.1.29. The output, V_o, can be represented by a generator, $E_o = A_{VD} \times V_D$, fed to the output through the output impedance, Z_o. E_o is the input differential signal, V_D, amplified by the open-loop differential gain, A_{VD}. Z_{IN} is the input impedance, and V_{IO} is the input offset voltage that causes the output voltage to be displaced from zero volts when there is no differential input signal. A_{VD} is usually a very large number (>20,000) in most modern day op amps; therefore, even a very small input signal drives the output into saturation. As a result, normal operation is with feedback from output to input to set the gain of the op amp at a particular value.

In Fig.1.30, a resistor, R, is connected from the output back to the inverting input to control the gain of the op amp with negative feedback.

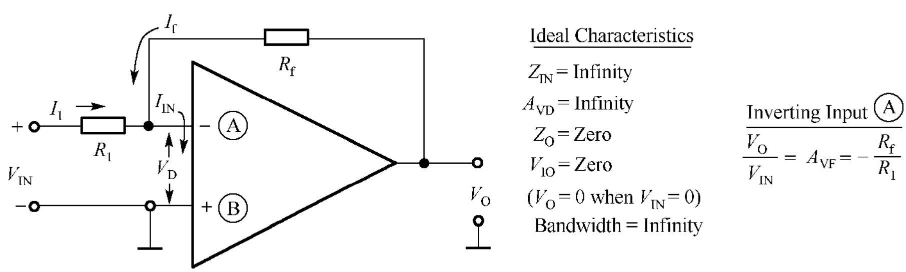


Fig.1.30 Op amp with negative feedback and signal to inverting input

If the output goes positive, as it would for an input signal on a going negative, a portion of the positive output signal is fed back to the input to cancel part of the input signal. In Fig.1.30, the ideal op amp characteristics are listed. One of these is Z_{IN} = infinity. As a result, $I_{IN} = 0$.

(2) Conditioning the Output of a Pressure Sensor

It is necessary to amplify the output signal from a pressure sensor in order to have a voltage great enough to input it to an analog-to-digital converter. A pressure sensor is connected to an op amp in Fig.1.31 that is acting as a difference amplifier. It is amplifying the difference voltage $V_2 - V_1$ identified as V_{IN} in Fig.1.31. There are specific requirements for the op amp to be a difference amplifier. The ratio R_3/R_2 must be equal to the ratio R_f/R_1. R_f/R_1 determines the differential gain. With R_f/R_1 equal to 20 for the circuit, R_3/R_2 must be 20. R_2 is 2kΩ; therefore, R_3 is 40kΩ. The reason that R_2 is 2kΩ is to have the input impedance to the sensing circuit, which is $R_1 + R_2$, as high as possible to keep from loading the pressure gauge bridge and causing inaccuracies. R_1 tends to be small to allow the gain to be high, but this keeps the input impedance low, which would load the circuit. There is a compromise here.

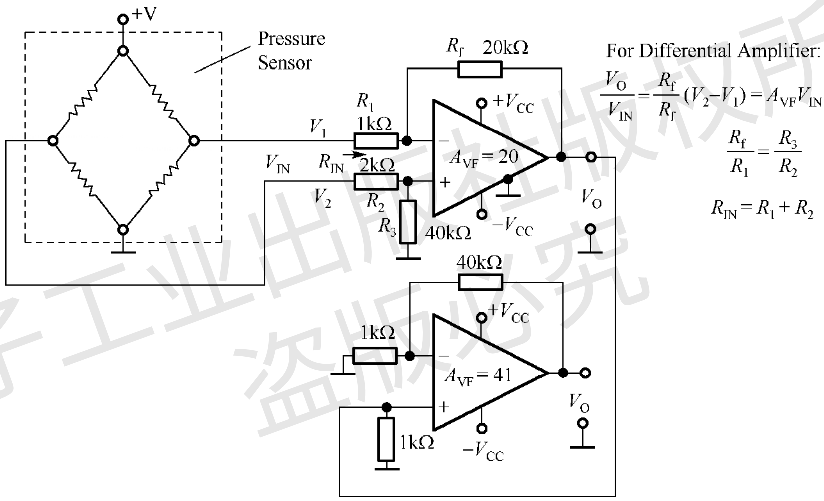


Fig.1.31 Amplifying a pressure-sensor output

The signal from the sensor is normally in millivolts (mV), and the input to the analog-to- digital converter needs to be 1V or more. If the input voltage is 2mV and the difference amplifier has a gain of 20, the output voltage will be $V_o = 20 \times 2 \times 10^{-3} = 40$mV. More amplification is needed. Another op amp with the signal fed to the noninverting input is added with a gain of 41. Its output voltage will be $V_o = 41 \times 40 \times 10^{-3} = 1.64$V.

Op amps are manufactured with dual circuits in a package; therefore, only one IC is used. The power supply voltages (plus and minus) are chosen for the convenience of the application. There are many op amps that operate from 3~4V to 20V.

One problem with instrumentation amplifier circuits such as Fig.1.31 is that the signal output from the sensor is very small, but the noise voltage picked up on the leads connecting the sensor to the amplifier may be 100 to 1000 times greater.

An op amp with a high common-mode rejection must be chosen for such applications.

Common-mode rejection means that any signal appearing on both inputs at the same time will not appear at the output.

Only the differential signals will be amplified. Common-mode rejection ratio is:

$$\text{CMRR} = A_{\text{VD}}/A_{\text{CM}} \tag{1.23}$$

where A_{VD} is the differential gain and A_{CM} the common-mode gain. In decibels:

$$\text{CMRR}_{\text{dB}} = 20\log_{10}A_{\text{VD}}/A_{\text{CM}} \tag{1.24}$$

Translation Methods and Skills of EST (English of Science and Technology)

——科技英语翻译方法与技巧：省略法

为了使译文更加严谨、精练、明确，翻译时往往可以省略原文中某些词语。

（一）省略冠词

一般说来，英语定冠词 the 和不定冠词 a 及 an 在句中用做泛指，常省略不译。另外，定冠词 the 用做特指，根据汉语表达习惯有时也可省略不译。

(1) Any substance is made up of atoms whether it is a solid，a liquid，or a gas．任何物质，无论它是固体、液体或气体，都是由原子构成的。

(2) The atom is the smallest particle of an element. 原子是元素的最小粒子。

(3) Other scientists，however，are afraid that the world may become too hot for human life. 而有些科学家则担心地球会升温，使人类无法生存。

(4) With the development of electrical engineering，power can be transmitted over long distance．随着电气工程学的发展，电力能被输送到非常遥远的地方去。

（二）省略代词

英语中表示泛指的人称代词、用做定语的物主代词、反身代词以及用于比较句中的指示代词英译汉时，根据汉语的表达习惯常可省略。

(1) If you know the frequency，you can find the wave length．如果知道频率，就能求出波长。

(2) Different metals differ in their conductivity．不同的金属具有不同的导电性能。

(3) When the signal we pick up has increased by 10 times as the gain may have been reduced by 8 times．信号增大到 10 倍，增益降低到 1/8。

（三）省略连词

英语中连词使用频率较高，而英译汉时常可省略不译。

(1) This system is totally enclosed and prevents air pollution from dust particles or gases. 此系统为全封闭式，能防止尘粒或烟气污染大气。

(2) When the temperature is maintained constant，the volume of a given sample of gas varies inversely with the pressure. 在温度保持不变的情况下，一定气体的体积与压力成反比。

(3) Like charges repel each other while opposite charges attract. 同性电荷相斥，异性电荷相吸。

（四）省略动词

英语谓语必须用动词，汉语不仅可以用动词作谓语，还可以直接用名词、形容词、主谓词组等作谓语。因此，英译汉时往往可以省略原文的谓语动词，使译文通顺、简练。

(1) The wire gets hot，for the current becomes too great. 电线发热，因为电流太大。

(2) Aluminum alloy has low specific electrical resistance and high thermal conductivity. 铝合金的电阻很低，而导热性很强。

(3) Evidently semiconductors have a lesser conducting capacity than metals. 显然，半导体的导电能力比金属差。

（五）省略介词

英语中介词使用频率较高，句中词与词之间的关系多用介词来表示，而汉语主要是通过语序与逻辑关系来表示。因此，英译汉时常可省略不译。

(1) In the transmission of electric power a high voltage is necessary. 远距离输电必须用高压。

(2) The instrument has worked well for six hours. 这台仪器已经正常工作了 6 小时。

(3) The density of air varies directly as pressure，with temperature being constant. 温度不变，空气的密度和压力成正比。

（六）省略引导词

英语中的两个引导词“it”和“there”，英译汉时一般省略不译。

(1) It is the gravitation which makes the satellites move round the earth. 地球引力使卫星绕地球运行。

(2) There are many kinds of atoms，differing in both mass and properties. 原子种类很多，质量与性质都不相同。

(3) There is a rapidly increasing range of uses for electronic computers. 电子计算机的应用范围正在迅速扩大。

（七）省略同义词或近义词

英语中有些同义词或近义词往往可以连用，或者表示强调，使意思更加明确；或者表示一个名称的不同说法。在英译汉时，往往省略其中一个词语。

(1) The mechanical energy can be changed back into electrical energy by means of a generator or dynamo. 利用发电机可以把机械能转变成电能。

(2) Insulators in reality conduct electricity but，nevertheless，their resistance is very high. 绝缘体实际上也导电，但其电阻很高。

(3) Most electricity still comes from fossil fuels，and so generates the greenhouse gas，carbon dioxide. 大部分电力仍来自于化石燃料，从而产生了温室气体二氧化碳。

Exercises

I. Determine the number of branches and nodes in the circuit shown in Fig.1.32. Identify which elements are in series and which are in parallel.

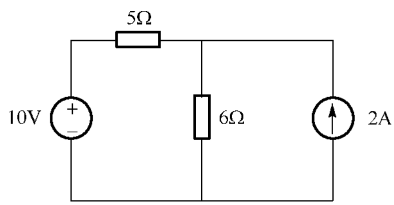


Fig.1.32 A circuit

II. Translate the following sentences into Chinese.

(1) An ac voltage source *V* in series with an impedance *Z* can be replaced with an ac current source of value $I=V/Z$ in parallel with the impedance *Z*.

(2) Although current and voltage are the two basic variables in an electric circuit, they are not sufficient by themselves. For practical purposes, we need to know how much power an electric device can handle.

(3) In any linear circuit containing multiple independent sources, the current or voltage at any point in the network may be calculated as the algebraic sum of the individual contributions of each source acting alone.

(4) A 16-bit code can represent 65 536 quantities. The first bit at the right edge of the code is called the least significant bit (LSB). The left-most bit is called the most significant bit (MSB).

(5) Since an 8-bit code can represent 256 segments, its codes for the same analog value are shown with the maximum analog signal of 1.5V equal to 255. Notice that the 8-bit code is two groups of 4-bit codes, which are also expressed in hexadecimal form.

(6) After the digital processing system completes its manipulation of the signal, the output digital codes are coupled to a digital-to-analog converter that changes the digital codes back to an equivalent analog signal.

III. Translate the following sentences into English.

(1) 电子电路通常可以被归类为模拟电路、数字电路或混合信号电路（模拟电路和数字电路的组合）。

(2) 有源元件能产生能量，而无源元件不能。

(3) 数/模转换之后所需的一个基本功能是滤波。

(4) 第一种方式——并行位转移意味着数字代码的所有位在同一时间输出。

(5) 由数/模转换器接收到的数字代码等于一个特定的模拟值。