Lesson 1 Introduction to Electronic Communications

1.1 Historical Perspective

The fundamental purpose of an electronic communication system is to transfer information[1] from one place to another. Thus, electronic communications can be summarized[2] as the transmission, reception, and processing of information between two or more locations using electronic circuits. The original source information can be in analog[3] (continuous) form, such as the human voice or music, or in digital (discrete) form, such as binary-coded numbers or alphanumeric codes. All forms of information, however, must be converted to electromagnetic energy before being propagated through an electronic communications system.

Samuel Morse developed the first electronic communications system in 1837. Morse used electromagnetic induction to transfer information in the form of dots, dashes, and spaces between a simple transmitter and receiver using a transmission line consisting of a length of metallic wire. He called his invention the telegraph. In 1876 Alexander Graham Bell and Thomas A. Watson were the first successfully transfer human conversation over a crude metallic wire communications system thy called the telephone.

Guglielmo Marconi successfully transmitted the first wireless radio signals through Earth's atmosphere in 1894, and in 1908 Lee DeForest invented the triode vacuum tube which provided the first practical means of amplifying electrical signals. Commercial radio began in 1920 when radio stations began broadcasting amplitude-modulated (AM) signals, and in 1933, Major Edwin Howard Armstrong invented frequency modulation (FM). Commercial broadcasting of FM began in 1936.

Although the fundamental concepts and principles of electronic communications have changed little since their inception, the methods and circuits used to implement them have undergone considerable change. In recent years, transistors and linear integrated circuits have simplified the design of electronic communications circuits, thus allowing for[4] miniaturization, improved performance and reliability, and reduced overall costs, In recent years, there has been an overwhelming need for[5] more and more people to communicate with each other. This tremendous need has stimulated a monumental growth in the electronic communications industry[6]. Modern electronic communications systems include metallic cable systems, microwave and satellite radio systems, and optical fiber systems.

A time chart showing the historical development of communications is given in Table 1-1. The reader is encouraged to spend some time studying this table to obtain appreciation for the chronology of communications. Note that although the telephone was developed late in the nineteenth century, the first transatlantic telephone cable was not completed until 1954.

Previous to this date, transatlantic calls were handled via shortwave radio. Similarly, although the British began television broadcasting in 1936, transatlantic television relay was not possible until 1962 when the Telstar Ⅰ satellite was placed into orbit. Digital transmission system—embodied by telegraph systems—were developed in the 1850s before analog systems—the telephone—in the twentieth century[7].

Table 1-1　Important dates in communications

Year	Event
Before 3000 B. C	Egyptians develop a picture language called hieroglyphics
A D. 800	Arabs adopt our present number system from India
1440	Johannes Gutenberg invents movable metal tape
1752	Benjamin Franklin's kite shows that lightning is electricity
1827	Georg Simon Ohm formulates his law ($I=E/R$)
1834	Carl F. Gauss and Ernst H. Weber build the electromagnetic telegraph
1838	Williams F. Cooke and Sir Charles Wheatstone build the telegraph
1844	Samuel F. B. Morse demonstrates the Baltimore and Washington, DC. telegraph line
1850	Gustav Robert Kirchhoff first publishes his circuit laws
1858	The first transatlantic cable is laid, and fails after 26 days
1864	James C. Maxwell predicts electromagnetic radiation
1871	The Society of Telegraph Engineers is organized in London
1876	Alexander Graham Bell develops and patents the telephone
1883	Thomas Edison discovers flow of electrons in a vacuum tube
1884	The American Institute of Electrical Engineers (AIEE) is formed
1887	Heinrich Hertz verifies Maxwell's theory
1900	Guglielmo Marconi transmits the first transatlantic wireless signal
1905	Reginald Fessenden transmits speech and music by radio
1906	Lee de Forest invents the vacuum-tube triode amplifier
1915	Bell System completes a U. S. transcontinental telephone line
1918	Edwin H. Armstrong invents the superheterodyne receiver circuit
1920	The first scheduled radio broadcasting J. R. Carson applies sampling to communications
1926	U. S demonstrates television
1927	Harold Black develops the negative-feedback amplifier at Bell Laboratories
1931	Teletypewriter service is initiated
1933	Edwin H. Armstrong invents FM
1935	Robert A. Watson-Watt develops the first practical radar
1936	The British Broadcasting Corporation (BBC) begins the first TV broadcasting
1937	Alex Reeves conceives pulse code modulation (PCM)
1941	John V. Atanasoff invents the computer at Iowa State College
1945	ENIAC electronic digital computer is developed at University of Pennsylvania
1947	Brattain, Bardeen, and Shockley devise the transistor at Bell Laboratories Steve O. Rice develops statistical representation for noise at Bell Laboratories
1948	Claude E. Shannon publishes his work on information theory
1950	Time-division multiplexing is applied to telephony
1953	NTSC color TV is introduced in U. S.
1957	First Earth satellite, Sputnik Ⅰ, is launched by USSR
1958	A. L. Schawlow and C. H. Townes publish the principles of the laser Robert Noyce of Fairchild produces the fist silicon IC
1961	Stereo FM broadcasting begin in U. S.

Year	Event
1962	The first active satellite, Telstar Ⅰ, relays TV between U. S. and Europe
1963	Bell System introduces the touch-tone phone The Institute of Electrical and Electronic Engineers (IEEE) is formed
1963—1966	Error-correction codes and adaptive equalization are developed
1964	The electronic telephone switching system (No. 1 ESS) is placed into service
1965	The first commercial communications satellite, Early Bird, is launched
1968	Cable television systems are developed
1971	Intel Corporation develops the first single-chip microprocessor, the 4004
1972	Motorola demonstrates the cellular telephone to the FCC
1976	Personal computer are developed
1979	64-KB random access memory ushers in the era of VLSI
1980	Bell System FT3 fiber optic communication is developed Compact disk is developed by Philips and Sony
1984	Macintosh computer is introduced by Apple
1985	FAX machines become popular
1989	"Pocket"cellular telephone is introduced by Motorola
1990—present	Era of digital signal processing with microprocessors, digital oscilloscopes, digitally tuned receivers, spread spectrum systems, ISDN, HDTV, digital satellite systems

1.2 Electronic Communications Systems

Communications Systems may be described by the block diagram shown in Figure 1-1. Regardless of the particular application, all communications systems involve three main subsystems: the transmitter, the channel, and the receiver. The message from the source is represented by the information input waveform $m(t)$. The message delivered to the sink is denoted by $\widetilde{m}(t)$. The [$\sim$] indicates that the message received may not be the same as that transmitted. That is the message at the sink may be corrupted by noise in the channel or there may be other impairments in the system, such as undesired filtering or undesired nonlinearities. The message information may be in analog or digital form, depending on the particular system, and it may represent audio, video, or some other type information. In multiplexed systems[8], there may be multiple input and output message sources and sinks. The spectra (or frequencies) of $m(t)$ and $\widetilde{m}(t)$ are concentrated about $f=0$; consequently, they are said to be baseband signals.

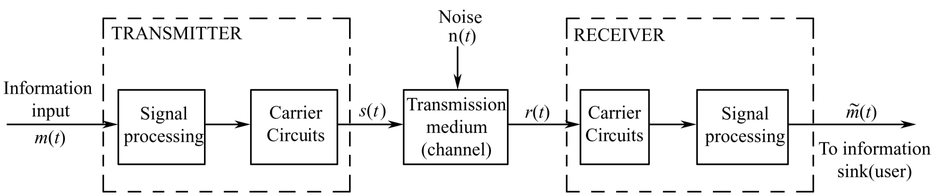

Figure 1-1 Communication system

The signal-processing block at the transmitter conditions the source for more efficient transmission[9]. For example, in an analog system, the signal processor may be an analog low-pass filter that is used to restrict the bandwidth of $m(t)$. In a hybrid system, the signal processor may be an analog-to-digital converter (ADC). This produces a "digital word" that represents samples of the analog input signal. In this case, the ADC in the signal processor is providing source coding of the input signal. In addition, the signal processor may also add parity bits[10] to the digital word to provide channel coding so that error detection and correction[11] can be used by the signal processor in the receiver to reduce or eliminate bit errors that are caused by noise in the channel. The signal at the output of the transmitter signal processor is a baseband signal because it has concentrated near $f=0$.

The transmitter carrier circuit converts the processed baseband signal into a frequency band that is appropriate for the transmission medium of the channel. For example, if the channel consists of a fiber optic cable, the carrier circuits convert the baseband input to light frequencies, and the transmitted signal $s(t)$ is light. If the channel propagates baseband signals, no carrier circuits are needed, and $s(t)$ can be output of the processing circuit at the transmitter. Carrier circuits are needed when the transmission channel is located in a band of frequencies around $f_c \gg 0$. In this case, $s(t)$ is said to be a bandpass because it is designed to have frequencies located in a band about f_c. For example, an amplitude modulated (AM) broadcasting station with an assigned frequency of 850 kHz has a carrier frequency of $f_c =$ 850 kHz. The mapping of the baseband input information waveform $m(t)$ into the bandpass signal $s(t)$ is called modulation.

1.3 The Electromagnetic Spectrum

In communication systems that use the atmosphere for the transmission channel, interference and propagation conditions are strongly dependent on the transmission frequency. Theoretically, any type of modulation (e.g., amplitude modulation, frequency modulation, single sideband, phase-shift keying, frequency-shift keying, etc.) could be used at any transmission frequency. However, to provide some semblance of order[12] and for political reasons, government regulations specify the modulation type, bandwidth, and type of information that can be transmitted over designed frequency bands.

On an international basis[13], frequency assignments and technical standards are set by the International Telecommunications Union (ITU). The ITU is a specialized agency of the United Nations, and the ITU administrative headquarters are located in Geneva, Switzerland, with a staff of 700 persons. This staff is responsible for administering the agreements that have been ratified by the 184 member nations of the ITU. In 1992, the ITU was restructured into three sectors. The Radio Communication Sector (ITU-R) provides frequency assignments and is concerned with efficient use of the radio frequency spectrum. The Telecommunications Standardization Section (ITU-T) examines technical, operating, and tariff questions. It recommends worldwide standards for the public telecommunications network (PTN) and related radio systems. The Telecommunication Development Sector (ITU-D) provides technical assistance, especially for developing countries. This encourages a full array[14] of telecommunication services to be economically provided and integrated into the worldwide telecommunication system. Before 1992, the ITU was organized into two main sectors: the International Telegraph and Telephone Consultative Committee (CCITT) and the International Radio Consultative Committee (CCIR).

Each member nation of the ITU retains sovereignty over the spectral usage and standards adopted in its territory. However, each nation is expected to abide by the overall frequency plan[15] and standards that are adopted by the ITU. Usually, each nation establishes an agency that is responsible for administration of the radio frequency assignments within its borders. In the United States, the FCC regulates and licenses radio systems for the general public, and state and local government. In addition, the National Telecommunication and Information Administration (NTIA) is responsible for U. S. government and U. S. military frequency assignments. The international frequency assignments are divided into subbands by the FCC to accommodate 70 categories of services and 9 million transmitters. Table 1-2 gives a general listing of frequency bands, their common designations, typical propagation conditions, and typical services assigned to these bands.

Table 1-2 FREQUENCY BANDS

Frequency Band	Designation	Propagation Characteristics	Typical Uses
3～30 kHz	Very low frequency (VLF)	Ground wave, low attenuation day & night, high atmospheric noise	Long-range navigation, submarine communication
30～300 kHz	Low frequency (LF)	Similar to VLF, slightly less reliable, absorption in daytime	Long-range navigation, marine communication, radio beacons
300～3000 kHz	Medium frequency (MF)	Ground wave and night sky wave, attenuation low at night and high in day, atmospheric noise	Maritime radio, direction finding, AM broadcasting
3～30 MHz	High frequency (HF)	Ionospheric reflection varies with time of day, season, frequency	Amateur radio, international broadcasting, military communication, telephone, telegraph, facsimile
30～300 MHz	Very high frequency (VHF)	Nearly line-of-sight (LOS) propagation, scattering, cosmic noise	TV, FM radio, AM aircraft communication, aircraft navigation
0.3～3 GHz	Ultra high frequency (UHF)	LOS propagation, cosmic noise	TV, cellular telephone, navigation, radar, microwave links, personal communication systems
3～30 GHz	Super high frequency (SHF)	LOS propagation, rainfall attenuation, atmospheric attenuation, high water vapor attenuation	Satellite communication, radar microwave links
30～300 GHz	Extremely high frequency (EHF)	LOS propagation, high water vapor attenuation, oxygen absorption	Radar, satellite, experimental
>1000 GHz	Infrared, visible light, ultraviolet	LOS propagation	Optical communication

1.4 Bandwidth and Information Capacity

The two most significant limitations on the performance of a communications system are noise and bandwidth. Noise will be discussed later. The bandwidth of an information signal is simply the difference between the highest and lowest frequencies contained in the information, and the bandwidth of a communications channel is the difference between the highest and lowest frequencies that the channel will allow to pass through it (i. e., its passband). The bandwidth of a communications channel must be large (wide) enough to pass all significant information frequencies. In other word, the bandwidth of the communications channel must be equal to or greater than the bandwidth of information. For example, voice frequencies contain signals between 300Hz and 3000 Hz. Therefore, a voice-frequency channel must have a bandwidth equal to or greater than 2700 Hz. If a cable television transmission system has a passband from 500 kHz to 5000 kHz, it has a bandwidth of 4500 kHz. As a general rule, a communications channel cannot propagate a signal that contains a frequency that is changing at a rate greater than the bandwidth of the channel.

Information theory is a highly theoretical study of the efficient use of bandwidth to propagate information through electronic communications systems. Information theory can be used to determine the information capacity of a communications system. Information capacity is a measure of how much information can be transferred through a communications system in a given period of time. The amount of information that can be propagated through a transmission system is a function of system bandwidth and transmission time. In 1920, R. Hartley of Bell Telephone Laboratories developed the relationship among bandwidth, transmission time, and information capacity. Hartley's law simply states that the wider the bandwidth and the longer the time of transmission, the more information that can be conveyed through the system. Mathematically, Hartley's law is stated as $I \propto B \cdot t$, where $I =$ information capacity, $B =$ system bandwidth (Hz), $t =$ transmission time (second). This equation shows that information capacity is a linear function and directly proportional to[16] both system bandwidth and transmission time. If the bandwidth of a communications channel doubles, the amount of information it can carry also doubles. If the transmission time increase or decrease, there is a proportional change in the amount of information that can be transferred through the system.

In general, the more complex the information signal, the more bandwidth required to transport it in a given period of time. Approximately 3 kHz of bandwidth is required to transmit voice-quality telephone signals. In contrast 200 kHz of bandwidth is allocated for commercial FM transmission of high-fidelity music, and almost 6 MHz of bandwidth is required for broadcast-quality television signals.

In 1948, C.E.Shannon (also of Bell Telephone Laboratories) published a paper in the Bell System Technical Journal relating the information capacity of a communications channel in bits-per-second (bps) to bandwidth and signal-to-noise ratio. Mathematically stated, the

Shannon limit for information capacity is $I = B\log_2\left(1+\frac{S}{N}\right)$, where I = information capacity (bps), B = bandwidth (Hz), S/N = signal-to-noise power ratio (unitless). For a standard voice-band communications channel with a signal-to-noise power ratio of 1000 (30 dB) and a bandwidth of 2.7 kHz, the Shannon limit for information capacity is I = 26.9 kbps.

Shannon's formula is often is misunderstood. The results of the preceding example indicate that 26.9 kbps can be transferred through a 2.7 kHz channel. This may be true, but it cannot be done with a binary system. To achieve an information transmission rate of 26.9 kbps through a 2.7 kHz channel, each symbol transmitted must contain more than one bit of information. Therefore, to achieve the Shannon limit for information capacity, digital transmission system that have more than two output conditions (symbols) must be used.

Words and Expressions

communication(s) [kəmju:ni'keiʃən] *n.* 通信，交流，交换（意见），交通，联络，传染（疾病）
information [infə'meiʃən] *n.* 信息，消息，情报，知识，通知
transmission [træz'miʃən] *n.* 发送，传播，传达，传动
reception [ri'sepʃən] *n.* 接收，接待，容纳，欢迎（会）
processing ['prəusesiŋ] *n.* 处理，进行，加工
analog ['ænələg] *n.* 模拟，相似（物），同源词
digital ['didʒitl] *adj.* 数字的，数码的，手指的
discrete [dis'kri:t] *adj.* 离散的，分立的，不连续的，无关联的
binary-coded number 二进制编码数
electromagnetic induction 电磁感应
telegraph ['teligra:f] *n.* 电报
telephone ['telifəun] *n.* 电话
triode vacuum tube 三极真空管（三极电子管）
broadcasting ['brɔ:dka:stiŋ] *n.* 广播
broadcasting station 广播电台，广播站
amplitude modulation (AM) 幅度调制
transistor [træn'sistə] *n.* 晶体管
linear integrated circuit 线性集成电路
overwhelming [əuvə'hwelmiŋ] *adj.* 汹涌澎湃的，势不可挡的
reliability [rilai'biliti] *n.* 可靠性
miniaturization [minjətʃərai'zeiʃən] *n.* 小型化
cable ['keibl] *n.* 电缆，绳索；*v.* 捆绑，拧成绳，架设电缆
microwave ['maikrəweiv] *n.* 微波
satellite ['sætəlait] *n.* 卫星，伴生矿；*a.* 卫星的，附属的，伴随的
optical fiber 光纤
chronology [krə'nɔlədʒi] *n.* 年代学；年表

transatlantic [trænzət'læntik] *adj*. 横越大西洋的
shortwave ['ʃɔːtweiv] *n*. 短波
hieroglyphic [haiərəu'glifik] *n*. 象形文字，难解的符号
negative-feedback amplifier 负反馈放大器
PCM（Pulse-Code Modulation）脉冲编码调制
time-division multiplexing（TDM）时分多路
USSR（Union of Soviet Socialist Republics）苏联
stereo FM 立体声调频
error-correction code 纠错编码
adaptive equalization 自适应均衡
random access memory（RAM）随机存取存储器
VLSI（Very Large Scale Integration）超大规模集成
FAX（facsimile）电传真，复制
cellular telephone 蜂窝电话，移动电话
oscilloscope ['ɔsiləskəup] *n*. 示波器
spread spectrum system 扩频系统
ISDN（Integrated Services Digital Network）综合业务数字网
HDTV（High Definition Television）高清晰度电视
block diagram 方框图
transmitter [trænz'mitə] *n*. 发射机，发送机（端）
channel ['tʃænl] *n*. 信道，通道，频道，沟道，海峡，河道，沟槽
receiver [ri'siːvə] *n*. 接收机，受话器，收受者，容器
impairment [im'pɛəmənt] *n*. 失真，损伤
linearity [lini'æriti] *n*. 线性
baseband ['beisbænd] *n*. 基带
bandwidth ['bændwidθ] *n*. 带宽，频带宽度
hybrid ['haibrid] *a*. *n*. 混合的，混合物
ADC（Analog-Digital Converter）模/数变换器
parity ['pæriti] *n*. 奇偶（性），等价，类似，比价，宇称（性）
carrier ['kæriə] *n*. 载波，载流子，携带者，传运（工具，机构）
bandpass signal 带通信号
single sideband（SSB）单边带
phase-shift keying（PSK）相移键控
semblance ['sembləns] *n*. 肖像，外貌，相似
standard ['stændəd] *n*. 标准，模范，本位，象征，旗帜
ITU（International Telecommunications Union）国际电信联盟
ratify ['rætifai] *v*. 批准
tariff ['tærif] *n*. 关税，税率，价格表
PTN（Public Telecommunications Network）公用电信网络

sovereignty [ˈsɔvrənti] *n.* 国家主权,至高无上之权利
territory [ˈteritəri] *n.* 领土,区域,土地
administration [ədminisˈtreiʃən] *n.* 管理,行政,措施
beacon [ˈbiːkən] *n.* 灯塔,航标
designation [dezigˈneiʃən] *n.* 名称,指示,任命
attenuation [ətenjuˈeiʃən] *n.* 衰减,薄弱,稀释
navigation [næviˈgeiʃən] *n.* 导航,航行学
amateur radio 业余无线电
LOS propagation 视线传播
absorption [əbˈsɔːpʃən] *n.* 吸收
ionospheric reflection 电离层反射
oxygen [ˈɔksidʒən] *n.* 氧
frequency assignment 频率配置
high fidelity (Hi-Fi) 高保真度
signal-to-noise 信噪比
mapping [ˈmæpiŋ] *n.* 映射
interference [intəˈfiərəns] *n.* 干扰

Notes

[1] information, intelligence, message 三词在通信技术中可能混用,都可译为:信息,消息,情报等,但 information 似乎用得更普遍。例如,信息技术就只能用 information technology (IT)。
[2] to be summarized as … 归结为……,简要叙述为……
[3] analog signal:时间和幅值皆连续分布的信号, discrete signal:时间离散分布的信号, digital signal:时间和幅值皆离散分布的信号。
[4] allowing for … 允许……,可以考虑……
[5] 此句中 for 引导原因状语。
[6] communications industry 通信行业
[7] 此句可译为:以电报为代表的数字传输系统研发于 19 世纪 50 年代;早于以电话为代表的模拟系统,它是 20 世纪才开发的。
[8] multiplexed system 多路(通信)系统
[9] 注意,此句中的 condition 是动词,作谓语,而非名词。for 引导目的状语。此句可译为:发射机中的信号处理单元对信源进行调理,以便更有效地传送。
[10] parity bit 奇偶校验位
[11] error detection and correction 误码检测和纠错
[12] the semblance of order 规范,有序的状态
[13] on an international basis 根据国际准则,按国际惯例
[14] a full array 全方位的,全面的

[15] the overall frequency plan　频率的整体规划
[16] directly proportional to …　正比于……

Exercises

1. Translate Table 1-1 into Chinese.

2. Translate Table 1-2 into Chinese.

3. Translate the text of Section 1.4 into Chinese.

4. Translate the following sentences into English.

(1) 模拟信息源产生的消息是一个连续集合,而数字信息源产生的则是消息的有限集合。
(2) 我国古代的烽火台也是一个通信系统。
(3) 证明当发出二进制数 1 和 0 的概率相等时,熵(entropy)是最大的。
(4) 信息容量是在给定时间内,通信系统能传送多少信息的量度。
(5) 带宽越宽,传送时间越长,系统传送的信息就越多。

5. Answer the following questions.

(1) When and by whom was the first electronic communications system developed?
(2) Is the telegraph system a digital communications one?
(3) What is the first amplifying device for electrical signals?
(4) Could you state Hartley's law and Shannon's formula?
(5) What are the designation for the following ranges?
(a) 3～30 kHz,　(b) 0.3～3 MHz,　(c) 3～30 GHz.

Reading Material

The purpose of a communication system is to carry information—bearing baseband signals from one place to another over a communication channel. But what do we mean by the term information? To address this issue, we need to invoke information theory. This broadly based mathematical discipline has made fundamental contributions, not only to communications, but also to computer science, statistical physics, statistical inference, and probability and statistics.

In the context of communications, information theory deals with mathematical modeling and analysis of a communication system rather than with physical sources and physical channels. In particular, it provides answers to two fundamental questions (among others): (1) What is the irreducible complexity below which a signal cannot be compressed? (2) What is the ultimate transmission rate for reliable communication over a noisy channel? The answers to these questions lie in the entropy of a source and the capacity of a channel, respectively. Entropy is defined in terms of the probabilistic behavior of a source of information; it is so named in deference to the parallel use of this concept in thermodynamics. Capacity is defined as the intrinsic ability of a channel to convey information; it is naturally related to the noise characteristics of the channel. A remarkable result that emerges from information theory is that if the entropy of the source is less than the capacity of the channel, then error-free communication over the channel can be achieved. It is therefore befitting that we begin our study of information theory by discussing the relationships among uncertainty, information, and entropy.

Suppose that a probabilistic experiment involves the observation of the output emitted by a discrete source during every unit of time (signaling interval). The source output is modeled as a discrete random variable, S, which takes on symbols from a fixed finite alphabet

$$S = \{s_0, s_1, \cdots, s_{K-1}\} \tag{R1. 1}$$

with probabilities

$$P(S = s_k) = p_k, \qquad k = 0, 1, \cdots, K-1 \tag{R1. 2}$$

Of course, this set of probabilities must satisfy the condition

$$\sum_{k=0}^{K-1} p_k = 1 \tag{R1. 3}$$

We assume that the symbols emitted by the source during successive signaling intervals are statistically independent. A source having the properties just described is called a discrete memoryless source, memoryless in the sense that the symbol emitted at any time is independent of previous choices.

Can we find a measure of how much information is produced by such a source? To answer this question, we note that the idea of information is closely related to that of uncertainty or surprise, as described next.

Consider the event $S = s_k$, describing the emission of symbol s_k by the source with probability p_k, as defined in Equation (R1. 2). Clearly, if the probability $p_k = 1$ and $p_i = 0$ for all $i \neq k$, then there is no "surprise", and therefore no "information", when symbol s_k is emitted, because we know what the message from the source must be. If, on the other hand, the source symbols occur with different probabilities, and the probability p_k is low, then there is more surprise, and therefore information, when symbol s_k is emitted by the source than when symbol s_i, $i \neq k$, with higher probability is emitted. Thus the words uncertainty, surprise, and information are all related.