Communication Systems

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Communication

- Means exchange of information between two points.
- The transmission of information so that the recipient understands what the sender intends.
- The successful transmission of information through a common system of symbols, signs, behavior, speech, writing, or signals.

Telecommunication (Tele + Communication)

The process of transmitting or receiving information over a distance by any electrical or electromagnetic medium. Information may take the form of voice, video, or data.

The science of information transport using wire, radio, optical, or electromagnetic channels to transmit/receive signals for voice or data communications using electrical means.

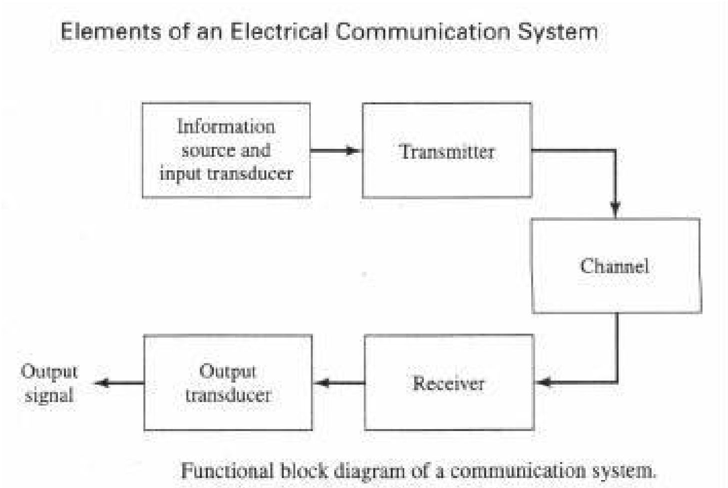
Telecommunication refers to the communication of information at a distance. This covers many technologies including radio, telegraphy, television, telephone, data communication and computer networking. Telecommunication can be point-to-point, point-to-multipoint or broadcasting, which is a particular form of point-to-multipoint that goes only from the transmitter to the receivers.

History of Communication

Visual Telegraph - 1794
Electric Telegraph - 1832
Telephone - 1876
Radio – 1895
Automatic switching of calls - 1916
Mobile Radio – 1920
Digital Transmission Network (PSTN) – 1963
Advanced Mobile Phone System – 1979
Global System for Mobile Communication – 1991
CDMA One, CDMA 1x,
GPRS, EDGE, UMTS, 3G, and 4G

Model of Communication System

Input signal – transducer-transmitter- medium-receiver-output transducer-output signal



Functional block diagram of a communication system.

Fundamental characteristics of Communication

The effectiveness of a data communications system depends on three fundamental characteristics: delivery, accuracy, and timeliness.

1. Delivery - The system must deliver data to the correct destination. Data must be received by the intended device or user and only by that device or user.

2. Accuracy - The system must deliver the data accurately. Data that have been altered in transmission and left uncorrected are unusable.

3. Timeliness - The system must deliver data in a timely manner. Data delivered late are useless. In the case of video and audio, timely delivery means delivering data as they are produced, in the same order that they are produced, and without significant delay. This kind of delivery is called real-time transmission.

Components of Communication systems

A data communications system has five components:

1. Message - The message is the information (data) to be communicated. It can consist of text, numbers, pictures, sound, or video—or any combination of these.

2. Sender. The sender is the device that sends the data message. It can be a computer, workstation, telephone handset, video camera, and so on.

3. Receiver. The receiver is the device that receives the message. It can be a computer, workstation, telephone handset, television, and so on.

4. Medium. The transmission medium is the physical path by which a message travels from sender to receiver. It could be a twisted-pair wire, coaxial cable, fiber optic cable, or radio waves (terrestrial or satellite microwave).

5. Protocol. A protocol is a set of rules that governs data communications. It represents an agreement between the communicating devices. Without a protocol, two devices may be connected but not communicating, just as a person speaking French cannot be understood by a person who speaks only Japanese.

Mode of Communication

A transmission may be simplex, half duplex, or full duplex. In simplex transmission, signals are transmitted in only one direction: one station is transmitter and the other is receiver. In half-duplex operation, both stations may transmit, but only one at a time. In full-duplex operation, both stations may transmit simultaneously. In the latter case, the medium is carrying signals in both directions at the same time.

Data – Information

The word data means "pieces of information". Types of data include numbers, words, sounds, and images.

We define data as entities that convey meaning or information.

Analog and digital data

Data can be analog or digital. An example of analog data is the human voice. Analog data take on the continuous values in some interval.

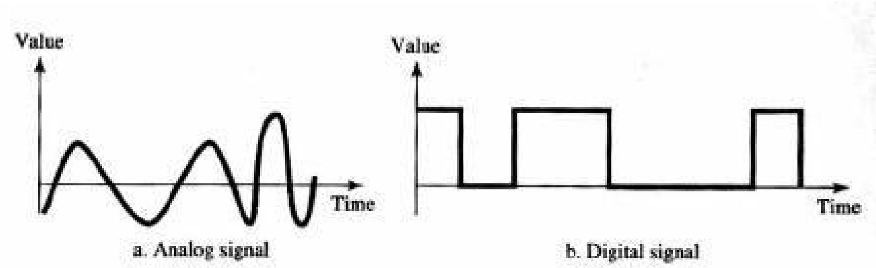
Digital data take on discrete values: examples are text and integers. Digital data is data stored in the memory of a computer in the form of 0s and 1s.

Signals

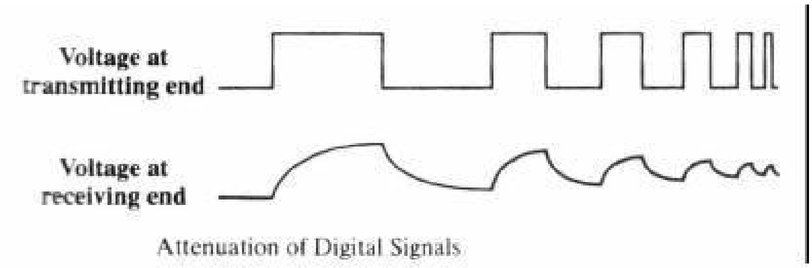
Signals are electric or electromagnetic representation of data. Signaling is the physical propagation of the signal along a suitable medium. Transmission is the communication of data by the propagation and processing of signals.

Analog and Digital signals

An analog signal is a continuously varying electromagnetic wave that may be propagated over a variety of media, depending on spectrum: examples are wire media, such a twisted pair and coaxial cable; fiber optic cable; and unguided media, such as atmosphere or space propagation.



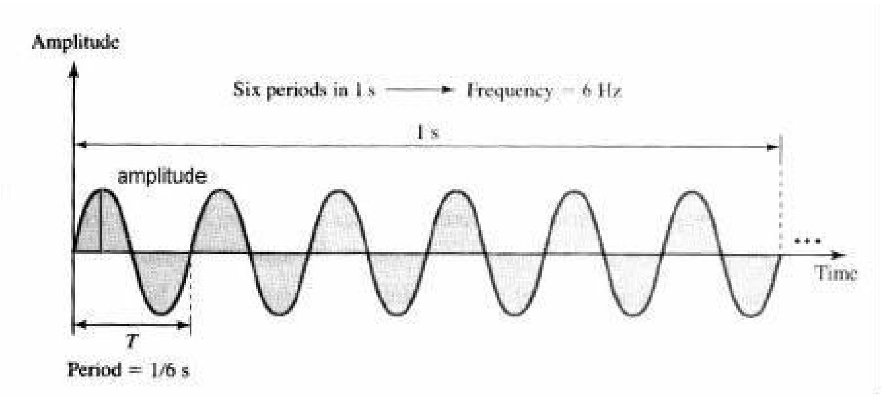
A digital signal is sequence of voltage pulses that may be transmitted over a wire medium for example a constant positive voltage level may represent binary 0 and a constant negative voltage level represent binary 1.



Attenuation of Digital Signals

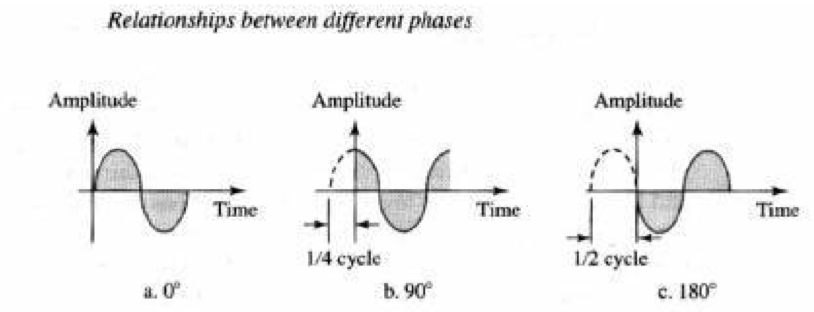
The principal advantages of digital signaling are that it is generally cheaper than analog signaling and is less susceptible to noise interference. The principal disadvantage is that digital signals suffer more from attenuation than do analog signals.

Electromagnetic (EM) waves

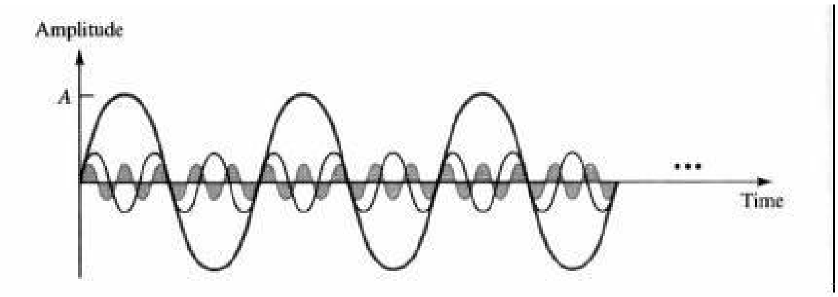


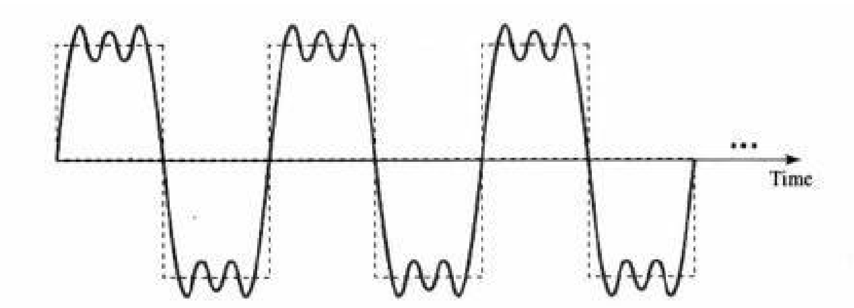
Properties of EM waves

Amplitude, frequency, phase



Simple signals, Composite signals





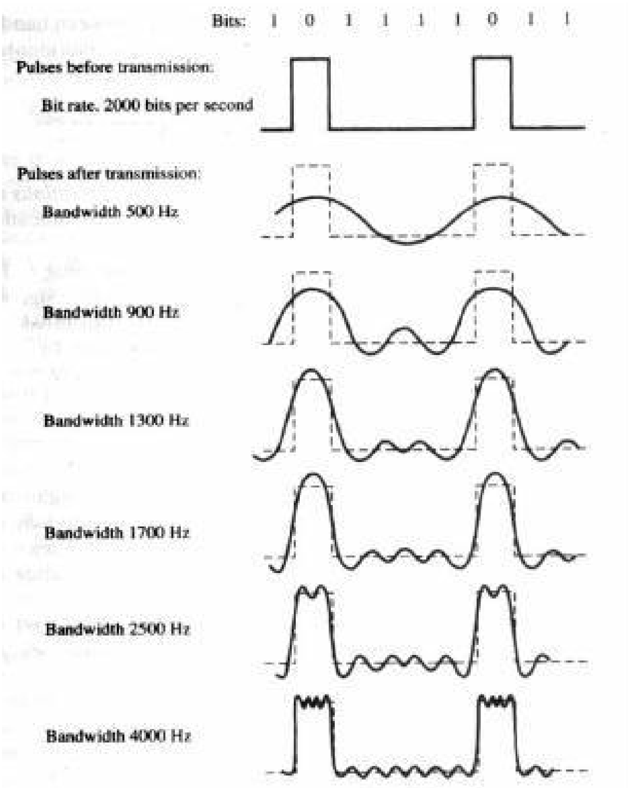
Composite signal is a mixture of simple signals of different freq and amp.

Band pass signals, base band signals

Definition of bandwidth

A signal needs to pass through a medium (cable or air). No transmission medium is perfect. A medium may pass some frequencies and may block or weaken others. This means that when we send a composite signal, containing many frequencies, at one end, we may not receive the same signal at the other end.

The range of frequencies that a medium can pass is called bandwidth. The bandwidth is a range and is normally referred to as the difference between two numbers. Sometimes people use the term bandwidth with regard to a signal. For example, they say, "The signal has a bandwidth of 1000 Hz." In this case, what they mean is that the signal has a spectrum with significant frequencies that span 1000 Hz.



Effect of Bandwidth on a Digital Signal

Transmission impairments

Signals travel through transmission media, which are not perfect. The imperfections cause impairment in the signal. This means that the signal at the beginning and end of the medium are not the same. What is sent is not what is received. Three types of impairment usually occur: attenuation, distortion, and noise.

Attenuation means loss of energy. When a signal, simple or composite, travels through a medium, it loses some of its energy so that it can overcome the resistance of the medium. That is why a wire carrying electrical signals gets warm, if not hot, after a while. Some of the electrical energy in the signal is converted to heat. To compensate for this loss, amplifiers are used to amplify the signal.

Decibel

To show that a signal has lost or gained strength, engineers use the concept of the decibel. The decibel (dB) measures the relative strengths of two signals or a signal at two different points. Note that the decibel is negative if a signal is attenuated and positive if a signal is amplified.

$$dB = 10 \log_{10}(P_2/P_1)$$

where P_1 and P_2 are the powers of a signal at points 1 and 2, respectively.

Imagine a signal travels through a transmission medium and its power is reduced to half. This means that $P_2 = 1/2\ P_1$; In this case, the attenuation (loss of power) can be calculated as

$$10 \log_{10} (P_2/P_1) = 10 \log_{10} (0.5P1/P1) = 10 \log_{10}(0.5) = -3 \text{ dB}$$

Engineers know that -3 dB or a loss of 3 dB is equivalent to losing half the power.

$$10 \log_{10} (P_2/P_1) = 10 \log_{10} (10P1/P1) = 10 \log_{10}(10) = 10 \text{ dB}$$

Imagine a signal travels through an amplifier and its power is increased ten times. This means that $P_2 = 10 \times P_1$. In this case, the amplification (gain of power) can be calculated as

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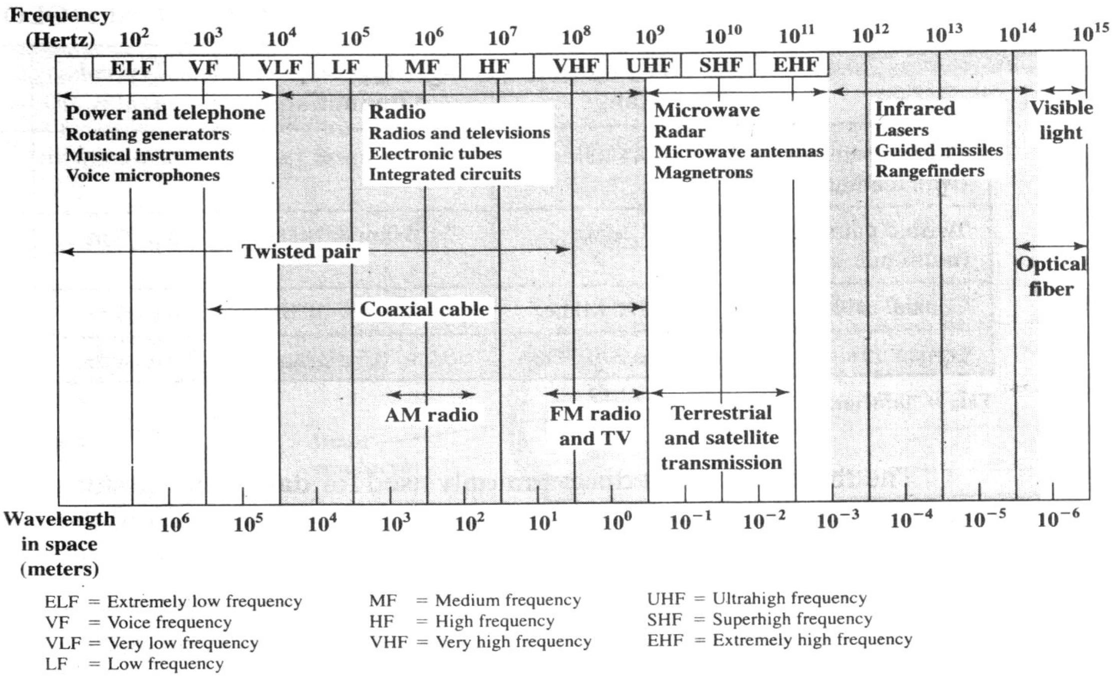
Distortion means that the signal changes its form or shape. Distortion occurs in a composite signal, made of different frequencies. Each signal component has its own propagation speed (see the next section) through a medium and, therefore, its own delay in arriving at the final destination.

Noise is another problem. Several types of noise such as **thermal noise**, **induced noise**, **crosstalk**, and **impulse noise** may corrupt the signal. *Thermal noise* is the random motion of electrons in a wire which creates an extra signal not originally sent by the transmitter. *Induced noise* comes from sources such as motors and appliances. These devices act as a sending antenna and the transmission medium acts as the receiving antenna. *Crosstalk* is the effect of one wire on the other. One wire acts as a sending antenna and the other as the receiving antenna. *Impulse noise* is a spike (a signal with high energy in a very short period of time) that comes from power lines, lightning, and so on.

Throughput (bps), Propagation Delay, bits, bauds

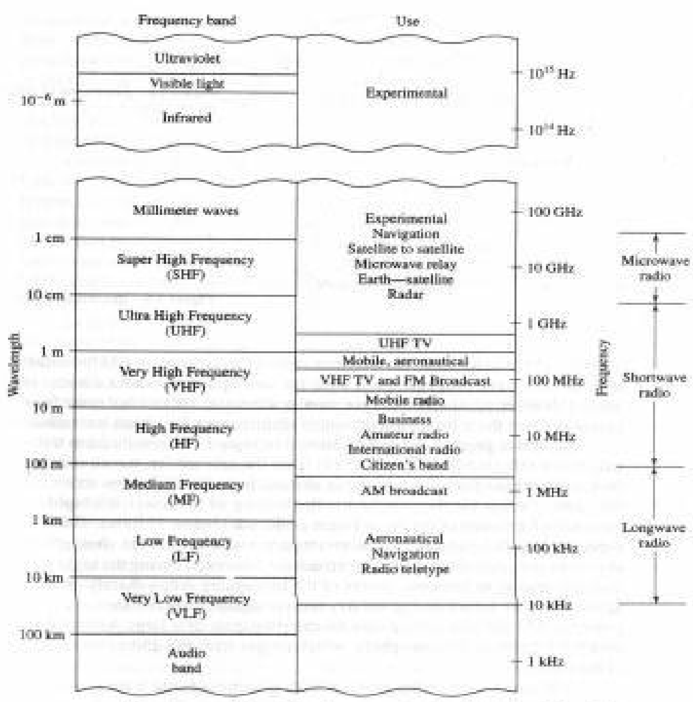
Transmission medium

Data transmission occurs between transmitter and receiver over some transmission medium. Transmission media may be classified as guided or unguided. In both cases, communication is in the form of electromagnetic waves. With guided media, the waves are guided along a physical path; examples of guided media are twisted pair, coaxial cable, and optical fiber. Unguided media, also called wireless, provide a means for transmitting electromagnetic waves but do not guide them; examples are propagation through air, vacuum, and seawater.

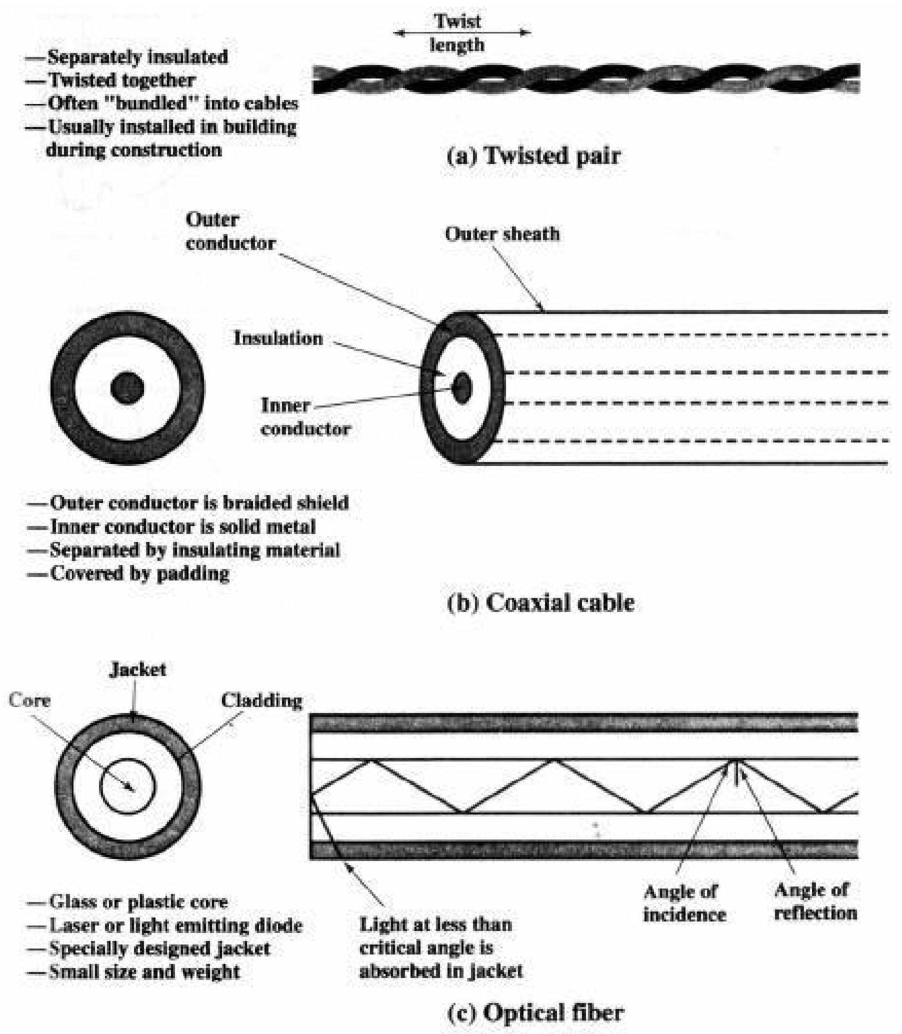


Electromagnetic Spectrum for Telecommunications

A guided transmission medium is point to point if it provides a direct link between two devices and those are the only two devices sharing the medium. In a multipoint guided configuration, more than two devices share the same medium.



Frequency range for wireless electromagnetic channels. (Adapted from Carlson, Sec. Ed.; © 1975 McGraw-Hill. Reprinted with permission of the publisher.)



Guided Transmission Media

twisted pair cable, category 5, coaxial cable, fiber optic cable, wireless medium – radio wave, microwave, satellite communication, ISM, UWB etc

Nyquist Theorem (Noiseless Channel)

For a noiseless channel, the **Nyquist bit rate** formula defines the theoretical maximum bit rate

$$\text{BitRate} = 2 \times \text{BandWidth} \times \log_2 L$$

In this formula, Bandwidth is the bandwidth of the channel, L is the number of signal levels used to represent data, and BitRate is the bit rate in bits per second.

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The bit rate can be calculated as:

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BitRate = 2 x 3000 x log2 2 = 6000 bps
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Shannon's Theorem (Noisy Channel)

In reality, we cannot have a noiseless channel; the channel is always noisy. In 1944, Claude Shannon introduced a formula, called the Shannon capacity, to determine the theoretical highest data rate for a noisy channel:

$$C = B \log_2(1 + SNR) = 3.32\ B\ \log_{10}(1 + SNR)$$

In this formula, Bandwidth is the bandwidth of the channel, SNR is the signal-to-noise ratio (P_{signal}/P_{noise}), and Capacity is the capacity of the channel in bits per second. The signal-to-noise ratio is the statistical ratio of the power of the signal to the power of the noise. Note that in the Shannon formula there is no indication of the signal level, which means that no matter how many levels we use, we cannot achieve a data rate higher than the capacity of the channel. In other words, the formula defines a characteristic of the channel, not the method of transmission.

In practice, the SNR is express in dB. We have to make it unitless form before using it in Shannon's formula.

$$(SNR)_{dB} = 10 \log_{10}(P_{signal}/P_{noise})$$

A telephone line normally has a bandwidth of 3000Hz (300 to 3300 Hz). The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as:

```
C = 3.32 x B log10(1+SNR)
      = 3.32 x 3000 log10(1+3162)
      = 9960 x log10(3163) = 34,860 bps
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We have a channel with a 1 MHz bandwidth. The SNR for this channel is 63; what is the appropriate bit rate and signal level?

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First, we use the Shannon formula to find our upper limit.

C = B log2 (1 + SNR) = 10^6 log2 (1 + 63)
      = 10^6 log2 (64) = 6 Mbps

Although the Shannon formula gives us 6 Mbps, this is the
upper limit. For better performance we choose something
lower, for example 4 Mbps. Then we use the Nyquist formula
to find the number of signal levels.
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$4 \times 10^6 = 2 \times 10^6 \times \log_2 L$

L = 4

Number of signal levels is 4.

Let us consider an example that relates the Nyquist and Shannon formulations. Suppose that the spectrum of a channel is between 3 MHz and 4 MHz and SNR = 24 dB. Then:

B = 4 MHz - 3 MHz = 1 MHz
$SNR_{dB} = 24dB = 10 \log_{10}(SNR)$
SNR = 251

Using Shannon's formula,

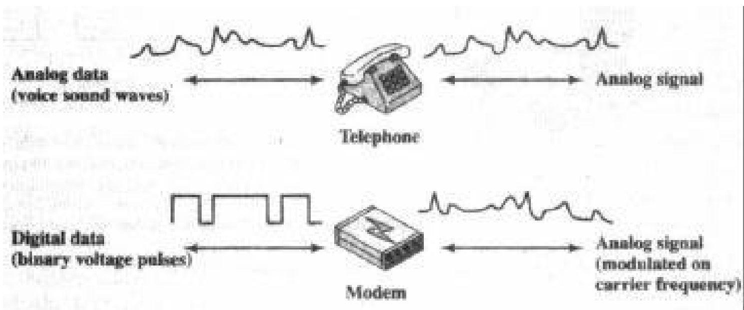
$C = 10^6 \times \log_{10} (1 + 251) \sim 10^6 \times 8 = 8$ Mbps

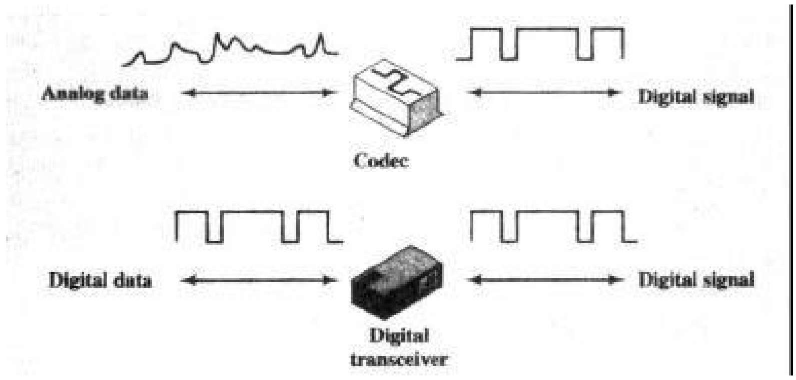
This is a theoretical limit and, as we have said, is unlikely to be reached. But assume we can achieve the limit. Based on Nyquist's formula, how many signaling levels are required? We have:

$C = 2 B \log_2 L$

$8 \times 10^6 = 2 \times (10^6) \times \log_2 L$
$4 = \log_2 L$
L = 16

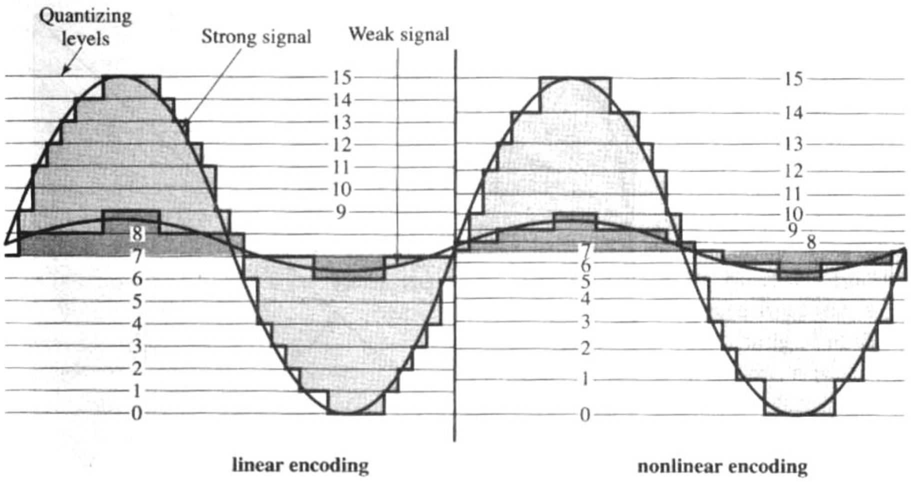
Analog/Digital Data to Analog/Digital Signals





Analog to Digital conversion

PCM technique



Effect of Nonlinear Coding

Sampling, Sampling Rate
Quantization
Quantization error

Analog and Digital Transmission

Analog transmission is a means of transmitting analog signals without regard to their content: the signals may represent analog data (e.g., voice) or digital data (e.g., binary data that pass through a modem). In either case, the analog signal will become weaker (attenuate) after certain distance. To achieve longer distances, the analog transmission system includes amplifiers that boost the energy in the signal. Unfortunately, the amplifier also boosts the noise components.

Digital transmission, in contrast, is concerned with the content of the signal. A digital signal can be transmitted only a limited distance before attenuation, noise, and other impairments endanger the integrity of the data. To achieve greater distances, repeaters are used. A repeater receives the digital signal, recovers the pattern of 1s and 0s, and retransmits a new signal.

The same technique may be used with an analog signal if it is assumed that the signal carries digital data. The transmission system has repeaters rather than amplifiers. The repeater recovers the digital data from the analog signal and generates a new, clean analog signal.

Advantage of Digital System

Data Transmission

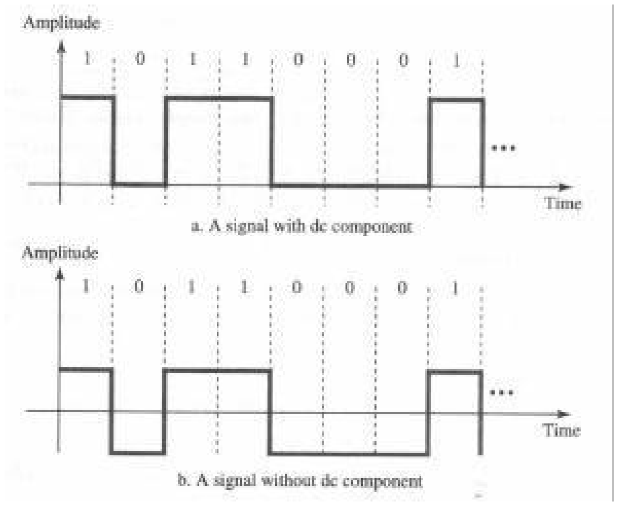
Digital transmission with digital signals

Line Coding

Line coding is the process of converting binary data, a sequence of bits, to a digital signal.

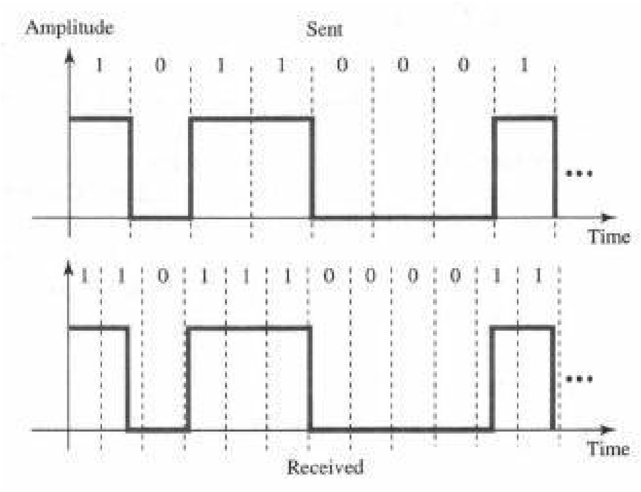
DC components

Some line coding schemes leave a residual direct-current (dc) component (zero frequency). This component is undesirable for two reasons. First, if the signal is to pass through a system (such as a transformer) that does not allow the passage of a dc component, the signal is distorted and may create errors in the output. Second, this component is extra energy residing on the line and is useless. Figure shows two line coding schemes. The first has a dc component: the positive voltages are not canceled by the negative voltages. The second has no dc component: the positive voltages are canceled by any negative voltages. The first does not pass through a transformer properly; the second does.



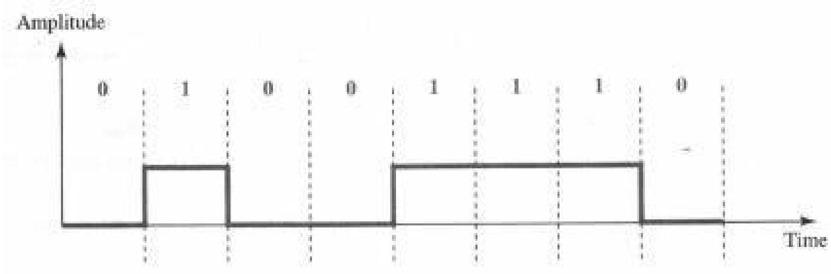
Self Synchronization

To correctly interpret the signals received from the sender, the receiver's bit intervals must correspond exactly to the sender's bit intervals. If the receiver clock is faster or slower, the bit intervals are not matched and the receiver might interpret the signals differently than the sender intended. The following figure shows a situation in which the receiver has a shorter bit duration. The sender sends 10110001, while the receiver receives 110111000011 (exaggerated situation).



Different Line Coding Schemes (Unipolar and Polar)

Uni-polar encoding is very simple and very primitive. Although it is almost obsolete today, its simplicity provides an easy introduction to the concepts developed with the more complex encoding systems and allows us to examine the kinds of problems that any digital transmission system must overcome.



Polar Coding - NRZ-L, NRZ-I, RZ, Manchester, Differential Manchester

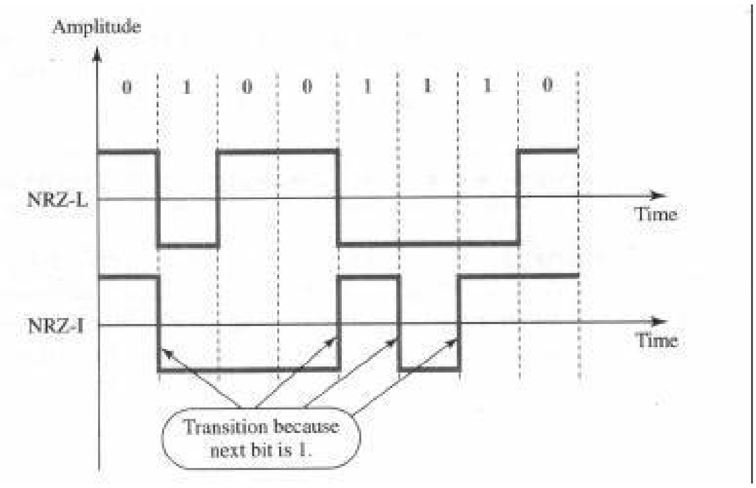
Polar encoding uses two voltage levels one positive and one negative. By using two levels, in most polar encoding methods the average voltage level on the line is reduced and the dc component problem seen in unipolar encoding is alleviated.

Of the many existing variations of polar encoding, we examine four of the most popular: Non-Return to Zero (**NRZ**), Return to Zero (**RZ**), **Manchester**, and **Differential Manchester**.

In Non-return to Zero (NRZ) encoding, the value of the signal is always either positive or negative. There are two popular forms of NRZ.

In **NRZ-L** (NRZ-level) encoding, the level of the signal depends on the type of bit that it represents. A positive voltage usually means the bit is a 0, while a negative voltage means the bit is a 1; thus, the level of the signal is dependent upon the state of the bit.

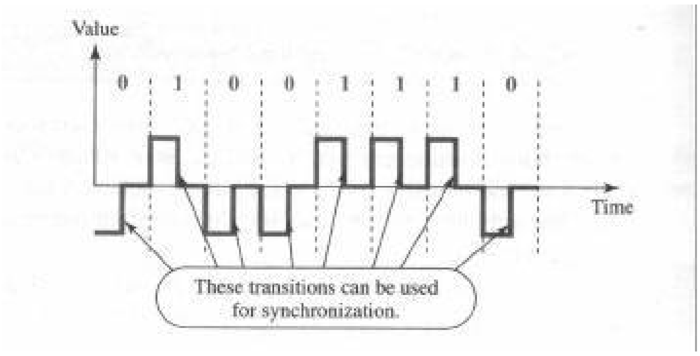
A problem can arise when the data contain a long stream of 0s or 1s. The receiver receives a continuous voltage and determines how many bits are sent by relying on its clock, which may or may not be synchronized with the sender clock.



In **NRZ-I** (NRZ-invert), an inversion of the voltage level represents a 1 bit. It is the transition between a positive and a negative voltage, not the voltage itself, which represents a 1 bit. A 0 bit is represented by no change. NRZ-I is superior to NRZ-L due to the synchronization provided by the signal change each time a 1 bit is encountered. The existence of 1s in the data stream allows the receiver to synchronize its timer to the actual arrival of the transmission. A string of 0s can still cause problems, but because 0s are not as likely, they are less of a problem.

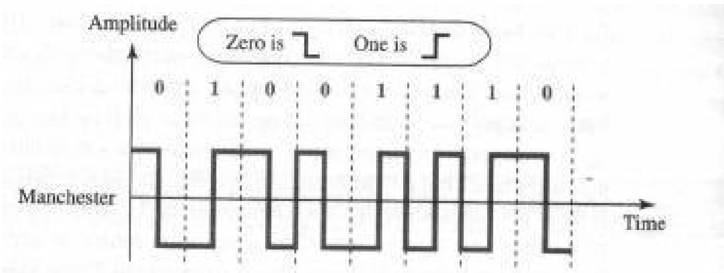
Figure shows the NRZ-L and NRZ-I representations of the same series of bits. In the NRZ-L sequence, positive and negative voltages have specific meanings: positive for 0 and negative for 1. In the NRZ-I sequence, the voltages are meaningless. Instead, the receiver looks for changes from one level to another as its basis for recognition of 1s.

Return to Zero (RZ) as you can see, anytime the original data contain strings of consecutive 1s or 0s, the receiver can lose its place. A solution is to somehow include synchronization in the encoded signal, something like the solution provided by NRZ-I, but one capable of handling strings of 0s as well as 1s.



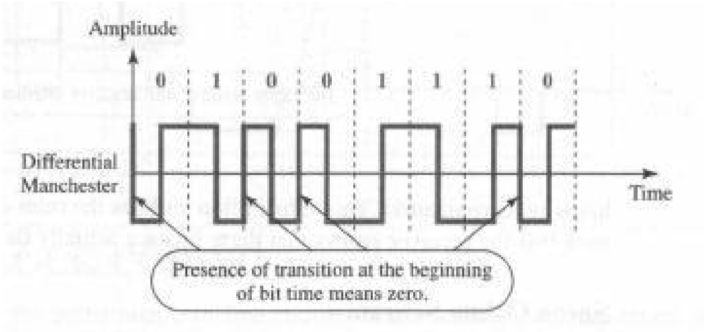
To ensure synchronization, there must be a signal change for each bit. The receiver can use these changes to build up, update, and synchronize its clock. As we saw above, NRZ-I accomplishes this for sequences of 1s. But to change with every bit, we need more than just two values.

One solution is **Return to Zero** (RZ) encoding, which uses three values: positive, negative, and zero. In RZ, the signal changes not between bits but during each bit. Like NRZ-L, a positive voltage means 1 and a negative voltage means 0. But, unlike NRZ-L, halfway through each bit interval, the signal returns to zero. A 1 bit is actually represented by positive-to-zero and a 0 bit by negative-to-zero, rather than by positive and negative alone.



The main disadvantage of RZ encoding is that it requires two signal changes to encode 1 bit and therefore occupies more bandwidth. But of the three alternatives have examined so far, it is the most effective.

Manchester encoding uses an inversion at the middle of each bit interval for both synchronization and bit representation. A negative-to-positive transition represents binary 1, and a positive-to-negative transition represents binary 0. By using a single transition for a dual purpose, Manchester encoding achieves the same level of synchronization as RZ but with only two levels of amplitude.

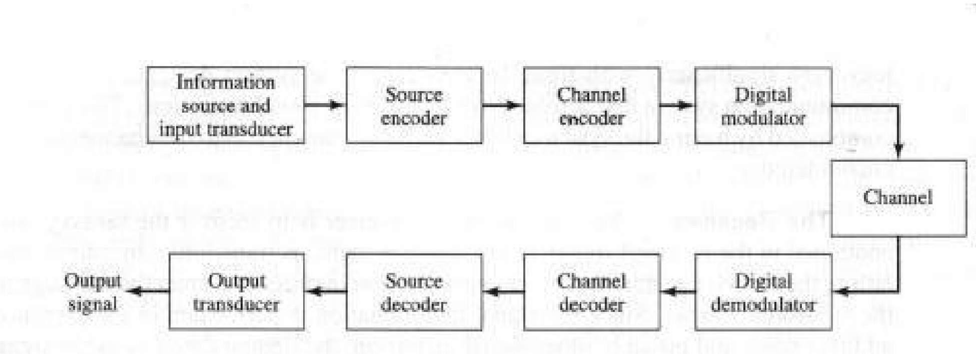


In **Differential Manchester** encoding, the inversion at the middle of the bit interval is used for synchronization, but the presence or absence of an additional transition at the beginning of the interval is used to identify the bit. A transition means binary 0, and no transition means binary 1. Differential Manchester encoding requires two signal changes to represent binary 0 but only one to represent binary 1. Figure shows differential Manchester encoding.

Bipolar encoding, like RZ, uses three voltage levels: positive, negative, and zero.

Comparative study

Digital transmission with analog signals



Basic elements of a digital communication system.

Digital Modulation
- Amplitude Shift Keying (ASK)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)

Analog Transmission

Analog modulation
- Amplitude Modulation (AM)
- Frequency Modulation (FM)
- Phase Modulation (PM)