PART 3 : PHYSICAL LAYER

Data Communication and Computer Network

VER 2023

Chap 3.1 Data and Signal

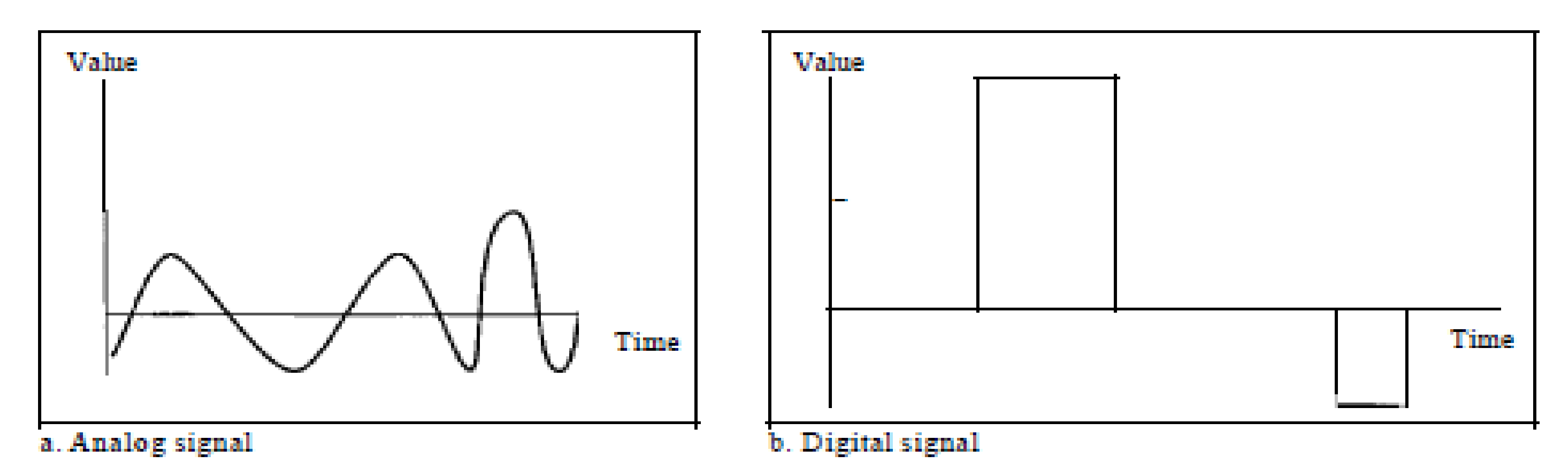
Introduction

- Data is an entity of that conveys information:
  - Data has to do with the form of something, such as arrays of integers, video frames, lines of text, or images.
  - Information refers to the content or meaning of the data or how it is interpreted. For example: facts, concepts, or instruction.

- Data can be analog or digital.
- The term **analog data refers to information that is continuous form, such as audio or video signal.**
- **Digital data refers to information that has discrete states, such as numbers from a computer or letters of the alphabet, or it can be a digitized from of or and analog signal.**

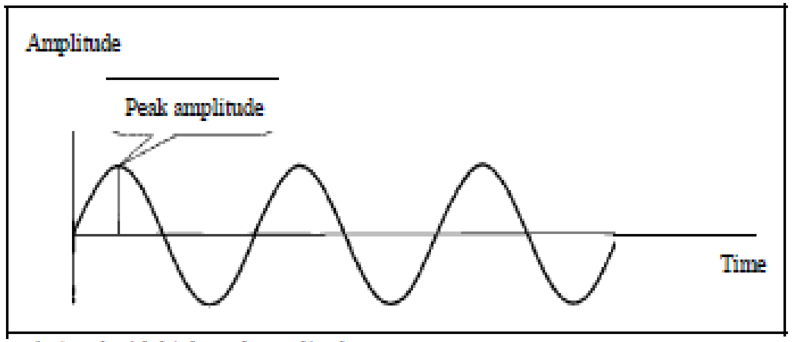
Introduction

- Analog data, such as the sounds made by a human voice, take on continuous values. When someone speaks, an analog wave is created in the air. This can be captured by a microphone and converted to an analog signal or sampled and converted to a digital signal.
- Digital data take on discrete values. For example, data are stored in computer memory in the form of 0s and 1s. They can be converted to a digital signal or modulated into an analog signal for transmission across a medium.

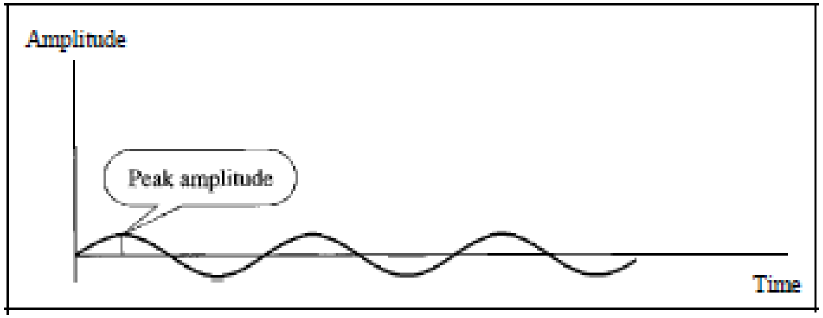


Analog Signal

- A sine wave can be represented by three parameters: the *amplitude, the frequency,* and the *phase.*
- *Amplitude : Is the size or magnitude of the waveform.*
  - *Symbol : A, measured : volts, amperes, or watts.*
- *Peak Amplitude :*
  - The peak amplitude of a signal is the absolute value of its highest intensity, proportional to the energy it carries. For electric signals, peak amplitude is normally measured in *volts.*
  - Example : The power in your house can be represented by a sine wave with a peak amplitude of 155 to 170 V. However, it is common knowledge that the voltage of the power in U.S. homes is 110 to 120 V.



a. A signal with high peak amplitude

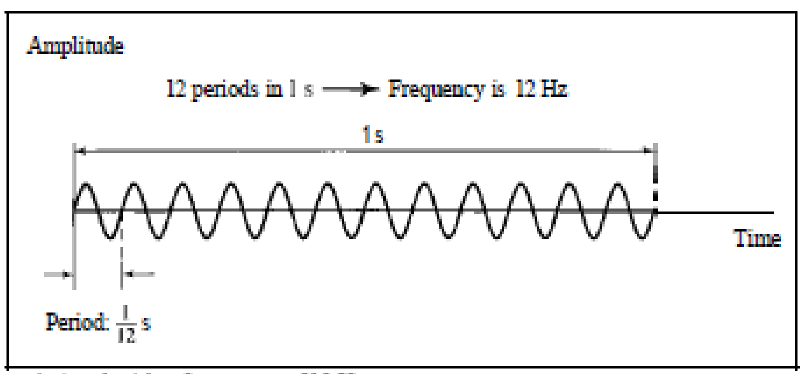


b. A signal with low peak amplitude

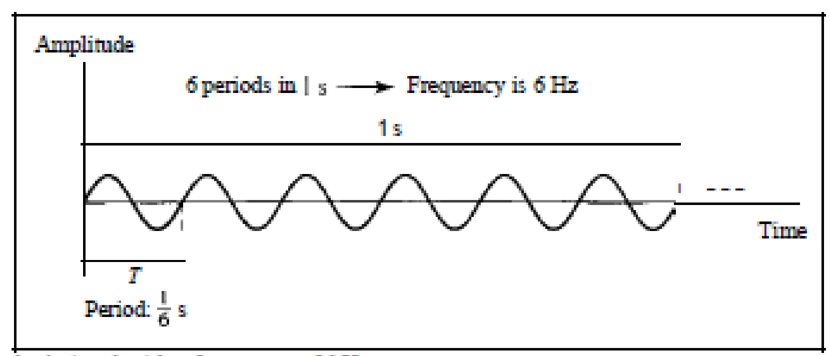
Analog Signal

- Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle.
- Frequency refers to the number of periods in I s.
  - Note that period and frequency are just. one characteristic defined in two ways. Period is the inverse of frequency, and frequency is the inverse of period, as the following formulas show.

$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

Analog Signal

- Period is formally expressed in seconds. Frequency is formally expressed in Hertz (Hz), which is cycle per second.

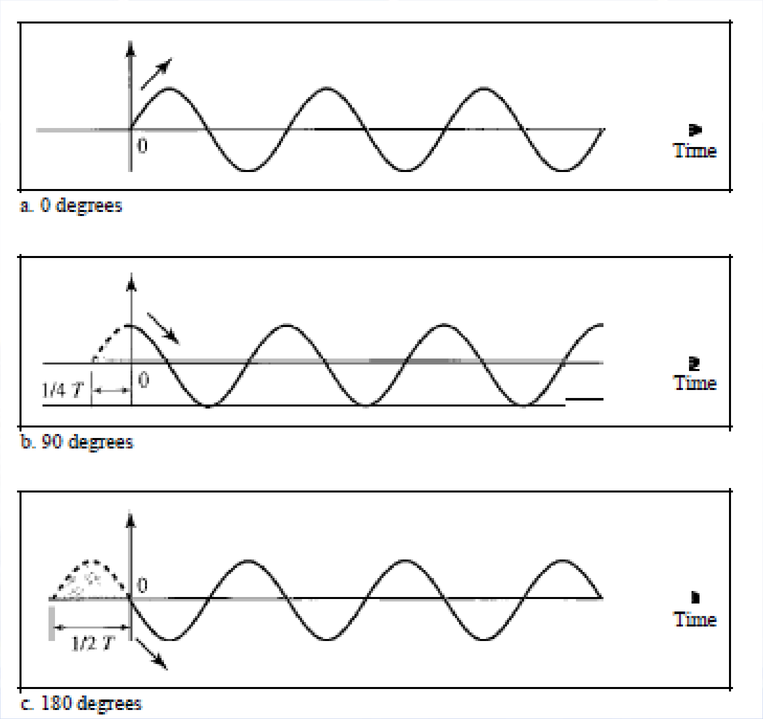
Unit	Equivalent	Unit	Equivalent
Second (s)	1s	Hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	Kilohertz (kHz)	10^{3}Hz
Microseconds (µs)	10^{-6} s	Megahertz (MHz)	10^{6} Hz
Nanoseconds (ns)	10^{-9} s	Gigahertz (GHz)	10^{9} Hz
Picoseconds (ps)	10^{-12} s	Terahertz (THz)	10^{12}Hz

The power we use at home has a frequency of 60 Hz (50 Hz in Europe). The period of this sine wave can be determined as follows:

$$T = \frac{1}{f} = \frac{1}{60} = 0.0166\, x\, 10^{3}\ ms = 16.6\ ms$$

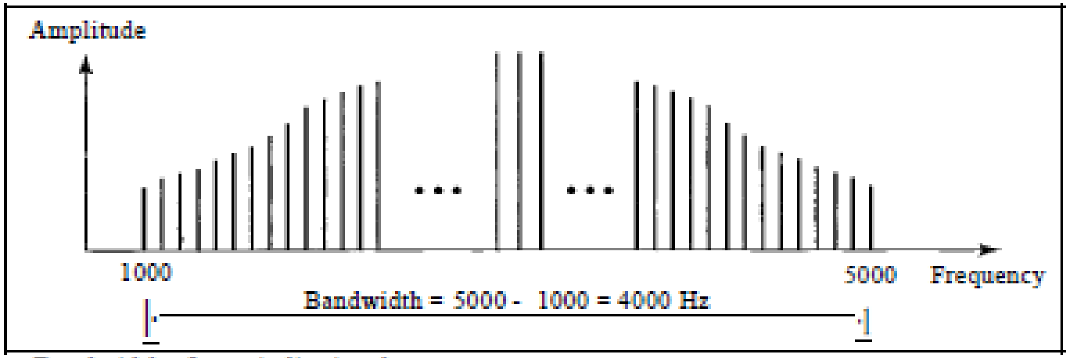
Analog Signal

- Phase :
  - The term phase describes the position of the waveform relative to time O. If we think of the wave as something that can be shifted backward or forward along the time axis, phase describes the amount of that shift. It indicates the status of the first cycle.



Bandwidth

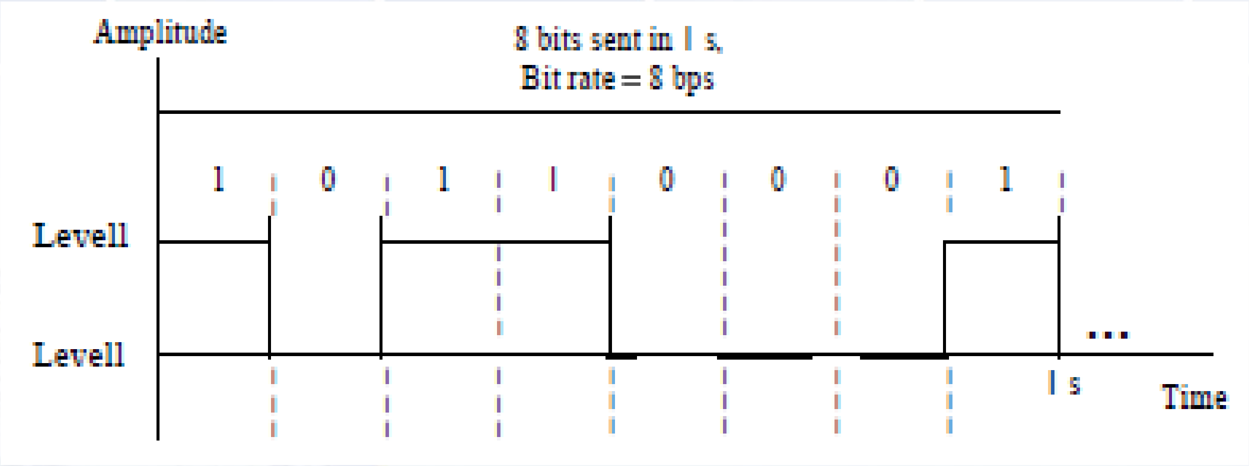
- The range of frequencies contained in a composite signal is its bandwidth. The bandwidth is normally a difference between two numbers.
  - For example, if a composite signal contains frequencies between 1000 and 5000, its bandwidth is 5000 - 1000, or 4000.



a. Bandwidth of a periodic signal

Digital Signal

- Information can also be represented by a digital signal. For example, a I can be encoded as a positive voltage and a 0 as zero voltage.



Bit Rate

- The bit rate is the number of bits sent in 1 s, expressed in bits per second (bps).
- Assume we need to download text documents at the rate of 100 pages per minute. What is the required bit rate of the channel?
- Solution

  A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits, the bit rate is

100 x 24 x 80 x 8 =1,636,000 bps =1.636 Mbps

Bit Length

- The bit length is the distance one bit occupies on the transmission medium.

  Bit length =propagation speed x bit duration

Bandwidth

- In networking, we use the term *bandwidth in two contexts.*
  - The first, *bandwidth in hertz, refers to the range of frequencies in a composite* signal or the range of frequencies that a channel can pass.
  - The second, *bandwidth in bits per second, refers to the speed of bit transmission* in a channel or link.

Bandwidth Measurements

Unit of Bandwidth	Abbreviation	Equivalence
Bits per second	bps	1 bps = fundamental unit of bandwidth
Kilobits per second	kbps	1 kbps = ~1,000 bps = 10^3 bps
Megabits per second	Mbps	1 Mbps = ~1,000,000 bps = 10^6 bps
Gigabits per second	Gbps	1 Gbps = ~1,000,000,000 bps = 10^9 bps
Terabits per second	Tbps	1 Tbps = ~1,000,000,000,000 bps = 10^{12} bps

Bandwidth Limitations

Some Typical Media	Bandwidth	Max. Physical Distance
50-Ohm Coaxial Cable (Ethernet 10BASE2, ThinNet)	10-100 Mbps	185m
50-Ohm Coaxial Cable (Ethernet 10BASE5, ThickNet)	10-100 Mbps	500m
Category 5 Unshielded Twisted Pair (UTP) (Ethernet 10BASE-T)	10 Mbps	100m
Category 5 Unshielded Twisted Pair (UTP) (Ethernet 100BASE-TX)(Fast Ethernet)	100 Mbps	100m
Multimode (62.5/125µm) Optical Fiber 100BASE-FX	100 Mbps	2000m
Singlemode (9/125µm core) Optical Fiber 1000BASE-LX	1000 Mbps (1.000 Gbps)	3000m
Wireless	11 Mbps	a few 100meters

Throughput

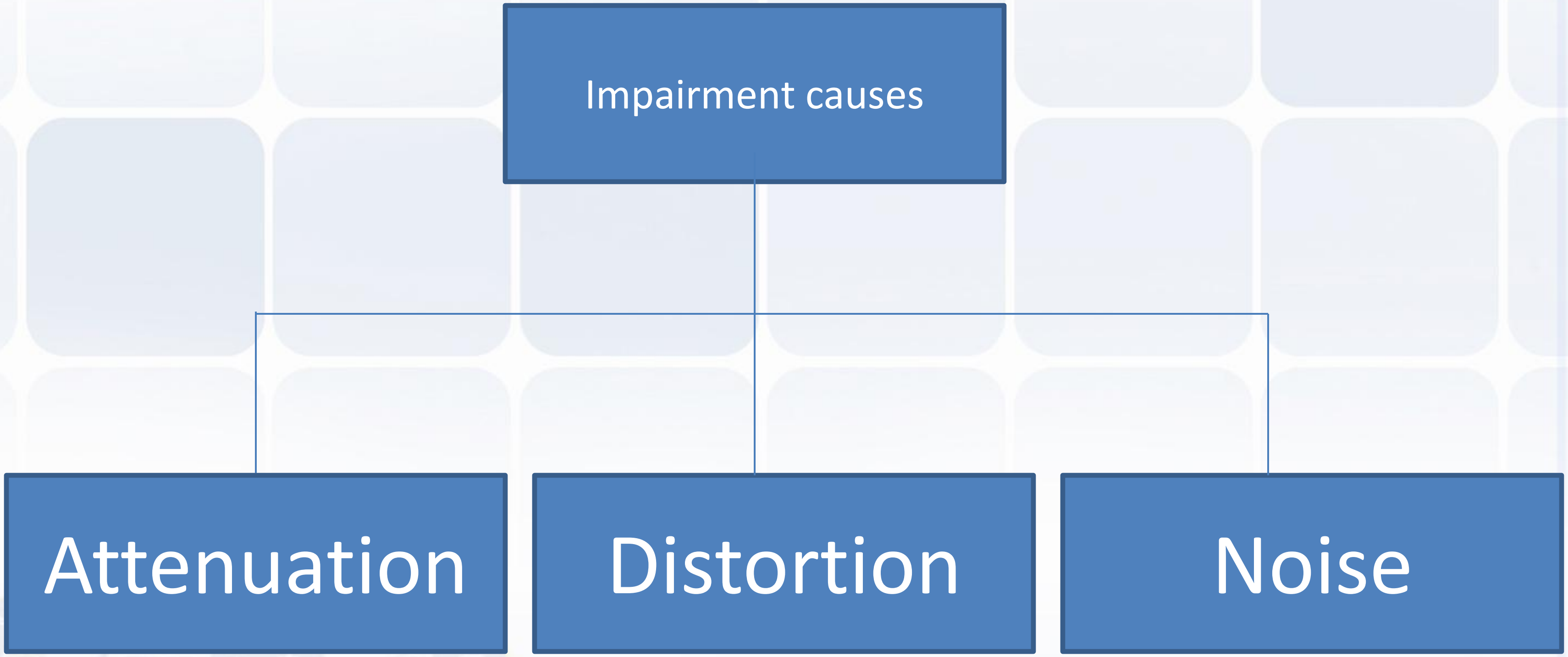
Throughput ≤ Digital Bandwidth of a Medium

- The throughput is a measure of how fast we can actually send data through a network.

- Although, at first glance, bandwidth in bits per second and throughput seem the same, they are different. A link may have a bandwidth of *B bps, but we can only send T bps* through this link with *T always less than B. In other words, the bandwidth is a potential* measurement of a link; the throughput is an actual measurement of how fast we can send data.

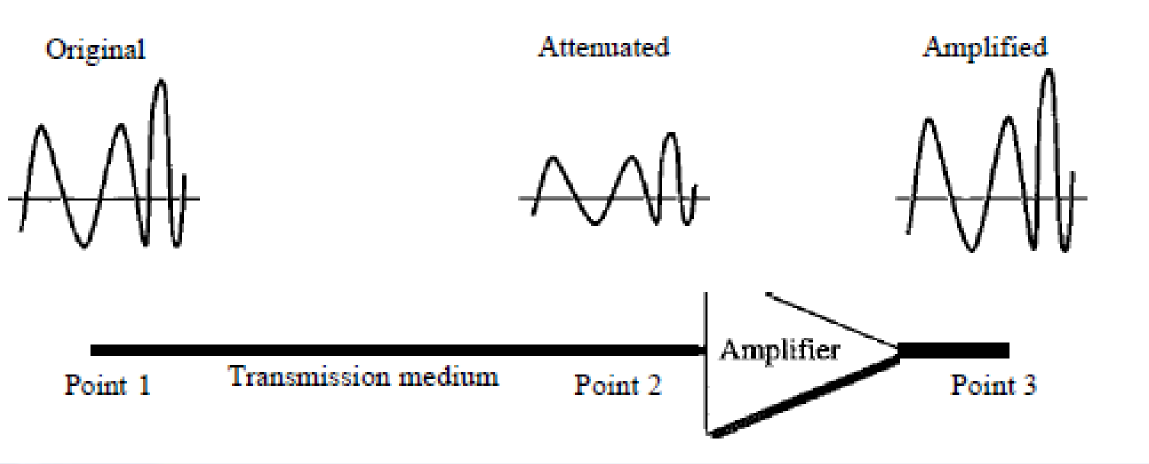
- For example, we may have a link with a bandwidth of 1 Mbps, but the devices connected to the end of the link may handle only 200 kbps. This means that we cannot send more than 200 kbps through this link.

Transmission Impairment



Attenuation

- Attenuation means a loss of energy. When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium. That is why a wire carrying electric 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.



Attenuation

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

$$dB = 10 \log_{10} \frac{P_2}{P_1}$$

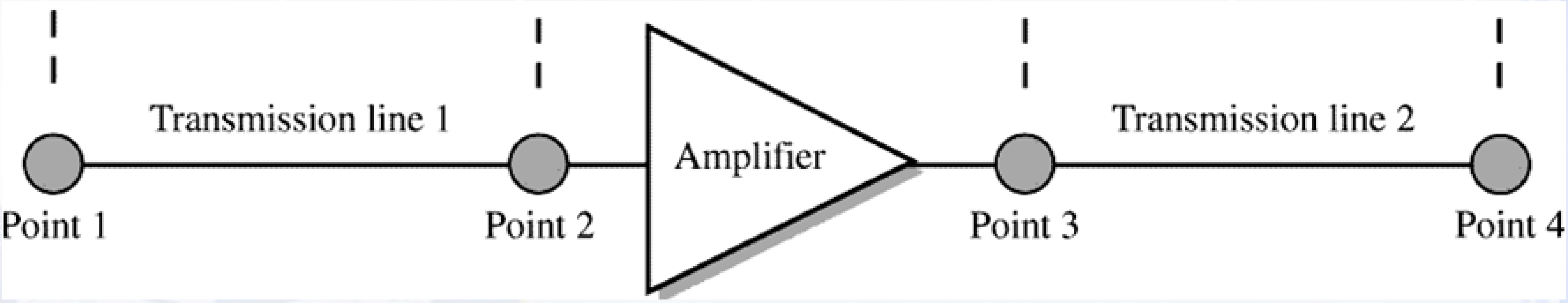
- P2 = destination, P1 = source
- Suppose a signal travels through a transmission medium and its power is reduced to one-half.
- This means that *P2 = ~ PI' In this case, the attenuation (loss of power) can be calculated as*

$$dB = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5\, P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3\, dB$$

- **A loss of 3 dB (-3 dB) is equivalent to losing one-half the power.**

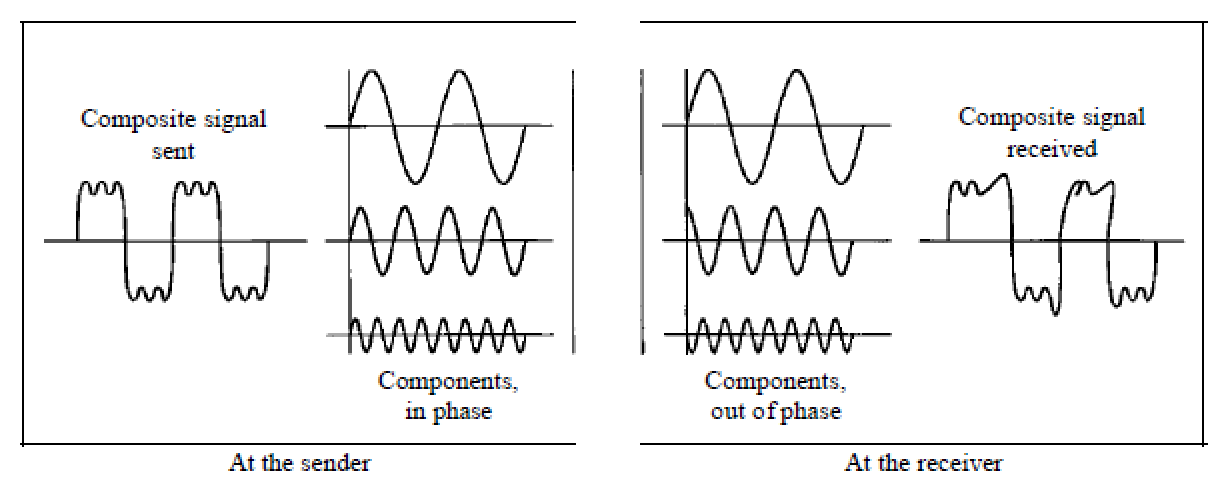
Example of Attenuation

- Consider the transmission path from point 1 to point 4 shown in Fig. bellow.
- Here the signal is attenuated by 9 db between points 1 and 2 . After getting a 14-dB boost from an amplifier at point 3, it is again attenuated by 3 dB between points 3 and 4. **Relative to point 1, the signal level in dB at point 4 is?**



Distortion

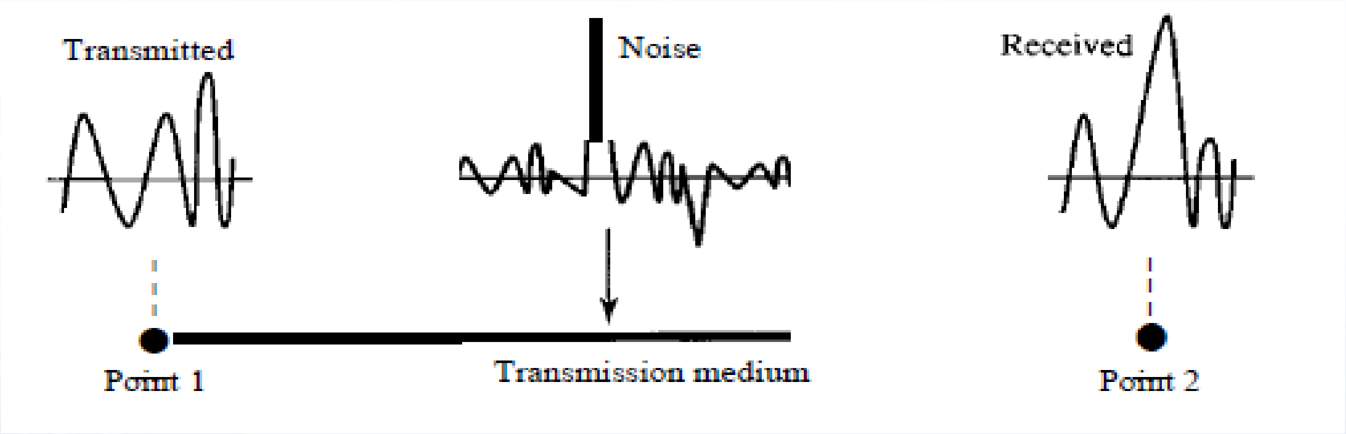
- Distortion means that the signal changes its form or shape as they travel along the channel.
- For a wireless channel, signal distortion is caused by multipath propagation effects.
- Distortion can occur in a composite signal made of different frequencies. Each signal component has its own propagation speed through a medium and, therefore, its own delay in arriving at the final destination. Differences in delay may create a difference in phase if the delay is not exactly the same as the period duration.
  - In other words, signal components at the receiver have phases different from what they had at the sender. The shape of the composite signal is therefore not the same.



Noise

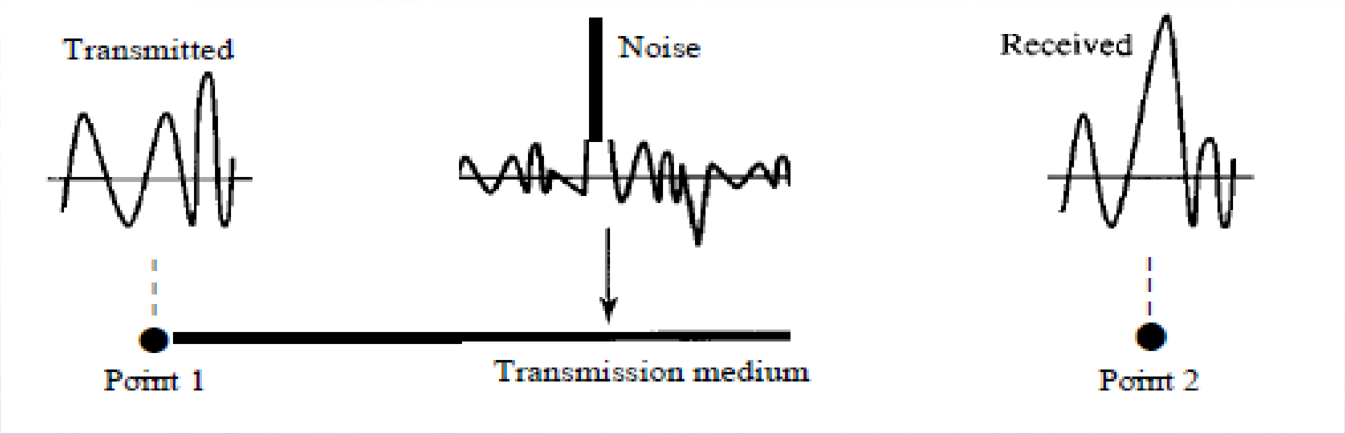
Noise may corrupt the signal.

- 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.



Noise

- 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 time) that comes from power lines, lightning, and so on.



Signal-to-Noise Ratio (SNR)

- The signal-to-noise ratio is defined as :

$$SNR = \frac{average\ signal\ power}{average\ noise\ power}$$

Because SNR is the ratio of two powers, it is often described in decibel units :

$$SNR_{db} = 10\ log_{10}\ SNR$$

Latency/Delay

- The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.
- We can say that latency is made of four components: propagation time, transmission time, queuing time and processing delay.
- Latency = propagation time +transmission time + queuing time + processing delay

Propagation Time

- Propagation time measures the time required for a bit to travel from the source to the destination. The propagation time is calculated by dividing the distance by the propagation speed.

- Propagation time = $\frac{\text{Distance}}{\text{Propagation speed}}$

Transmission Time

- The time required for transmission of a message depends on the size of the message and the bandwidth of the channel.

- Transmission time = $\frac{\text{message size}}{\text{bandwidth}}$

Queuing Time

- The third component in latency is the queuing time, the time needed for each intermediate or end device to hold the message before it can be processed.
- The queuing time is not a fixed factor; it changes with the load imposed on the network. When there is heavy traffic on the network, the queuing time increases.
- An intermediate device, such as a router, queues the arrived messages and processes them one by one. If there are many messages, each message will have to wait.

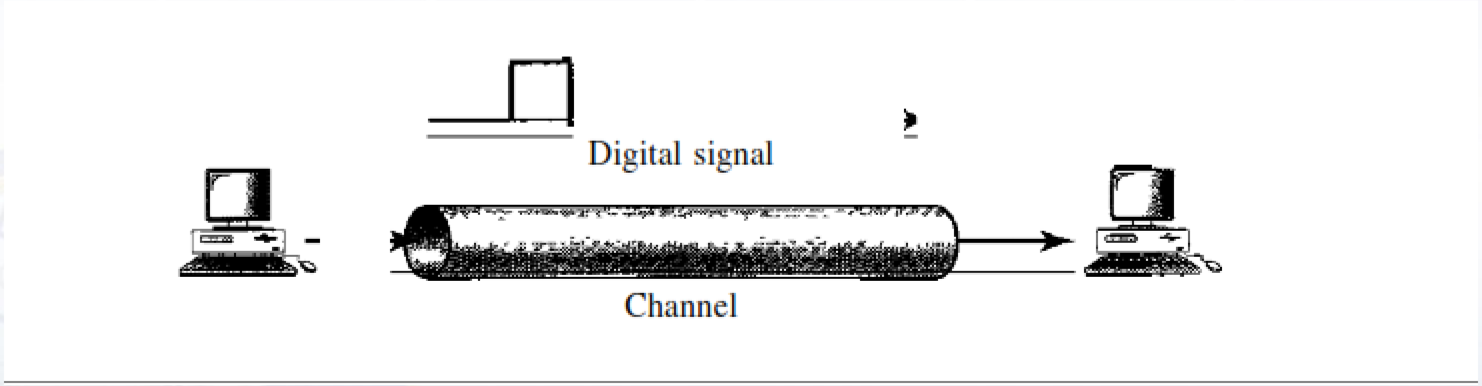
Jitter

- Another performance issue that is related to delay is **jitter**. **We can roughly say that jitter** is a problem if different packets of data encounter different delays and the application using the data at the receiver site is time-sensitive (audio and video data, for example)

Chap 3.2 Digital Transmission

Baseband Transmission

- Baseband transmission means sending a digital signal over a channel without changing the digital signal to an analog signal.



Baseband Transmission

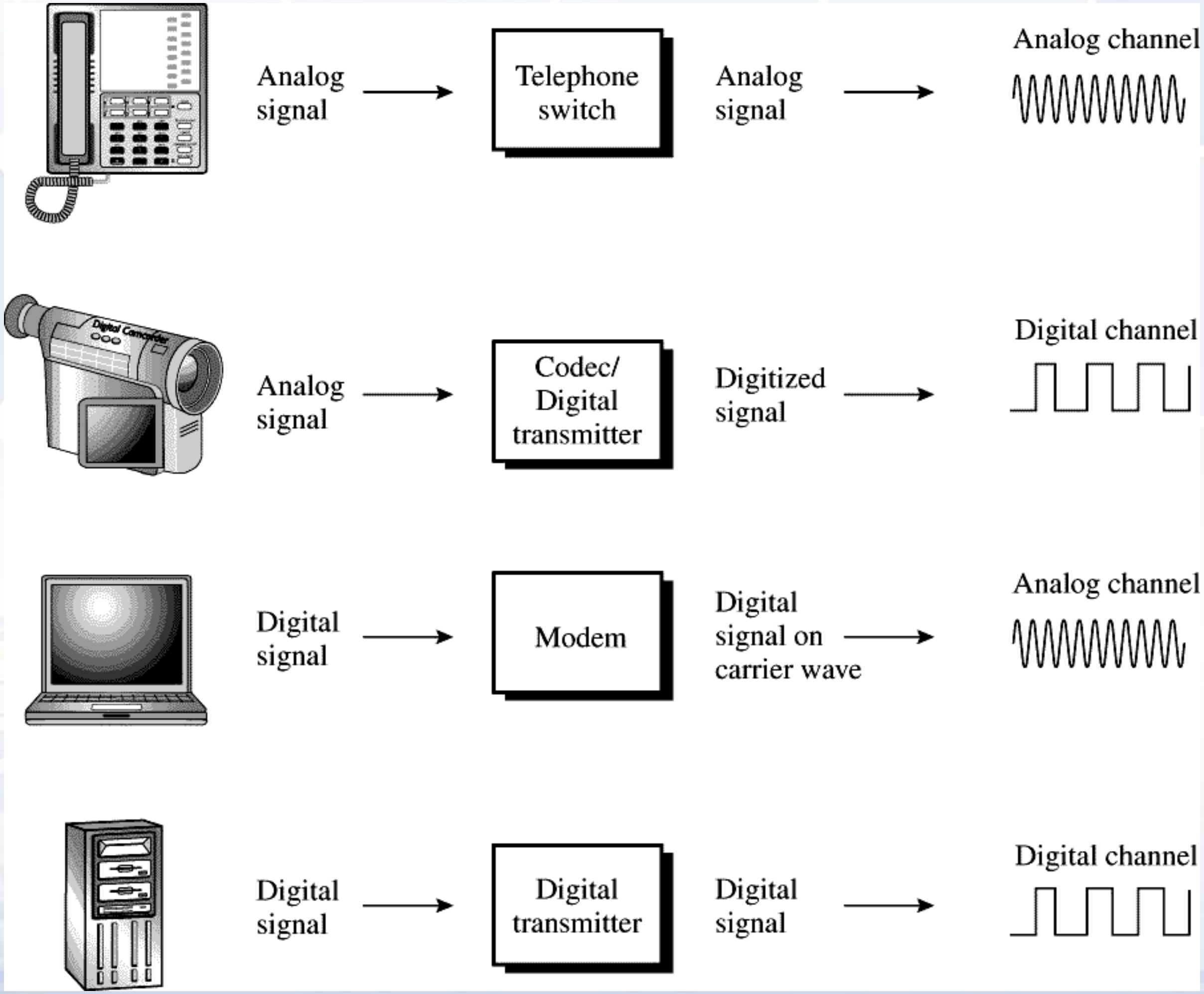
- From the picture above :
  - This is the case if we have a dedicated medium with a bandwidth constituting only one channel. For example, the entire bandwidth of a cable connecting two computers is one single channel.
  - As another example, we may connect several computers to a bus, but not allow more than two stations to communicate at a time.

Broadband Transmission (Using Modulation)

- Broadband transmission or modulation means changing the digital signal to an analog signal for transmission.
- Modulation allows us to use a bandpass channel-a channel with a bandwidth that does not start from zero. This type of channel is more available than a low-pass channel.

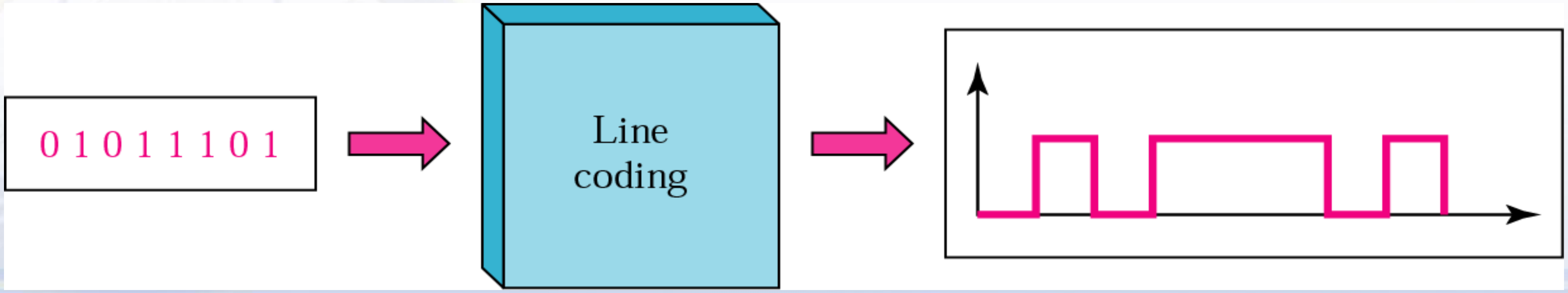
Note :
If the available channel is a bandpass channel, we cannot send the digital signal directly to the channel; we need to convert the digital signal to an analog signal before transmission.

Analog and digital signaling of analog and digital data

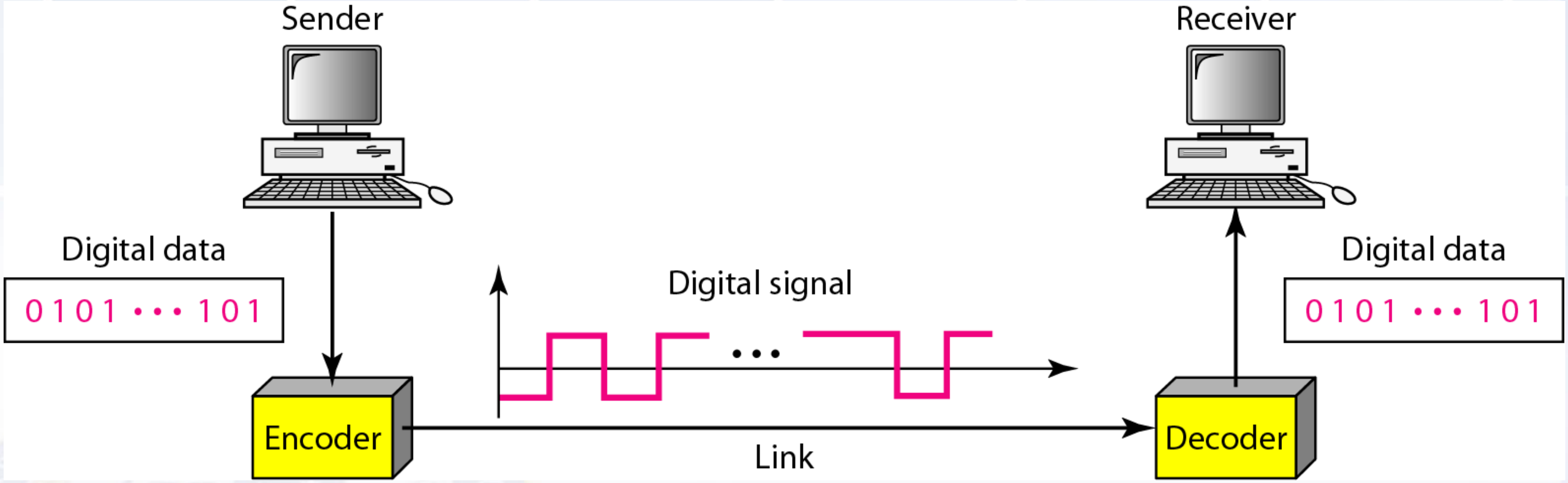


Digital – to -Digital Conversion

- Line coding
  - Line coding is the process of converting digital data to digital signals.
    - We assume that data, in the form of text, numbers, graphical images, audio, or video, are stored in computer memory as sequences of bits.
  - Line coding converts a sequence of bits to a digital signal.
    - At the sender, digital data are encoded into a digital signal;
    - At the receiver, the digital data are recreated by decoding the digital signal



Line Coding and Decoding



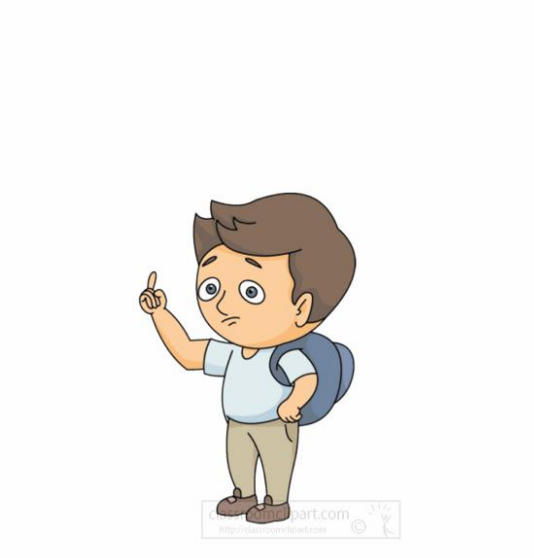
Signal Element Versus Data Element

- In data communications, ***our goal is to send data elements.***
  - A data element is the smallest entity that can represent a piece of information: ***this is the bit***.
  - In digital data communications, a signal element carries data elements. A signal element is the shortest unit (timewise) of a digital signal.
  - In other words, data elements are what we need to send; signal elements are what we can send.
  - Data elements are being carried; signal elements are the carriers.

Analogy

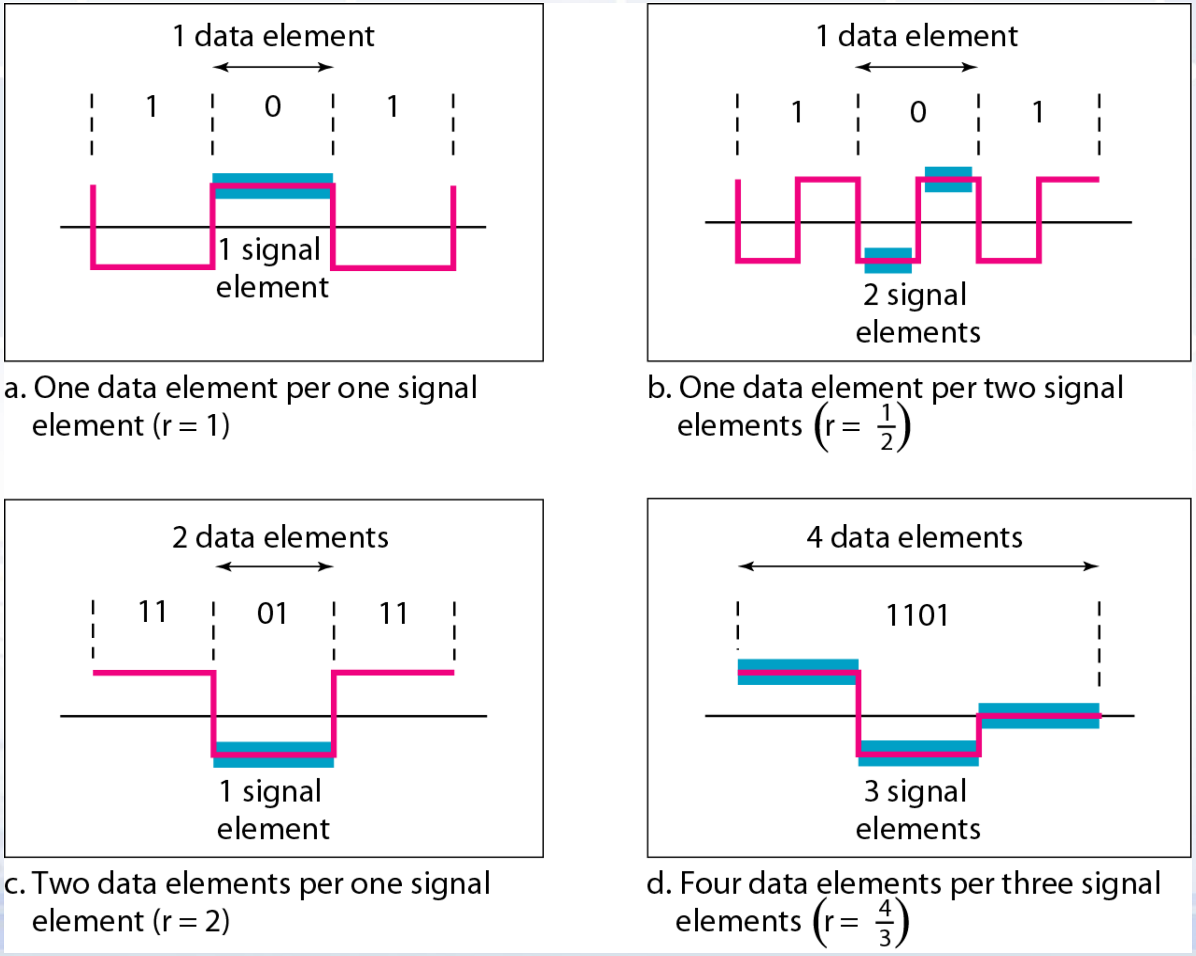
- Signal element :

- Data element :



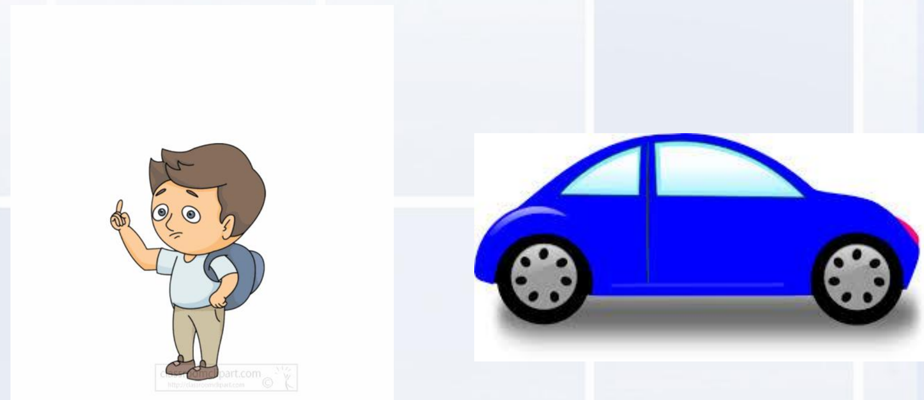
Signal Element Versus Data Element

We define a ratio ***r*** which is the number of data elements carried by each signal element.

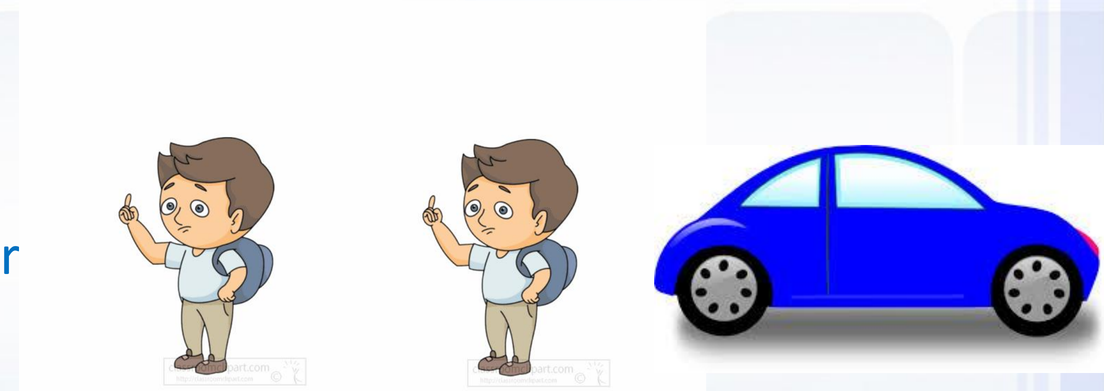


Analogy

- *r = 1*
  - One data element per one signal element

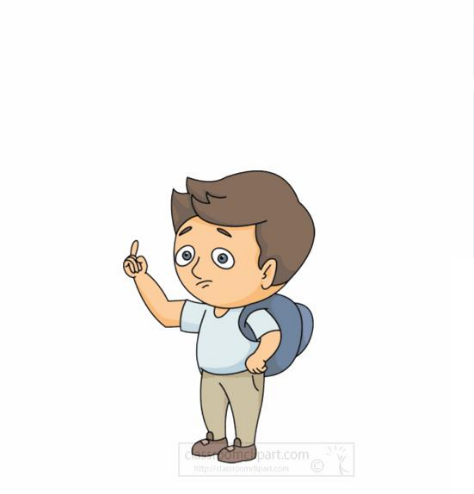


- *r > 1*
  - more data element per one signal element
  - r = 2
    - a signal element carries two data elements



Analogy

- *r = 1/2*
  - two signal elements (two transitions) to carry each data *element.*



Data Rate Versus Signal Rate

- The data rate defines the number of data elements (bits) sent in 1s. The unit is bits per second (bps).
- The signal rate is the number of signal elements sent in 1s. The unit is the baud.
- The data rate is sometimes called the bit rate; the signal rate is sometimes called the pulse rate, the modulation rate, or the baud rate.
- One goal in data communications is to increase the data rate while decreasing the signal rate.
- Increasing the data rate increases the speed of transmission; decreasing the signal rate decreases the bandwidth requirement.

Bit rate and Baud rate

- Relationship between data rate and signal rate (bit rate and baud rate).
- The baud or signal rate can be expressed as:

S = c x N x 1/r bauds

- ✓ N is data rate
- ✓ c is the case factor (worst, best & avg. - which varies for each case- we like avg., however)
- ✓ r is the ratio between data element & signal element

Example

A signal is carrying data in which one data element is encoded as one signal element (r = 1). If the bit rate is 100 kbps, what is the average value of the baud rate if c is between 0 and 1?

Solution

We assume that the average value of c is 1/2 . The baud rate is then

$$S = c \times N \times \frac{1}{r} = \frac{1}{2} \times 100{,}000 \times \frac{1}{1} = 50{,}000 = 50 \text{ kbaud}$$

Bandwidth and Baud Rate

- We can say that the baud rate, not the bit rate, determines the required bandwidth for a digital signal.
- If we use the transportation analogy, the number of vehicles affects the traffic, not the number of people being carried.
- Although the actual bandwidth of a digital signal is infinite, the effective bandwidth is finite.

Data Rate

- The minimum bandwidth can be given as :

$$B_{min} = c \times N \times \frac{1}{r}$$

Data Rate

- We can solve for the maximum data rate if the bandwidth of the channel is given :

$$N_{max} = \frac{1}{c} \times B \times r$$

Baseline Wandering

- A receiver will evaluate the average power of the received signal (called the baseline) and use that to determine the value of the incoming data elements.
  - If the incoming signal does not vary over a long period of time, the baseline will drift and thus cause errors in detection of incoming data elements.
- A long string of Os or 1s can cause a drift in the baseline (baseline wandering) and make it difficult for the receiver to decode correctly.

DC Components

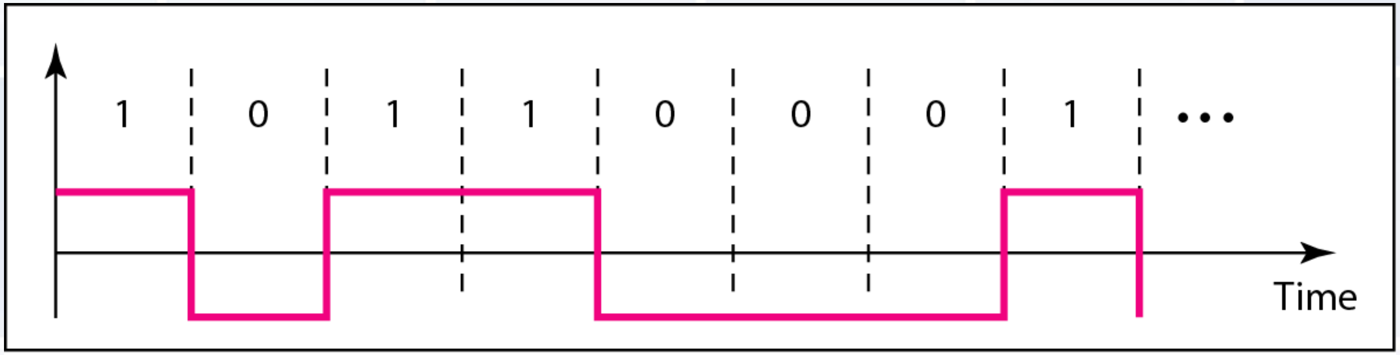
- When the voltage level remains constant for long periods of time, there is an increase in the low frequencies of the signal. Most channels may not support the low frequencies.
- For example, a telephone line cannot pass frequencies below 200 Hz.

Self-synchronization

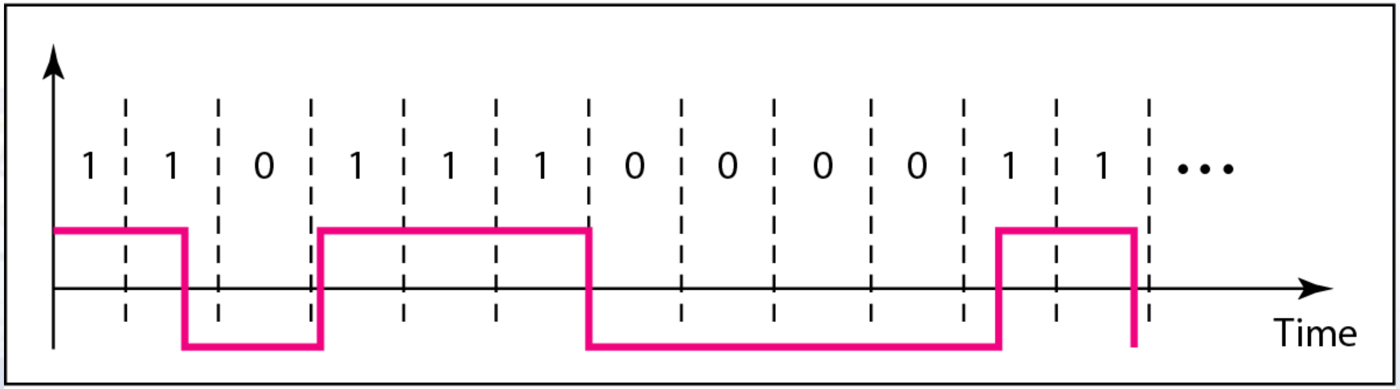
- To correctly interpret the signals received from the sender, the receiver's bit intervals must correspond exactly to the sender's bit intervals.
  - If the receiver clock is faster or slower, the bit intervals are not matched and the receiver might misinterpret the signals

Lack of Self-synchronization

The sender sends 10110001, while the receiver receives 110111000011



a. Sent



b. Received

Example

In a digital transmission, the receiver clock is 0.1 percent faster than the sender clock. How many extra bits per second does the receiver receive if the data rate is 1 kbps? How many if the data rate is 1 Mbps?

Solution

At 1 kbps, the receiver receives 1001 bps instead of 1000 bps.

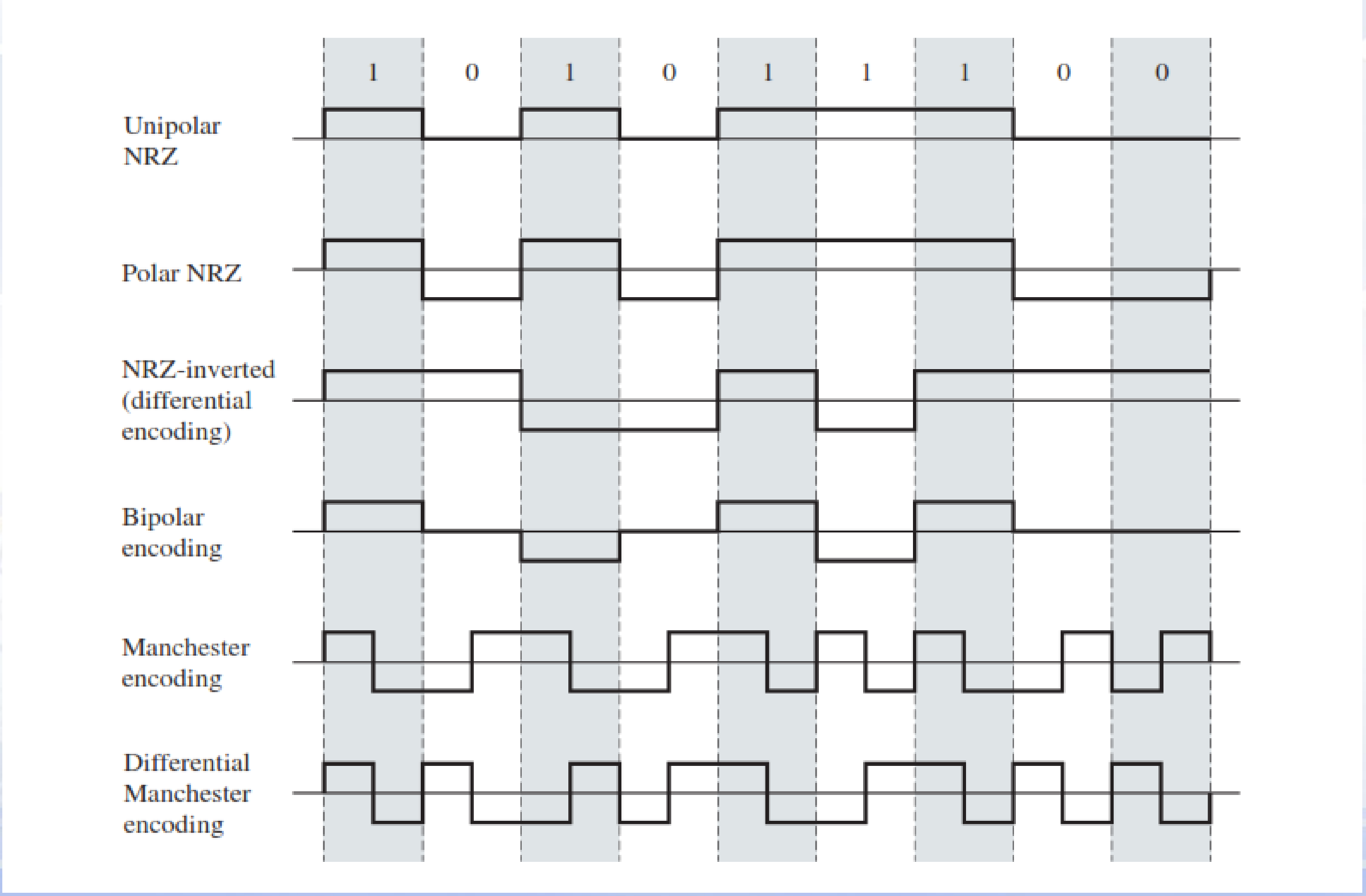
1000 bits sent	1001 bits received	1 extra bps

At 1 Mbps, the receiver receives 1,001,000 bps instead of 1,000,000 bps.

1,000,000 bits sent	1,001,000 bits received	1000 extra bps

Line Coding Scheme

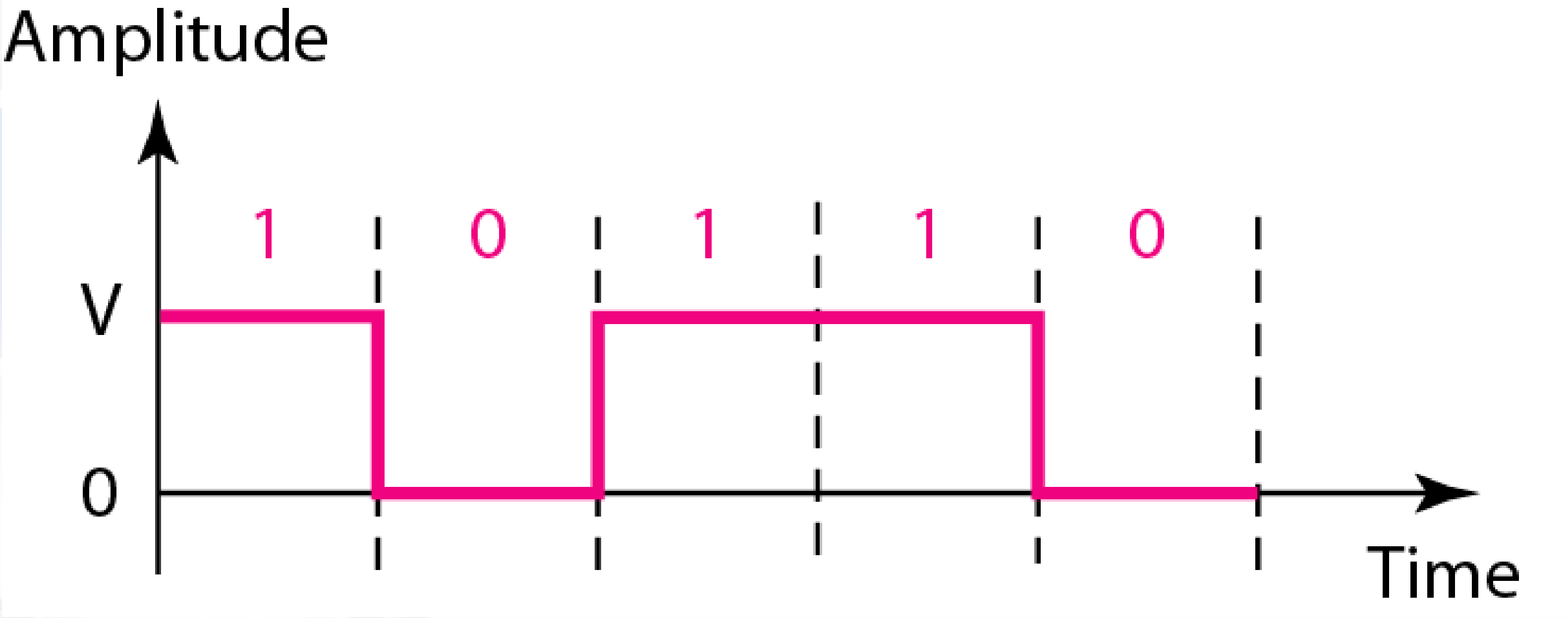
Line coding is the method used for converting binary information sequence into a digital signal in a digital communication system.



Unipolar

- All signal levels are on one side of the time axis - either above or below.
- NRZ - Non Return to Zero scheme is an example of this code.
  - The positive voltage defines bit I and the zero voltage defines bit O.
- Scheme is prone to baseline wandering and DC components. It has no synchronization or any error detection. It is simple but costly in power consumption.

Unipolar - NRZ



Polar - NRZ

- The voltages are on both sides of the time axis.
- Polar NRZ scheme can be implemented with two voltages. E.g. +V for 1 and -V for 0.
- There are two versions:
  - NZR - Level (NRZ-L) - positive voltage for one symbol and negative for the other
  - NRZ - Inversion (NRZ-I) - the change or lack of change in polarity determines the value of a symbol. E.g. a “1” symbol inverts the polarity a “0” does not.

Polar NRZ-L and NRZ-I schemes

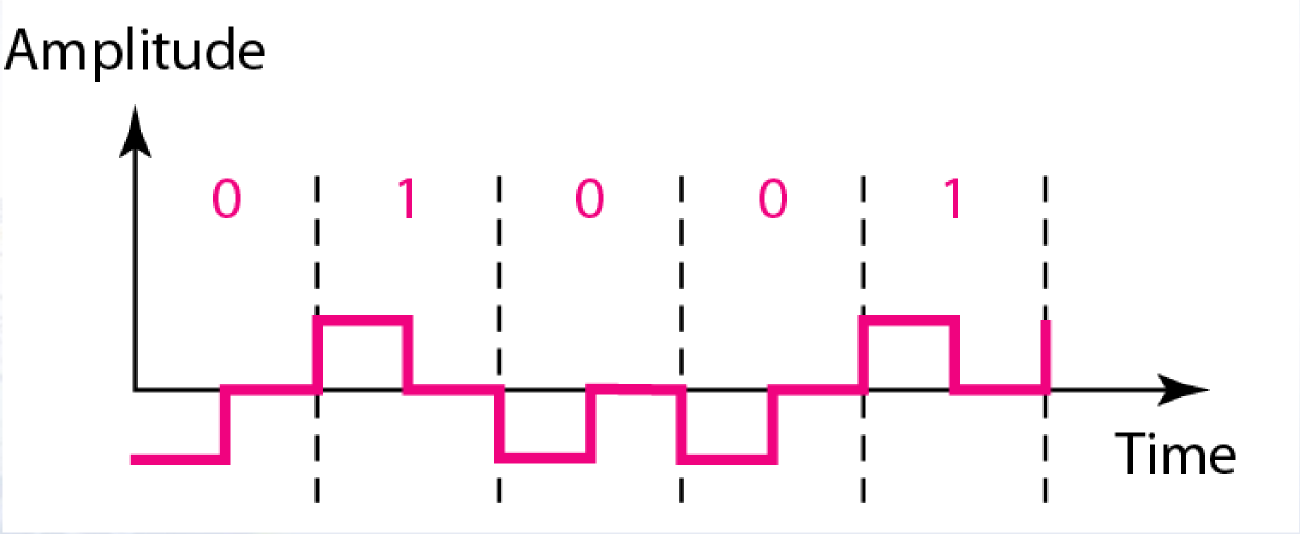
The picture can't be displayed.

Polar NRZ-L and NRZ-I schemes

NRZ-L and NRZ-I both have a DC component problem and baseline wandering, it is worse for NRZ-L. Both have no self synchronization &no error detection. Both are relatively simple to implement.

Polar - RZ

- The Return to Zero (RZ) scheme uses three voltage values. +, 0, -.
- the signal changes not between bits but during the bit.
  - In below figure we see that the signal goes to 0 in the middle of each bit. It remains there until the beginning of the next bit



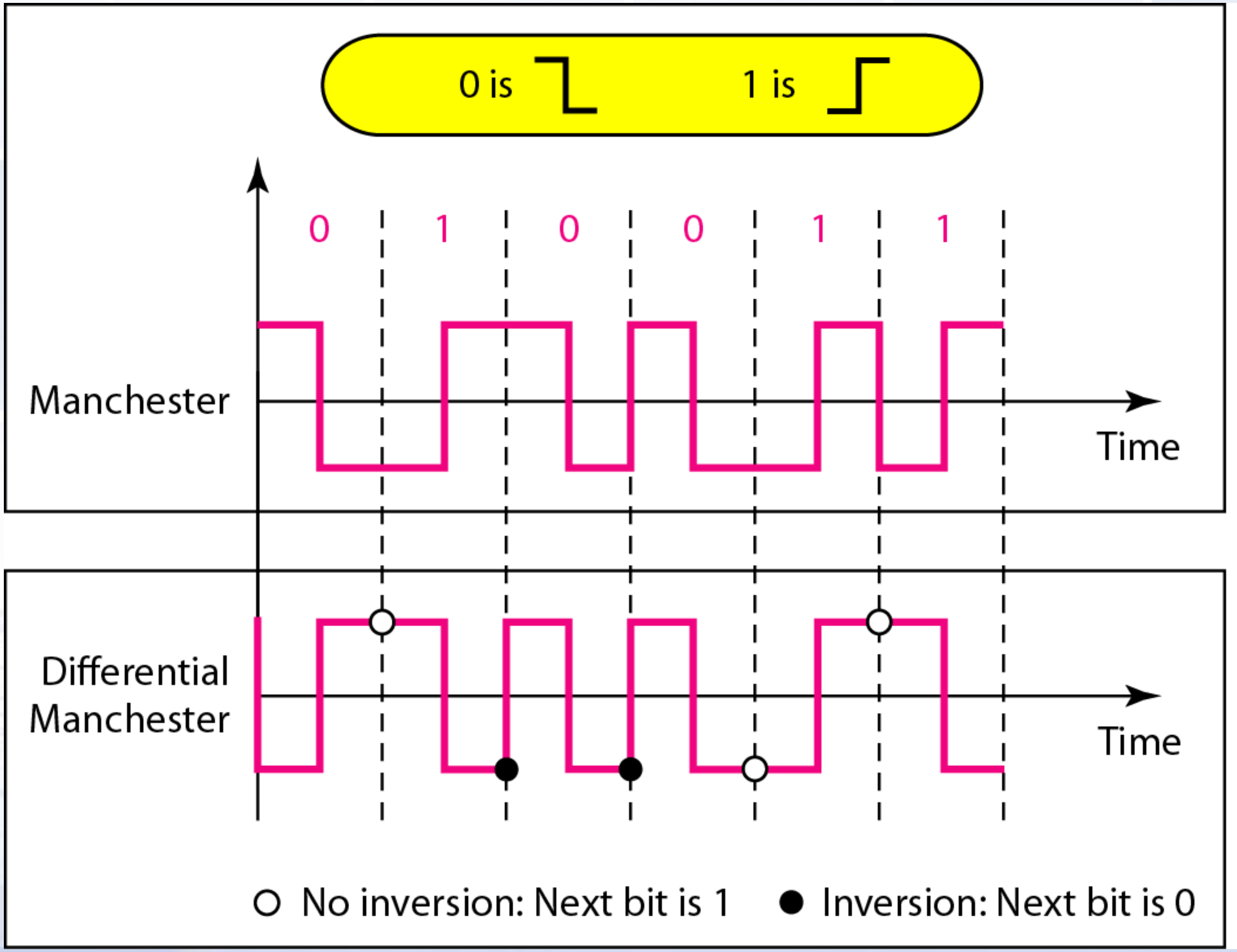
Polar - RZ

- No DC components or baseline wandering.
- Self synchronization - transition indicates symbol value.
- More complex as it uses three voltage level. It has no error detection capability.

Polar - Biphase: Manchester and Differential Manchester

- Manchester coding consists of combining the NRZ-L and RZ schemes.
  - Every symbol has a level transition in the middle: from high to low or low to high. Uses only two voltage levels.
- Differential Manchester coding consists of combining the NRZ-I and RZ schemes.
  - Every symbol has a level transition in the middle. But the level at the beginning of the symbol is determined by the symbol value. One symbol causes a level change the other does not.

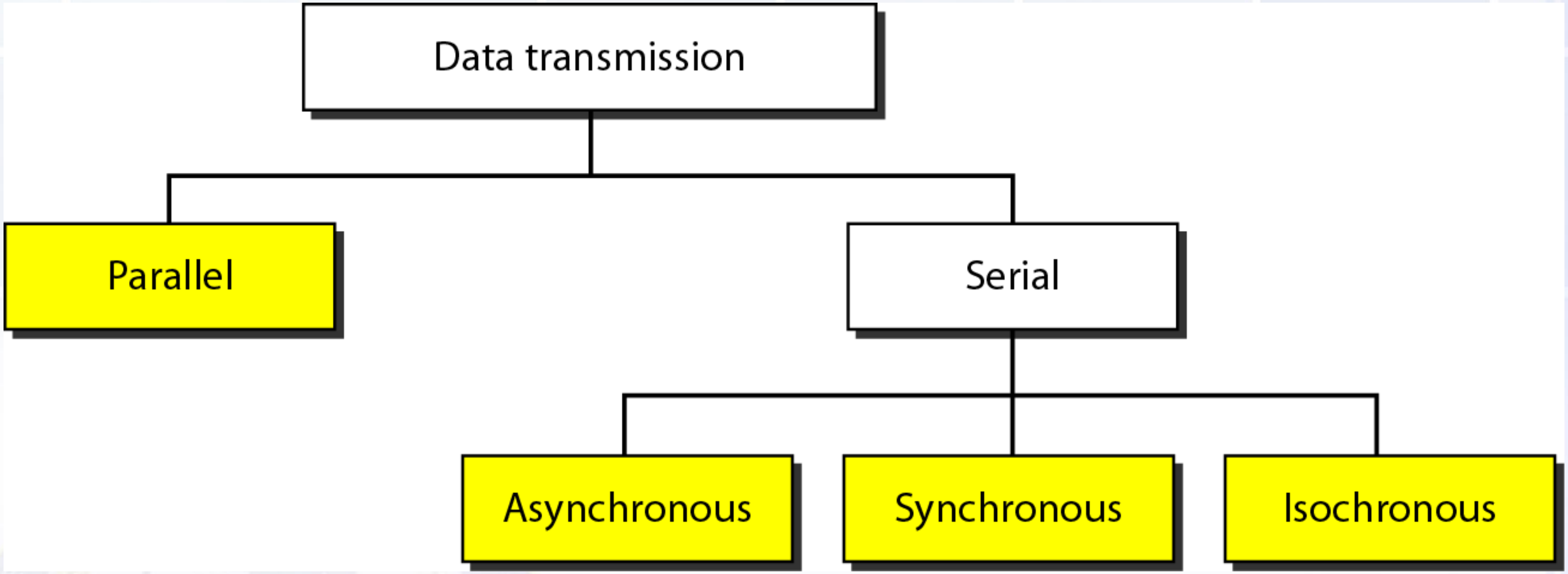
Polar - Biphase: Manchester and Differential Manchester



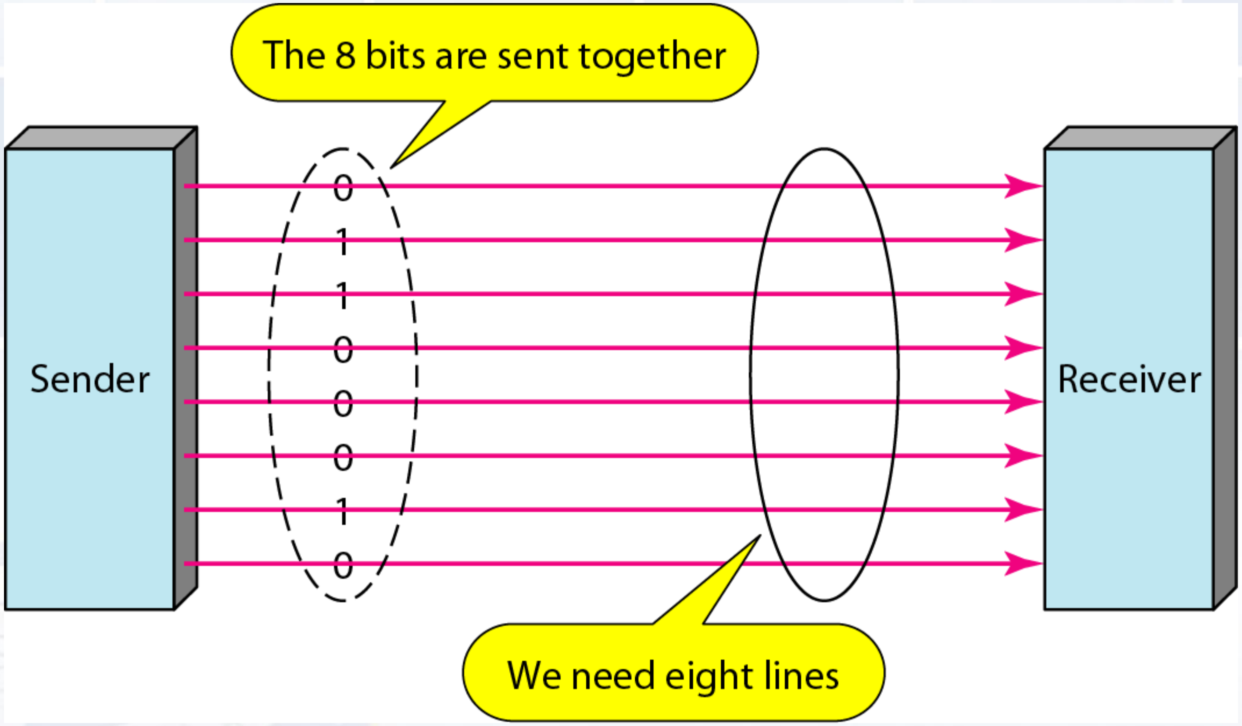
Bipolar

- There are three voltage levels: positive, negative, and zero. The voltage level for one data element is at zero, while the voltage level for the other element alternates between positive and negative.
- Bipolar coding has been using for long distance transmission where the bandwidth efficiency is important.
- In LANs, where the distances are short, bandwidth efficiency is less important than cost per station.
- The Manchester encodings are used in Ethernet and token-ring LAN standards.

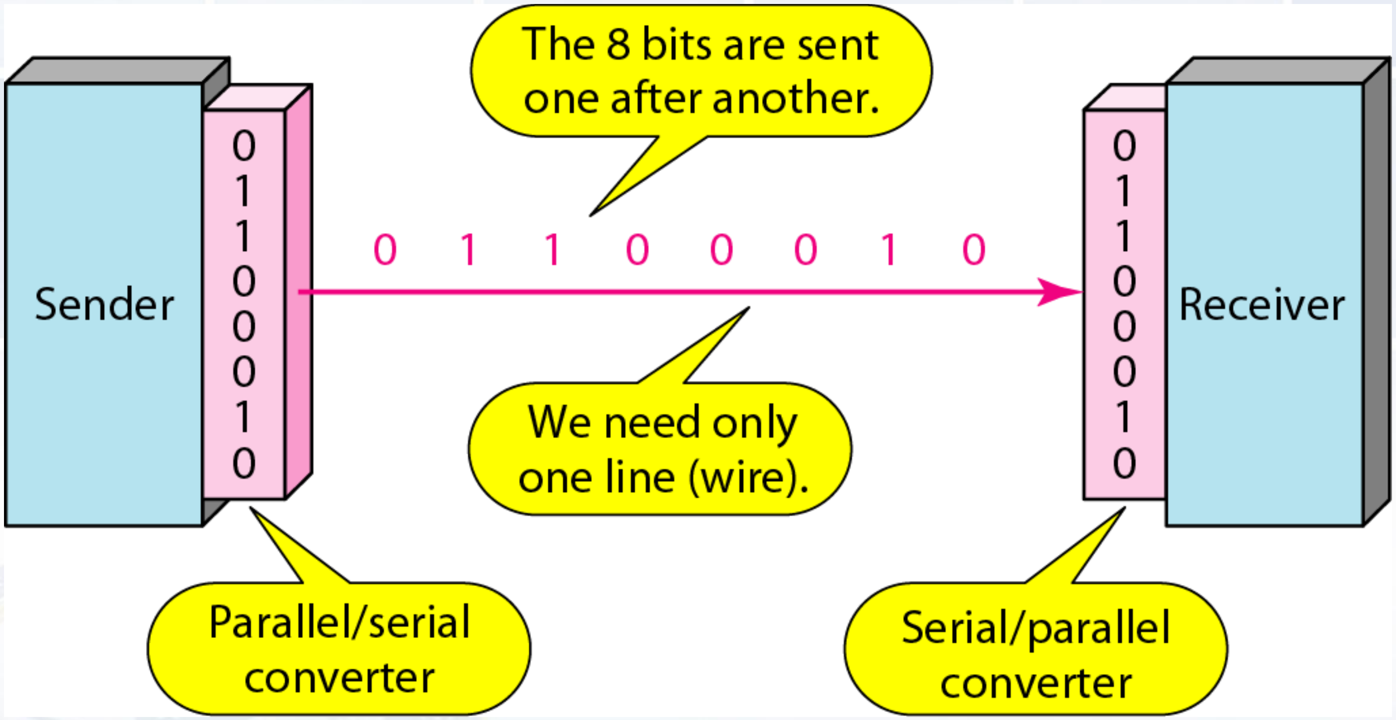
Data transmission and modes



Parallel transmission

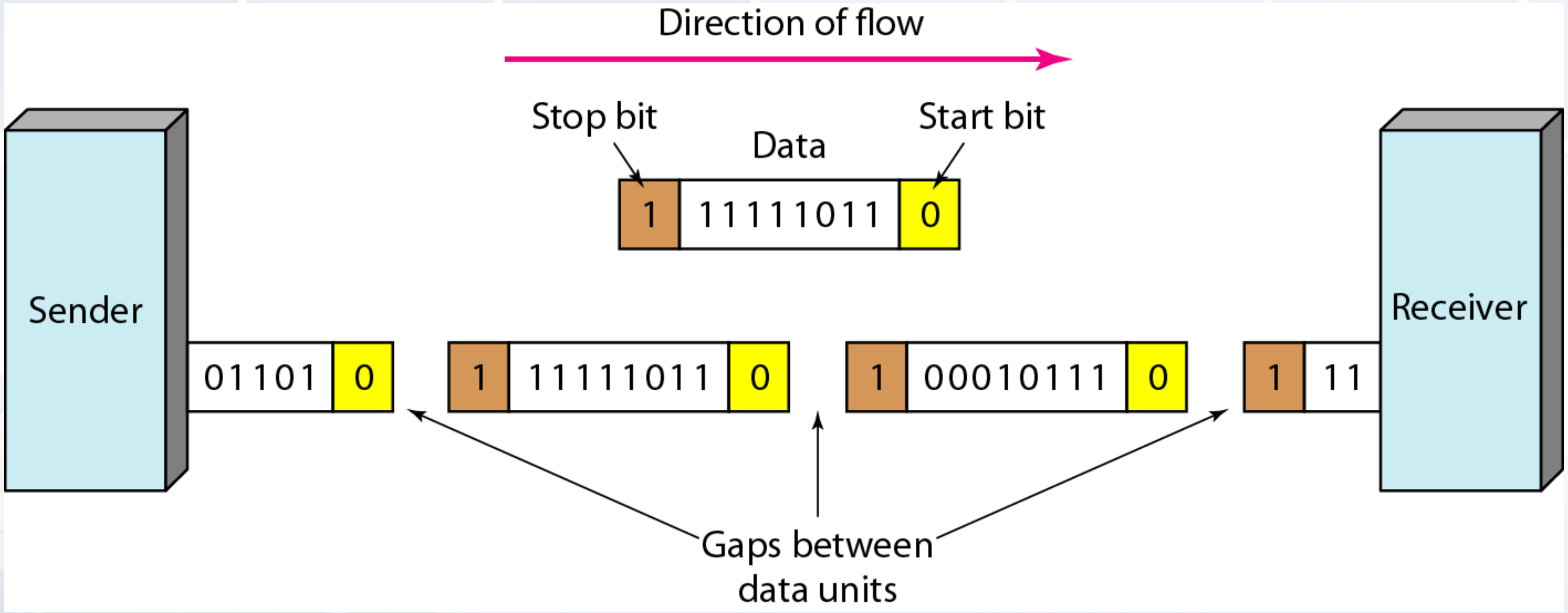


Serial transmission



Asynchronous Transmission

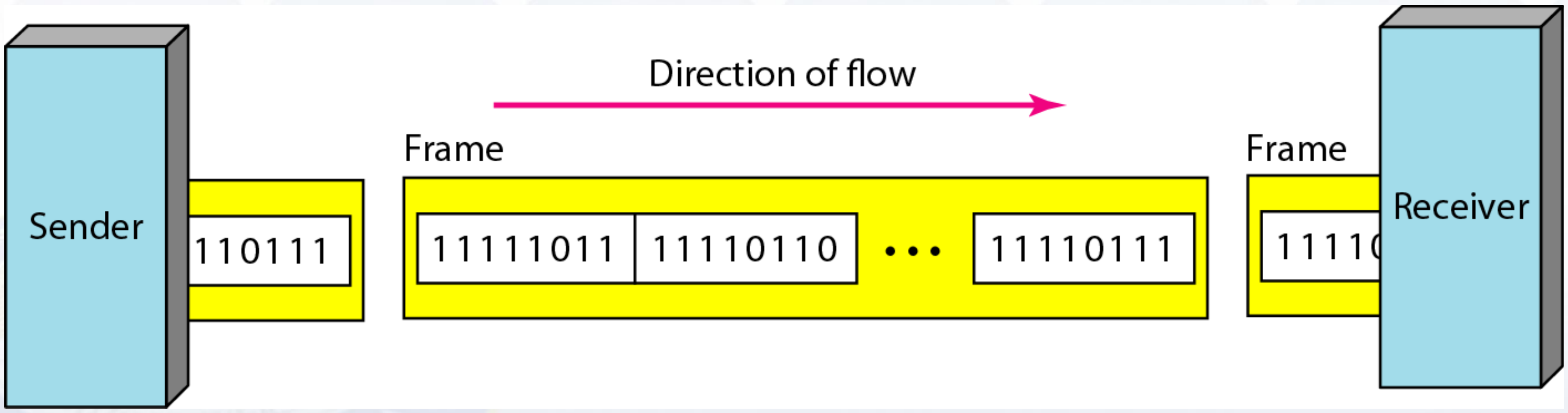
We send 1 start bit (0) at the beginning and 1 or more stop bits (1s) at the end of each byte.
There may be a gap between each byte.



It is "asynchronous at the byte level," bits are still synchronized; their durations are the same.

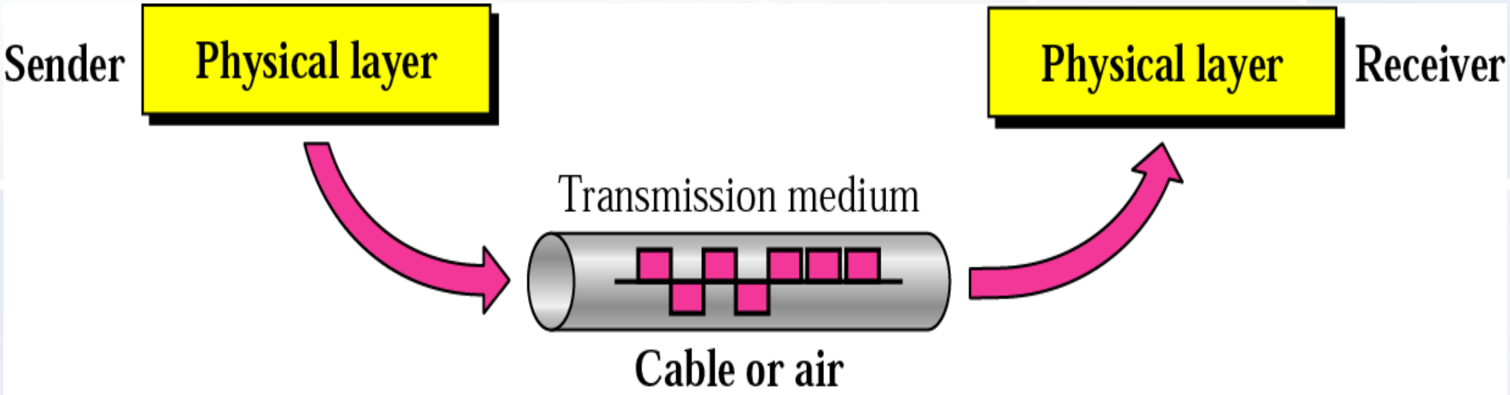
Synchronous Transmission

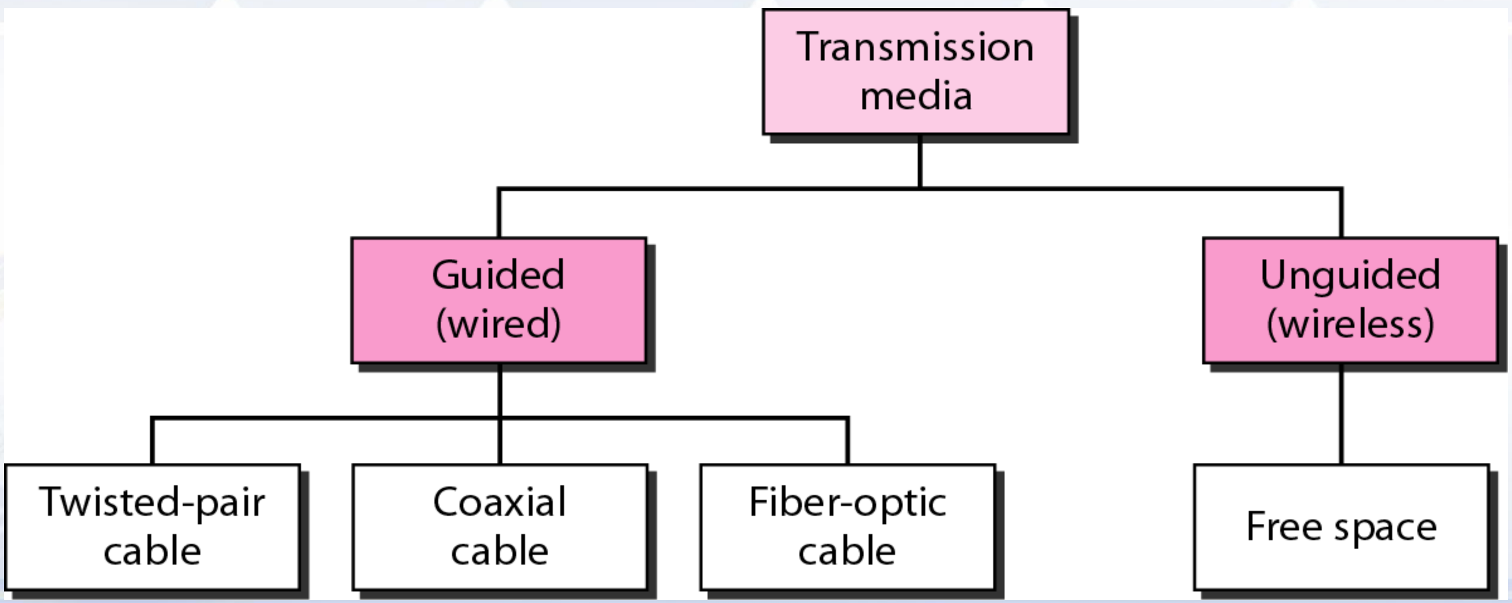
We send bits one after another without start or stop bits or gaps.
It is the responsibility of the receiver to group the bits.



Chap 3.3 : Cabling – The Guided Media

Physical Media





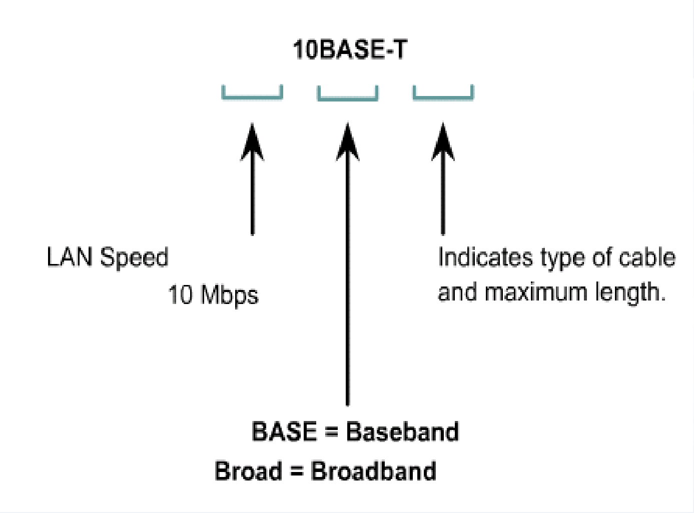
Physical Media

- **Copper**
  - Coaxial Cable - Thick dan Thin
  - Unshielded Twisted Pair - CAT 3,4,5,5e&6, 7
- **Optical Fiber**
  - Multimode
  - Singlemode
- **Wireless**
  - Short Range
  - Medium Range
  - Satellite

Cable

- The ability and specification of cable are depend on:
  - The size of packet data sent out.
  - The speed of data transmission.
  - Distance.

<u>Cable specification :</u>

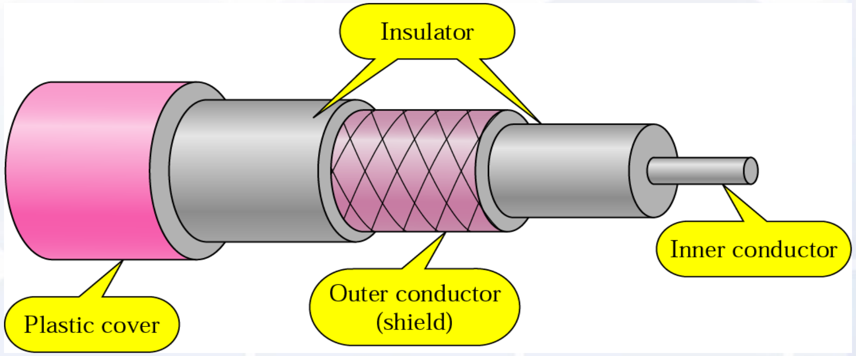


10Base2 →

Cable type : coaxial
Max distance : 185 m

Copper Media: Coaxial Cable

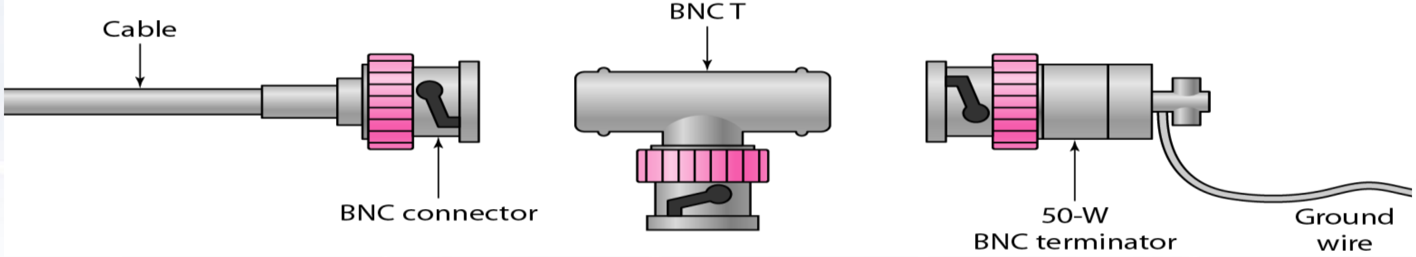
- Using repeater to streghten signal.
- Support high bandwidth.
- Coaxial cable is a copper-cored cable surrounded by a heavy shielding.
- Outer conductor shields the inner conductor from picking up stray signal from the air.



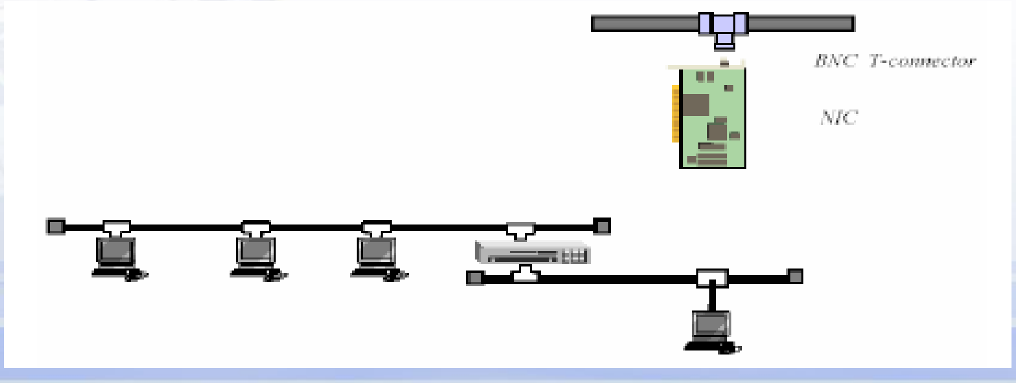
Copper Media: Coaxial Cable

Used for data communication:

- **Thicknet(RG-11):** it connect 100 devices with range 500 m (more expensive).
- **Thinnet (RG-58):** it connect 30 devices within 185 m (cheaper).
- Used BNC connector to connect coaxial cable.



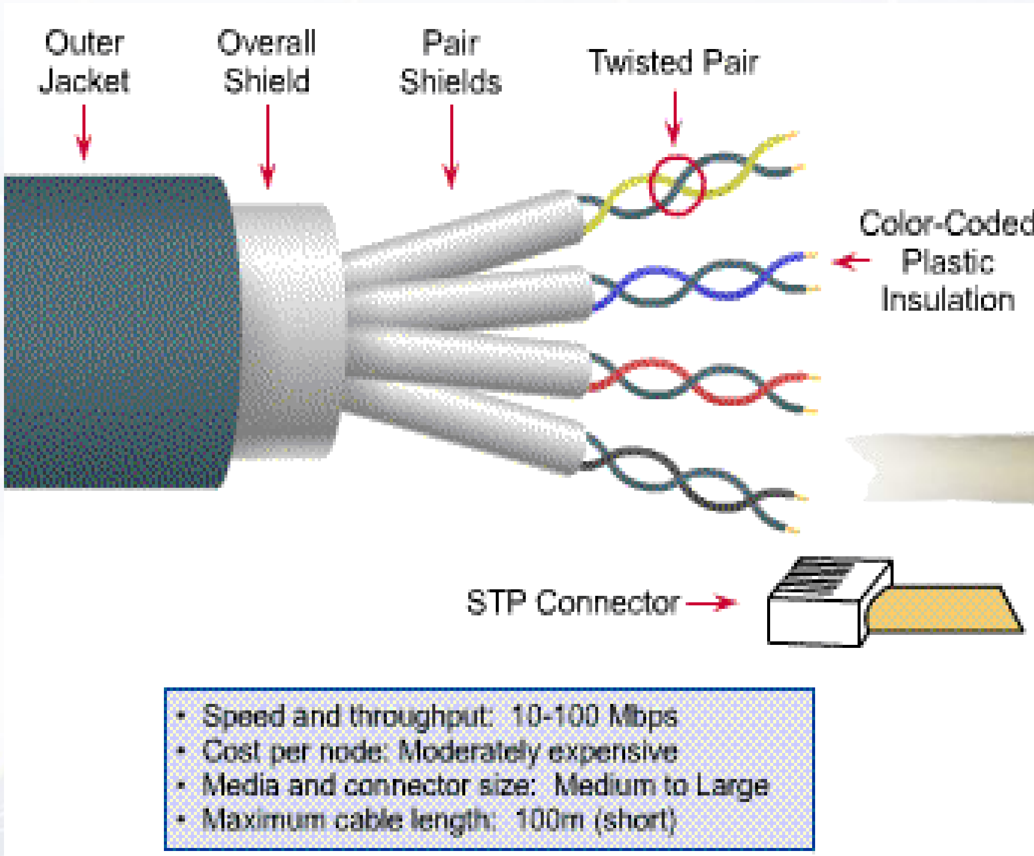
Bus topology uses coaxial thinnet

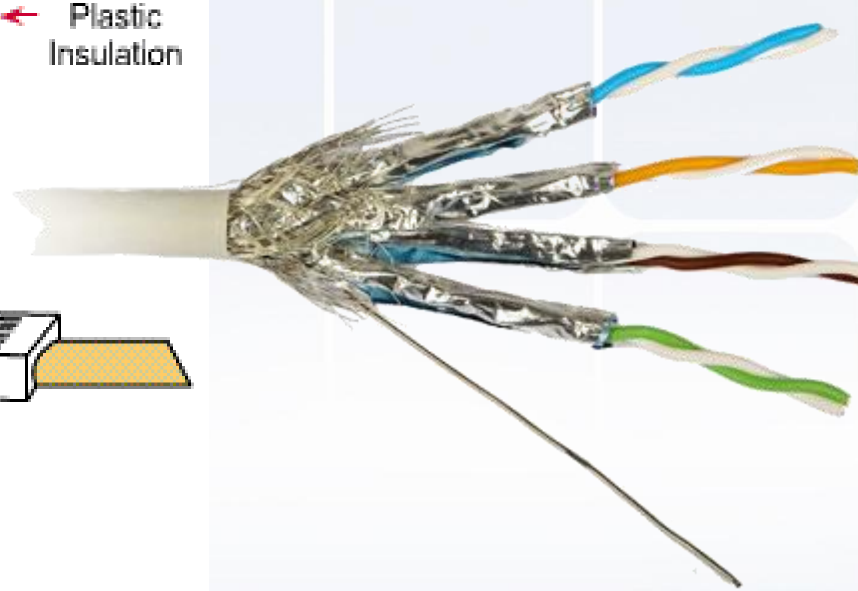


Copper Media: Twisted Pair

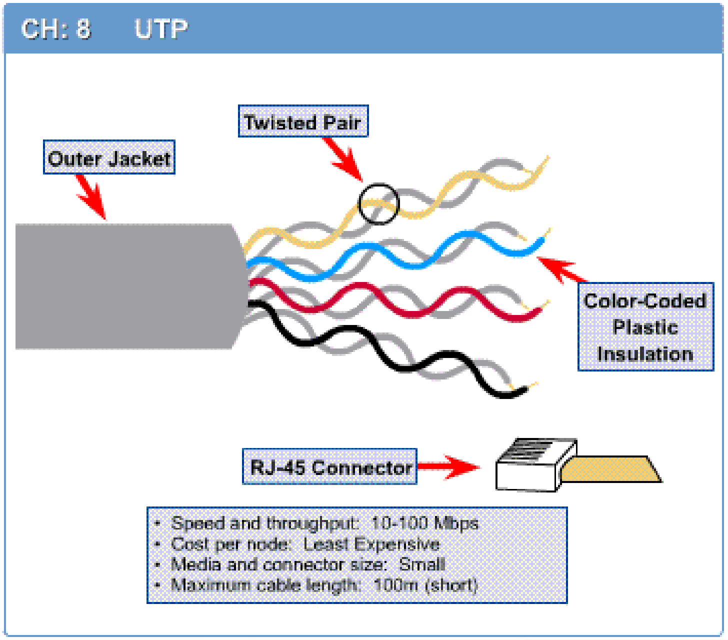
- Twisted-pair is a type of cabling that is used for telephone communications and most modern Ethernet networks.
- A pair of wires forms a circuit that can transmit data. The pairs are twisted to provide protection against crosstalk, the noise generated by adjacent pairs.
- There are two basic types, shielded twisted-pair (STP) and unshielded twisted-pair (UTP).

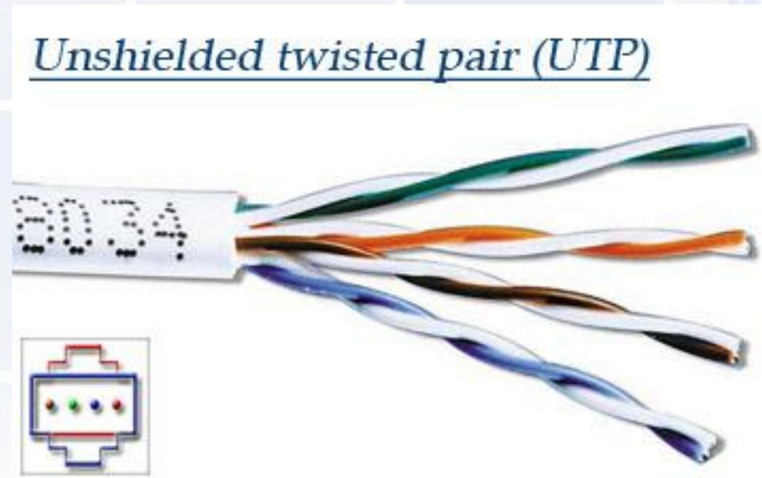
Shielded Twisted Pair (STP)

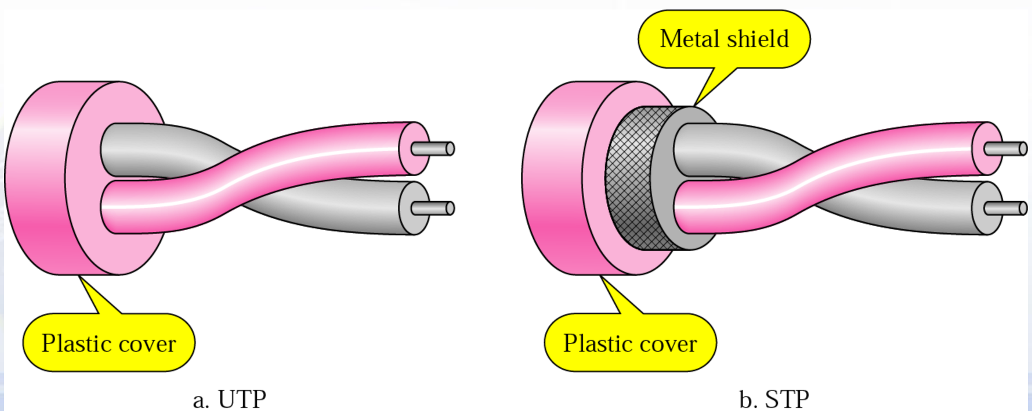




Unshielded Twisted Pair (UTP)

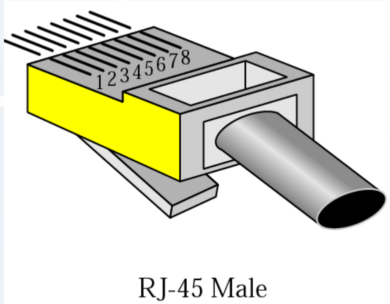


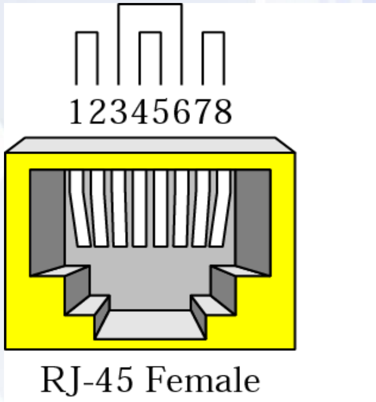




Unshielded Twisted Pair (UTP)

- Consists of 4 pairs (8 wires) of insulated copper wires typically about 1 mm thick.
- The wires are twisted together in a helical form.
- Twisting reduces the interference between pairs of wires.
- High bandwidth and High attenuation channel.
- Flexible and cheap cable.
- Category rating based on number of twists per inch and the material used
- CAT 3, CAT 4, CAT 5, Enhanced CAT 5 and now CAT 6.





UTP Connector

Categories of UTP: CAT 3 and CAT 4

CAT 3

- Bandwidth 16 Mhz
- 11.5 dB Attenuation
- 100 ohms Impedance
- Used in voice applications (telephone connections) and 10baseT (10Mbps) Ethernet

CAT 4

- 20 MHz Bandwidth
- 7.5 dB Attenuation
- 100 ohms Impedance
- Used in 10baseT (10Mbps) Ethernet

Categories of UTP: CAT 5 and 5e

CAT 5

- 100 MHz Bandwidth
- 24.0 dB Attenuation
- 100 ohms Impedance
- Used for high-speed data transmission
- Used in 10BaseT (10 Mbps) Ethernet & Fast Ethernet (100 Mbps)

CAT 5e

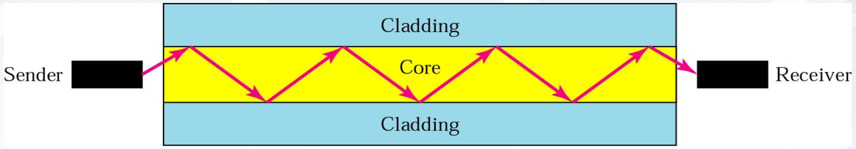
- 150 MHz Bandwidth
- 24.0 dB Attenuation
- 100 ohms Impedance
- Transmits high-speed data
- Used in Fast Ethernet (100 Mbps), Gigabit Ethernet (1000 Mbps) & 155 Mbps ATM

Categories of UTP: CAT 6

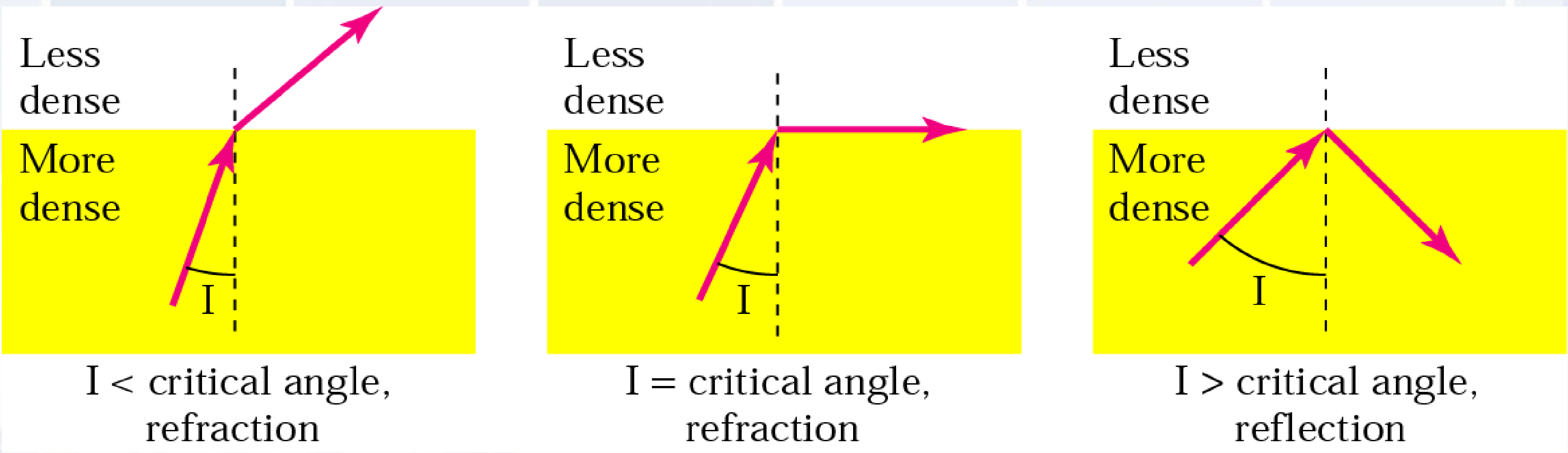
- 250 MHz Bandwidth
- 19.8 dB Attenuation
- 100 ohms Impedance
- Transmits high-speed data
- Used in Gigabit Ethernet (1000 Mbps) & 10 Gig Ethernet (10000 Mbps)

Fiber Media

- Optical fibers use light to send information through the optical medium.
- It uses the principal of total internal reflection.
- Modulated light transmissions are used to transmit the signal.



Total Internal Reflection

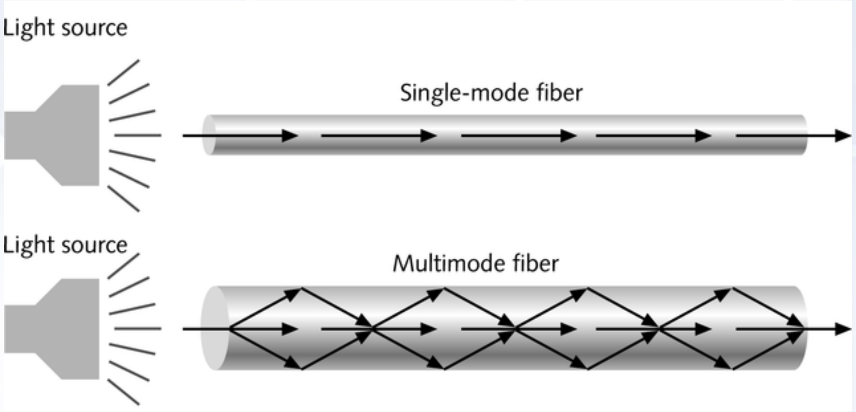


Fiber Media

- Light travels through the optical media by the way of total internal reflection.
- Modulation scheme used is intensity modulation.
- Two types of Fiber media :
  - Multimode
  - Singlemode
- Multimode Fiber can support less bandwidth than Singlemode Fiber.
- Singlemode Fiber has a very small core and carry only one beam of light. It can support Gbps data rates over > 100 Km without using repeaters.

Single and Multimode Fiber

- **Single-mode fiber**
  - Carries light pulses along single path
  - Uses Laser Light Source
- **Multimode fiber**
  - Many pulses of light generated by LED travel at different angles

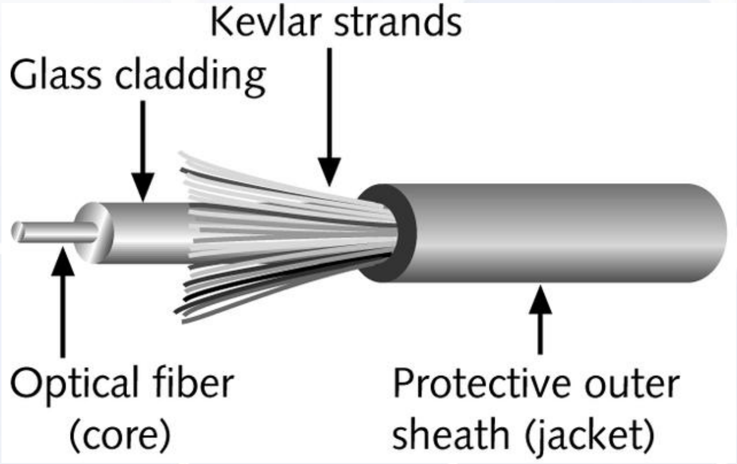


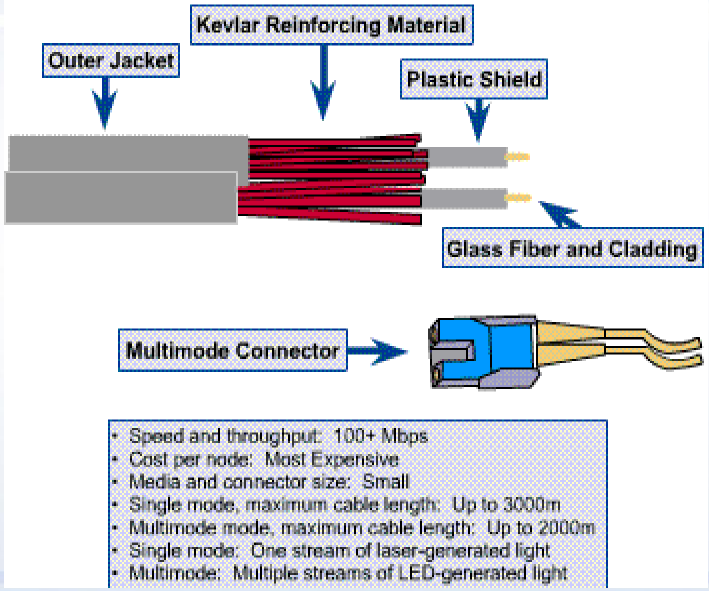
Fiber Media

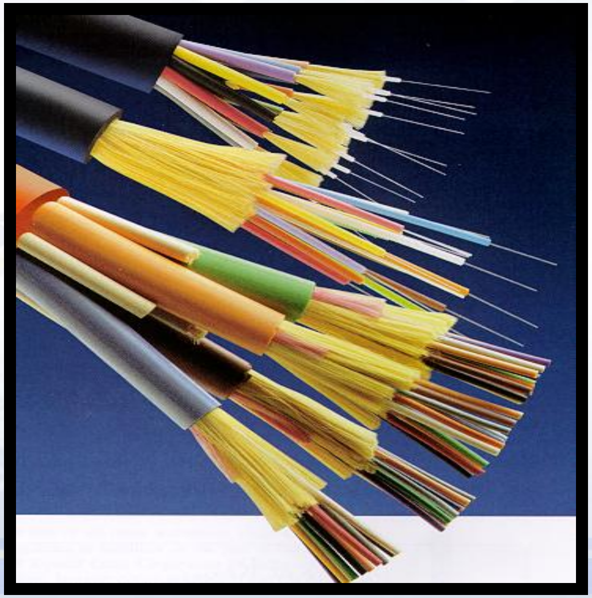
- The bandwidth of the fiber is limited due to the dispersion effect.
- Distance Bandwidth product of a fiber is almost a constant.
- Fiber optic cables consist of multiple fibers packed inside protective covering.
- 62.5/125 µm (850/1310 nm) multimode fiber
- 50/125 µm (850/1310 nm) multimode fiber
- 10 µm (1310 nm) single-mode fiber

Fiber-Optic Cable

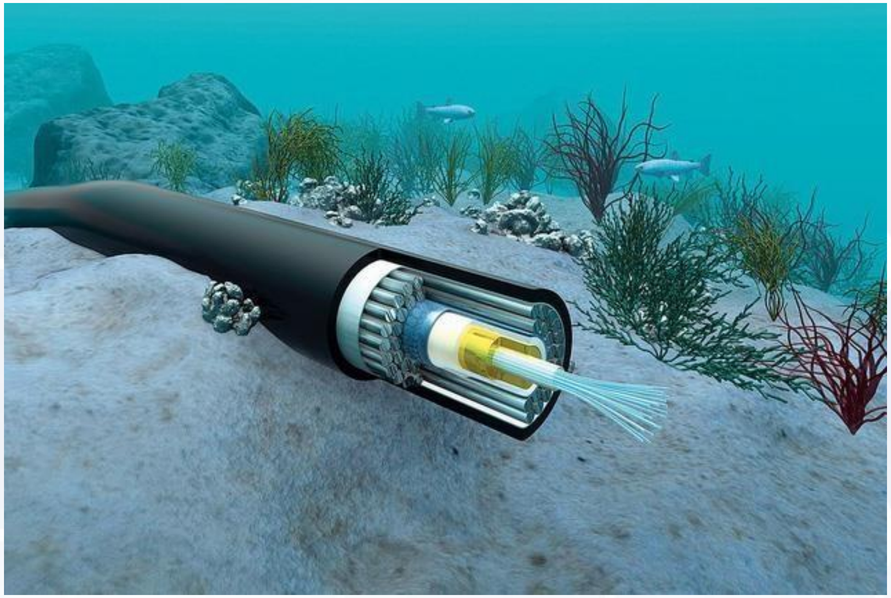
- Contains one or several glass fibers at its core.
- Surrounding the fibers is a layer called cladding.
- FO Cable may have 1 to over 1000 fibers

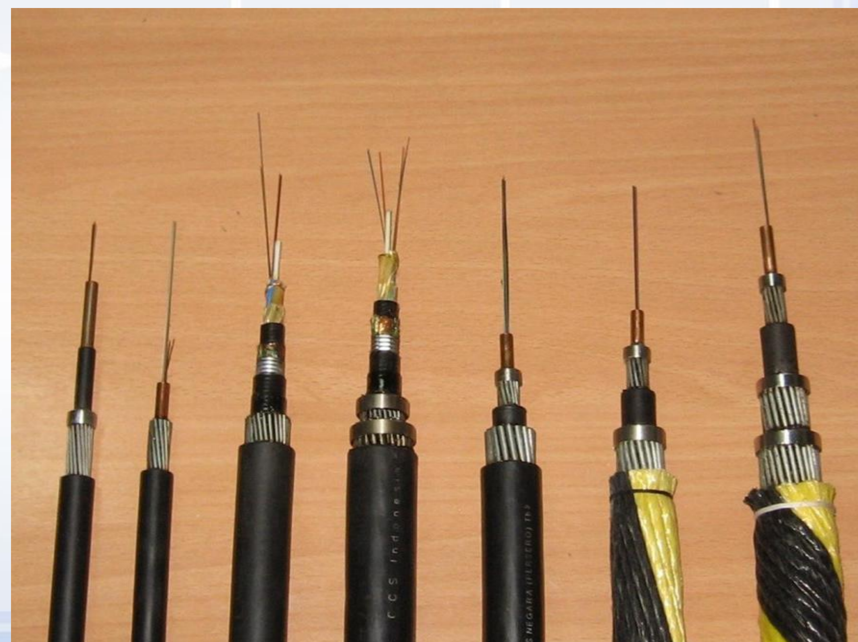






Fiber Optic – Submarine Cable





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