Lecture 5

Fundamental Data Communications

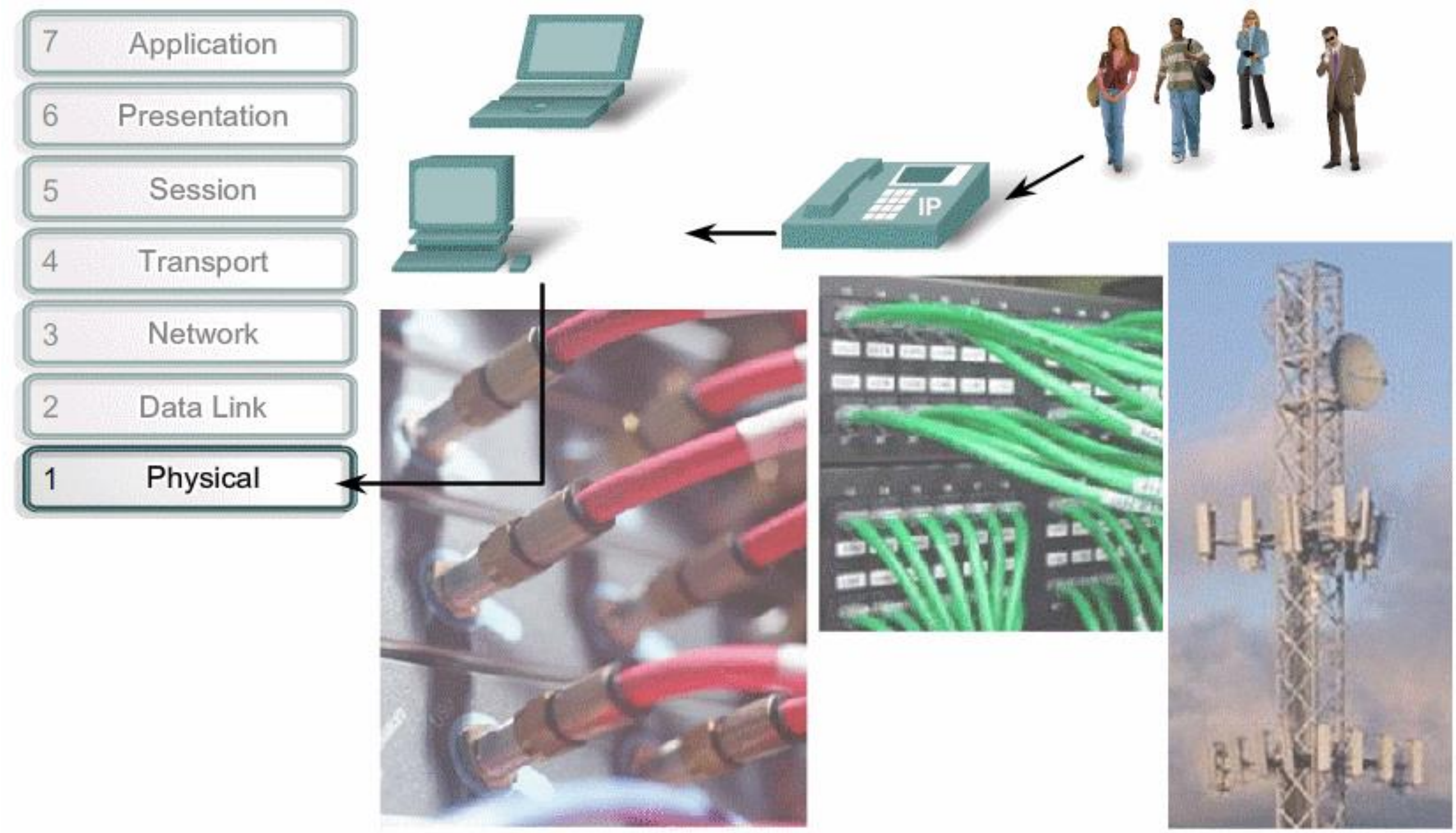
Topics in This Lecture

- **Physical Layer** Overview
- **Overview** of data communications
- Components in **communication systems**
- Analog signal vs digital signal
- Sine **Waves** and **Signal** Characteristics
- **Time** and **Frequency** Domain Representations
- Bandwidth
- Baud rate and data rate
- Signal coding example—Manchester encoding
- Analog to digital conversion (A/D)
- Transmission media
- Ethernet cables
- Channel capacity

Chapters 5, 6, 7

Physical Layer

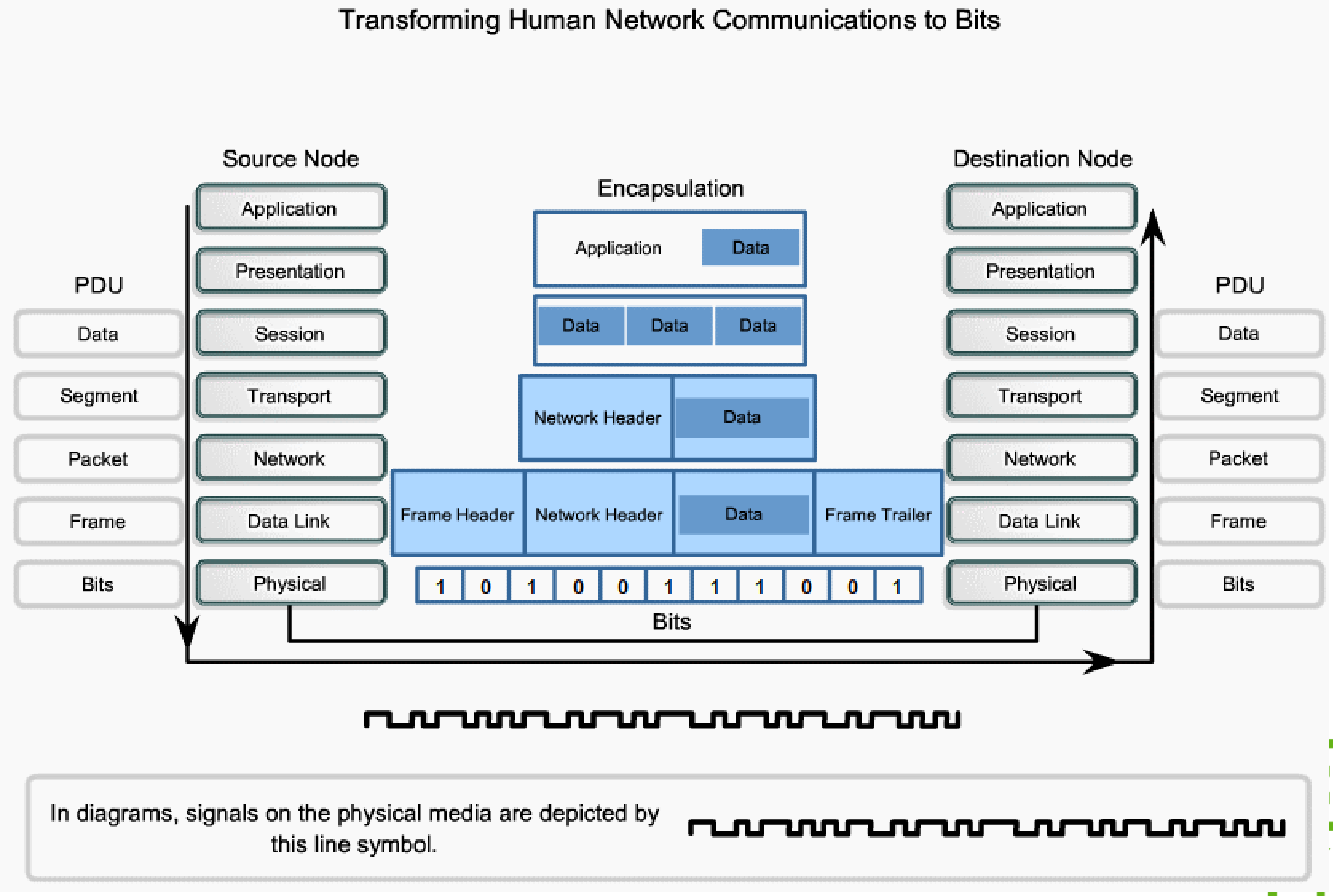
- From Cisco course material



The Physical layer interconnects our data networks.

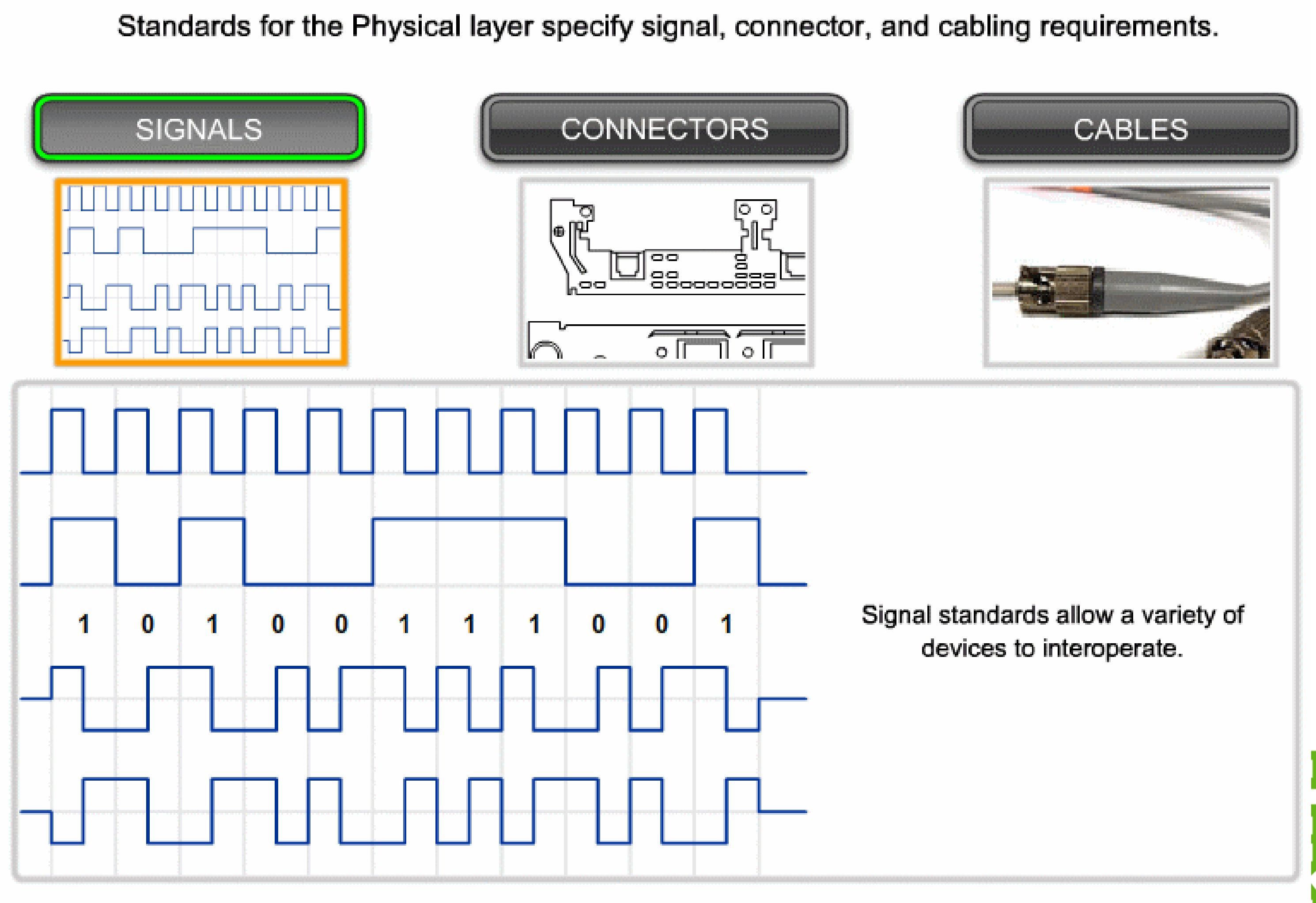
Signal representation and transmission

- From Cisco course material



Physical Layer Standards

- From Cisco course material



Physical Layer Standards

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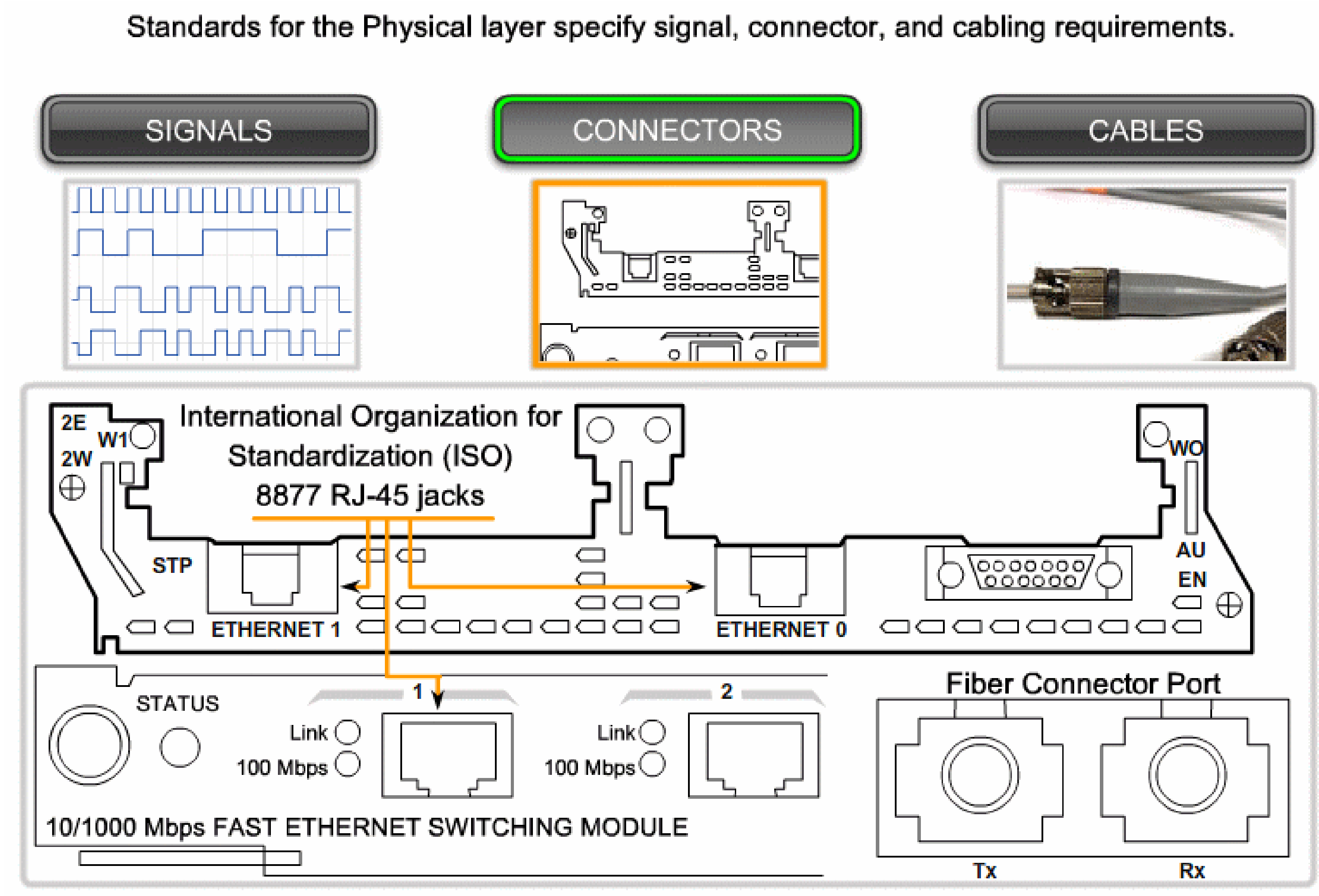

Physical Layer Standards

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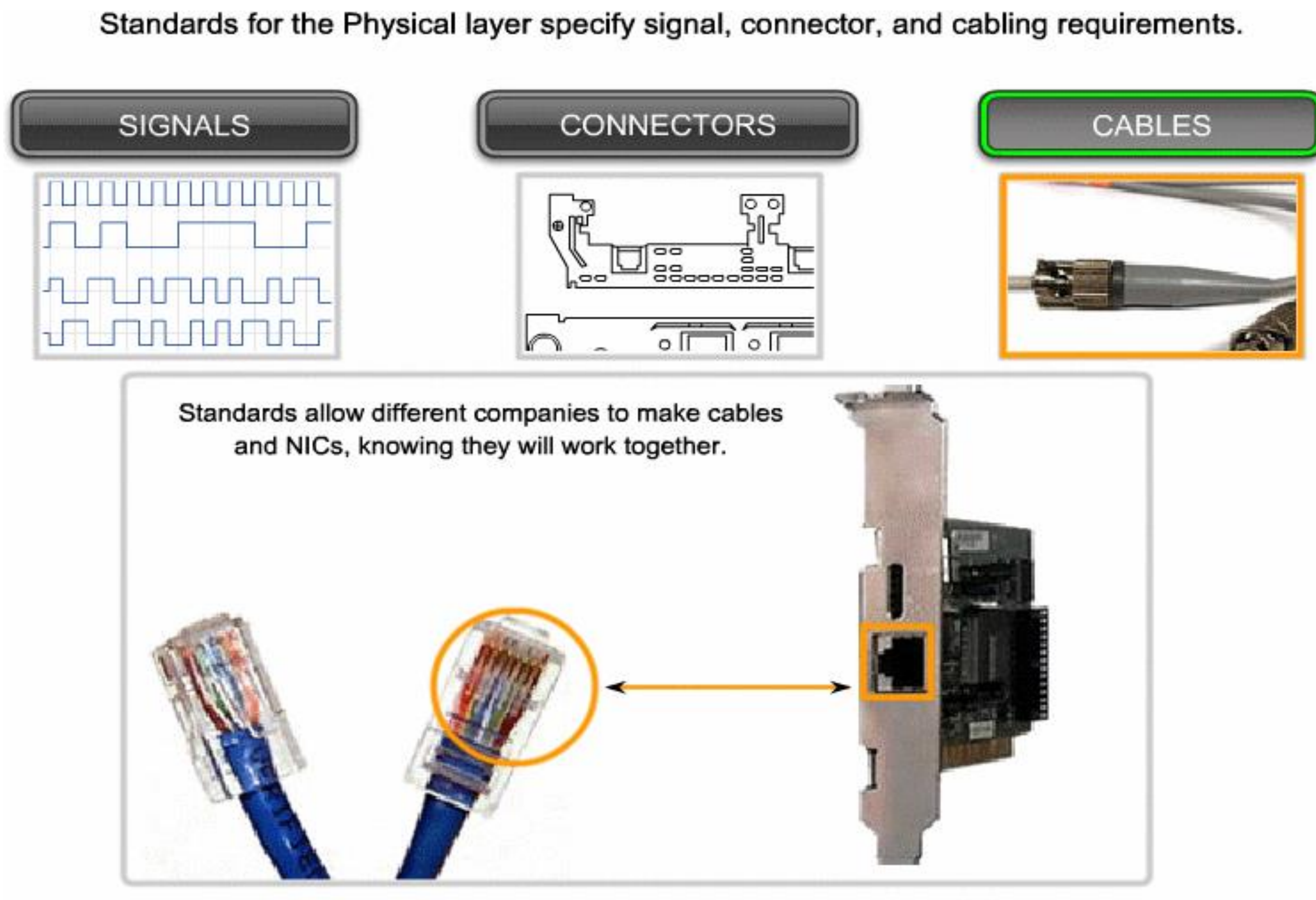

What is about data communications?

- As Figure 5.1 illustrates, the subject is a combination of ideas and approaches from three disciplines
- How information is transmitted via physical media

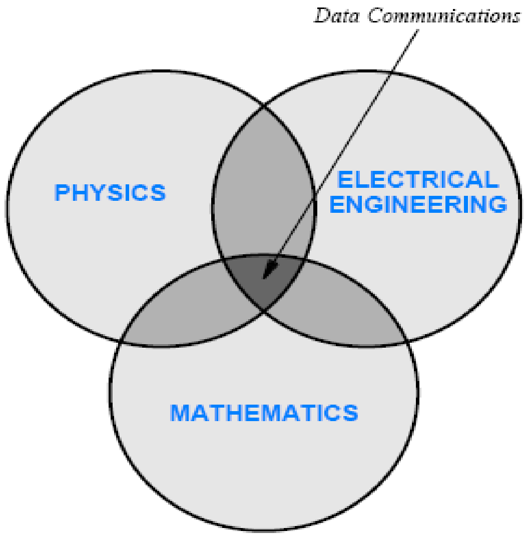

Figure 5.1 The subject of data communications lies at the intersection of Physics, Mathematics, and Electrical Engineering.

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The Essence of Data Communications

- Physics:
  - electric current, light, and other forms of electromagnetic radiation
- Electrical Engineering:
  - Information is digitized and digital data is transmitted
- Mathematics is used in description and analysis

Conceptual Pieces of a Communication System

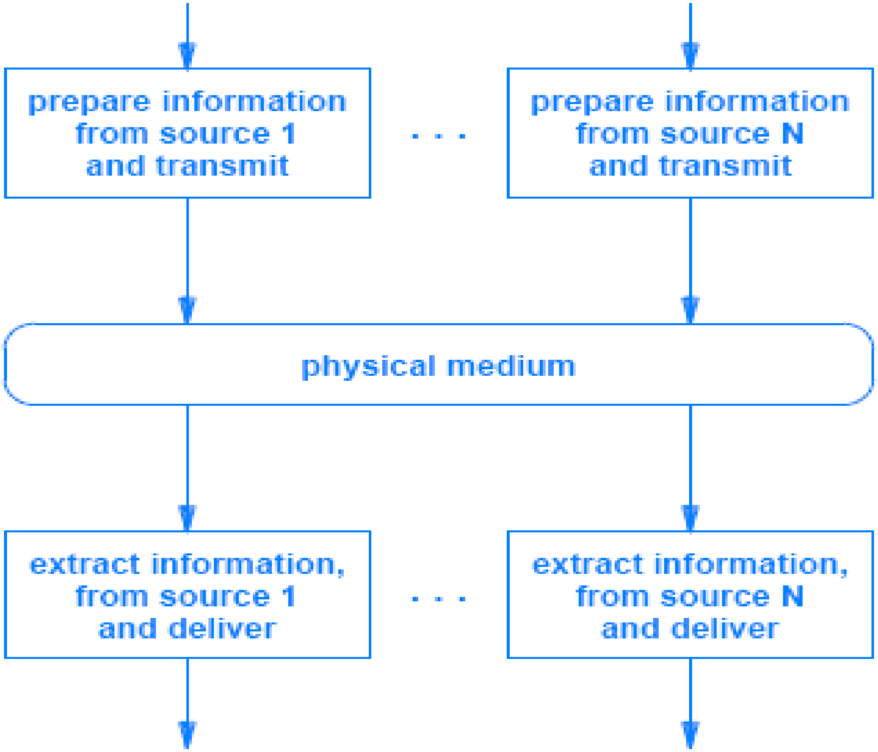
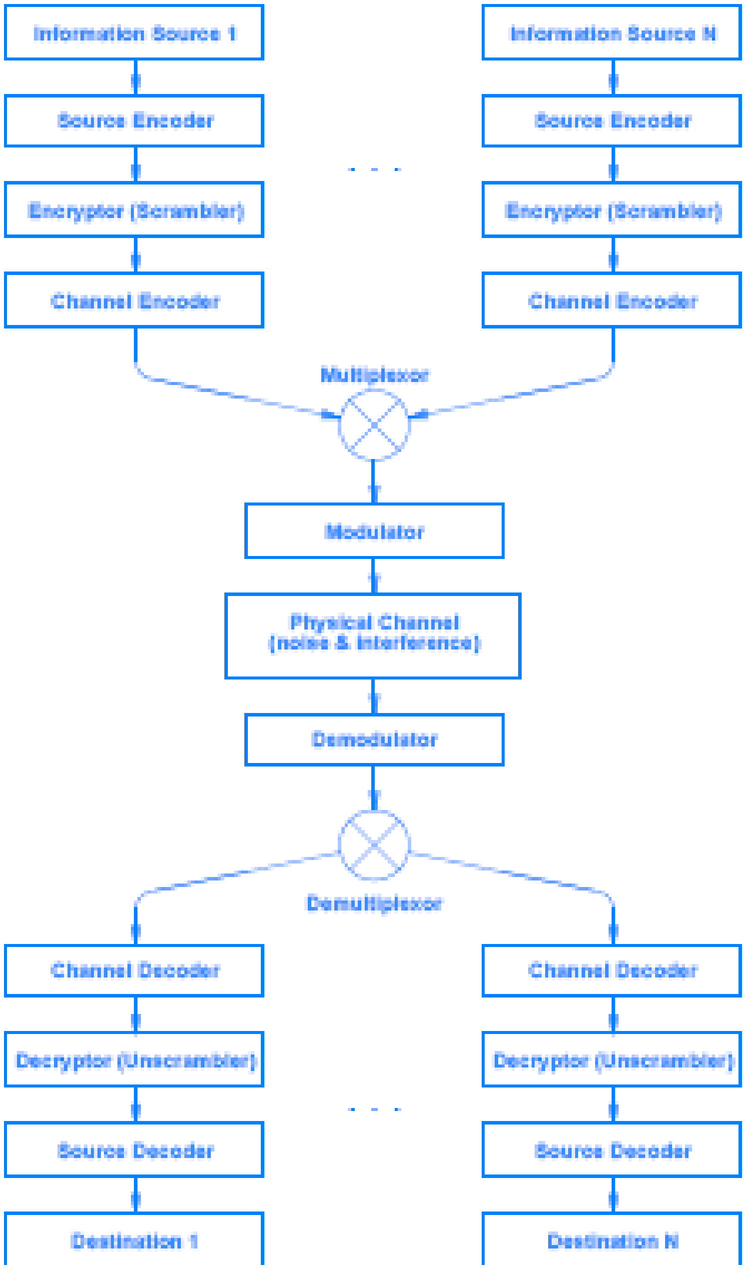


Figure 5.2 A simplistic view of data communications with a set of sources sending to a set of destinations across a shared medium.

The Conceptual Pieces of a Communication System

- Data communications is much more complex
  - Information can arrive from many types of sources, information must be digitized (A/D)
    - Source encoding
  - If privacy is a concern, the information may need to be encrypted
    - encryption
  - Extra data must be added to protect against channel errors
    - Channel encoding
  - To send multiple streams of information across a shared media
    - multiplexing


Information Source 1
Information Source N
Source Encoder
Source Encoder
Encryptor (Scrambler)
Encryptor (Scrambler)
Channel Encoder
Channel Encoder
Multiplexor
Modulator
Physical Channel
(noise & interference)
Demodulator
Demultiplexor
Channel Decoder
Channel Decoder
Decryptor (Unscrambler)
Decryptor (Unscrambler)
Source Decoder
Source Decoder
Destination 1
Destination N

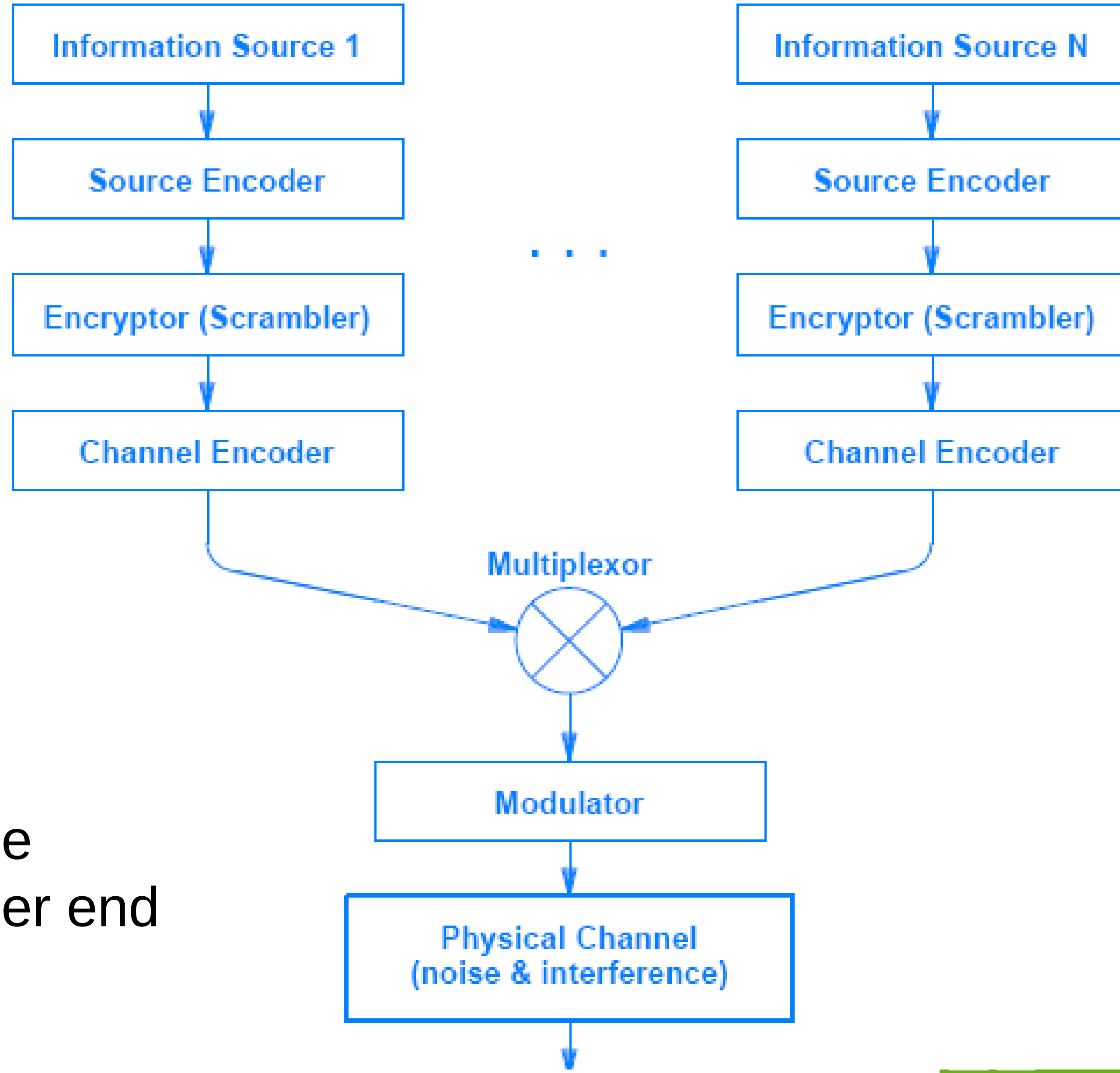
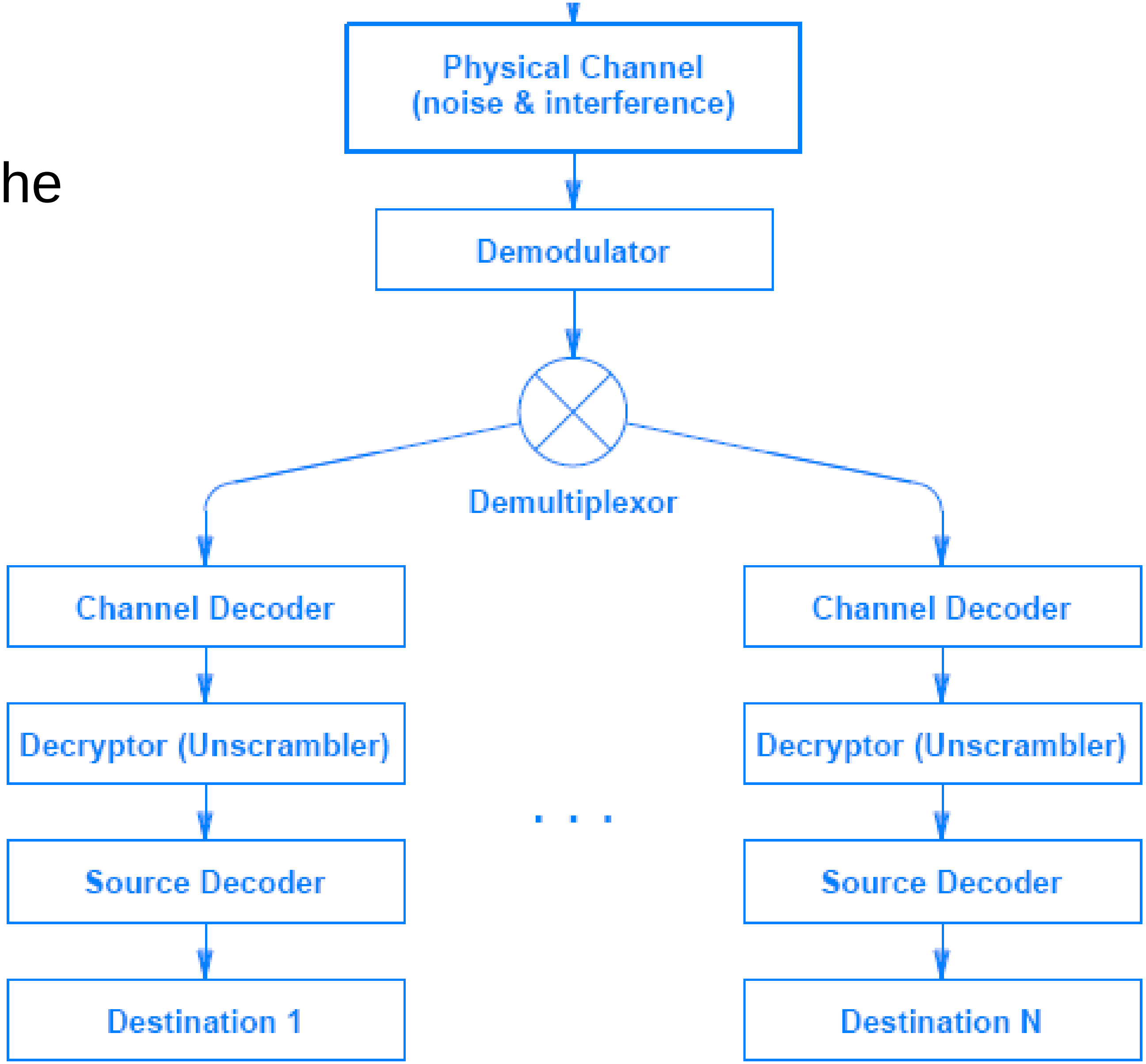


Figure 5.3

Processing at the transmitter/sender end

Figure 5.3

Processing at the receiver end



Analog and Digital Signals

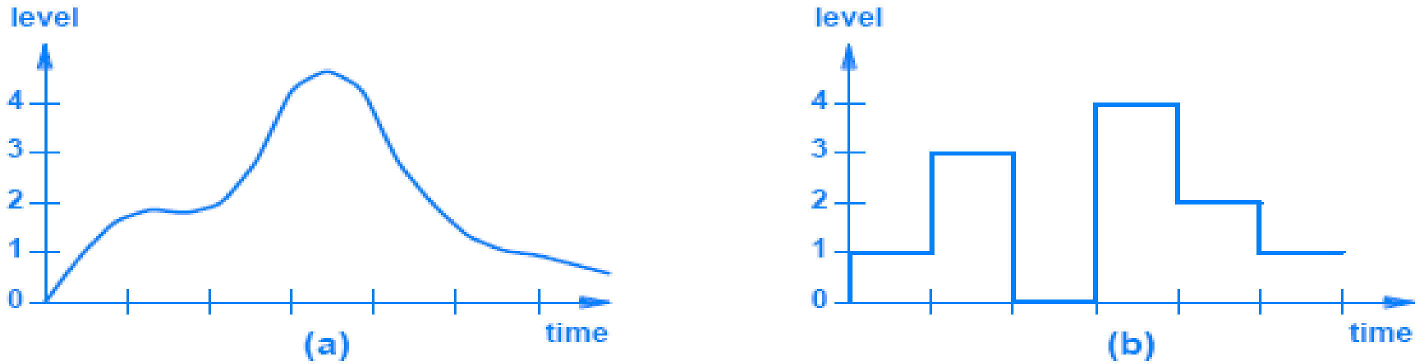
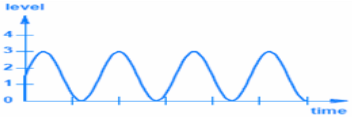


Figure 6.1 Illustration of (a) an analog signal, and (b) a digital signal.

- An analog signal characterized by a continuous mathematical function
  - when the input changes from one value to the next, it does so by moving through all possible intermediate values
- A digital signal has a fixed set of valid levels
  - each change consists of an instantaneous move from one valid level to another

Sine Waves

- Much of the analysis in data communications involves the use of sinusoidal functions
  - especially sine, which is usually abbreviated sin
- $g(t) = A \sin(2\pi f t + \theta)$
- Sine waves are especially important in information sources
  - because natural phenomena produce sine waves
  - electromagnetic radiation can be represented as a sine wave



Sine Waves and Signal Characteristics

- Frequency:
  - the number of oscillations per unit time (usually seconds) ➔ Hertz (Hz)
- Amplitude:
  - the difference between the maximum and minimum signal heights
- Phase:
  - how far the start of the sine wave is shifted from a reference time

Sine Waves and Signal Characteristics

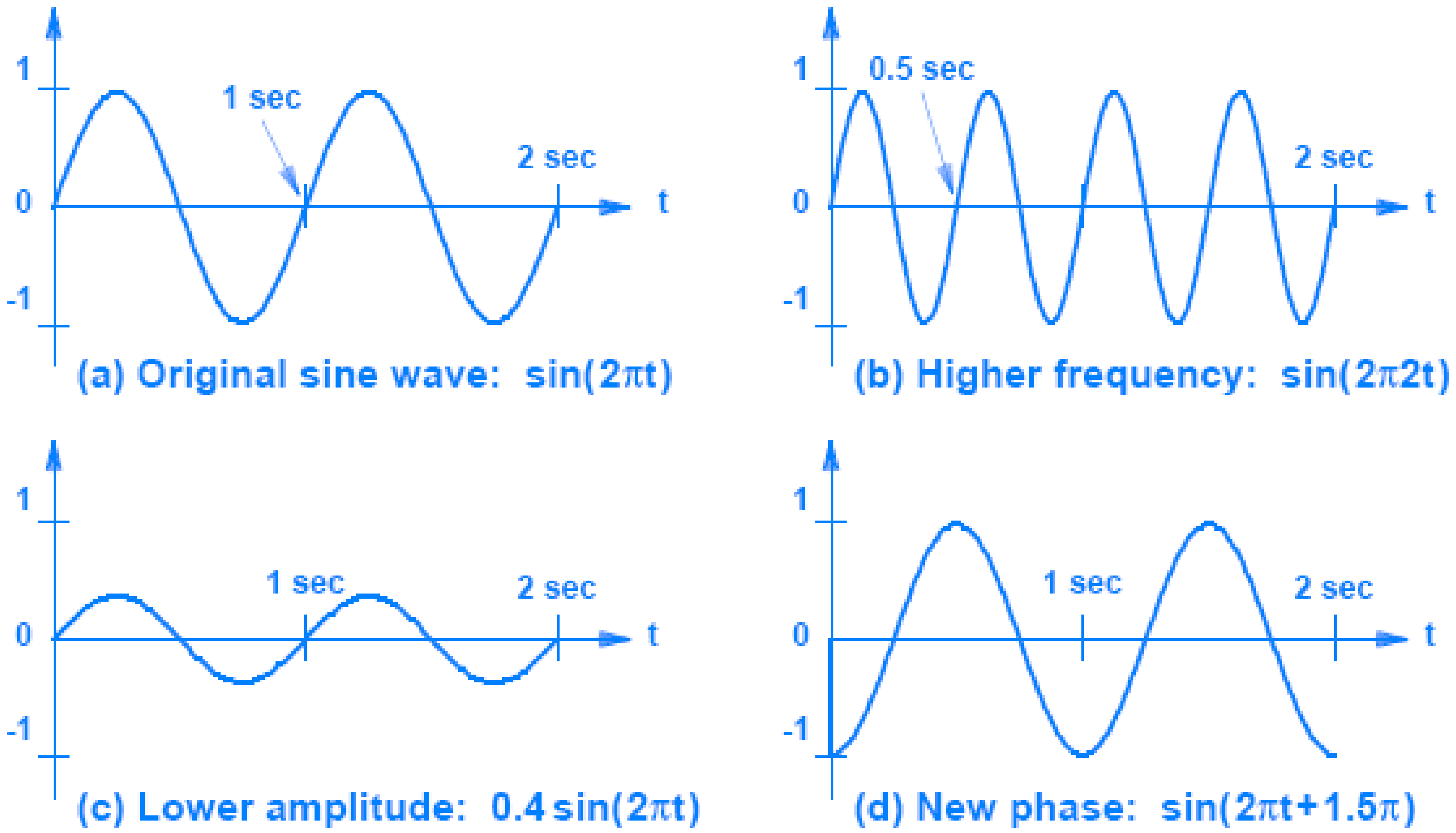


Figure 6.3 Illustration of frequency, amplitude, and phase characteristics.

Period and Frequency

- the period T is the time required for one cycle
  T = 1 / f   where f is the frequency
- The example sine wave in Figure 6.3a has
  – a period *T* = *1* seconds
  – and a frequency of *1 / T* or *1* Hertz or 1 Hz
- The example in Figure 6.3b has
  – a period of *T* = *0.5* seconds
  – its frequency is *2* Hz
- Both examples are considered extremely low frequencies
- Typical communication systems use high frequencies
  – often measured in millions of cycles per second

Poll question

- A periodic signal completes one cycle in 0.001 s. What is the frequency?

https://sv.surveymonkey.com/r/5WJHJV5

Frequency and time unit

- Time and frequency

Time Unit	Value	Frequency Unit	Value
Seconds (s)	10^0 seconds	Hertz (Hz)	10^0 Hz
Milliseconds (ms)	10^{-3} seconds	Kilohertz (KHz)	10^3 Hz
Microseconds (μs)	10^{-6} seconds	Megahertz (MHz)	10^6 Hz
Nanoseconds (ns)	10^{-9} seconds	Gigahertz (GHz)	10^9 Hz
Picoseconds (ps)	10^{-12} seconds	Terahertz (THz)	10^{12} Hz

Figure 6.4 Prefixes and abbreviations for units of time and frequency.

Composite Signals

- Signals like the ones illustrated in Figure 6.3 are classified as simple
  - because they consist of a single sine wave that cannot be decomposed further
- Most signals are classified as composite
  - the signal can be decomposed into a set of simple sine waves
- Figure 6.5 illustrates a composite signal
  - formed by adding two simple sine waves

Composite Signals

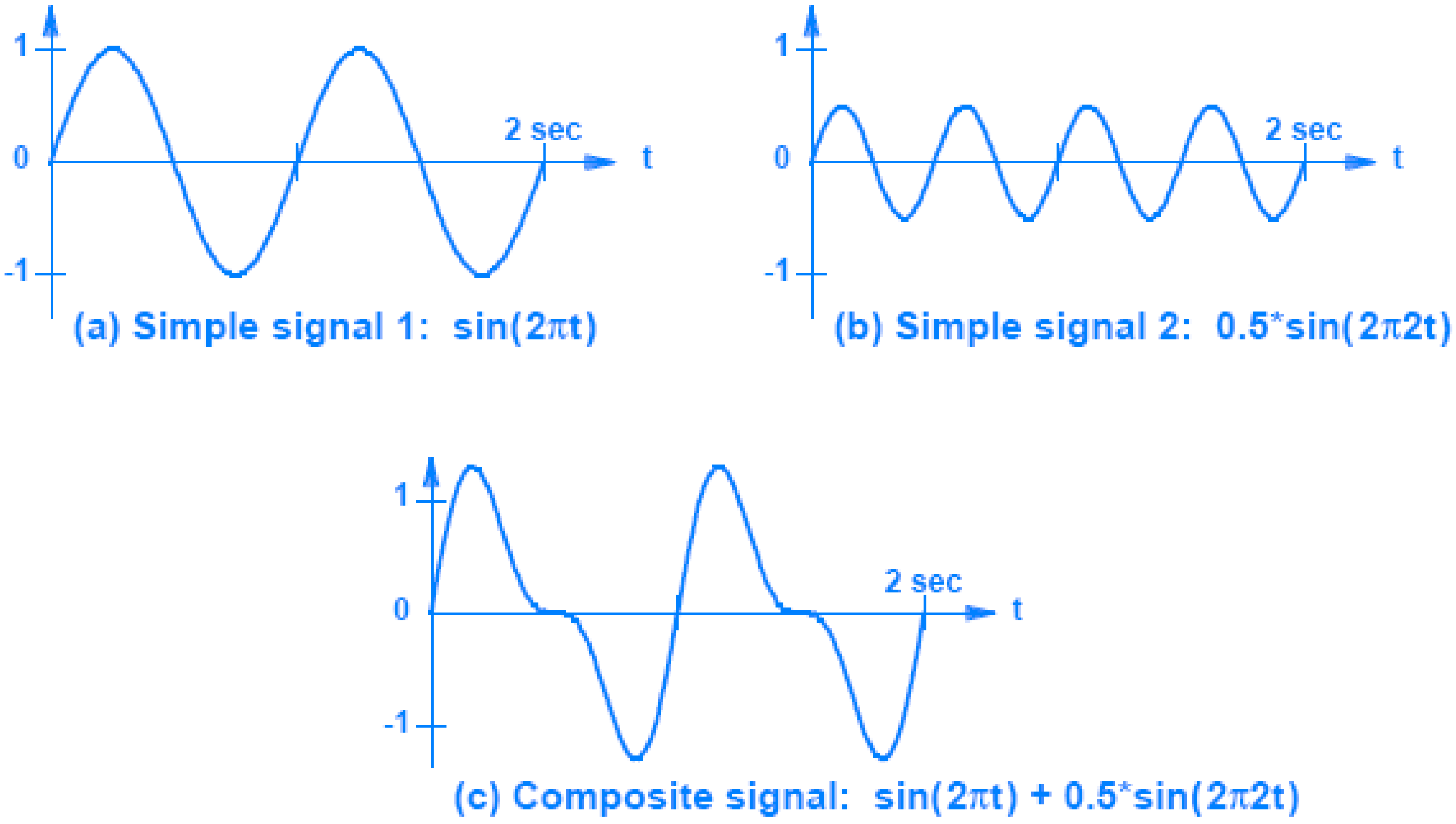


Figure 6.5 Illustration of a composite signal formed from two simple signals.

Time and Frequency Domain Representations

- A graph of a signal as a function of time is known as time domain representation
- The other representation is known as a frequency domain
  - A frequency domain graph shows a set of simple sine waves that constitute a composite function
  - The y-axis gives the amplitude, and the x-axis gives the frequency
- The function $A\sin(2\pi t)$ is represented by a single line of height A that is positioned at $x = t$

Time and Frequency Domain Representations

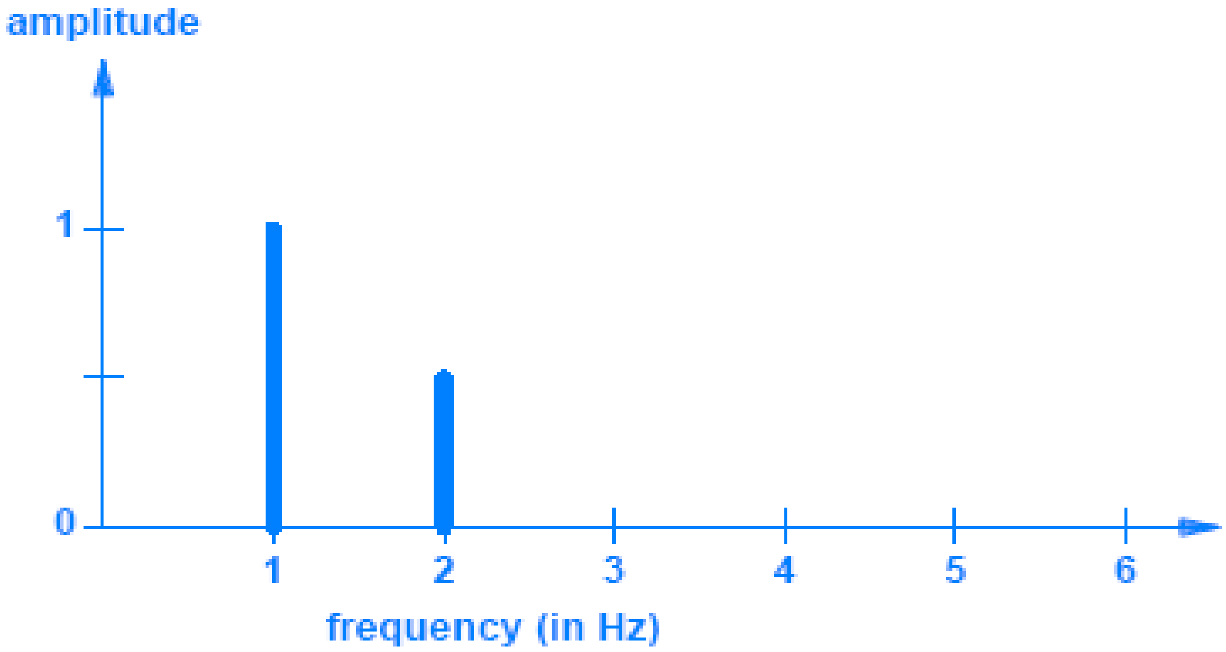


Figure 6.6 Representation of sin(2πt) and 0.5sin(2π2t) in the frequency domain.

Bandwidth of an Analog Signal

- In networking and communication, the definition of bandwidth varies; here we describe analog bandwidth
  - We define the bandwidth of an analog signal to be the difference between the highest and lowest frequencies of the constituent parts
- Figure 6.7 shows a frequency domain plot with frequencies measured in Kilohertz (KHz)
  - Such frequencies are in the range audible to a human ear
  - In the figure, the bandwidth is the difference between the highest and lowest frequency (5 KHz - 1 KHz = 4 KHz)

Bandwidth of an Analog Signal

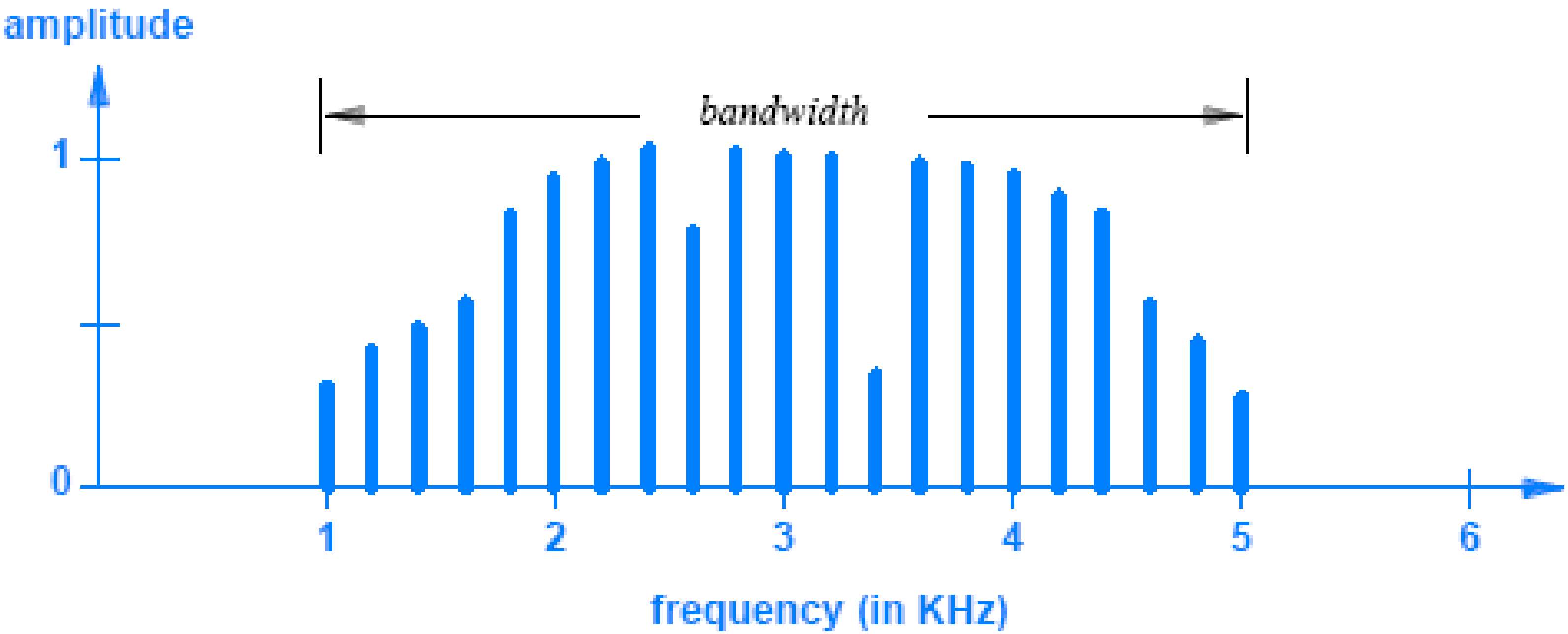
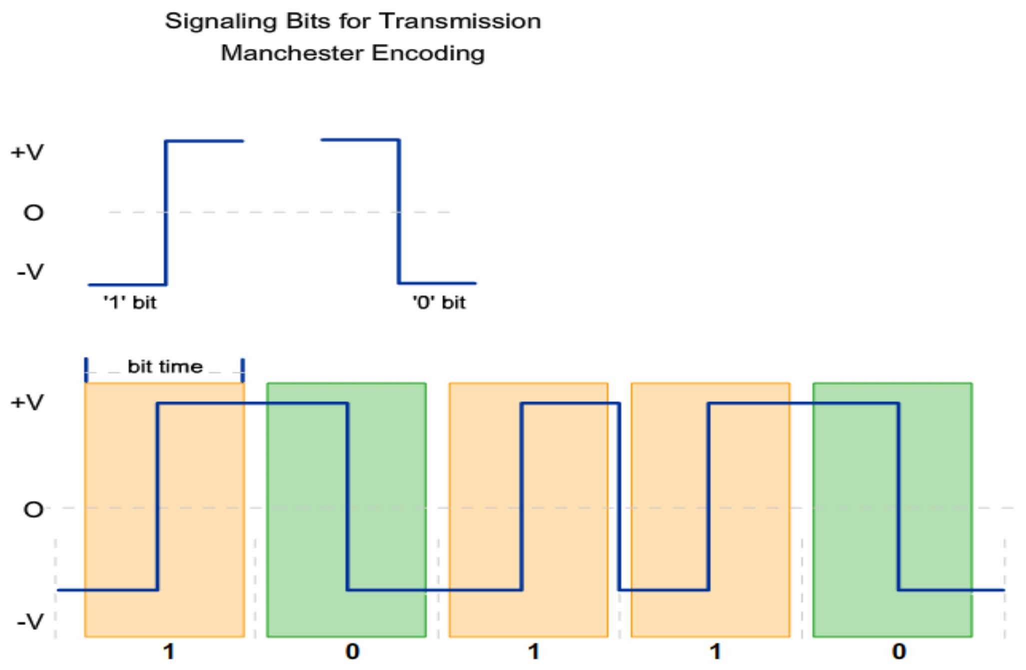


Figure 6.7 A frequency domain plot of an analog signal with a bandwidth of 4 KHz.

Manchester Encoding Used in Ethernet

- In Manchester Encoding, changes in signal levels are used to carry information
  - The transitions occur in the "middle" of the bit time



Converting an Analog Signal to Digital

- Many sources of information are analog
  - which means they must be converted to digital form for further processing (e.g., before they can be encrypted)
- There are two basic approaches:
  - pulse code modulation (PCM)
  - delta modulation (DM)
- In PCM, the level of an analog signal is measured repeatedly at fixed time intervals and converted to digital form

Converting an Analog Signal to Digital

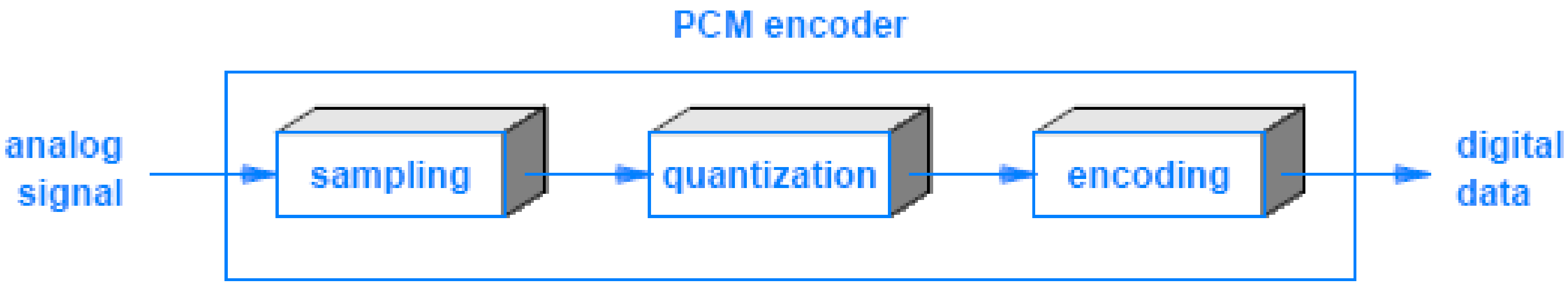


Figure 6.14 The three steps used in pulse code modulation.

Converting an Analog Signal to Digital

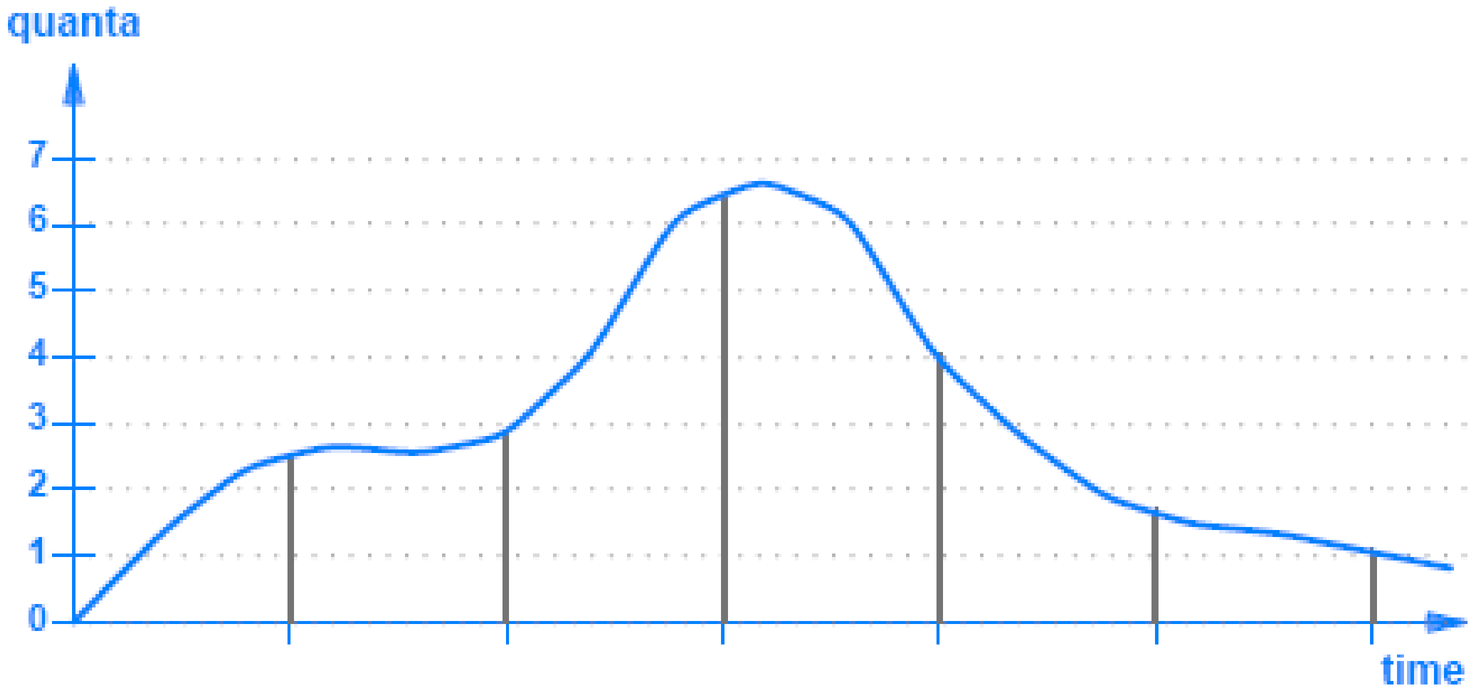


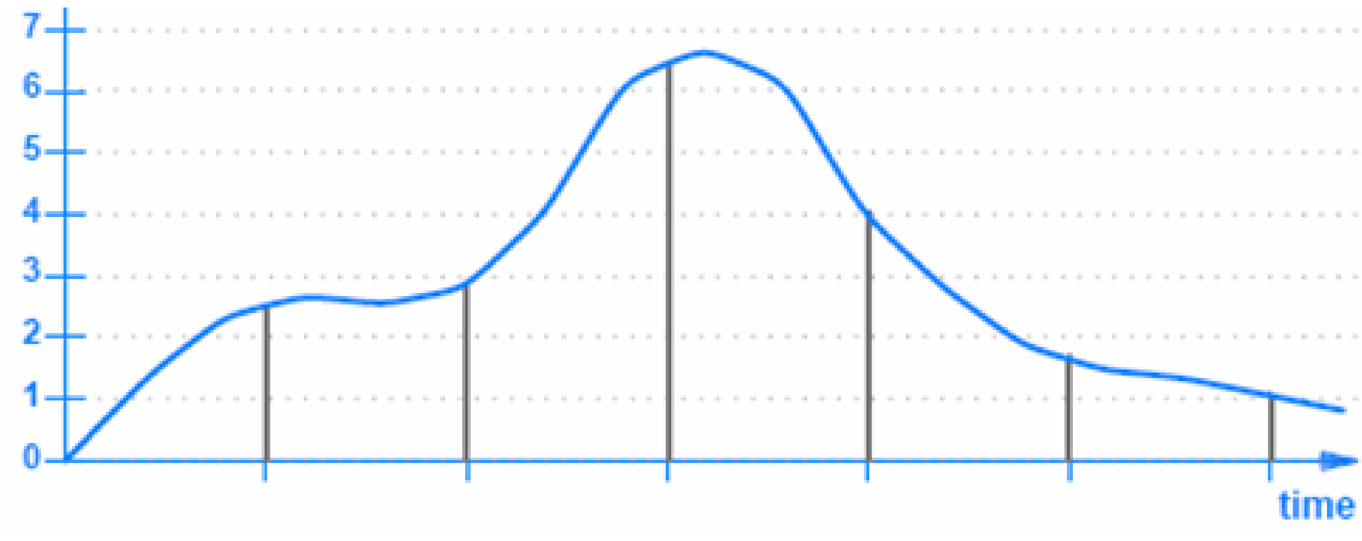
Figure 6.15 An illustration of the sampling and quantization used in pulse code modulation.

Converting an Analog Signal to Digital

- The three steps used PCM
- First stage is known as sampling
  - each measurement is known as a sample
- A sample is quantized
  - by converting it into a small integer value
  - the quantized value is not a measure of voltage or any other property of the signal
  - the range of the signal from the minimum to maximum levels is divided into a set of slots, typically a power of 2
- Then encoded into a specific format

Converting an Analog Signal to Digital

- In the Figure 6.15
  - the six samples are represented by vertical gray lines
  - a sample is quantized to the closest quantum interval
  - for example, the third sample, taken near the peak of the curve, is assigned a quantized value of 6
  - Animation: convert analog to digital.swf



Data compression

- A technique to reduce the number of bits required to represent data
  - reduce the transmission time for data
- Two types of compression
  - Lossy – some information is lost during the compression
    - JPG for image; MP4 for video
  - Lossless – all information is retained
    - ZIP

Guided and Unguided Transmission

- Transmission media
  - Commonly used media for transmission
- How to divide transmission media into classes?
  - By type of path: communication can follow an exact path such as a wire, or can have no specific path, such as a radio transmission
  - By form of energy: electrical energy is used on wires, radio transmission is used for wireless, and light is used for optical fiber
- We use the terms guided (wired) and unguided (wireless) transmission to distinguish between physical media
  - copper wiring or optical fibers provide a specific path and a radio transmission that travels in all directions through free space

A Taxonomy by Forms of Energy

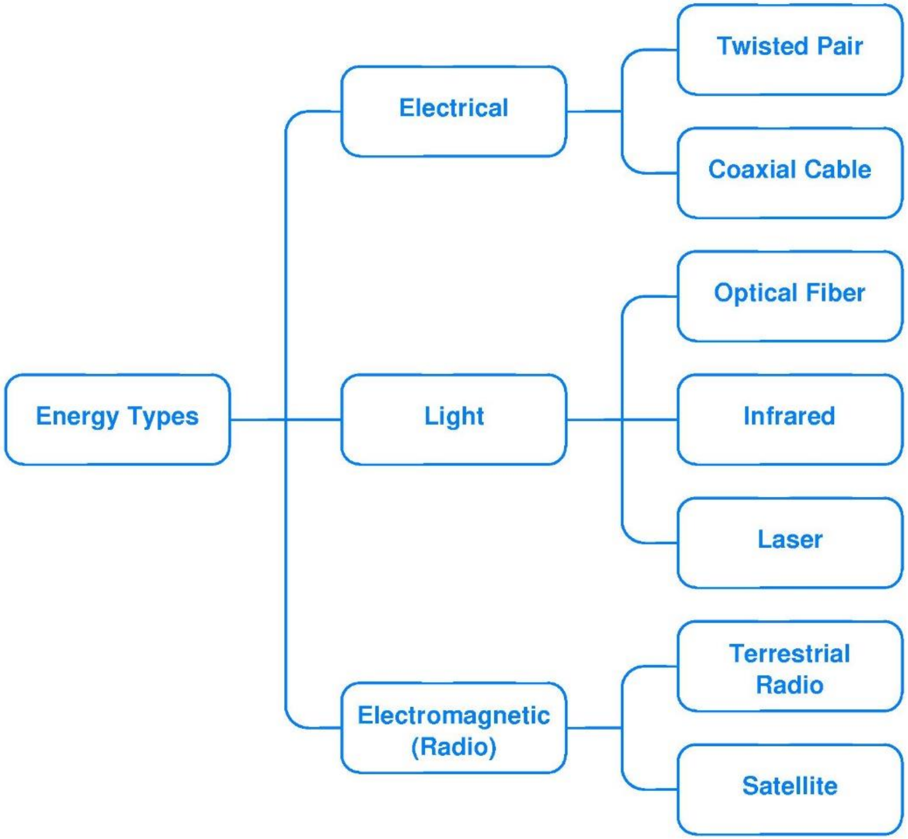


Figure 7.1 A taxonomy of media types according to the form of energy used.

Shielding Coaxial Cable

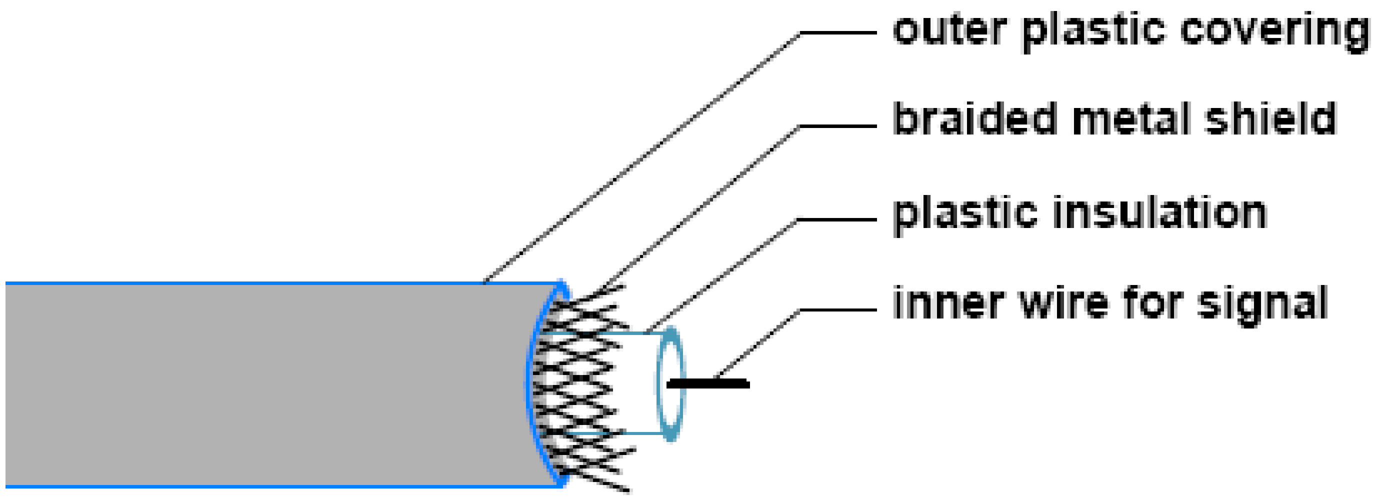


Figure 7.3 Illustration of coaxial cable with a shield surrounding the signal wire.

Twisted Pair Copper Wiring

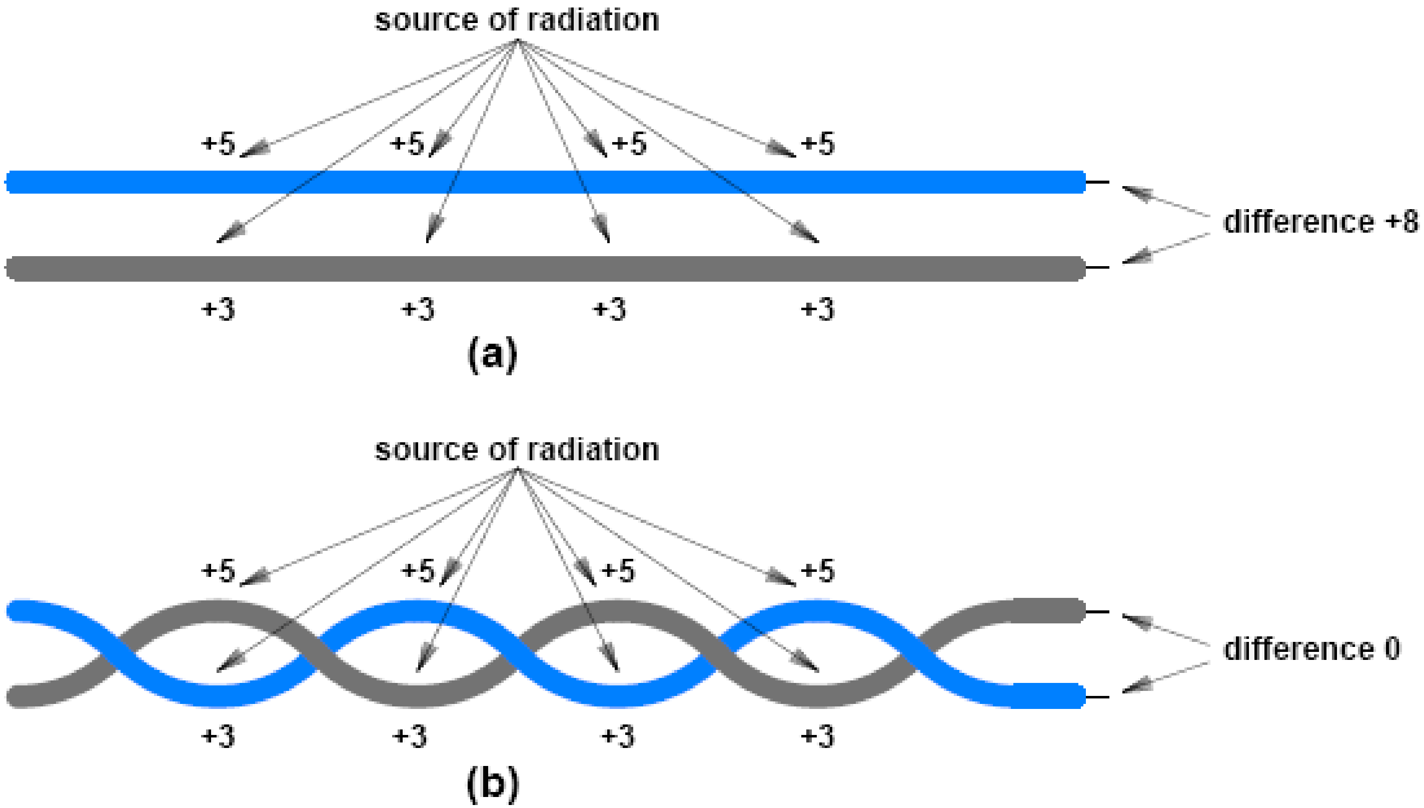


Figure 7.2 Unwanted electromagnetic radiation affecting (a) two parallel wires, and (b) twisted pair wiring.

Categories of Twisted Pair Cable

Category	Description	Data Rate (in Mbps)
CAT 1	Unshielded twisted pair used for telephones	< 0.1
CAT 2	Unshielded twisted pair used for T1 data	2
CAT 3	Improved CAT2 used for computer networks	10
CAT 4	Improved CAT3 used for Token Ring networks	20
CAT 5	Unshielded twisted pair used for networks	100
CAT 5E	Extended CAT5 for more noise immunity	125
CAT 6	Unshielded twisted pair tested for 200 Mbps	200
CAT 7	Shielded twisted pair with a foil shield around the entire cable plus a shield around each twisted pair	600

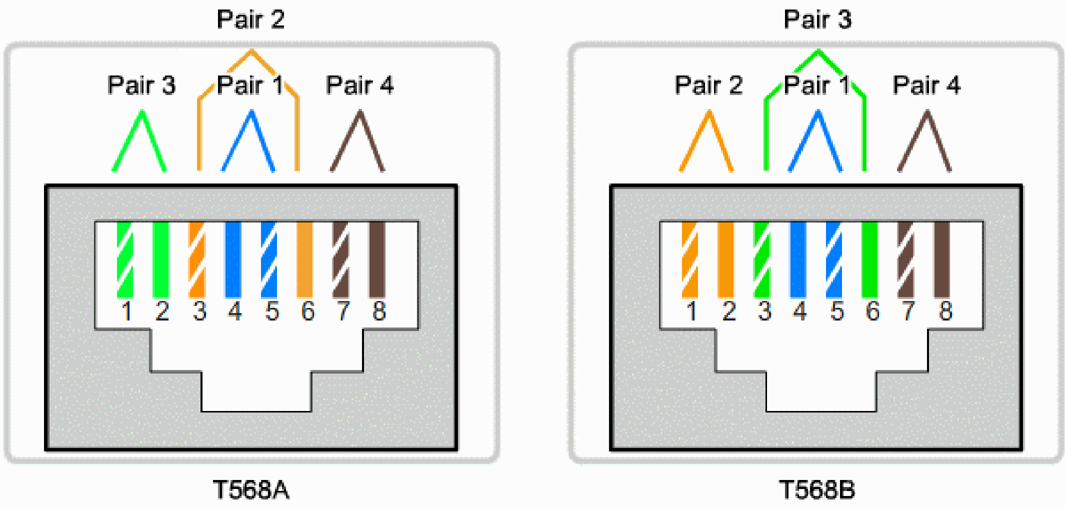
Figure 7.4 Twisted pair wiring categories and a description of each.

Cables

- From Cisco course material

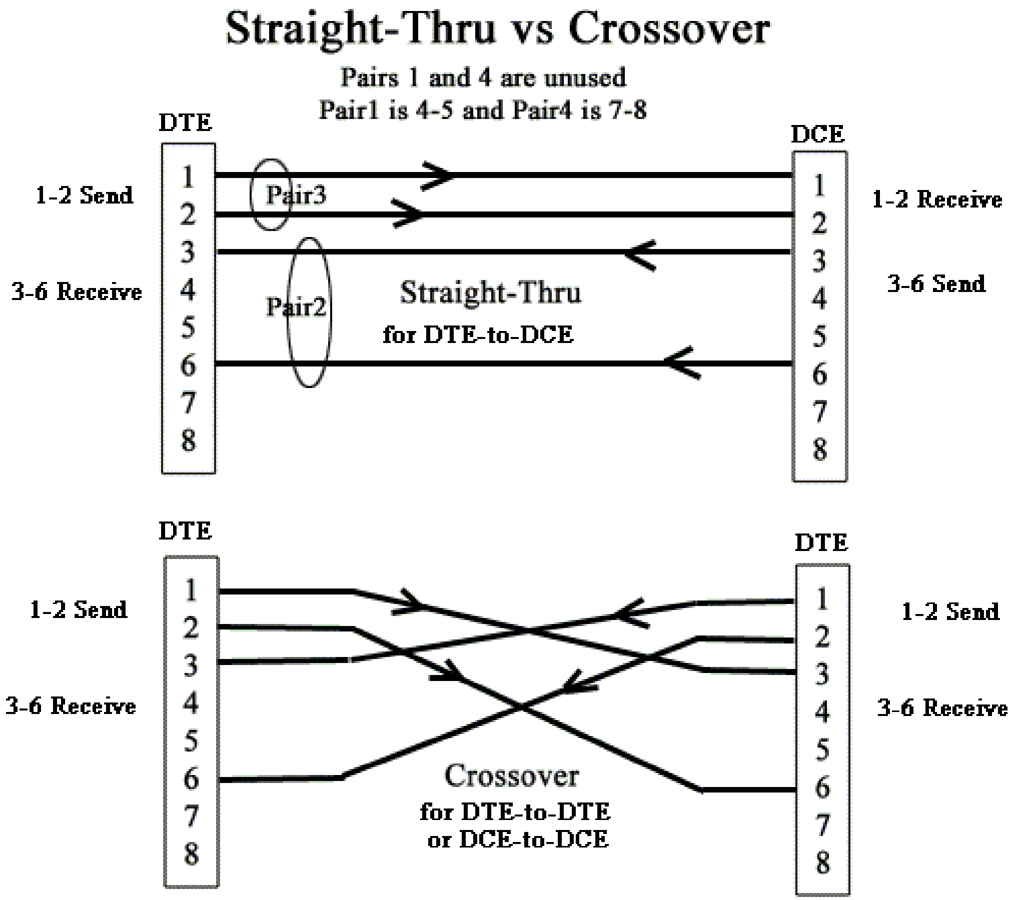
Straight-through, Crossover, and Rollover Cable Types

Cable Type	Standard	Application
Ethernet Straight-through	Both ends T568A or both ends T568B	Connecting a network host to a network device such as a switch or hub.
Ethernet Crossover	One end T568A, other end T568B	Connecting two network hosts. Connecting two network intermediary devices (switch to switch, or router to router).
Rollover	Cisco proprietary	Connect a workstation serial port to a router console port, using an adapter.



More on Twisted Pair Cables

- http://www.infocellar.com/networks/cables/twisted-pair-cables.htm



Discussion: How to copy files between computers?

- If you buy a new PC, how to copy data from one PC to another?
  - Methods?
  - Which one is the fastest?

Tradeoffs Among Media Types

- The choice of medium is complex
- Choice involves the evaluation of multiple factors, such as:
  - Cost
    - materials, installation, operation, and maintenance
  - Data rate
    - number of bits per second that can be sent
  - Delay
    - time required for signal propagation or processing
  - Effect on signal
    - attenuation and distortion
  - Environment
    - susceptibility to interference and electrical noise
  - Security
    - susceptibility to eavesdropping (avlyssning, 窃听)

Measuring Transmission Media

- The two most important measures of performance used to assess a transmission medium:
  - Propagation delay
    - the time required for a signal to traverse the medium
  - Channel capacity
    - the maximum data rate that the medium can support
- Propagation delay
  - the amount of time it takes for the head of the signal to travel from the sender to the receiver over a medium

    t = distance / propagationspeed
  - In wireless communication, propagation speed is the speed of light. In copper wires, the propagation speed is typically about 67% of speed of light
    - Speed of light 299,792,458 m/s or about $3x10^8$ meter/second

Channel capacity

- Channel capacity
  - the maximum data rate that the medium can support
- Nyquist discovered a fundamental relationship between the bandwidth of a transmission system and its capacity to transfer data known as Nyquist Theorem
  – It provides a theoretical bound on the maximum rate at which data can be sent without considering the effect of noise $D = 2\,B\,\log_2 K$
  – If a transmission system uses K possible signal levels and has an analog bandwidth B, the maximum data rate in bits per second, D, is

The Effect of Noise on Communication

- Nyquist's Theorem provides an absolute maximum that cannot be achieved in practice
  - a real system is subject to small amounts of electrical noise
  - such noise makes it impossible to achieve the theoretical maximum transmission rate
- Claude Shannon extended Nyquist's work to specify the maximum data rate that could be achieved over a transmission system that experiences noise
  - The result, called Shannon's Theorem

$$C = B \log_2(1 + S/N)$$

where

- C is the effective limit on the channel capacity in bits per second
- B is the hardware bandwidth
- S/N is the signal-to-noise ratio, the ratio of the average signal power divided by the average noise power

Power levels

- Once two power levels have been measured, the difference is expressed in decibels, defined as follows:

$$dB = 10\log_{10}\left(\frac{P_2}{P_1}\right)$$

- Using dB as a measure has two interesting advantages:
  - First, it can give us a quick idea about outcome of an operations:
    - a negative dB value means that the signal has been attenuated
    - a positive dB value means the signal has been amplified
  - Second, if a communication system has multiple parts arranged in a sequence
    - The dB measures of the parts can be summed to produce a measure of the overall system

Example

- The voice telephone system has a signal-to-noise ratio of approximately 30 dB and an analog bandwidth of approximately 3000 Hz
  - To convert signal-to-noise ratio dB into a simple fraction
    - divide by 10 and use the result as a power of 10

      (i.e., 30/10 = 3, and 10^3 = 1000, so the signal-to-noise ratio is 1000)
  - Shannon's Theorem can be applied to determine the maximum number of bits per second that can be transmitted across the telephone network:

$$C = 3000 \times \log_2(1 + 1000)$$

  or approximately 30,000 bps
- Engineers recognize this as a fundamental limit; faster transmission speeds will only be possible if the signal-to-noise ratio can be improved

Maximal Data Rate

- If a **binary** signal is sent over a **3-kHz** channel with **SNR**=**20dB**. What is the maximum achievable data rate?

Nyquist: date rate = 2B $\log_2$ K

= 2 * 3000 * $\log_2$ 2 = 6000 bps

Shannon : R

$$= B\log_2(1+S/N)$$

$$= 3000\log_2(1+100) \approx 19000 bps$$

Answer: 6000 bps

Example

- Television channels are 6 MHz wide. How many bits per second can be sent if 4-level digital signals are used ?