Principles of Data Communication

ICT 2156

IPSITA UPASANA

Objectives of the Course

- To understand basics of data communication.
- To understand error detection and correction techniques.
- To understand data link layer protocols.
- To understand the performance of media access protocols.

Course Outcomes

- Outline the basics of data communication.
- Compute frame check sequence and error correction codes.
- Explain data link layer protocol.
- Compute the performance of media access protocols.

Syllabus

- **Data Communication fundamentals:**

  Introduction to Data Communication, Signals, Digital representation of information, Basic properties of data communication system, Time and frequency domain characterization of communication channels, Nyquist signaling rate, Shannon Channel capacity

  Line coding-NRZ, bipolar, Manchester, Differential Manchester encoding, Modems and digital modulation- ASK, FSK, PSK, QAM.

- **Properties of Media and Digital Transmission Systems:**

  Twisted pair, Coaxial cable, Optical fiber, Wireless transmission.

- **Error detection and correction:**

  Asynchronous and synchronous transmission, Error detection and correction basics, Parity check, Internet checksum, Polynomial codes, Block codes, Hamming code.

Syllabus

- **Peer to Peer Protocols:**

  Peer to peer protocols and service models, ARQ protocols- Stop and wait, Go back N, selective repeat, Transmission efficiency of ARQ protocols

  Other adaptation functions- Sliding window flow control, Timing recovery for synchronous services, Reliable stream service, Data link control- HDLC datalink control, point to point control.

  Multiplexing- FDM, TDM, STDM.

- **Media Access sublayer and LAN:**

  Introduction to layered architecture, Protocols, Approaches to sharing transmission Medium, Random Access Protocols, Token Passing protocols, IEEE LAN standards, Bridges, MAN[IEEE802.6], FDDI.

Books

1. Stallings W., *Data & Computer Communications (9e),* Pearson Education Inc., Noida, 2017.

2. Forouzan B., *Introduction to data communication & networking (4e),* Tata McGraw Hill, New Delhi-2014.

3. Garcia A. L., Widjaja I., *Communication Networks (2e),* Tata McGraw Hill, 2011.

Introduction to Data Communications

- What is Data Communication?

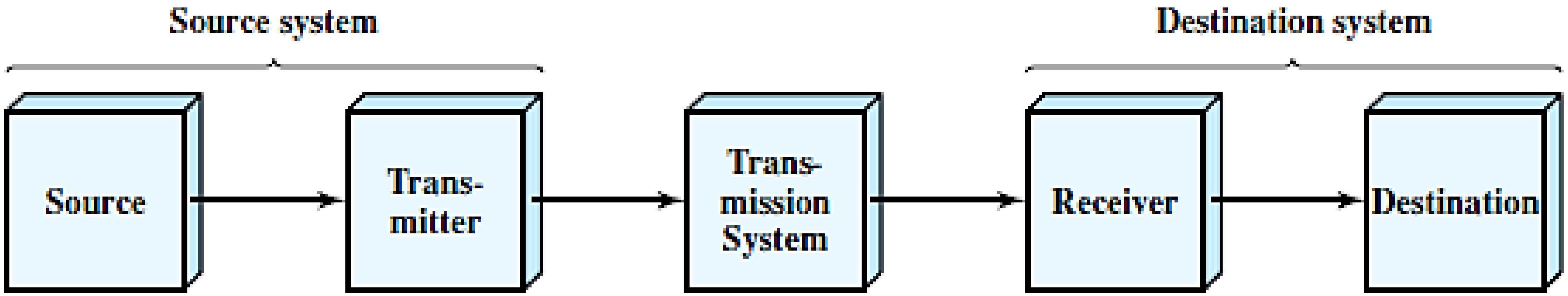
Introduction to Data Communications

- Effective Data Communication.
  - Accuracy
  - Delivery
  - Timeliness
  - Jitter
- Data versus Signals.
- Signaling and Transmission.

Introduction to Data Communications

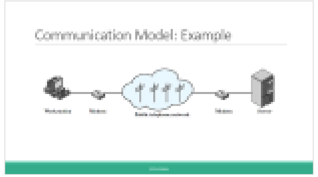
- Factors responsible for evolution of Data Communications and networks.
    - Traffic Growth
    - Services
    - Technology

Communication Model

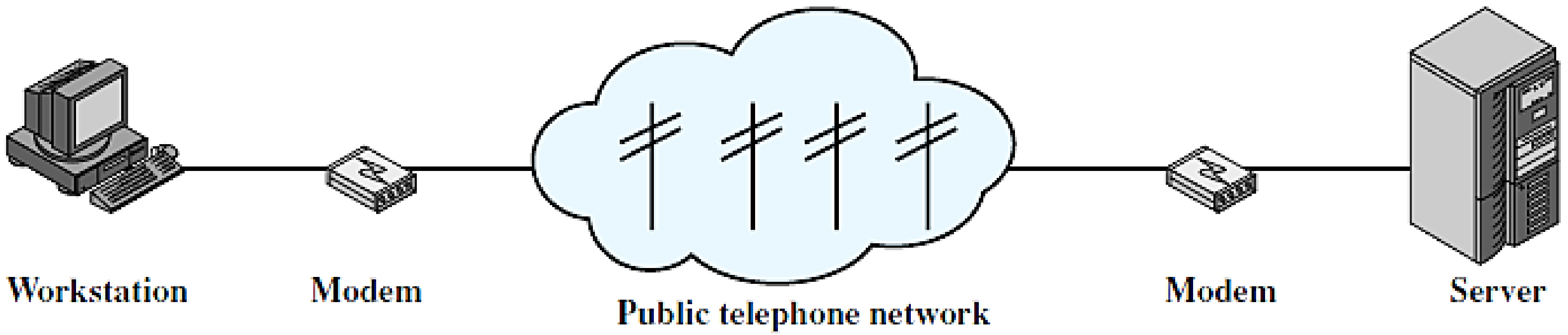


(a) General block diagram

Communication Tasks?



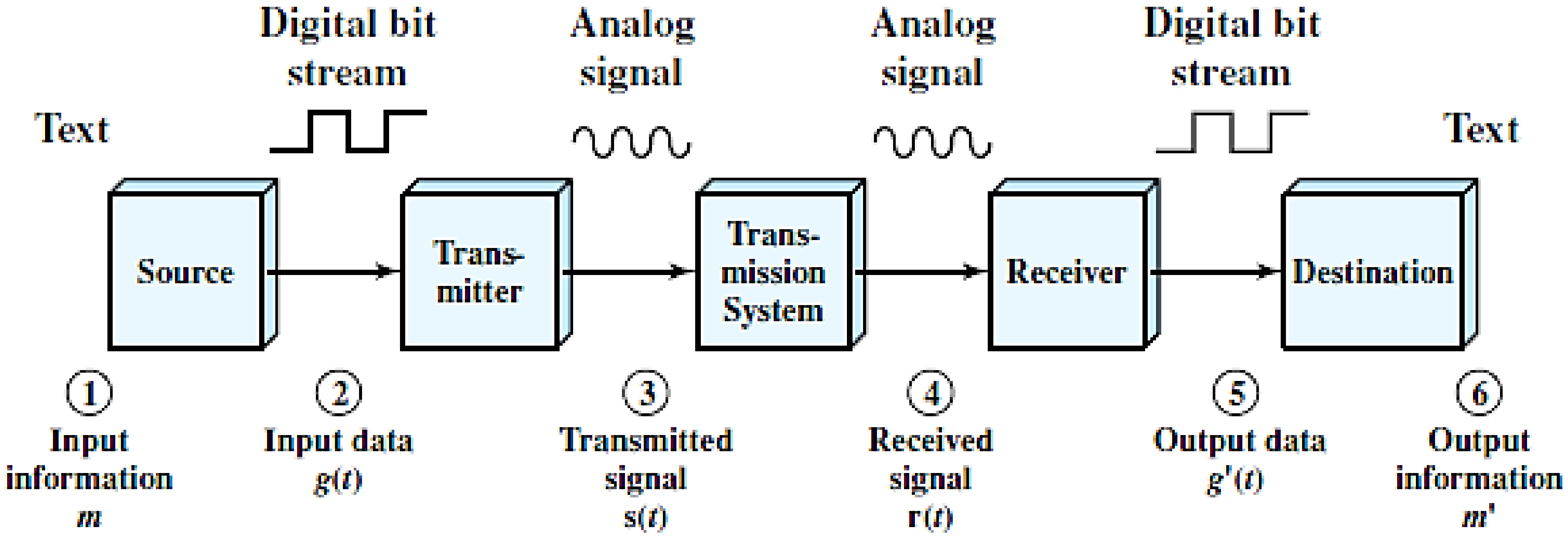
Communication Model: Example



Communication Tasks

- Transmission System Utilization
- Interfacing
- Signal Generation
- Synchronization
- Exchange Management
- Error detection and Correction
- Flow Control
- Addressing
- Routing
- Recovery
- Message Formatting
- Security
- Network Management

Communication Model: a new perspective



Transmission Medium

- Medium used to transmit data.
- Example: Cable, air, etc.

Types of Data

- Analog data

  Continuous, take continuous values.

- Digital data

  Discrete state, take discrete values.

- Examples?

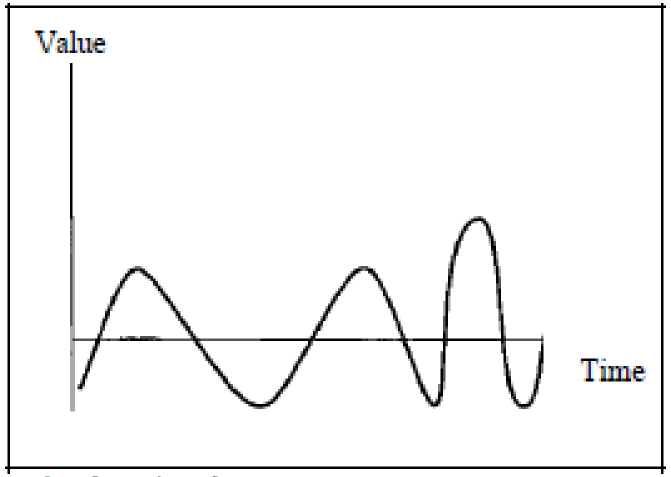
Signals

- Analog and Digital.
- Periodic and Non-periodic.
- Simple and Composite.

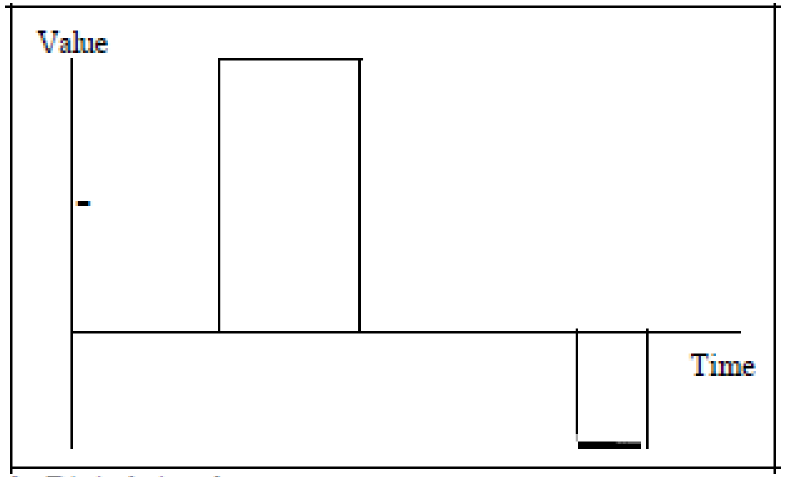
- Representation of Signals:
    - Time Domain, $s(t)$
    - Frequency Domain, $S(f)$

Signals

- Analog and Digital.
  - Analog: infinite number of values in a range.
  - Digital: can have only a limited number of values.



a. Analog signal



b. Digital signal

- Periodic and Non-periodic.

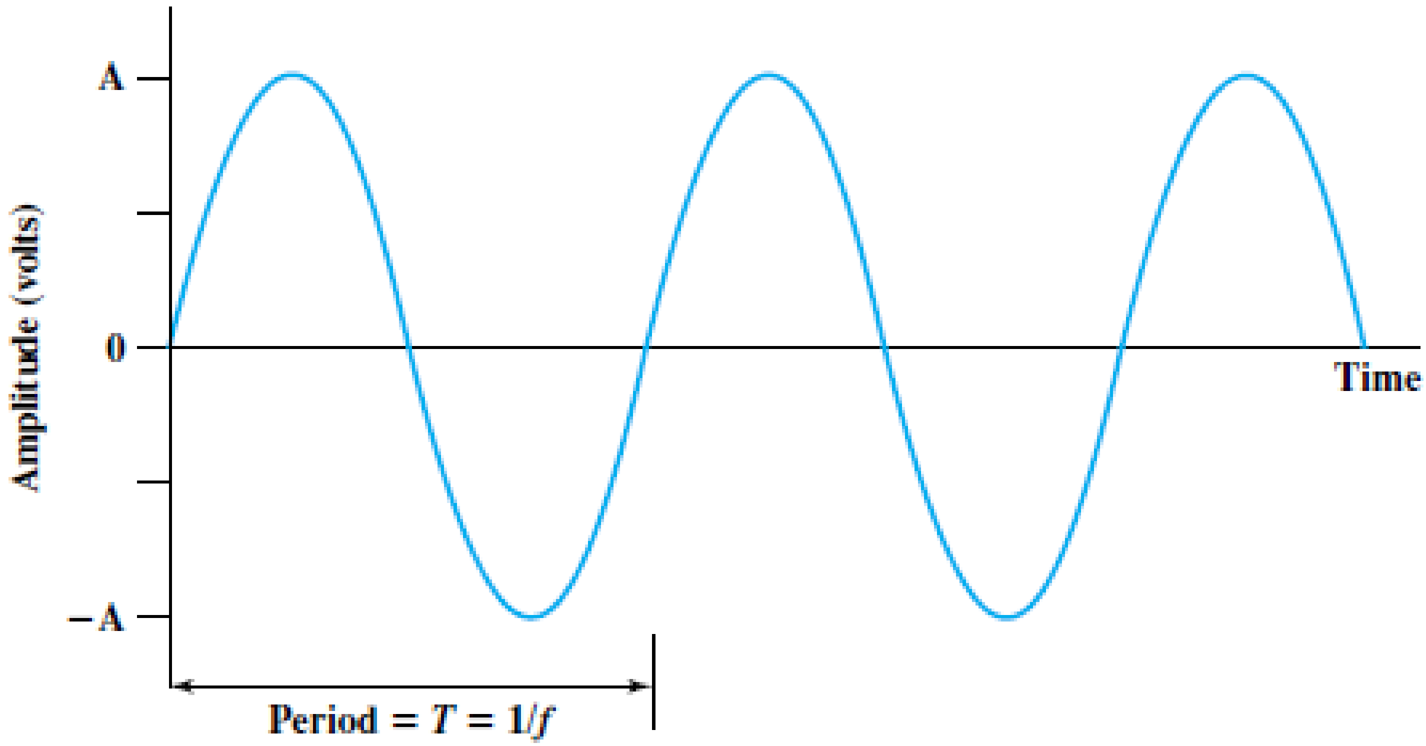
Signals

- Analog and Digital.
- Periodic and Non-periodic.
  - **Periodic**: completes a pattern within a measurable time frame (period) and repeats that pattern over subsequent identical periods. The completion of one full pattern is called a **cycle**.
  - **Nonperiodic**: changes without exhibiting a pattern or cycle that repeats over time.
- In DC, we commonly use Periodic Analog Signals and Non-periodic Digitals Signals. Why?

Periodic Analog Signal

- Amplitude, *A (volts)*
- Frequency, *f (Hz or cps)*
- Phase,ϕ (rad)

- Wavelength, λ =vT



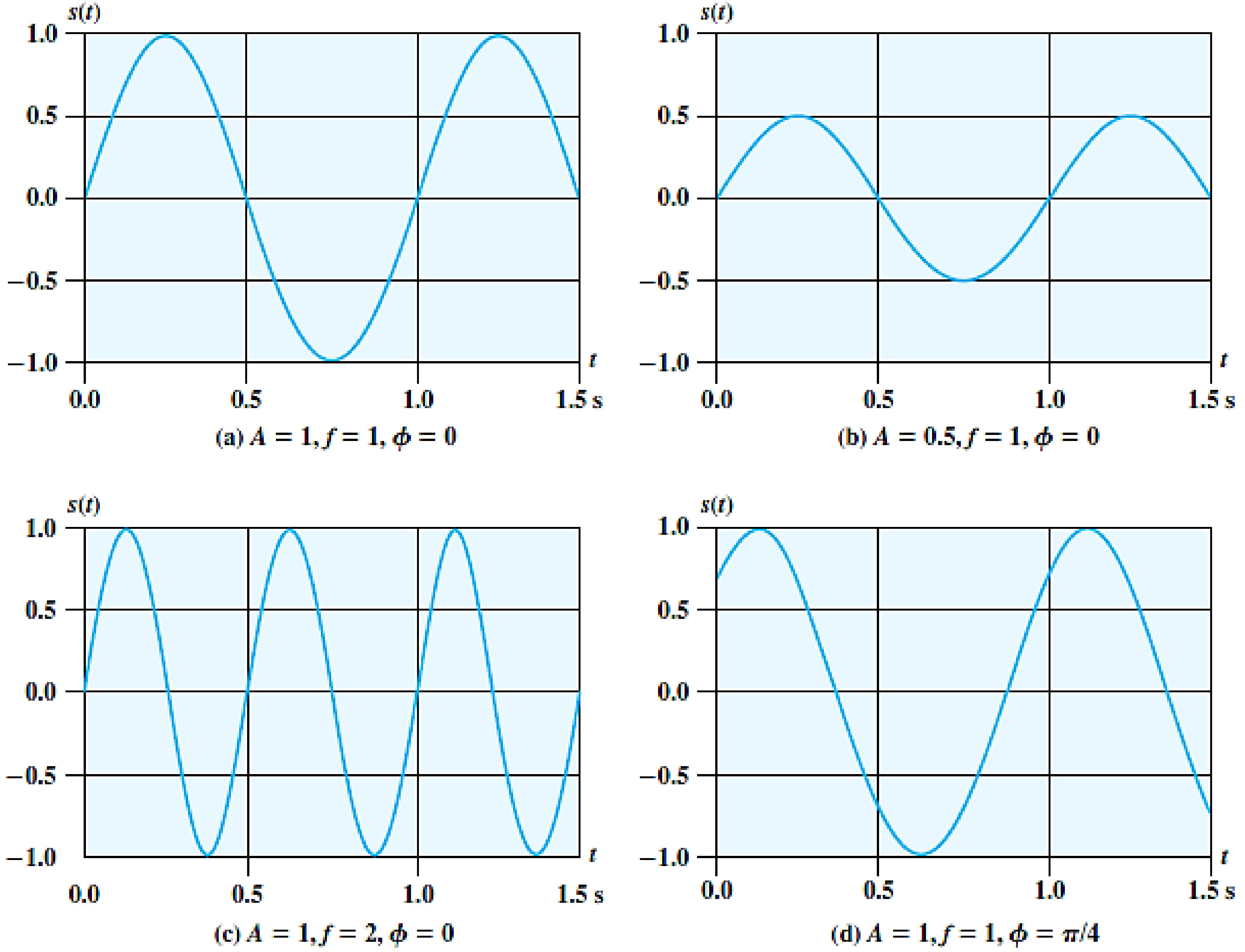
(a) Sine wave

Some Frequency Domain Concepts

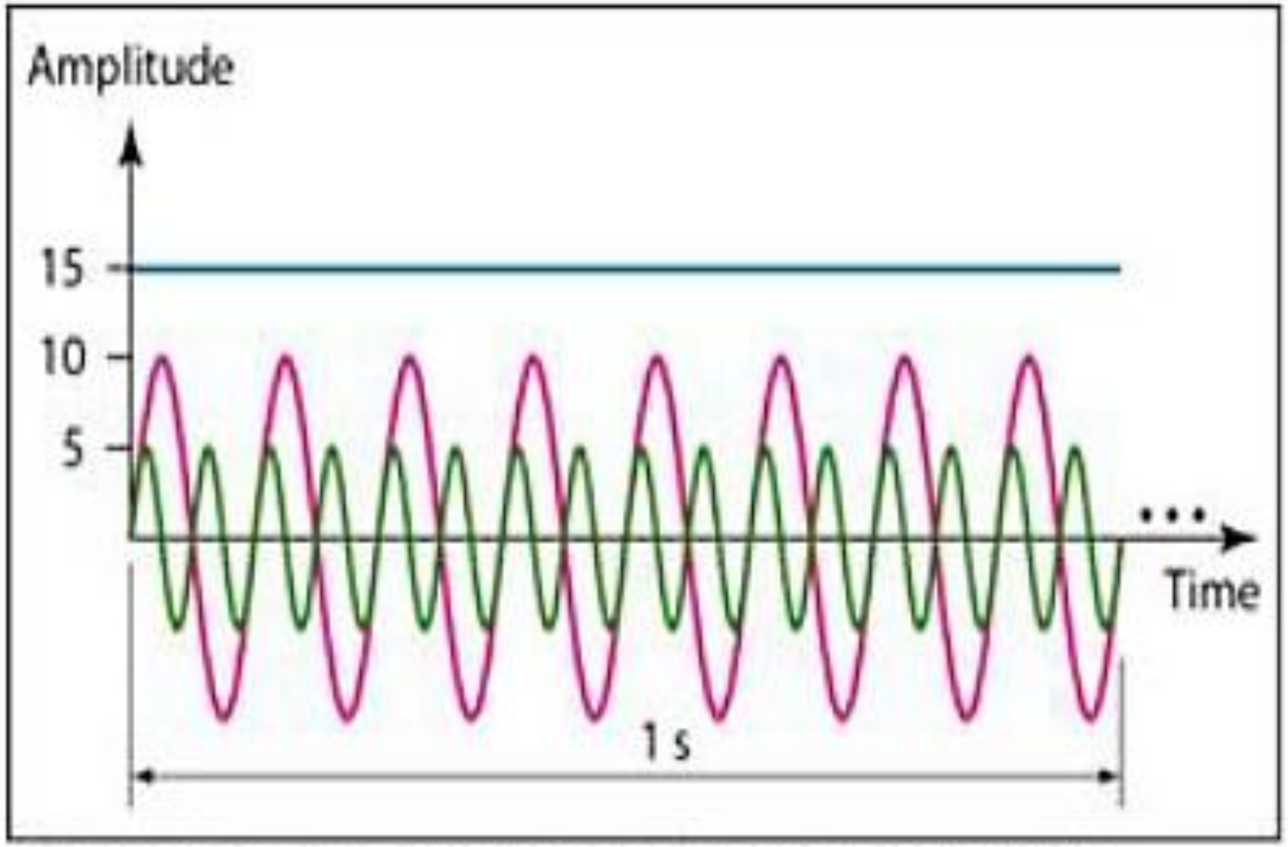
- Spectrum of a signal
  - Range of frequencies that it contain.
- Bandwidth
  - Absolute BW
  - Effective BW
- If signal contains component with zero frequency, signal has a **DC Component.**

Time Domain Representation of a Sine Wave

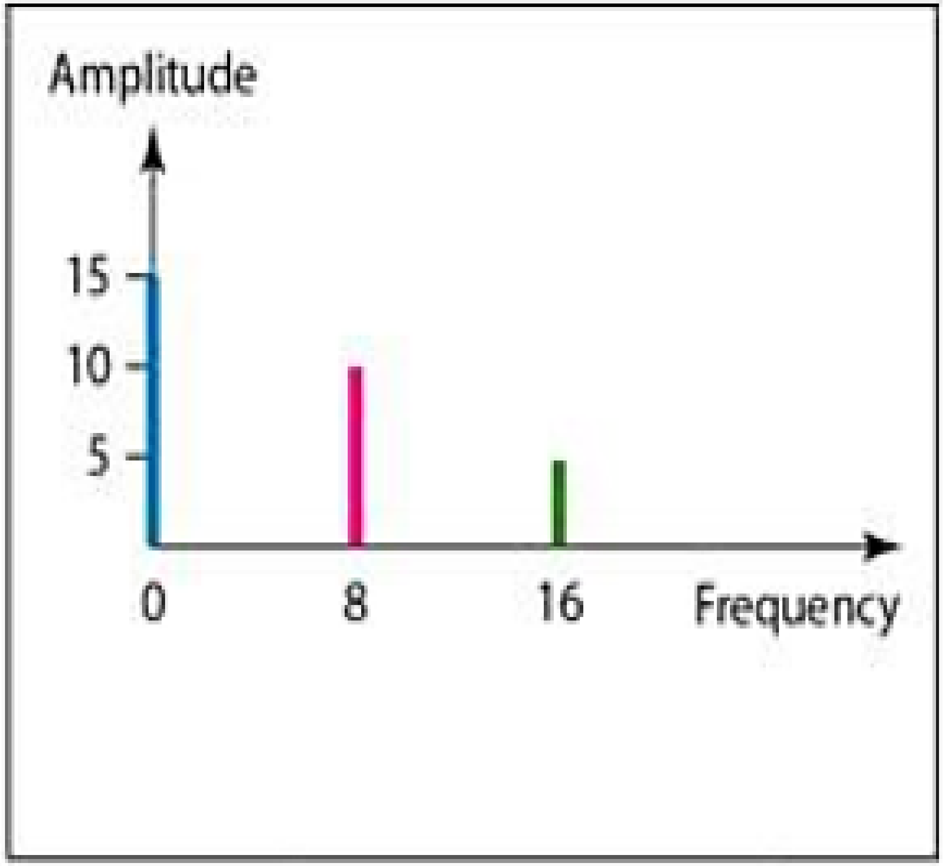
$s(t) = A \sin(2\pi f t + \phi)$



Frequency Domain Representation



a. Time-domain representation of three sine waves with frequencies 0, 8, and 16



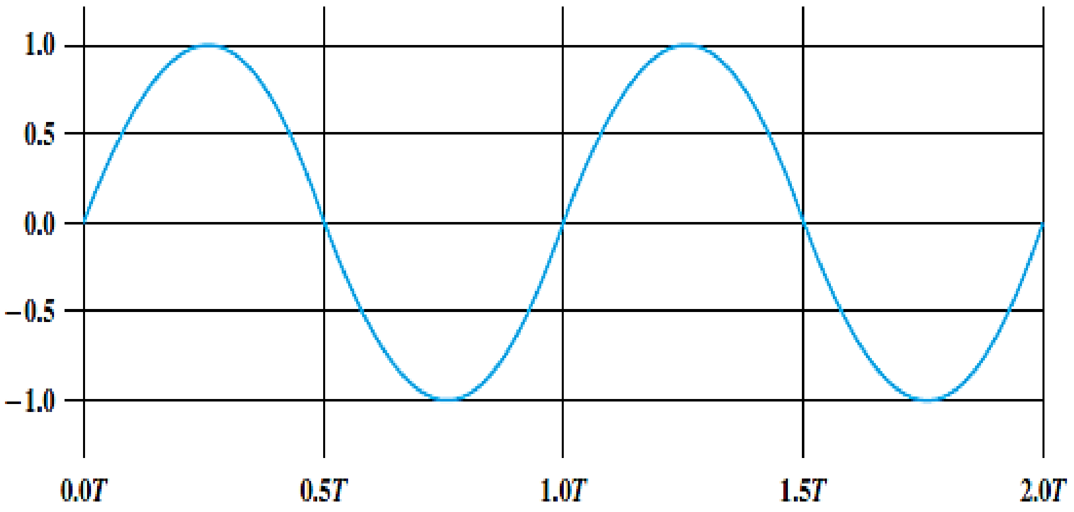
b. Frequency-domain representation of the same three signals

Simple and Composite Signal

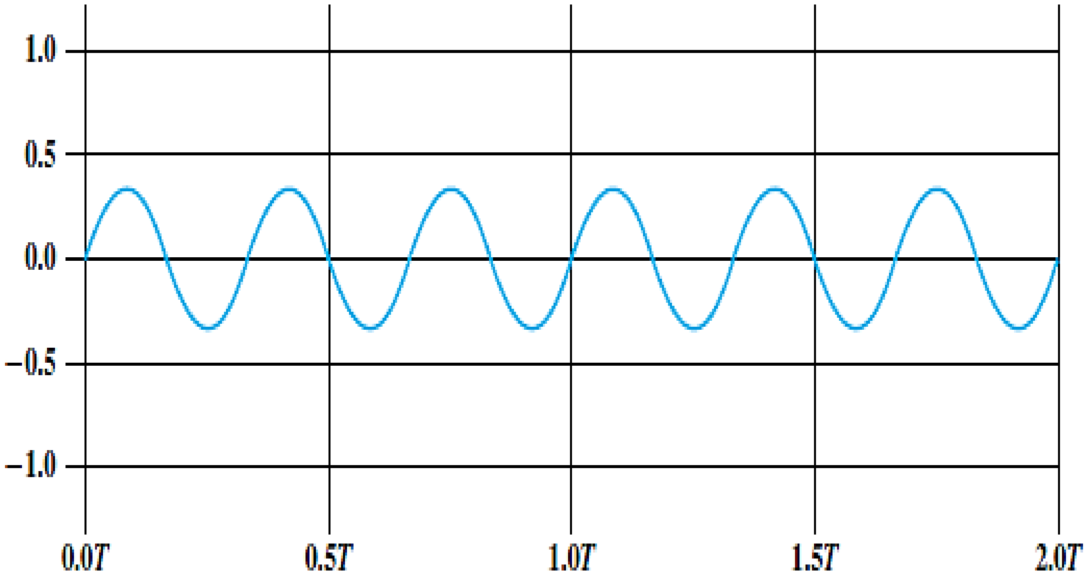
- Applications of Simple signal?
- Composite Signal:
  - a combination of simple sine waves with different frequencies, amplitudes, and phases.

On decomposition:

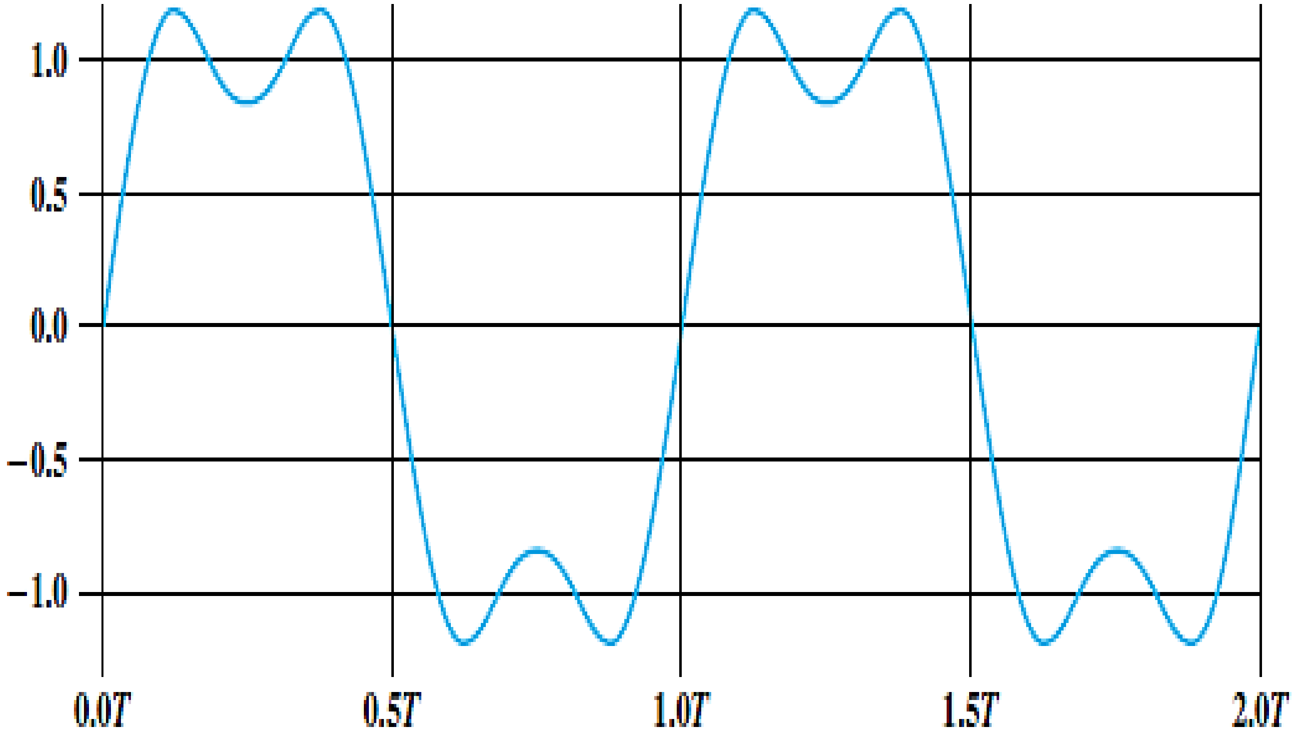
Periodic Composite Signal	Series of signals with **discrete frequencies**.
Non-periodic Composite Signal	Combination of sine waves with **continuous frequencies**.



(a) $\sin(2\pi ft)$



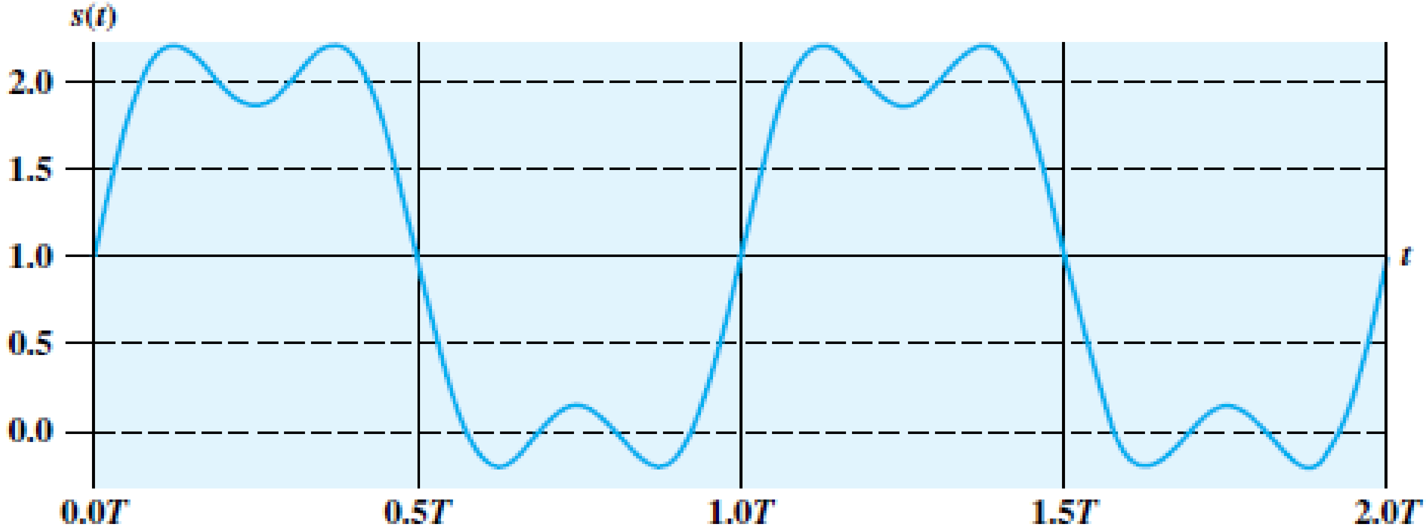
(b) $(1/3)\sin(2\pi(3f)t)$



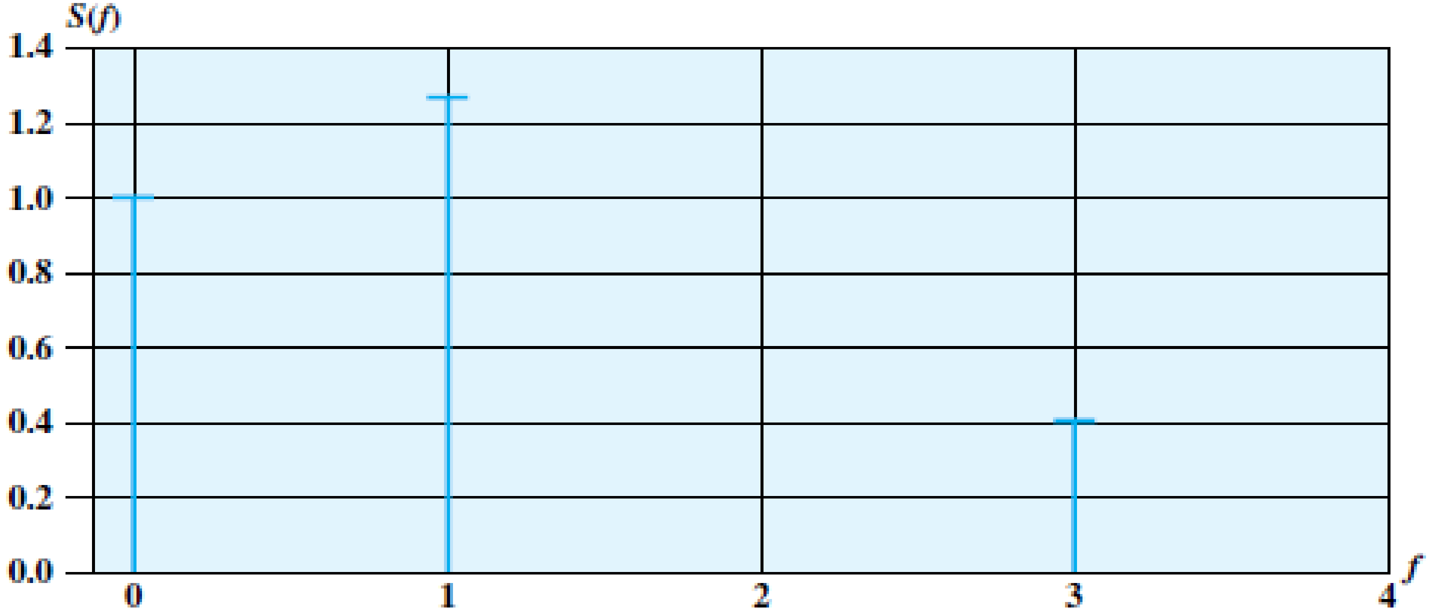
(c) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$

Fundamental Frequency
Harmonic Frequency

Signal with DC Component

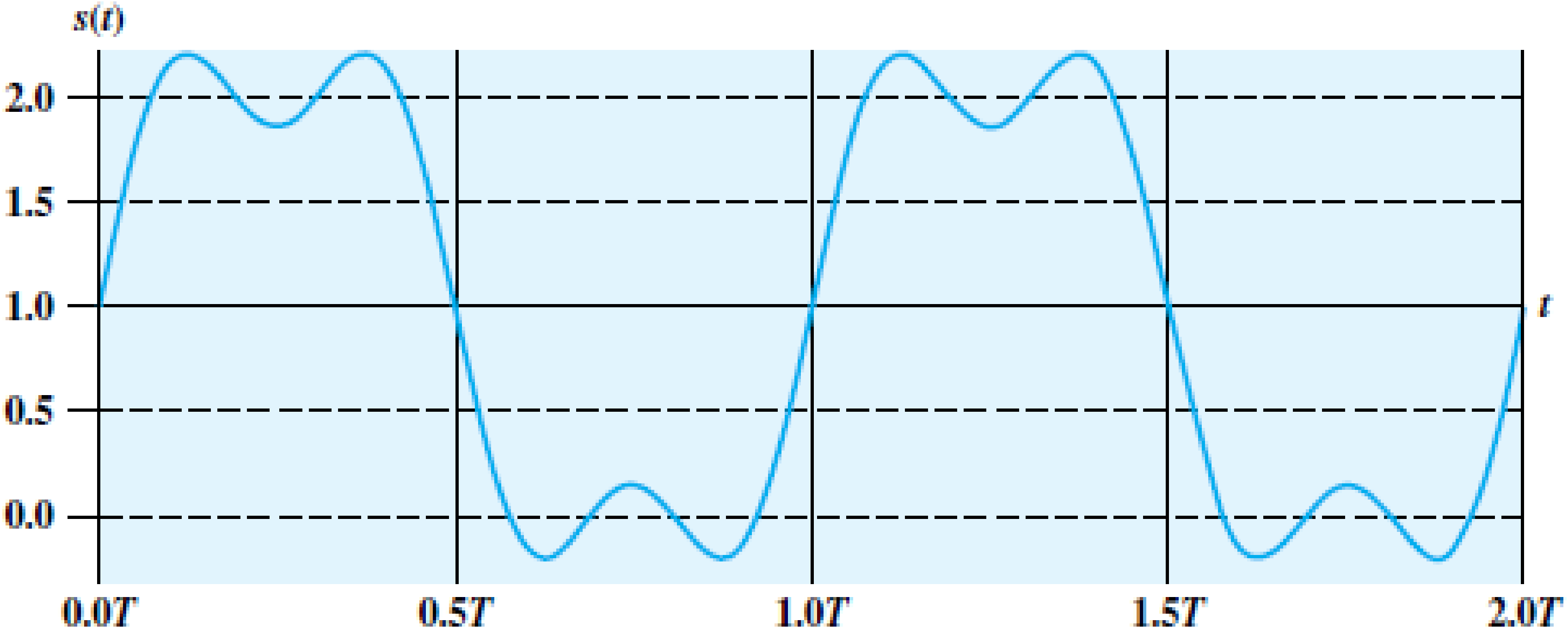


(a) $s(t) = 1 + (4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$



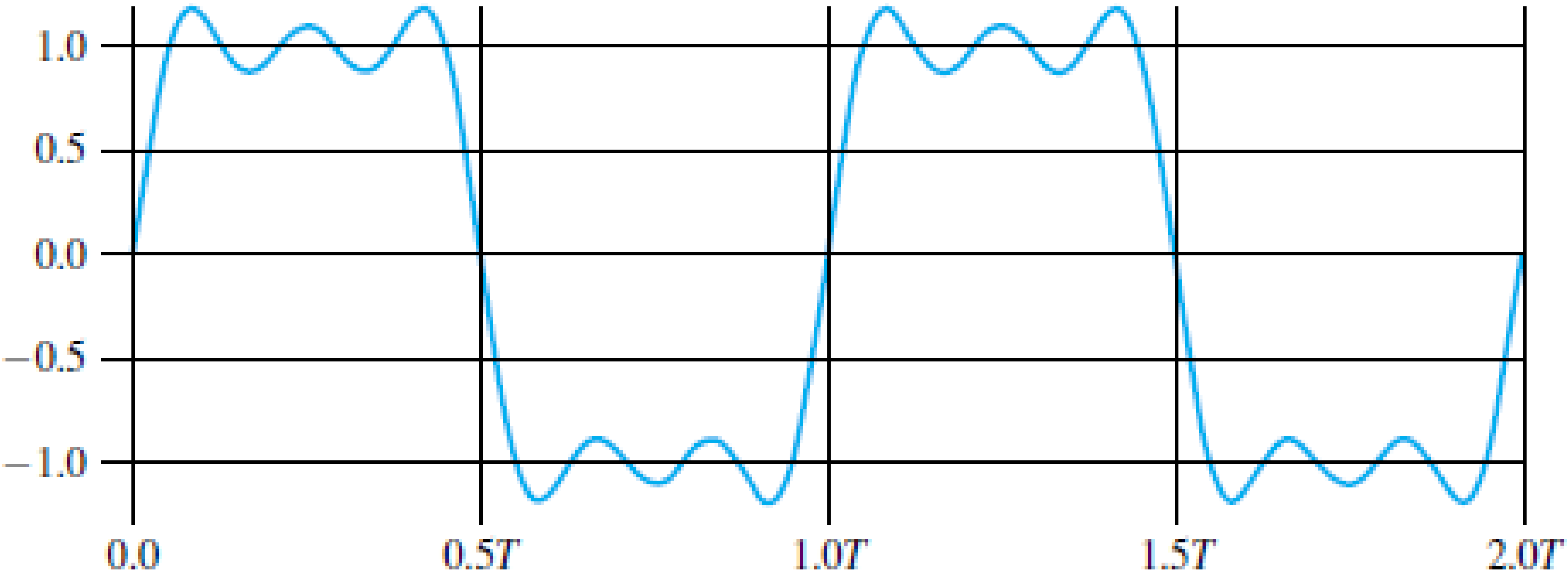
(b) $S(f)$

Frequency Components of a Square Wave



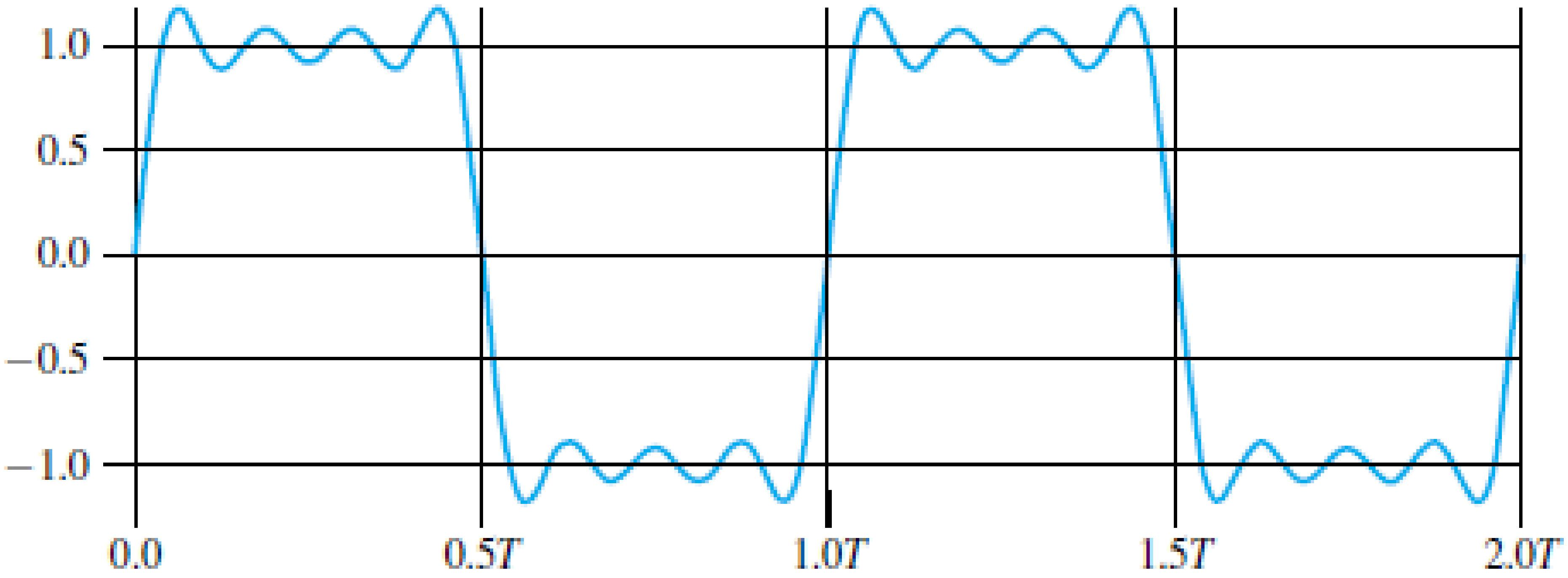
(a) $s(t) = 1 + (4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$

Frequency Components of a Square Wave



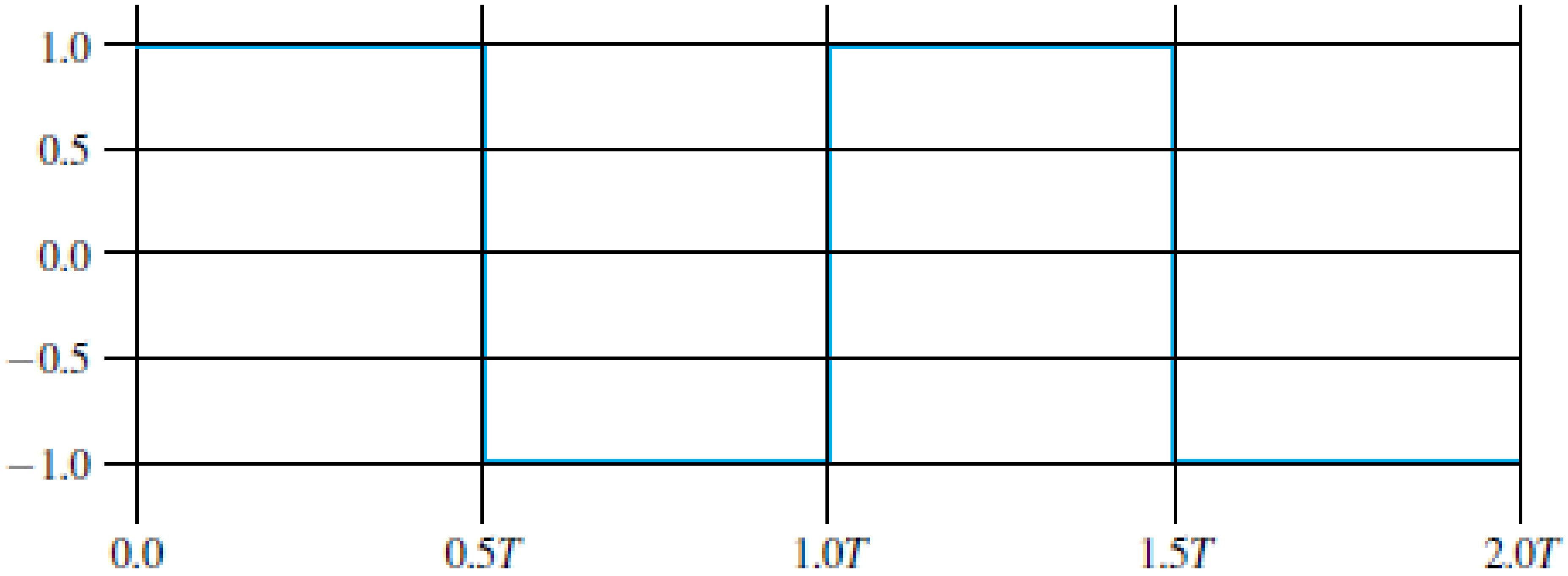
(a) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$

Frequency Components of a Square Wave



(b) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t) + (1/7)\sin(2\pi(7f)t)]$

Frequency Components of a Square Wave

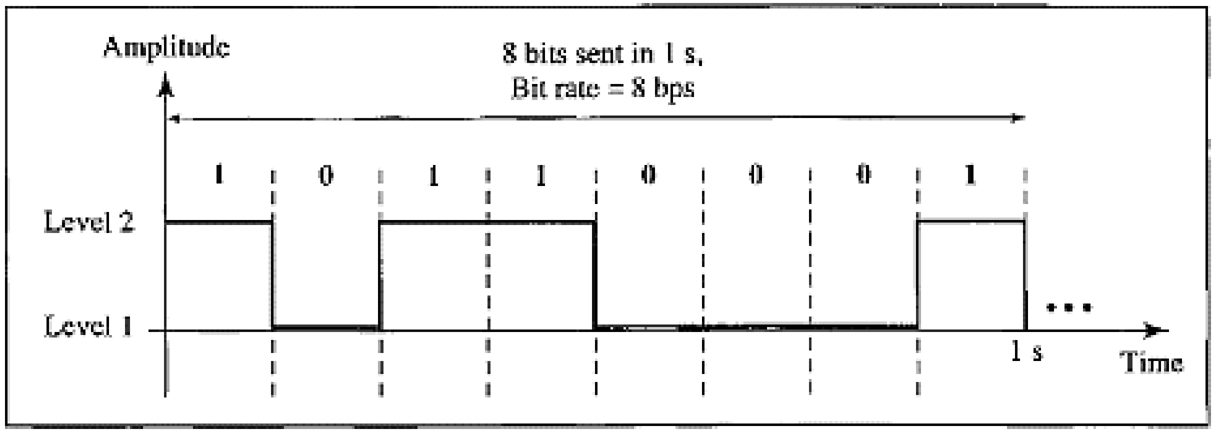


(c) $(4/\pi) \sum (1/k)\sin(2\pi(kf)t)$, for k odd

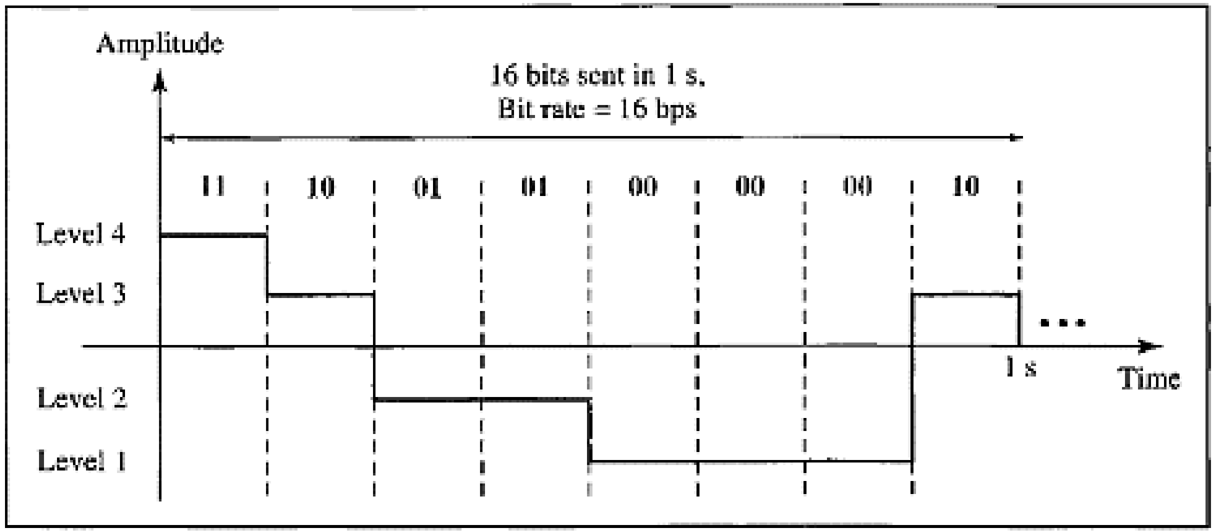
Relationship between Data Rate and Bandwidth

- Signal, $s(t) = (4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$
- Case:1
  - Bandwidth= 4MHz.
  - Harmonic and fundamental frequency?
  - Assume, 2 bits are being transmitted in 1 T, what is the data rate?
- Case:2
  - Bandwidth = 8MHz
- Signal, $s(t) = (4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$
- Case:3
  - f= 2 MHz

Digital Signal



a. A digital signal with two levels



b. A digital signal with four levels

Digital Signal Concepts

- **Bit interval(T):** Time required to send a single bit.
- **Bit rate:** Number of bit intervals per second.(1/T)
- **Propagation time:** Time required for signal to travel from one point of transmission medium to another.

Propagation time=Distance/ Propagation speed

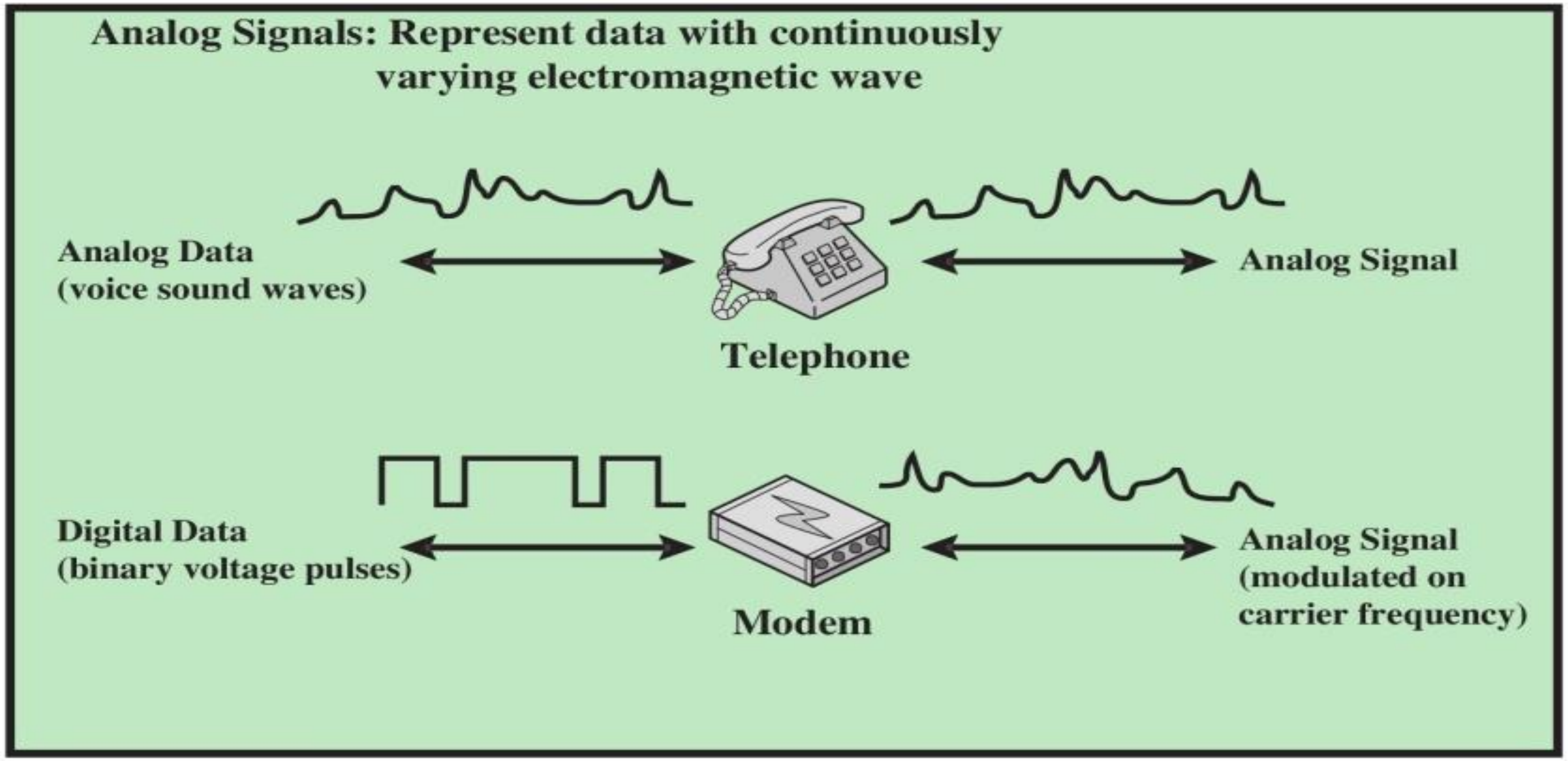
- **Bit Length:** The distance one bit occupies on the transmission medium.

Bit Length = propagation speed * bit duration

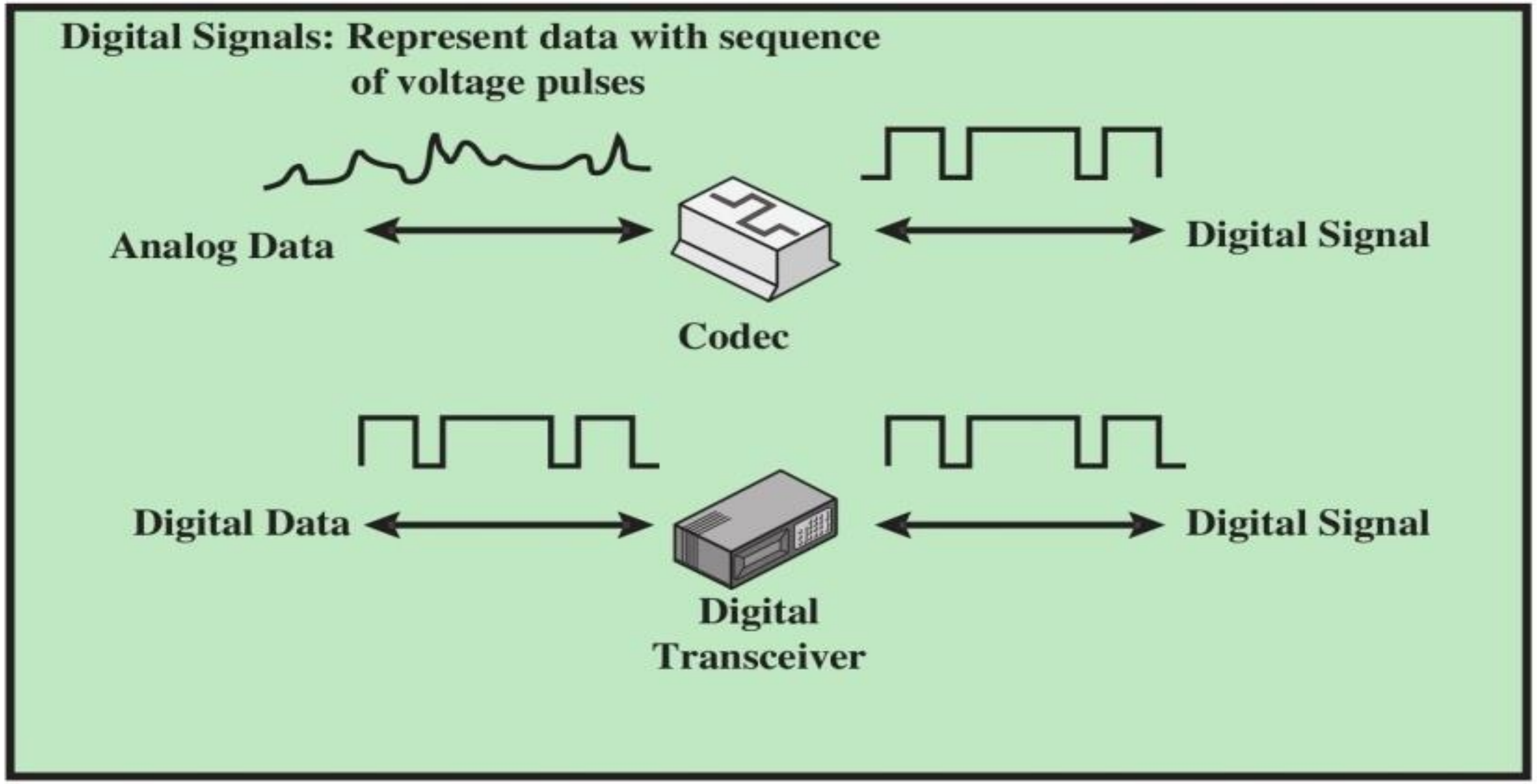
Tradeoffs

- Bandwidth
  - Bandwidth is a limited resource.
  - Greater the bandwidth, greater the cost.
- Data Rate
  - Digital data is approximated by signal of limited bandwidth.
  - Greater the bandwidth, greater the data rate.
- Accuracy
  - Receiver must be able to interpret received signal, even with transmission impairments.

Analog Signaling of Analog and Digital Data



Digital Signaling of Analog and Digital Data



Data, Signals, Transmission: Analog and Digital

(a) Data and Signals

	Analog Signal	Digital Signal
Analog Data	Two alternatives: (1) signal occupies the same spectrum as the analog data; (2) analog data are encoded to occupy a different portion of spectrum.	Analog data are encoded using a codec to produce a digital bit stream.
Digital Data	Digital data are encoded using a modem to produce analog signal.	Two alternatives: (1) signal consists of two voltage levels to represent the two binary values; (2) digital data are encoded to produce a digital signal with desir ed properties.

Shift Keying

Line Encoding Techniques

Data, Signals, Transmission: Analog and Digital

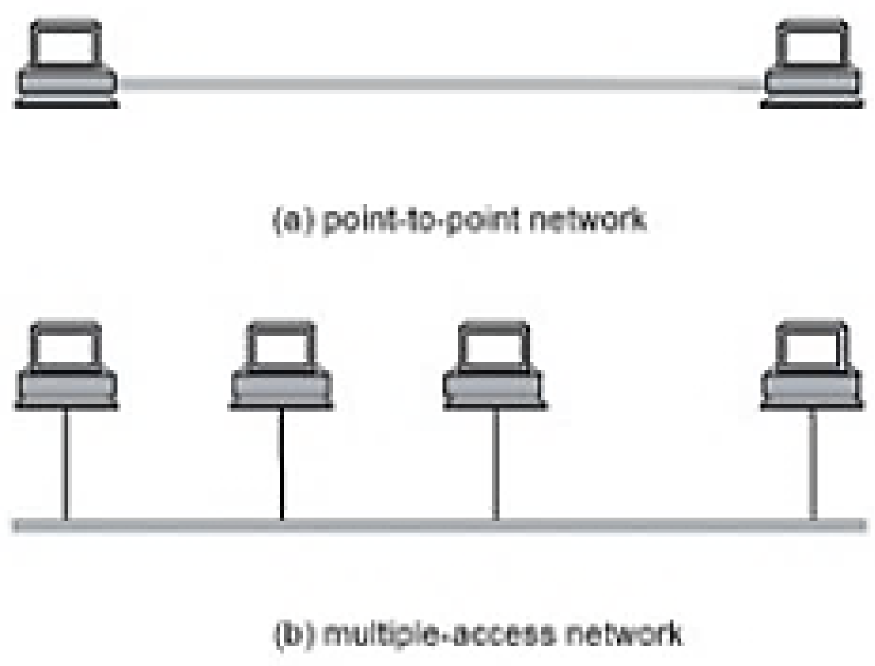
(b) Treatment of Signals

	Analog Transmission	Digital Transmission
Analog Signal	Is propagated through amplifiers; same treatment whether signal is used to represent analog data or digital data.	Assumes that the analog signal represents digital data. Signal is propagated through repeaters; at each repeater, digital data are recovered from inbound signal and used to generate a new analog outbound signal.
Digital Signal	Not used	Digital signal represents a stream of 1s and 0s, which may represent digital data or may be an encoding of analog data. Signal is propagated through repeaters; at each repeater, stream of 1s and 0s is recovered from inbound signal and used to generate a new digital outbound signal.

- Digital transmission is preferred technology today:
  - Technology: cost and size.
  - Data Integrity : Repeaters vs Amplifiers.
  - Capacity Utilization: easier with digital.
  - Digital equipment, efficiently combine signals from different sources.
  - Security.

Transmission Terminology

- Guided and Unguided Media
- Direct Link
- Point to point and Multipoint (guided)
- Simplex, half-duplex, full-duplex [ANSI]

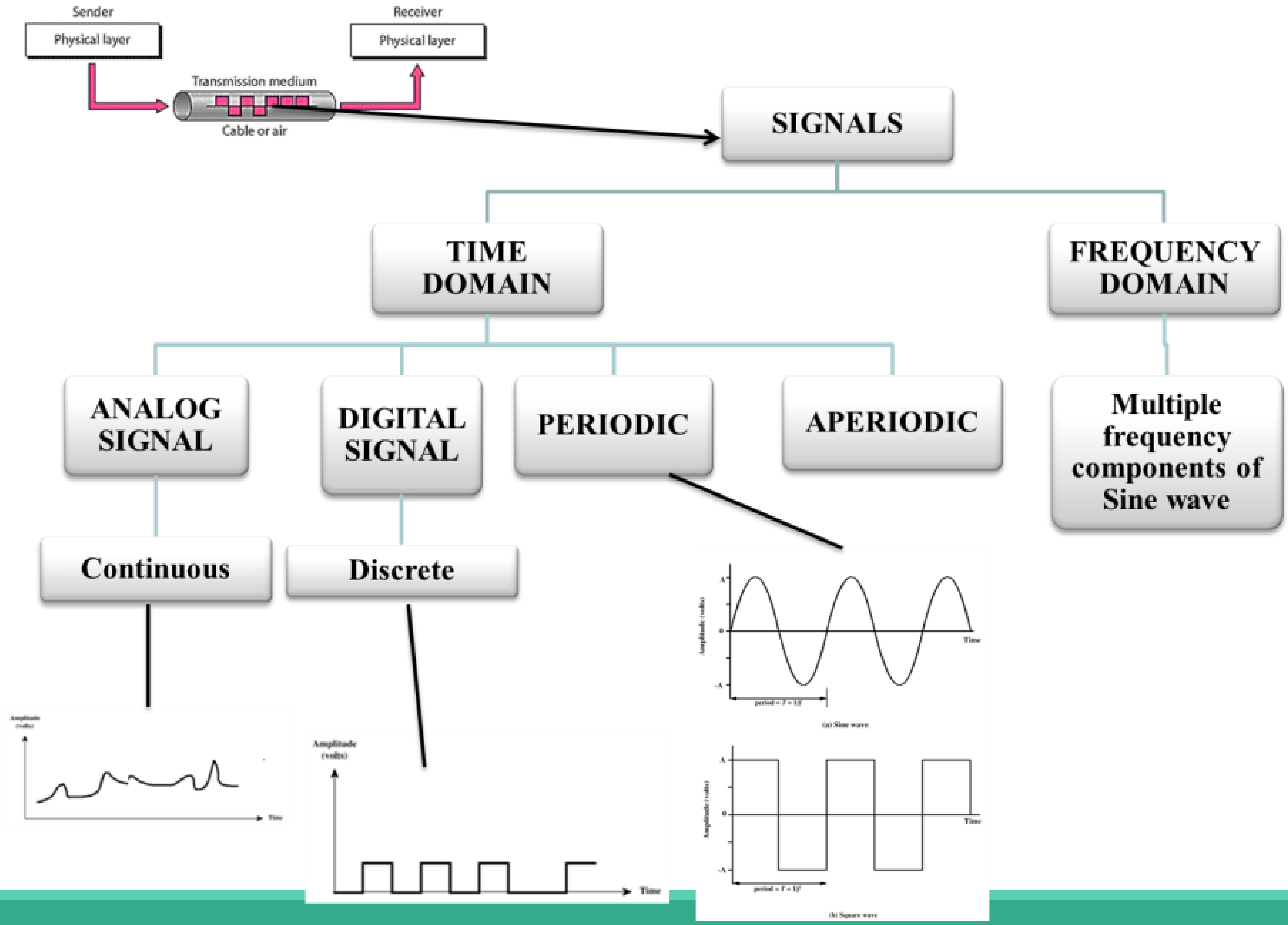


Recap

- Signal: Electric or electromagnetic representations of data.
- Signaling: Physical propagation of signal along a suitable medium.
- Transmission: Communication of data by propagating and processing signals.
- Data Communication Model.
- Communication Tasks.

Recap

- Types of Signals.: Analog-Digital, Periodic-Nonperiodic, Simple-Composite.
- Analog signal is continuously varying electromagnetic wave.
- Digital signal is sequence of voltage pulses.
- Amplitude, Frequency, Period, Phase.
- Wavelength = **v*T** or **v*f***
- Time Domain and Frequency Domain Representation.
- Digital signals are generally cheaper and less susceptible to interference.


Sender
Physical layer
Receiver
Physical layer
Transmission medium
Cable or air
SIGNALS
TIME DOMAIN
FREQUENCY DOMAIN
ANALOG SIGNAL
DIGITAL SIGNAL
PERIODIC
APERIODIC
Multiple frequency components of Sine wave
Continuous
Discrete
Amplitude (volts)
Time
(a) Sine wave
(b) Square wave

Transmission Impairments

- The signal that is received may **differ** from the signal that is transmitted due to various **transmission impairments**.

  - Attenuation and attenuation distortion
  - Delay Distortion
  - Noise

Attenuation: reduction in strength

- Guided Media: exponential (dB/distance)
- Unguided Media: *f* (distance, makeup of atmosphere)

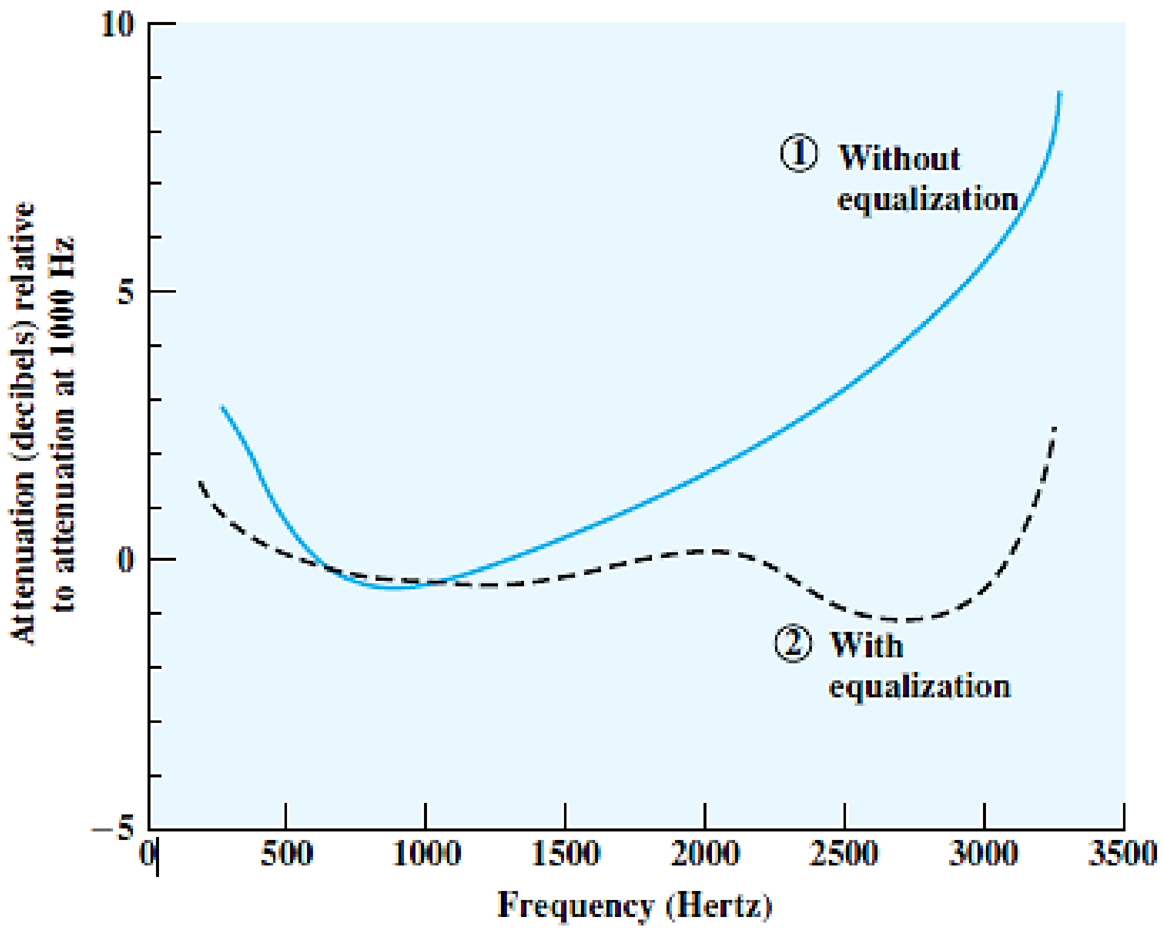
- Considerations:

Signal Strength and use of amplifiers/repeaters

1. A received signal must have sufficient strength.
2. The signal must maintain a level sufficiently higher than noise to be received without error.
3. Attenuation varies with frequency. ⇒ Signal Distorted; Reduces intelligibility

Apply equalization to overcome.

Attenuation for a Voice Channel



Delay Distortion

- Component signals with different frequencies have different propagation speeds through cable.
- Phase shift between the different frequency components; hence the distortion.
- **Intersymbol interference**: signal components of one-bit position of a digital signal will spill over into other bit positions.
- To overcome apply **equalization**.

Noise

- Thermal noise
- Intermodulation noise
- Crosstalk
- Impulse noise

Noise

- **Thermal noise**
  - Due to thermal agitation of electrons.
  - Uniformly distributed across the bandwidths used in communications systems: **White Noise.**
  - The amount of thermal noise to be found in a bandwidth of 1 Hz in any device or conductor is: $N_0 = k\,T$ (W/Hz)
  - Amount of thermal noise, $N = k\,T\,B$ Watts.

Noise

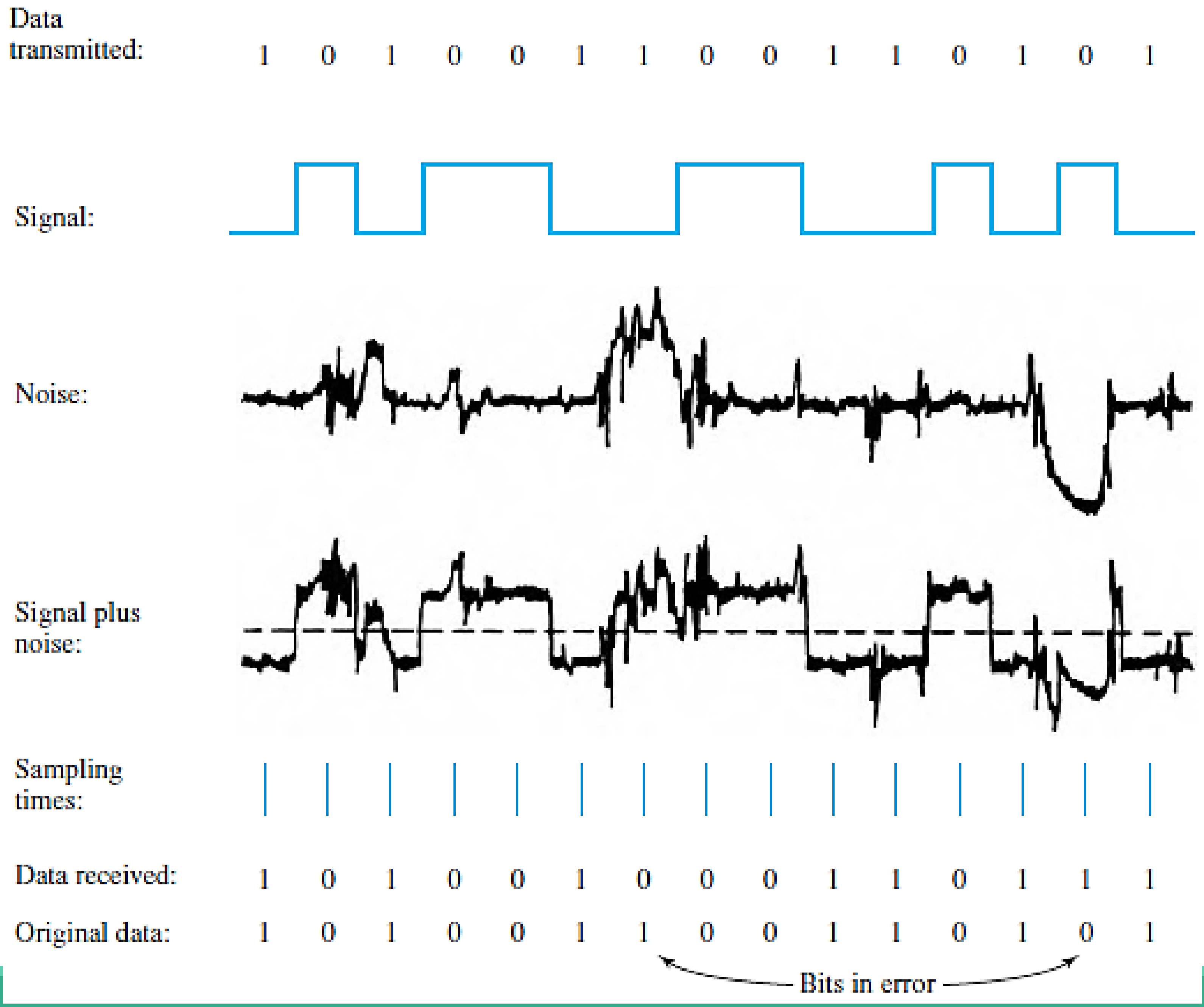
- **Intermodulation noise**
  - When signals at different frequencies share the same transmission medium.
  - Produced by nonlinearities in the transmitter, receiver, and/or intervening transmission medium.

- **Crosstalk**
  - Unwanted electrical coupling of different signals in any media.
  - Typically, crosstalk is of the same order of magnitude as, or less than, thermal noise.

Noise

- **Impulse noise**
  - External electromagnetic disturbances, such as lightning, and faults and flaws in the communications system.
  - Non-continuous.
  - Consisting of irregular pulses or noise spikes of short duration.
  - Relatively high amplitude
  - Minor annoyance for analog data; primary source of error in digital data.

Effect of Noise on a Digital Signal



Channel Capacity

- The maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions.
- Objective: To get as high a data rate as possible at a particular limit of error rate for a given bandwidth.
- Make efficient use of available BW.
- Data rate depends on BW, **Noise**, Error rate, and levels of signals we use.

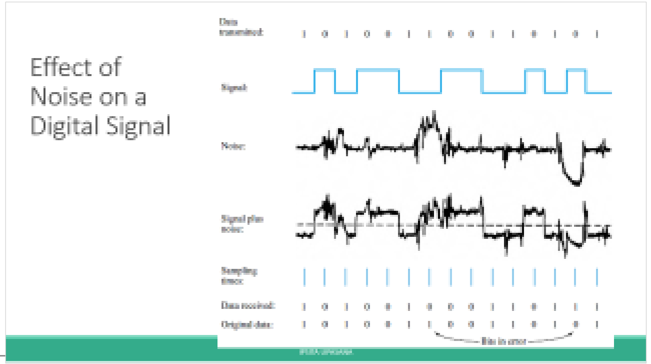
Nyquist Bandwidth: Noiseless Channel

- What will happen to the data rate, if a channel is noise free?
- If the **rate of signal** transmission is 2*B*, then a signal with frequencies no greater than *B* is sufficient to carry the signal rate.
- Given a bandwidth of *B*, the highest signal rate that can be carried is 2*B*.

$$C = 2B \log_2 M$$

- Increasing the levels of a signal may reduce the reliability of the system.

Shannon Capacity



- The presence of noise can corrupt one or more bits. More the data rate, more bits may get corrupted by noise.
- For a given level of noise, a greater signal strength would improve the ability to receive data correctly in the presence of noise.
- **Signal-to-noise ratio: SNR**

$$\mathrm{SNR_{dB}} = 10 \log_{10} \frac{\text{signal power}}{\text{noise power}}$$

- High SNR : high-quality signal, low number of required intermediate repeaters.

Shannon Capacity

- Why is SNR important in the transmission of digital data?
- Because it sets the upper bound on the achievable data rate.
- Shannon's maximum channel capacity (error-free), in bits per second:
  - $$C = B \log_2 (1 + SNR)$$
- Formula assumes white noise. What conclusion can be drawn from this?
- What happens to SNR, if the bandwidth is increased?

Summary

- Types of Transmission Impairments?
- Types of Noise?
- Can thermal noise be eliminated? Result?
- Which types of noise discussed have reasonably predictable and relatively constant magnitudes?
- What are the factors that data rate is dependent on?
- Theoretical maximum bit-rate for a noiseless channel is given by Nyquist capacity.
- The Shannon capacity gives us the upper limit; the Nyquist formula tells us how many signal levels we need.

Problems

Q1: Given a receiver with an effective noise temperature of 294 K and a 10-MHz bandwidth, what is the thermal noise level at the receiver's output in decibel-watts? (Boltzmann's constant, k = 1.38 * 10-23 J/K)

Q2: The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB}?

Q3: Suppose that the spectrum of a channel is between 3 MHz and 4 MHz and SNR_{dB} =24dB. Based on Nyquist's formula, how many signaling levels are required?

Q4: We have a channel with a 1-MHz bandwidth. The SNR for this channel is 63. What are the appropriate bit rate and signal level?

Book:

- William Stallings, *Data & Computer Communications (9e),* Pearson Education Inc., Noida, 2017, **Chapter: 1, 3.**