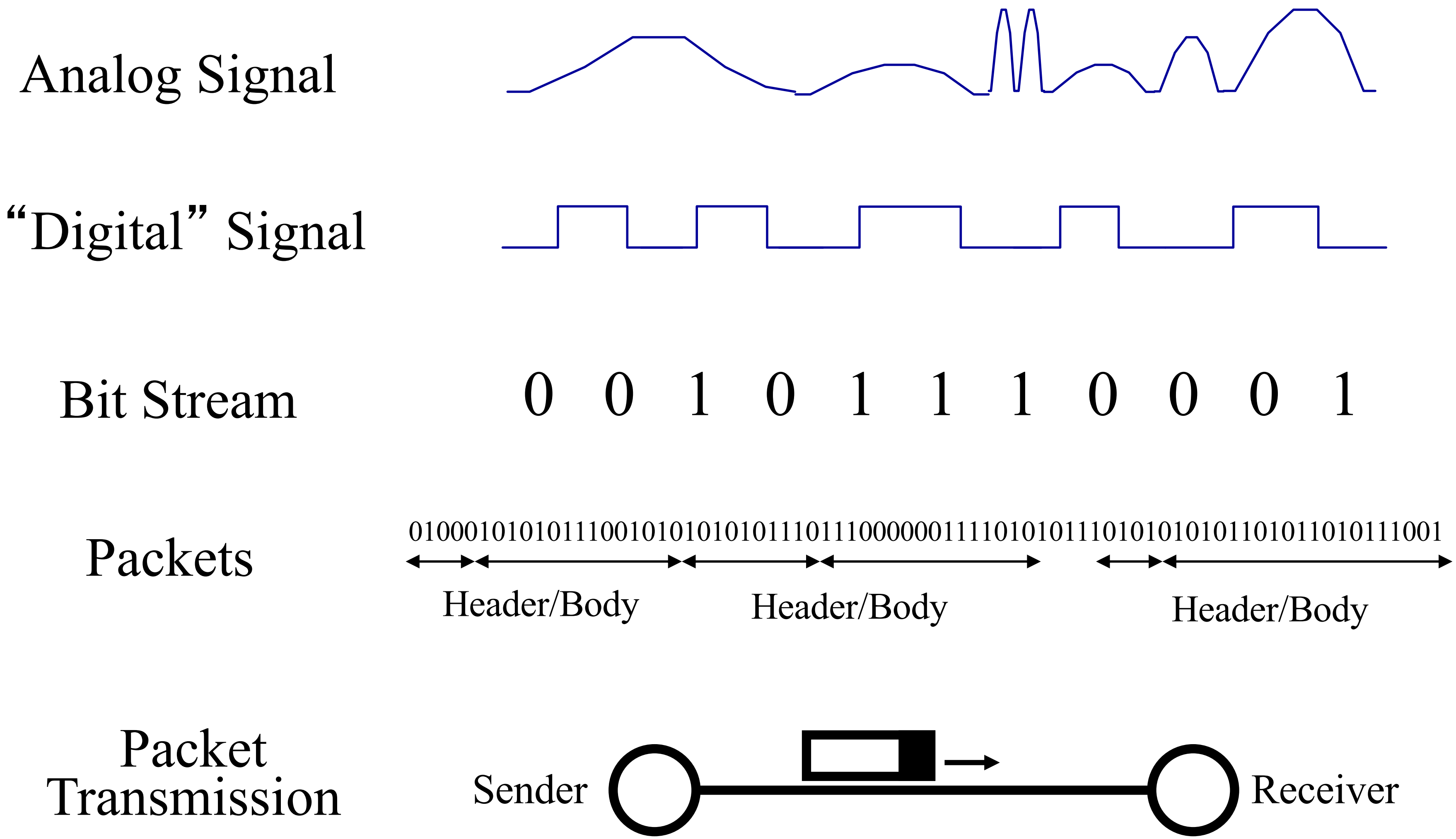
Chapter 2: Physical layer

ONE LOVE. ONE FUTURE.

Overview

- Physical layer is responsible for transmission of a stream of bits
  - Put bits from a machine to a medium
  - Pick bits from the medium give to receiver
- Some issues
  - Medium
  - Line Encoding: representing the digital logic levels using the physical attributes associated with the media.
  - Multiplexing

From signal to packet



Model of data transmission system

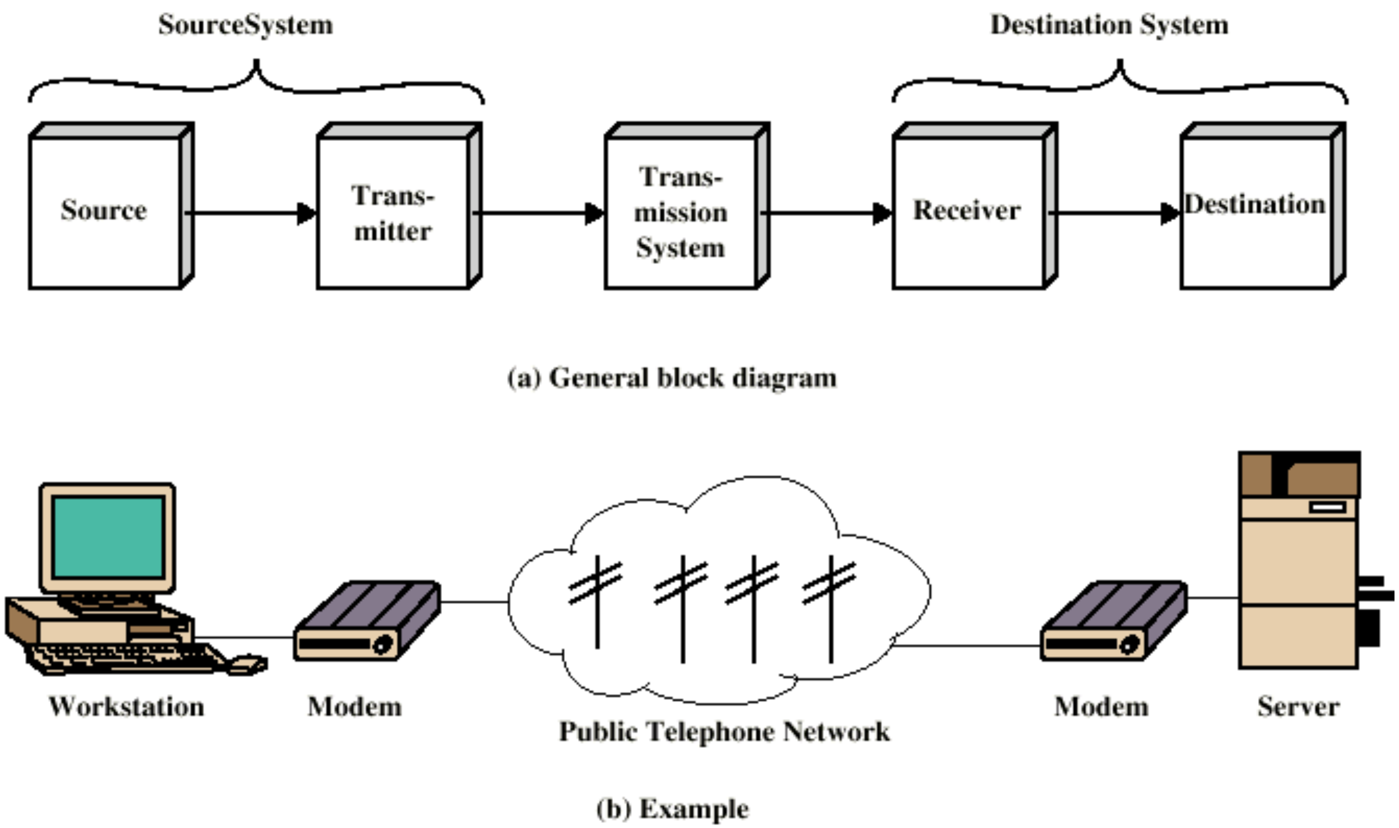


Figure 1.1 Simplified Communications Model

Data Communication networks

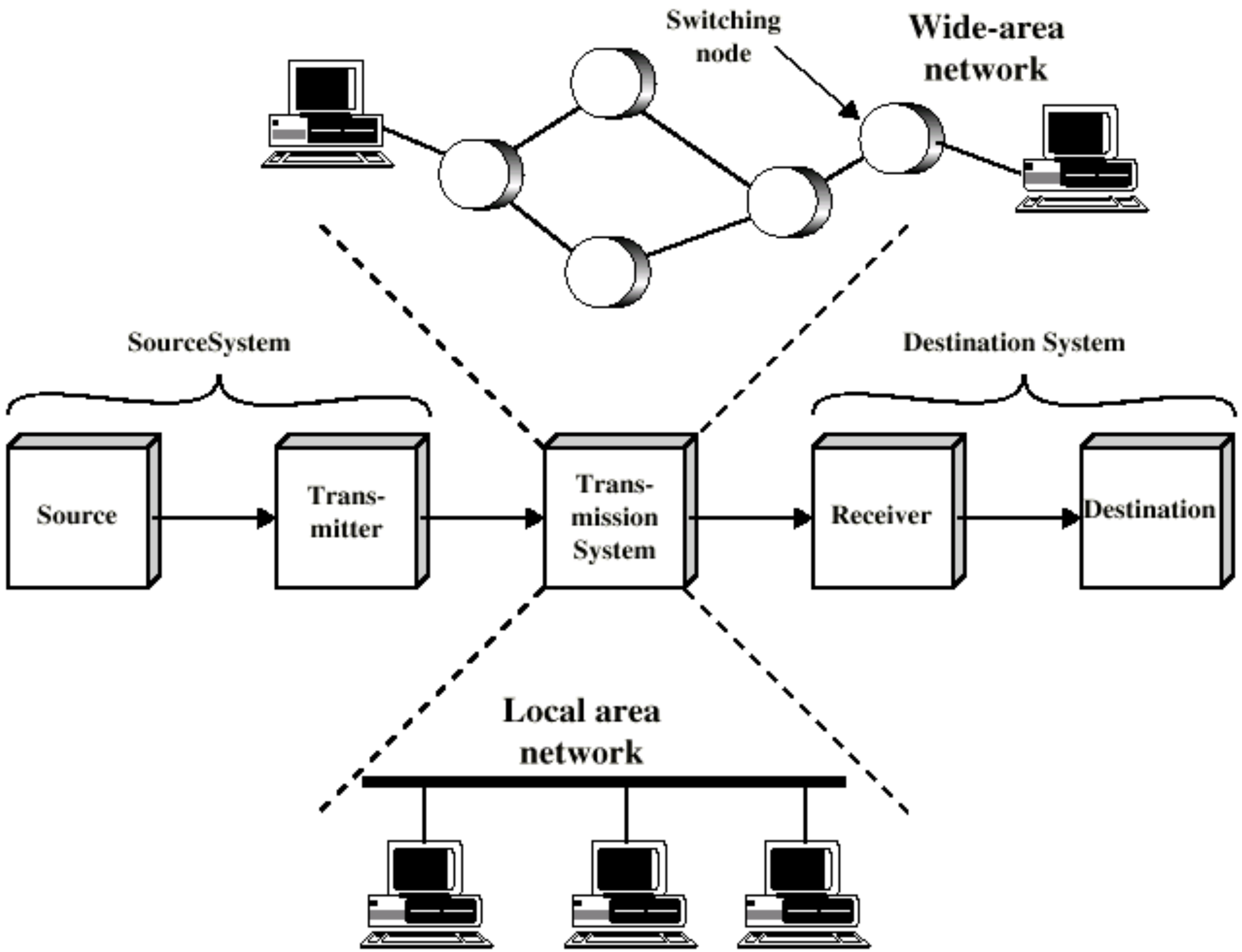
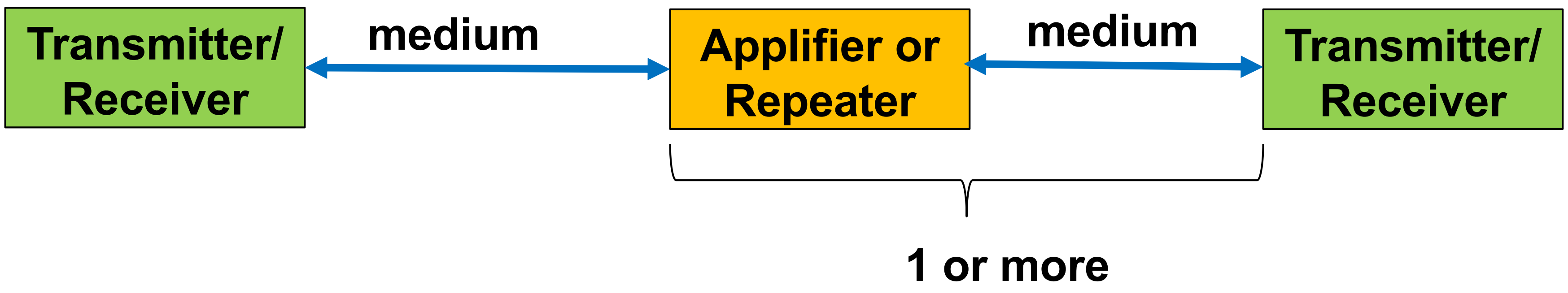


Figure 1.3 Simplified Network Models

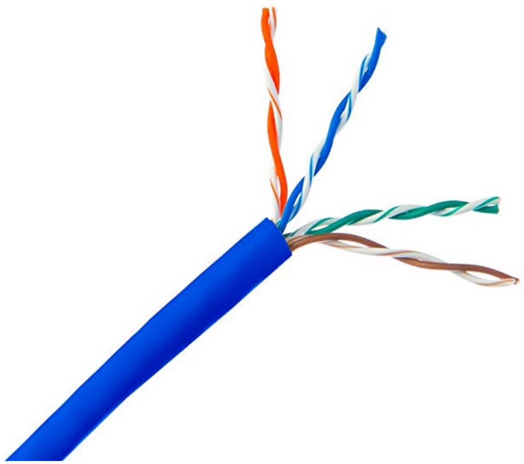
Direct Data transmission system



Communication Media

- Wired media: cable guides signals
  - Twisted Pair
  - Coaxial Cable
  - Fiber Optics
- Wireless media: no cable guides signal
  - Radio
  - Infra red
  - Light
  - …

Twisted pair



(a)

(b)

(a) Category 3 UTP.

(b) Category 5 UTP.

Twisted pair

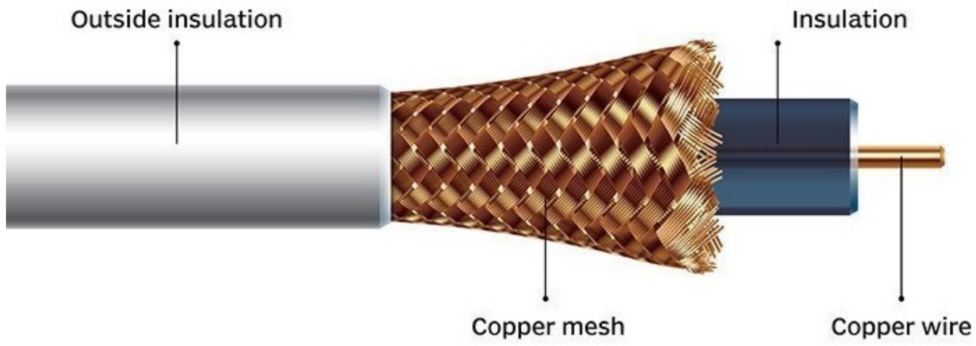
- Contains several pairs of copper, cable in the one pair is twisted together.
- Two kinds of twisted pair:
  - STP-Shielded Twisted Pair:
    - There is a metal coat, not popular
  - UTP-Unshielded Twisted Pair:
    - No metal coat, popular

Evaluation

- Cheap, simple
- Widely used
- Weak resistance to noice
- Short Transmission distance

- Need amplification after each 5km in analog transmission
- In digital transmission
  - Need repeater after each 2 km
- In Ethernet LAN deployment < 100m
- Limited speed (100Mbps)

Coaxial cable



Category	Impedance	Use
RG-59	75 Ω	Cable TV
RG-58	50 Ω	Thin Ethernet
RG-11	50 Ω	Thick Ethernet

Structure:

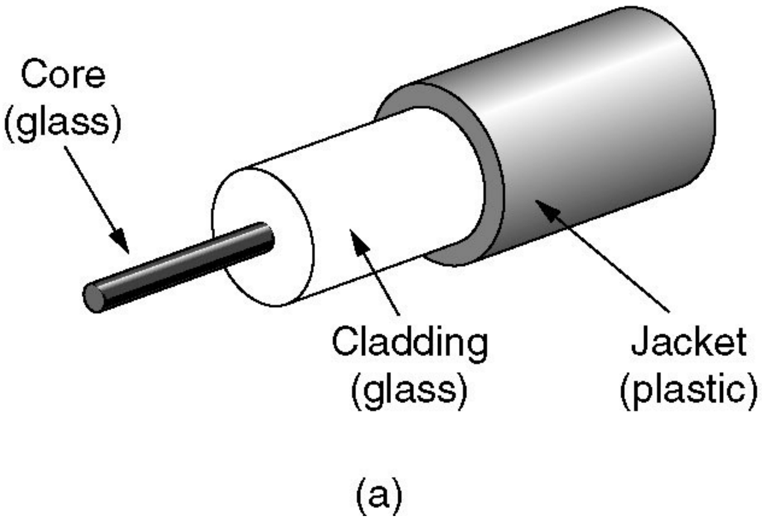
- Inner conduct is coated by an insulator enviroment
- Shielded by a metal grill
- A plastic cover for protection.

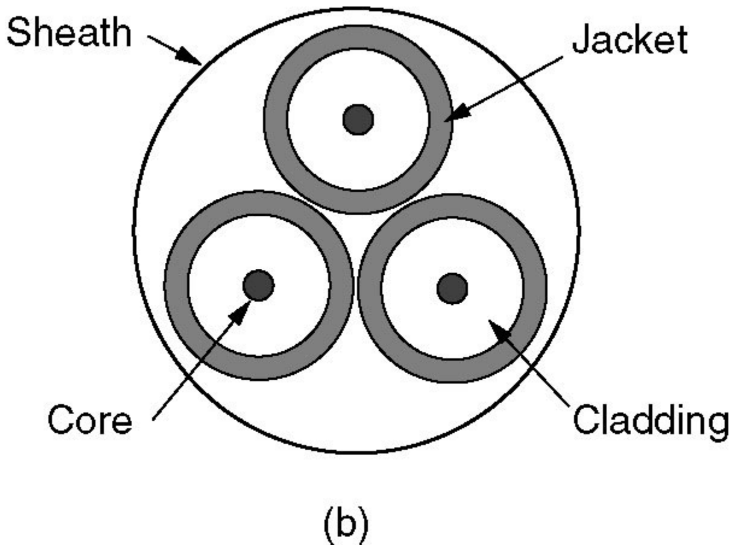
Application

- Using in TV transmission
- For transmission of telephone signal
  - 10,000 calls in the same time
  - Is being replaced by fiber optics
- Linking the computers of the short distance
- LAN 10BaseT, 100BaseT, …

- For digital transmission
  - Repeater should be used after each 1km
  - More repeater is needed for high speed transmission

Optical fiber

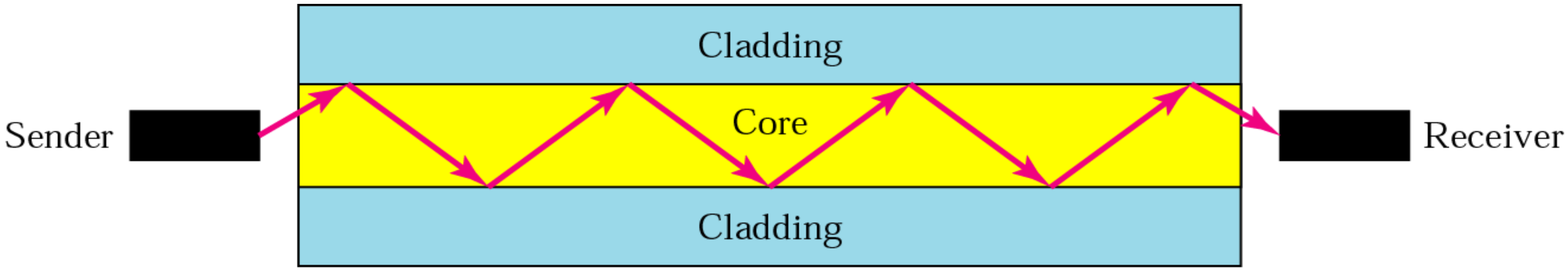


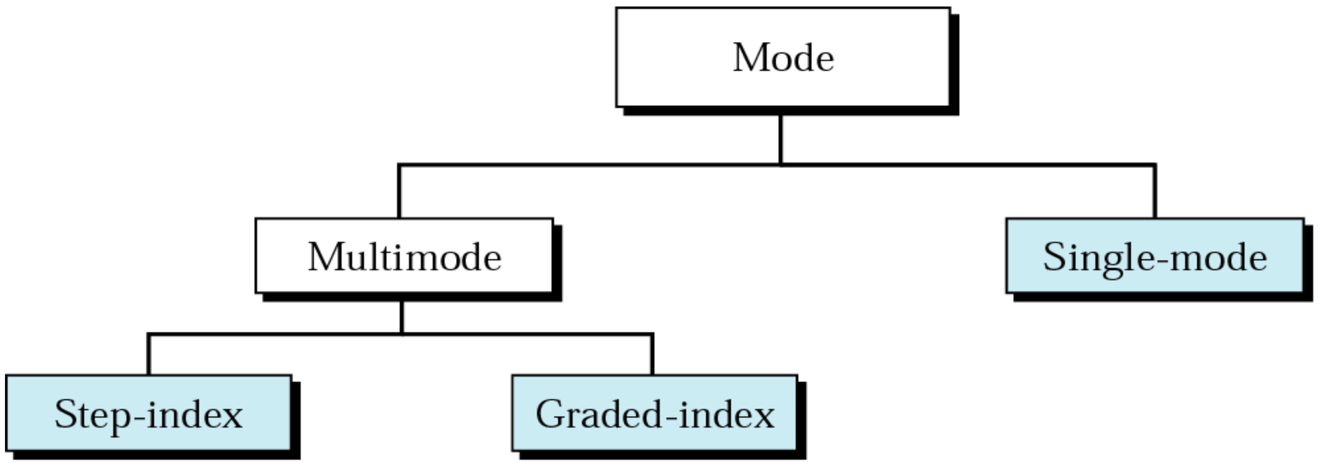


(a) Single core

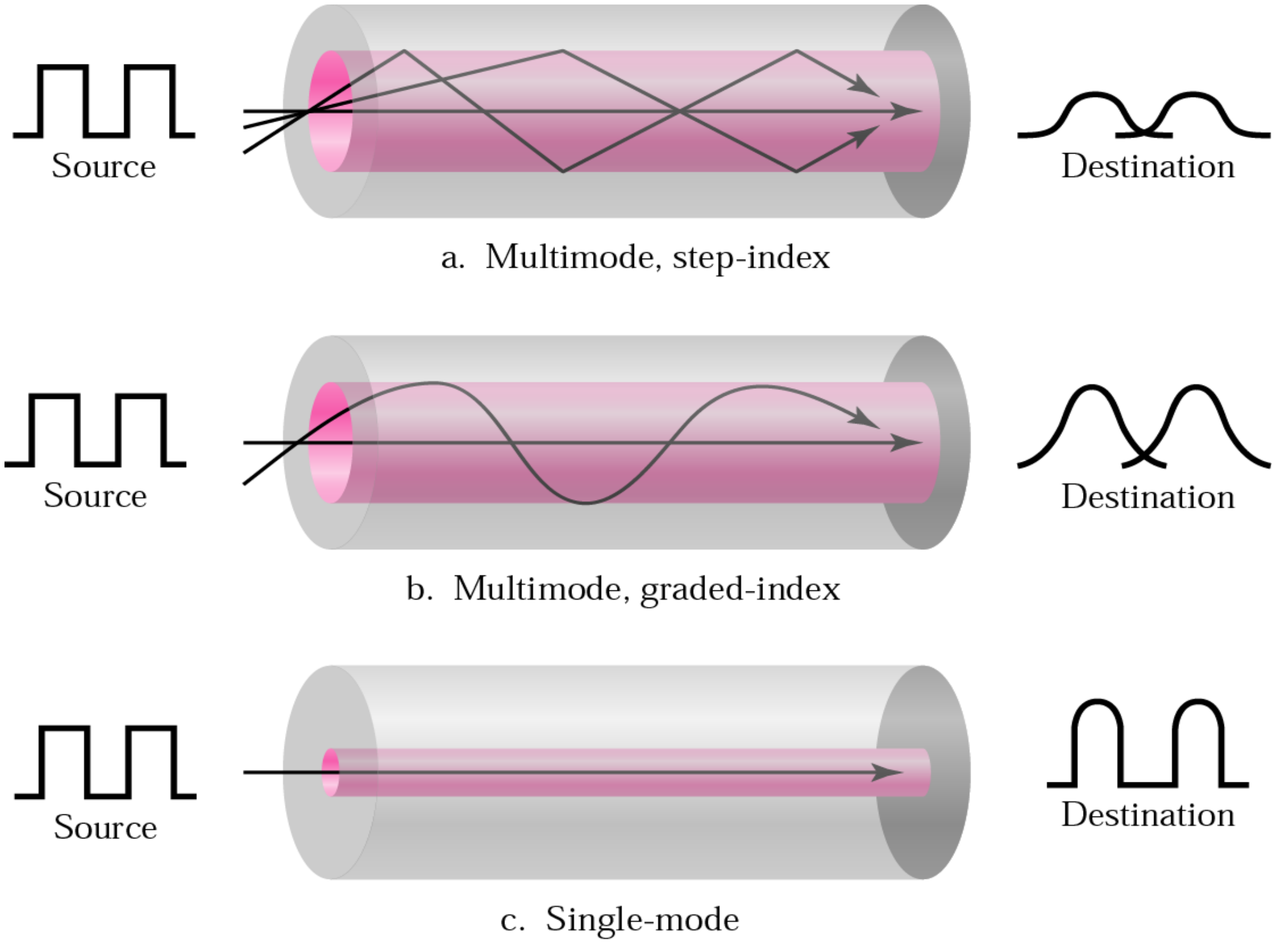
(b) Cable with 3 cores

Optical fiber transmission mode





Optical fiber



Optical fiber

- Multimode stepped index :
  - Several beam travel in slightly different direction
  - Beams arrive in different delay
  - Pulse can easily distort
- Multimode graded index:
  - Index reduce gradually from the center to cladding.
  - Beams closed to center travel slower than cladding. Beams travel in curve form.
  - Reduce pulse distortion.

Optical fiber

- Single mode:
  - Index change less from center to cladding in comparison with multimode.
  - Beams travel along the center axe.
  - Pulses experience less distortion.

Application of optical fiber

- Used for long distance transmission
- Used for communication in metropolitan networks
- Used for connecting routers of ISP
- Used in backbone part of a LAN

- Advantage in comparison with other cables
  - Large data rate
  - Small and light cable
  - Low attenuation
  - Better isolation from electromagnetic environment
  - Large distance between repeaters
    - Multimode →10km
    - Singlemode →40 km

Wireless media

- Terrestrial microwave
  - Used for metropolitan connection, for cellular network
- Microwave satellite
  - Used in TV, Long distance telephone communication
- Radio broadcast
- Infrared
  - Small scope, low data rate, unable to travel through the wall

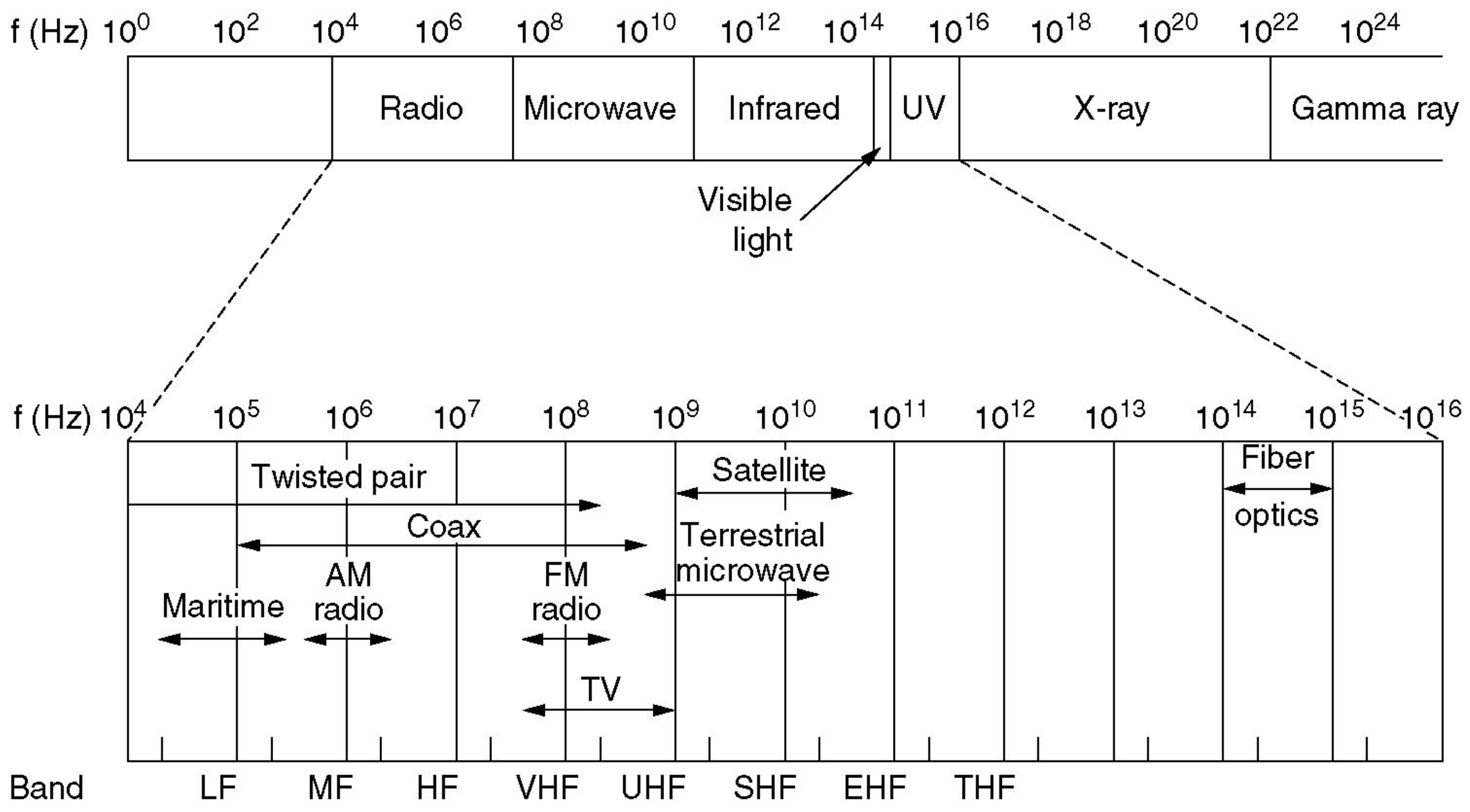
Wireless media

- Radio wave:
  - Wavelengths: 1mm – 100.000km
  - Frequencies: 3 Hz – 300 GHz
  - Ex: Bluetooth, WIFI
- Microwave:
  - Wavelengths: 1mm-1 m
  - Frequencies: 300 MHz-300 GHz
  - Terrestrial microwave : metro connection, cellular communication
  - Satelite microwave: TV, long distance telephone

Wireless media

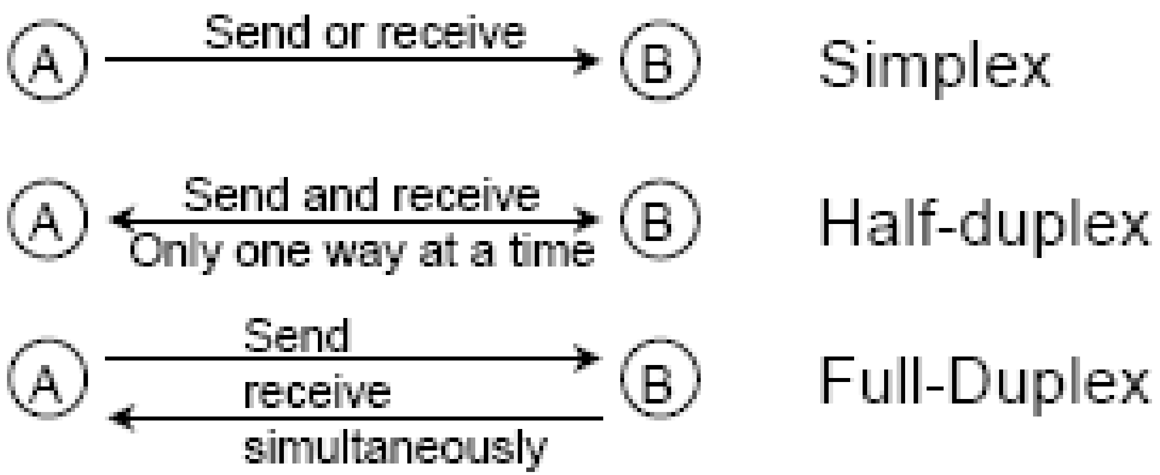
- Infra red:
  - Wavelengths: 700 nm- 1 mm
  - frequency: 300 GHz-430 THz
  - Small scope, no wall penetration
  - Ex: use in remote controls
- Free Space Optics
  - Wavelengths: 850nm, 1300nm, 1550 nm

Frequency range of transmission channels



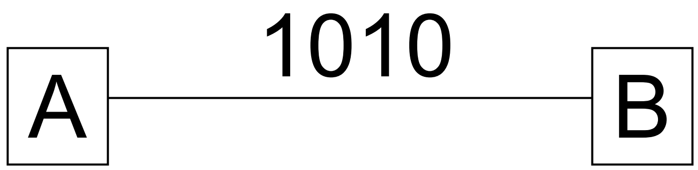
Transmission methods

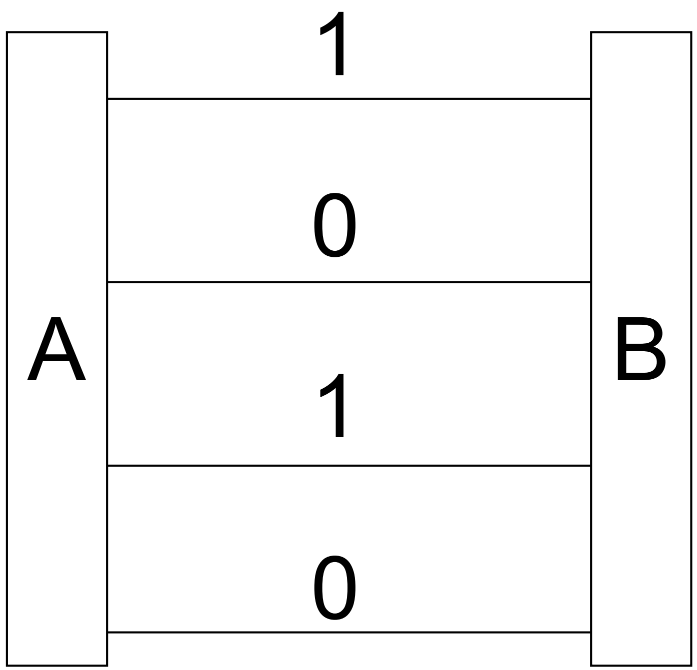
- Simplex: Data is trasmitted in one direction
- Full Duplex: Data can be transmitted in both directions at the same time
- Half duplex: Data can be transmitted in both directions but one direction at a time.



Transmission format

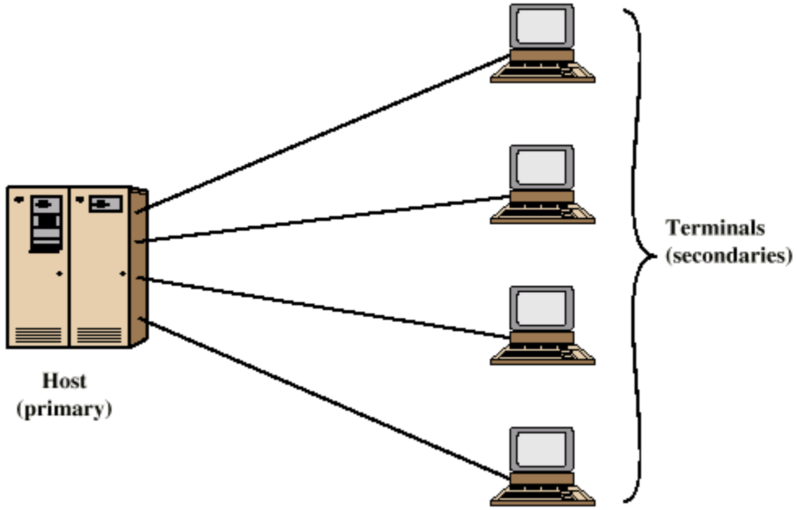
- Sequent transmission: Transmit 1 bit at a moment (over a signal line)
- Parallel transmission: Transmit multiple bits at the same time (over multiple signal lines)



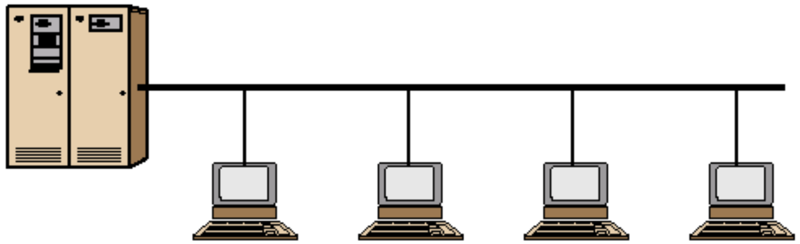


Topology

- Point-to-point
  - Star
  - Ring
  - Mesh
- Point-to-multipoint
  - Bus
  - Ring
  - Star

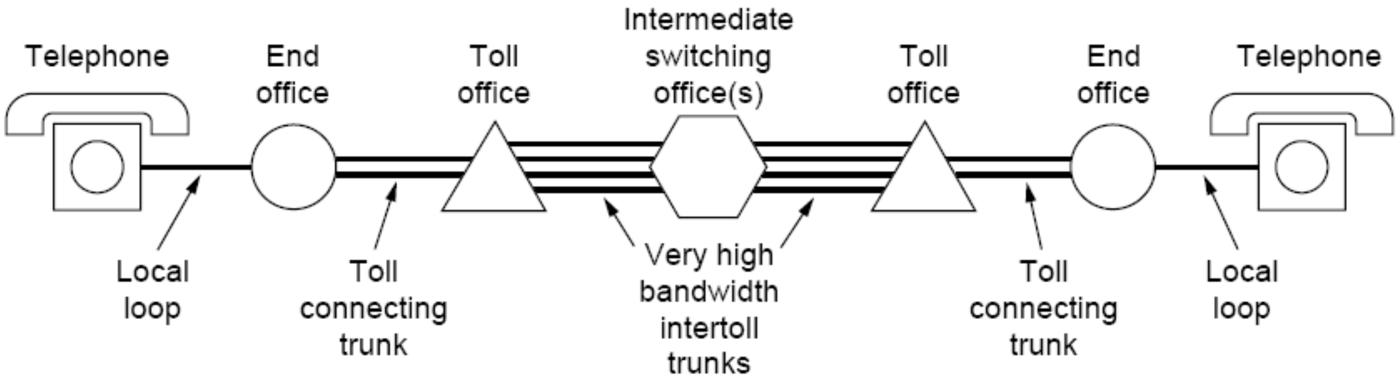


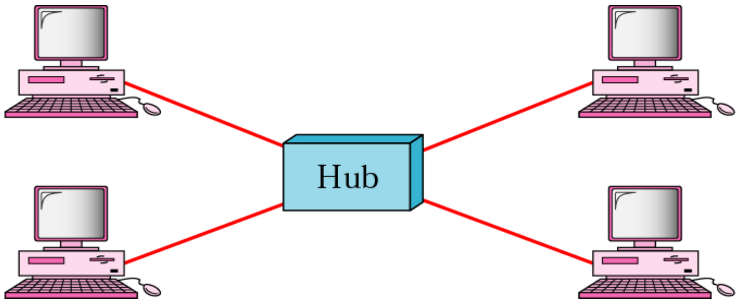
(a) Point-to-point

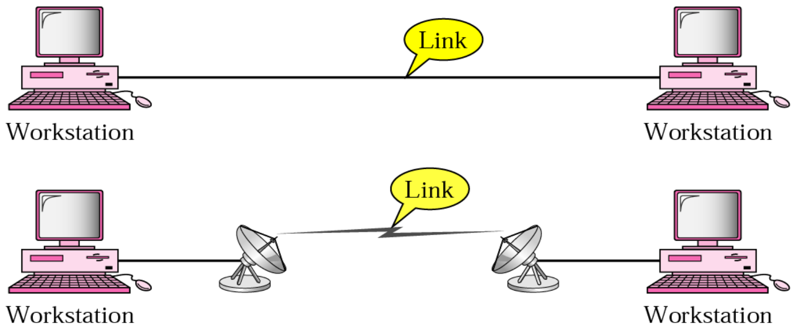


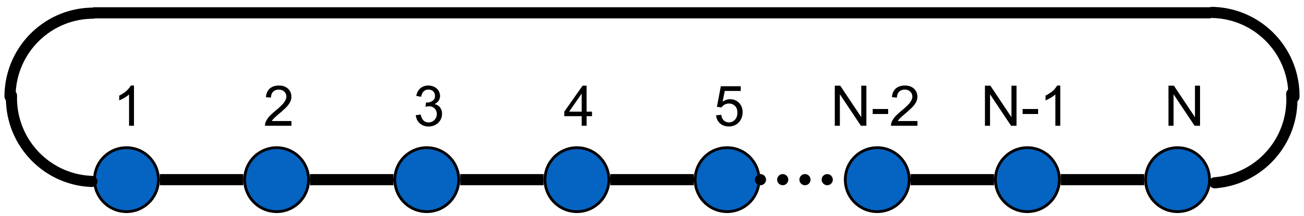
(b) Multipoint

Point -to-Point







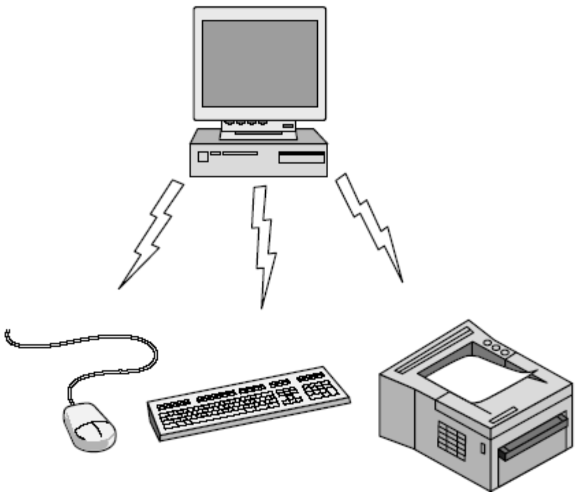


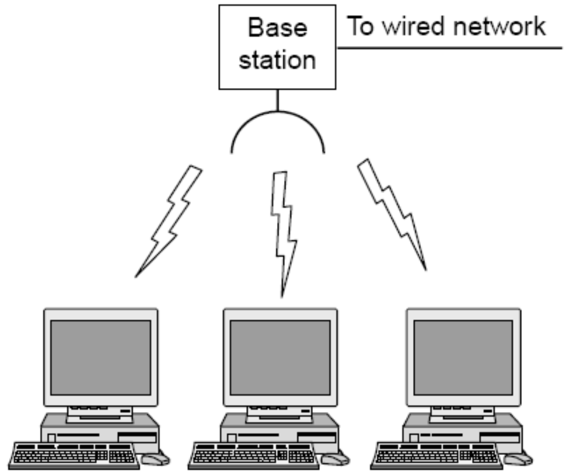
Point-to-point

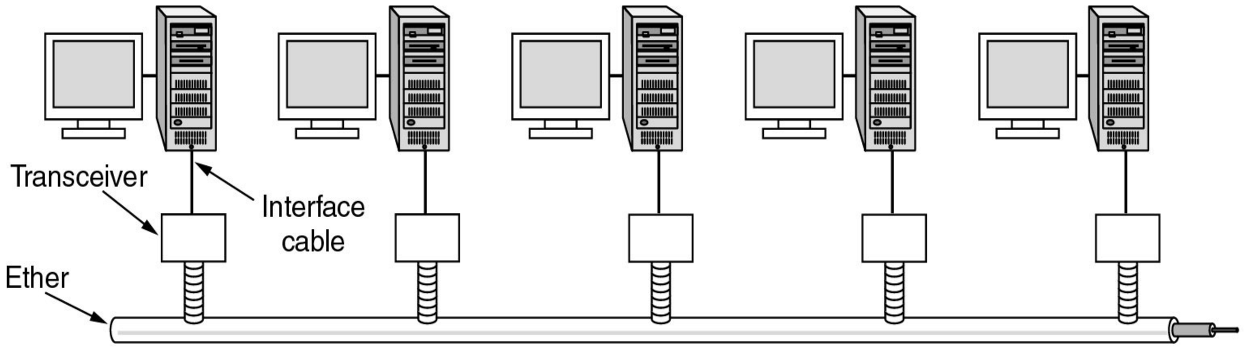
In point-to-point topology, a transmission line connects two devices.

- Link between two devices:
  - 1 line (half duplex) or
  - 2 lines (duplex)
- *In case of half duplex transmission, there may be collision if two devices on the same link send data at the same time*

Point-to-multipoint





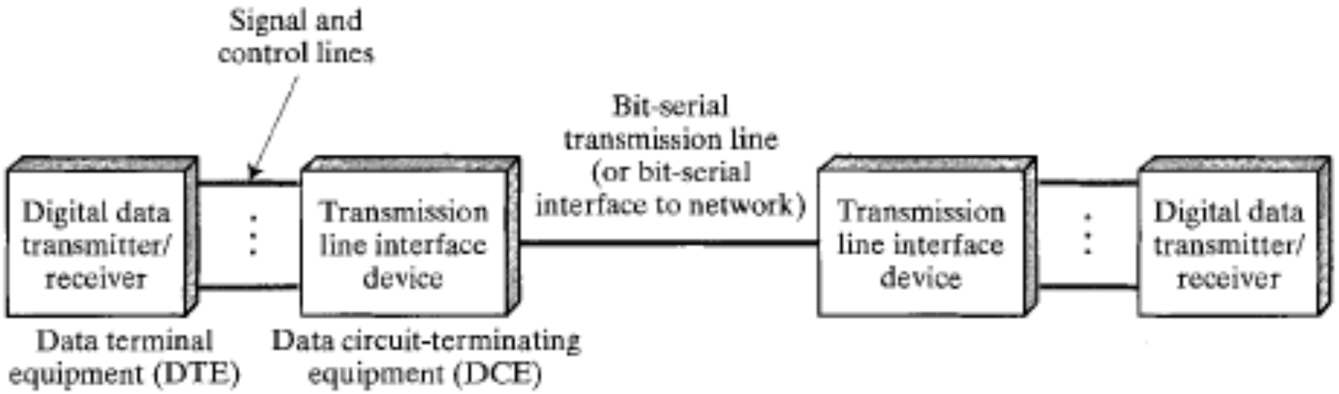


Point-to-multipoint

- Common character of point-to-multipoint topo is to use a unique medium to connects multiple nodes.
- Data is broadcasting over the medium
- Collision when two nodes transmit signal in the same time
- Need a control mechanism to allow a single node to transmit →*multiple access method* → see in Datalink layer.

Medium interface

- Data terminal equipment (DTE)
  - Have data to transmit but has no feature for transmission
  - Need an additional device for accessing the media
- Data circuit terminating equipment (DCE)
  - transmit bits on the media
  - transmit data and control information to another DCE
- Need a clear interface standard between DTE - DCE



(a) Generic interface to transmission medium

(b) Typical configuration

Medium interface

The medium interface is defined according to different aspects:

- Mechanism
  - Define the form of the interface, number of pins for assuring the interfaces match together
- Electrics
  - Define the level of voltage to be used
  - Define the length of pulse (frequency)
  - Define enconding method
- Functionalities
  - Functionality of each pins
  - There are 4 groups of pins: data, control, synchronization, ground
- Procedure
  - Lists of events to perform for transmitting data

Example: EIA-232-E/RS-232

- Define for serial communication
- Mechanism: ISO 2110
- Electrics: V. 28
- Functionality: V. 24
- Procedure: V. 24

Example: V.24 /EIA-232-E

- Mechanic:
  - 25 or 15 pins
  - Transmission distance 15m
- Electrics
  - Digital data
  - 1=-3v, 0=+3v (NRZ-L)
  - Data rate 20kbps
  - Transmission distance< 15m

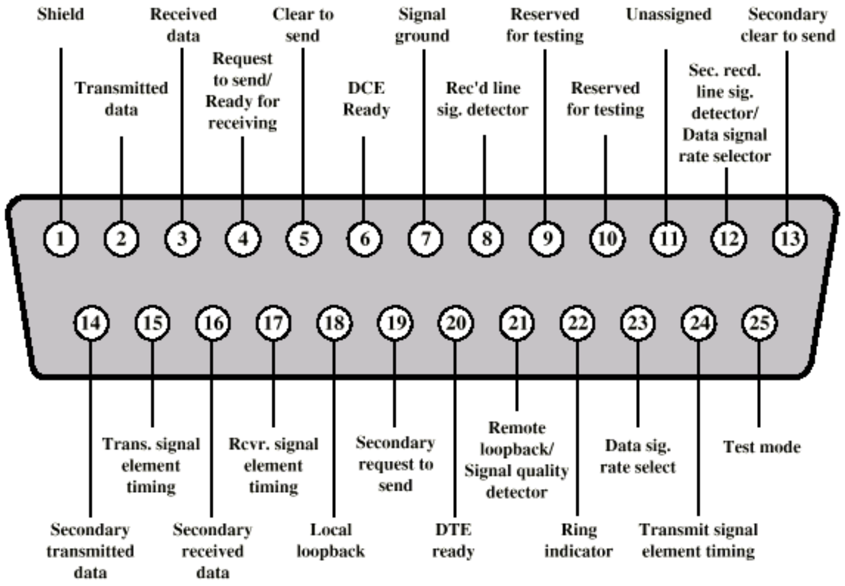


Figure 6.5 Pin Assignments for V.24/EIA-232 (DTE Connector Face)

Encoding Technics: Data to Signals representations

Introduction

Digital data - digital signal

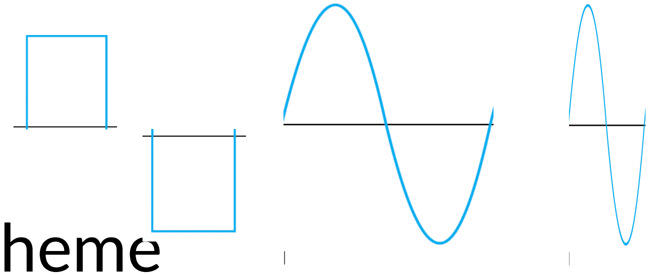
Digital data - analogical signal

Analogical data - digital signal

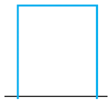
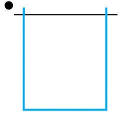
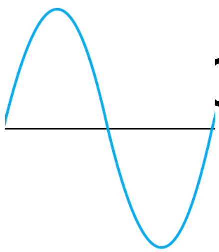
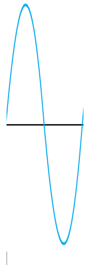
Analogical data - analogical signal

Reading: Chapter 5, Data and Computer Communications, William Stallings

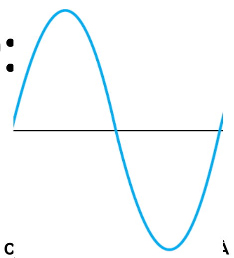
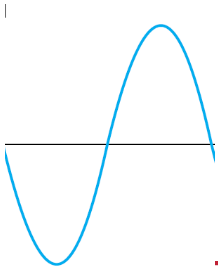
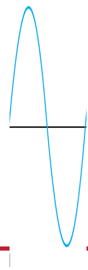
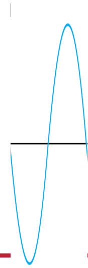
Basic ideas

- Representing data by symbols
- A symbol is an elementary signal: 

- Set of mapping is the Encoding scheme

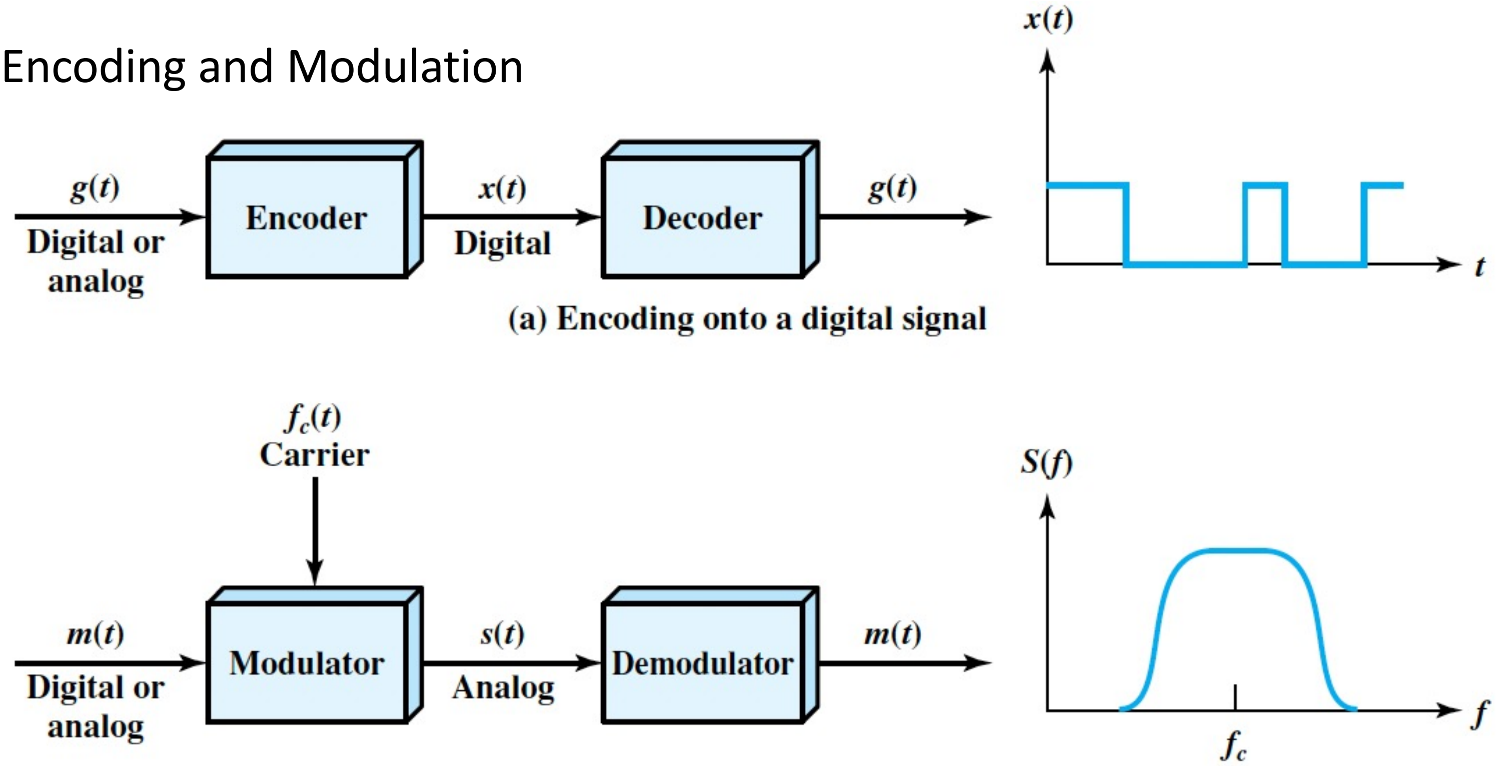
  Ex: 1  , 0:  or 1:  0: 

- Encoding could be performed by bit or by a group of bits e.g., 2 or 4 or 8 bits.

Ex: 00:  01:  10:  11: 

Basic ideas

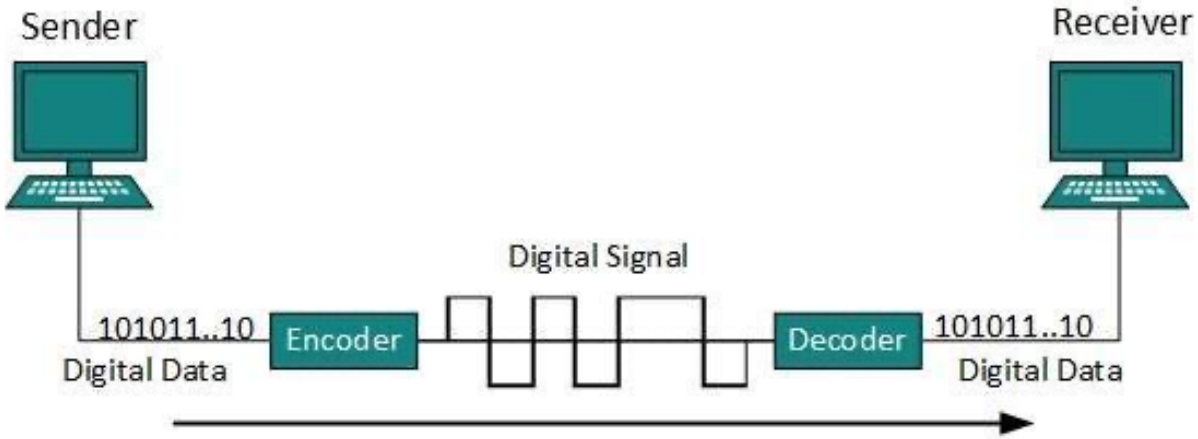
Encoding and Modulation



(a) Encoding onto a digital signal

(b) Modulation onto an analog signal

Line coding: represent digital data by digital signals



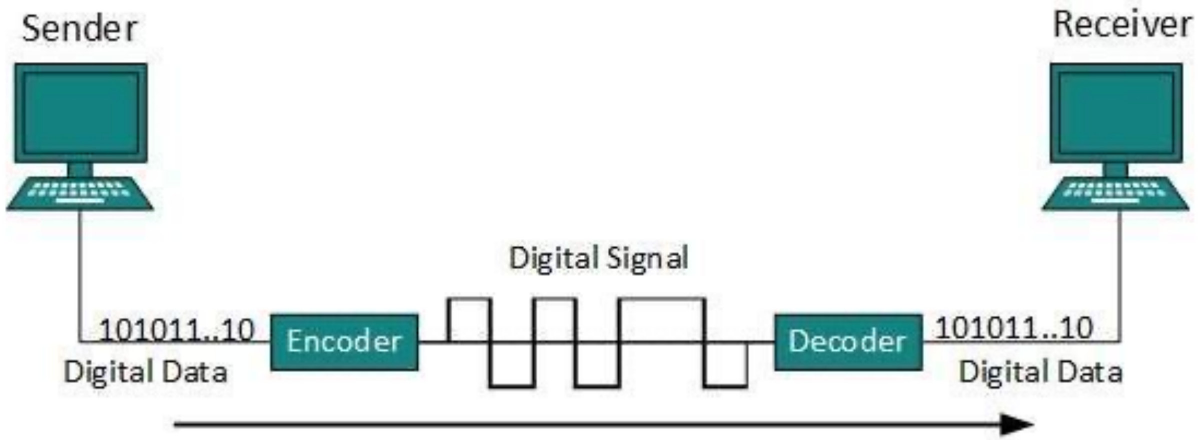
- Use different digital signals at different voltage levels to represent digital data (bits 0 and 1)
  - *"A digital signal is one in which the signal intensity maintains a constant level for some period of time and then abruptly changes to another constant level"*

(Data and Computer Communications, 8th Edition, William Stallings)

- An element signal / A symbol/ A pulse of signal
  - Case of digital signal: the shortest signal maintaining a constant level
- Senders encodes a flow of bits → flow of symbols
- Receiver: picks signals, detects symbols, decodes to bits

Line coding: represent digital data by digital signals

- Receiver should know when a symbol starts or ends: clock synchronization between sender and receiver
- There are many ways to represent 0 and 1 → different encoding methods

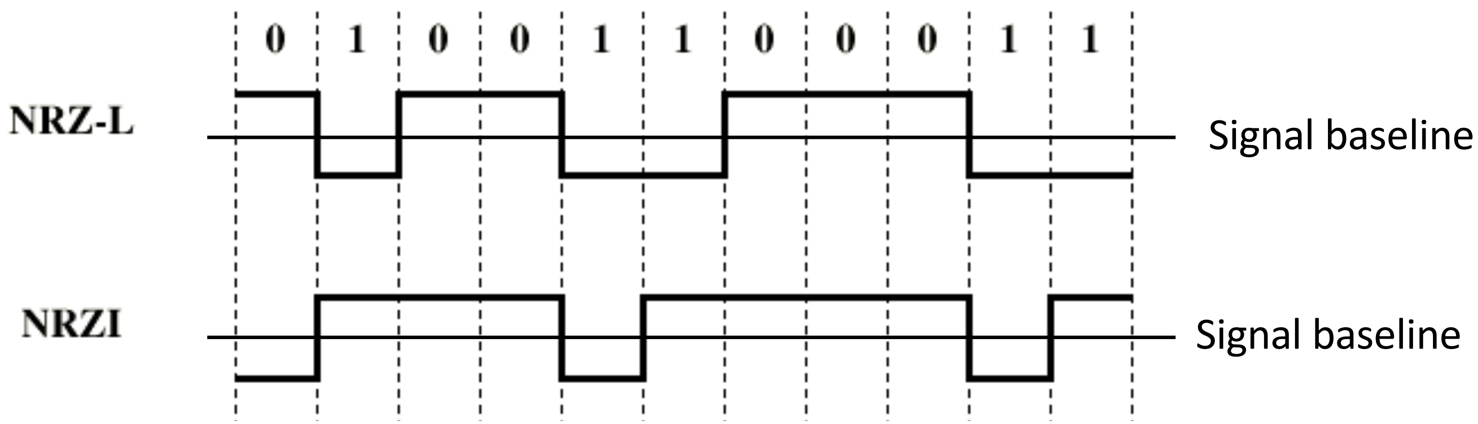


Some line codes

- NRZ
  - NRZ-L,NRZI
- Bipolar
  - Bipolar alternate mark inversion
  - Pseudoternary
- Biphase encoding
  - Manchester
  - Differential Manchester

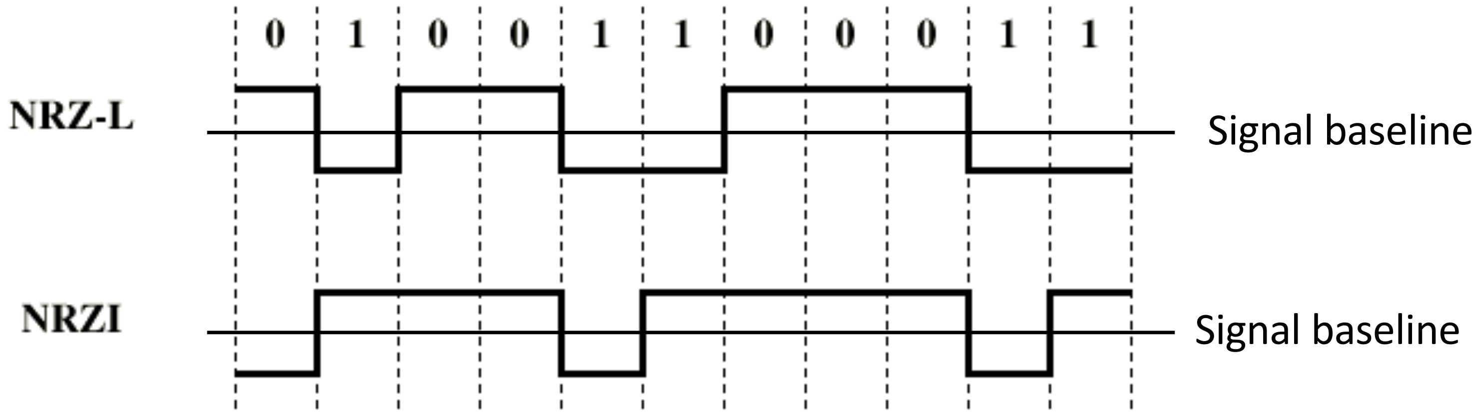
NRZ-L Non Return to Zero Level

- During bit time, signal does not go back to 0 level
- Signal level is not changed during bit time.
- NRZ-L Non return to zero level
  - Bit 1 signal is in low/high level
  - Bit 0 signal is in high/low level
- 1 bit → 1 symbol



NRZ-I Non return to zero invert

- Bit 0: signal level is not changed at the begining of bit time
- Bit 1: signal level is changed at the begining of bit time
- A differential encoding method :
  - 0 and 1 are represented by the signal level change, not by the level itself.
  - Reliable/ simple.



Line code consideration

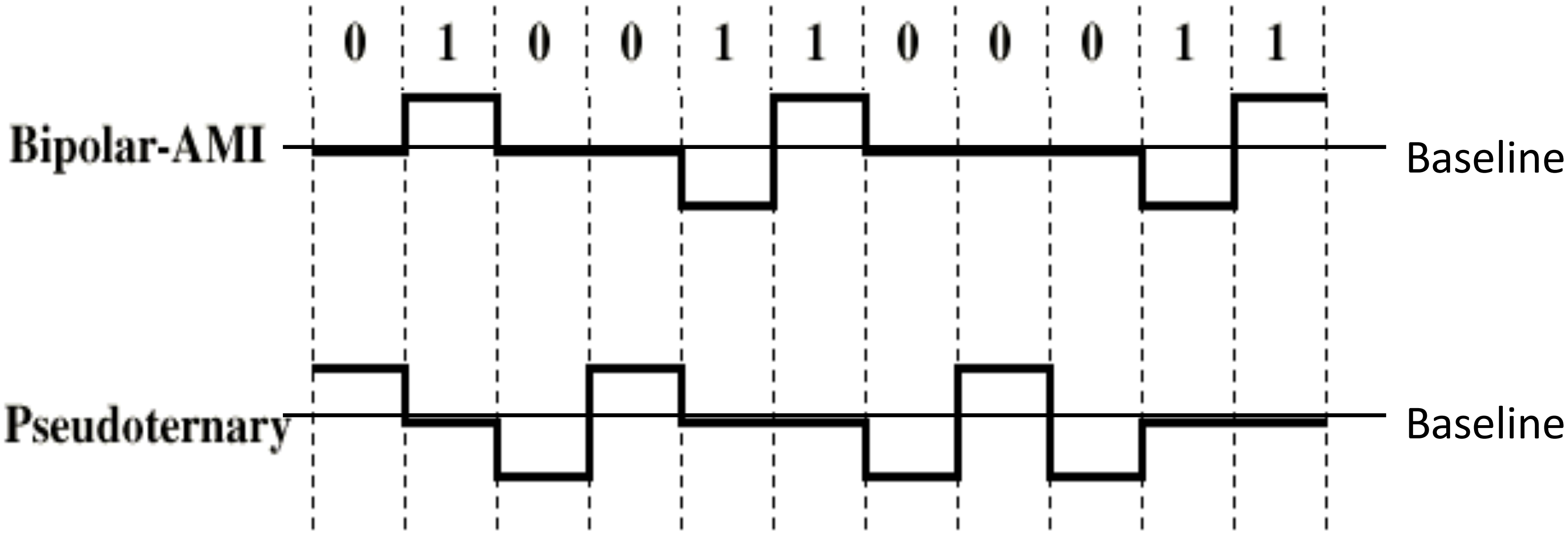
- 3 aspects should be considered in any encoding method:
  - **Data speed:** number of bits could be sent per second given symbol rate
  - **Clock recovery on receiver side**: If the clock recovery is correctly at receiver side, the received signal can be incorrectly seperated into symbols ➔ cause error in the received data.
  - **DC-component**: Directed Current vontage component.
    - DC-component makes recepter mistakenly detect level of signal (by wrongly detect signal baseline)
    - Encoding should avoid DC-component by maintaining signal mean amplitude around 0.

NRZ

- NRZ advantages
  - Simple, utilise the maximum capacity of the line
- NRZ weaknesses
  - NRZ does not contain factors supporting clock synchronization
    - Example: when sending a flow of 20 bits 1s, the signal maintains one level and can be detected wrongly at receivers as 19 bits 1s.
  - Contain DC-component when sending a chain of 1s.
- Application
  - Encoding data on magnetic storage
  - Not popular in data transmission

Bipolar AMI

- Use more than 2 signal levels for 1 bit
- Bipolar alternate mark inversion
  - 0 : No signal
  - 1: Presence of signal. Two consequent 1s have two different signal levels
- pseudoternary
  - 1 : No signal
  - 0 : Presence of signal. Two consequent 0 have two different signal levels



Bipolar AMI

- No DC component
  - Mean of signal lever is always 0
- Good synchronization when sending many bit 1s
- Lost of synchronization when sending many bit 0s
- 3 possible signal levels for 1 bit:
  - Not optimal in transmission line usage.
  - Receiver needs to distinguish 3 levels of signal

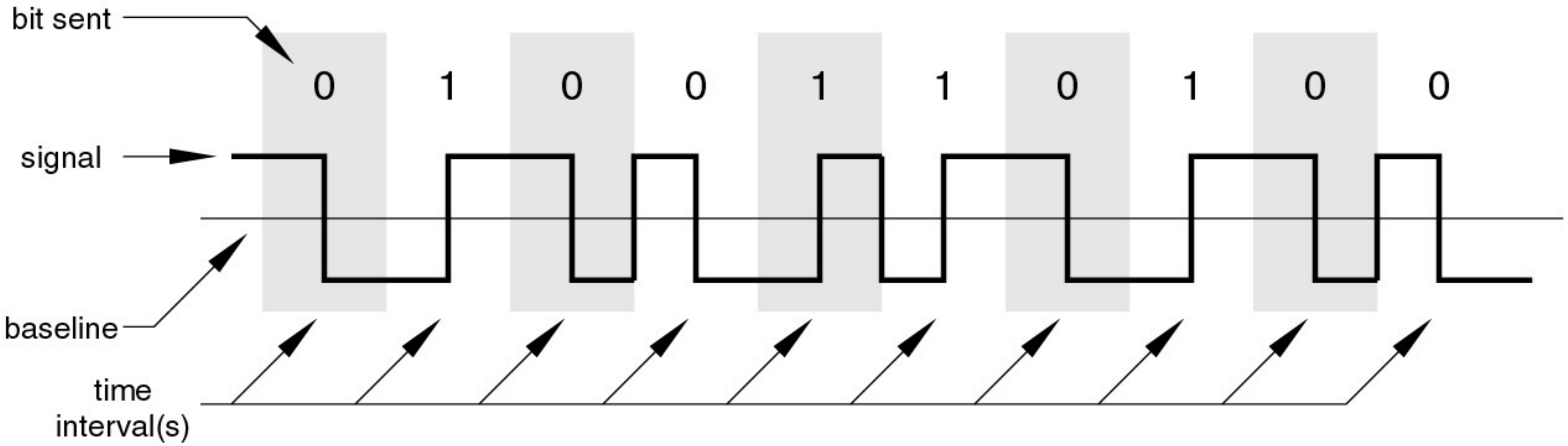
Biphase: Manchester

- Manchester: Always change signal level in the middle of bit time
  - Bit 1: Signal change from low level to high level. 
  - Bit 0: Signal change from high level to low level 

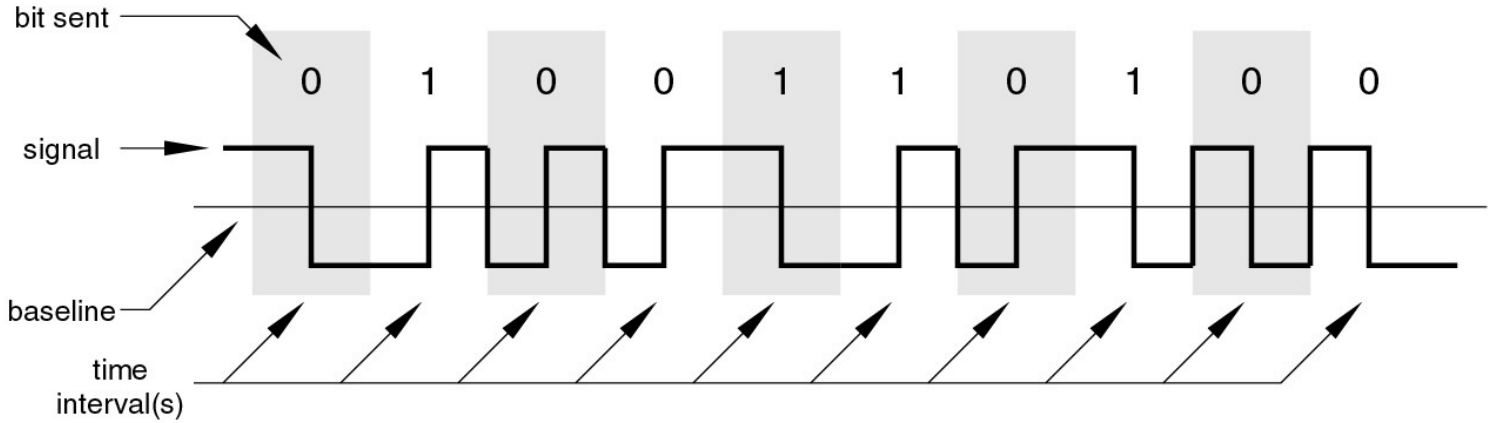
  - Level change provides a synchonisation mechanism.
- Differential Manchester:
  - 0: signal level change at the begining of bit
  - 1: **no** signal level change at the begining of bit
  - Always change signal level in the middle of bit time for synchronization purpose

Manchester encoding

Manchester Encoding



Differential Manchester Encoding

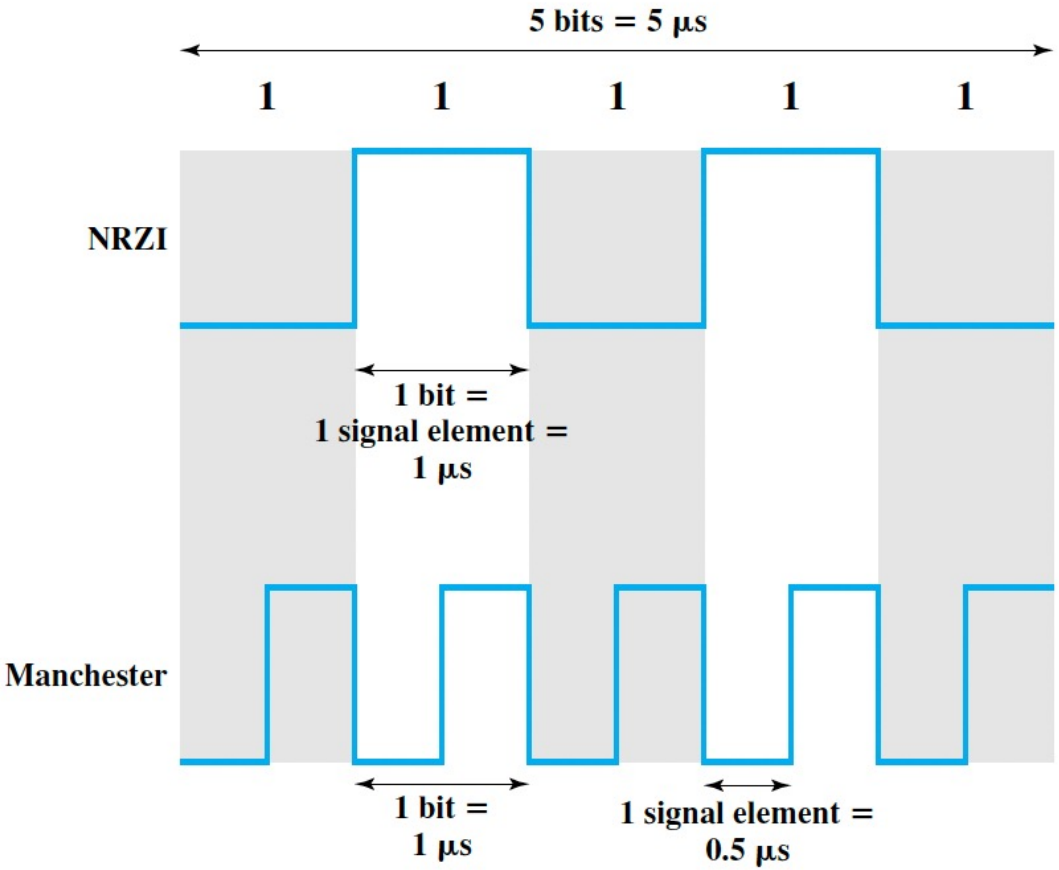


Units in transmitting digital data in digital transmission

Term	*Units*	*Definition*
Data unit	bit	A single bit, Value 0 or 1
Data rate	bit/s	Rate transmitting bit
Signal element /Symbol	Pulse voltage of constant amplitude	Part of a signal that occupies the shortest interval of a signal code
Symbol rate/pulse rate	Number of symbol/s (baud)	Number of symbols generated in a unit of time

Symbol rate

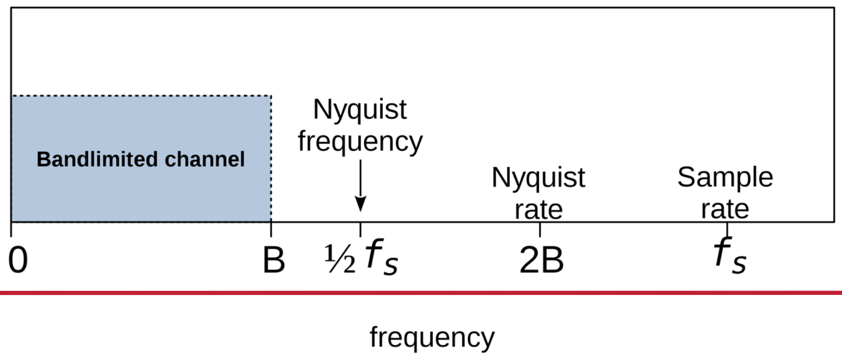
- Number of symbol changes, waveform changes, or signaling events across the transmission medium per unit of time
- Unit: Baud/s = symbol/s



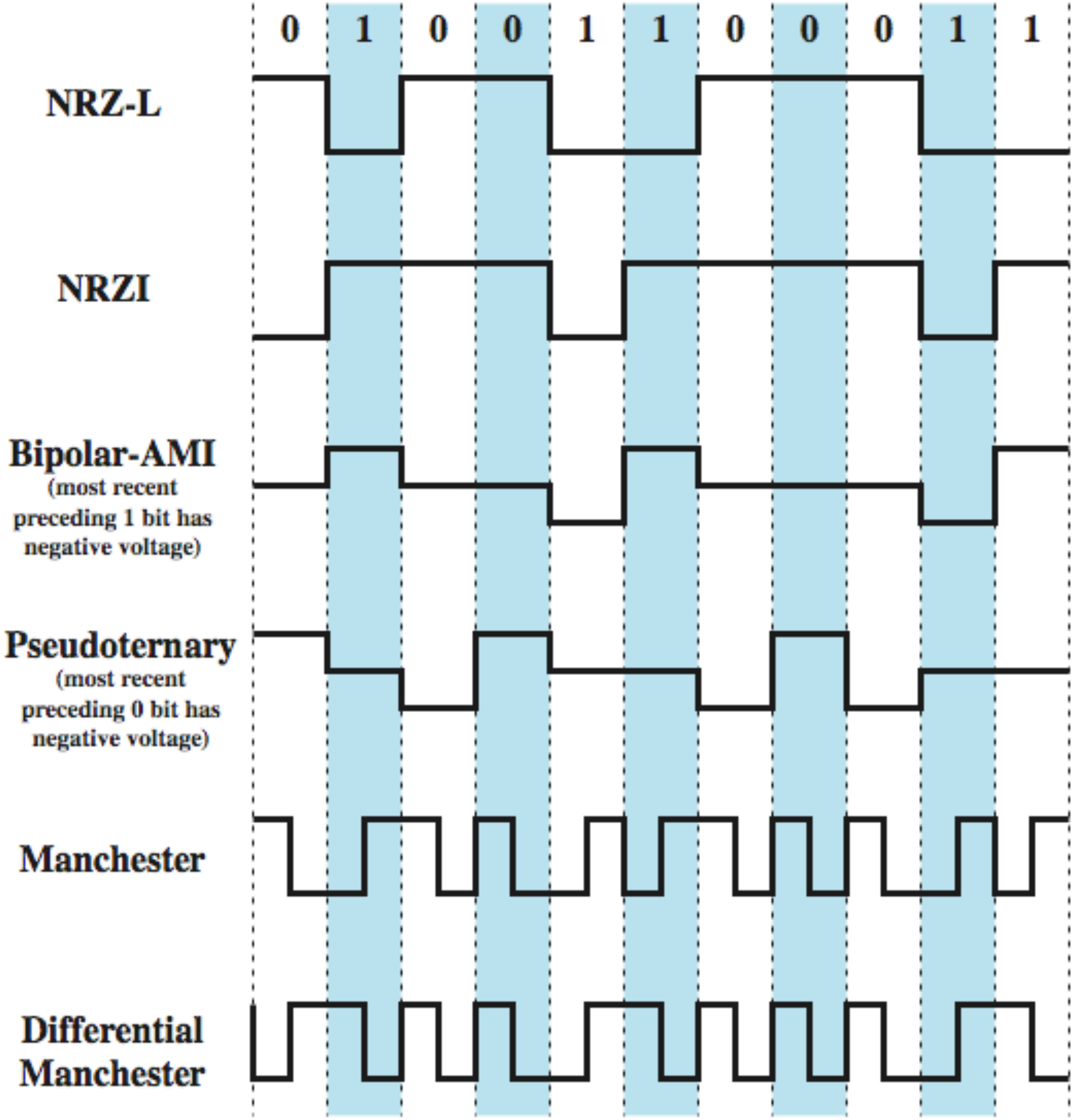
Nyquist rate

- Nyquist rate: 2 times bandwidth of a transmission line
  - Bandwidth: B (Hz)
  - Nyquist rate = 2B (Hz)
- The maximum pulse rate for a baseband channel is the Nyquist rate, and is double the bandwidth
  - Bandwidth B (Hz)→ max pulse rate is 2B pulse/s
- Data rate (bps) = pulse rate * number of bits represented by a symbol/pulse.
  - Data rate using NRZ-L?
  - Data rate using Manchester encoding?
- Baseband transmission: signal is directly sent using its original frequency
- Passband transmission: signal is shifted to frequency around carrier frequency.

Relationship of Nyquist frequency & rate (example)



Line codes


0 1 0 0 1 1 0 0 0 1 1
NRZ-L
NRZI
Bipolar-AMI
(most recent preceding 1 bit has negative voltage)
Pseudoternary
(most recent preceding 0 bit has negative voltage)
Manchester
Differential Manchester

Exercise-01

1. Draw the signal generated when we encode following data using different encodings:
    - 11000000 11001101
    - NRZ-L
    - Bipolar AMI
    - Manchester

2. We know that the following signal is generated from some data using standard Manchester encoding, assume that you act as receiver, please
    - Identify the starting and ending points of signal corresponding to bits
    - Identify the original data sent

Exercise-02

- We know that the following signal is generated from some data using standard Manchester encoding, assume that you act as receiver, please
  - Identify the starting and ending points of signal corresponding to bits
  - Identify the original data sent

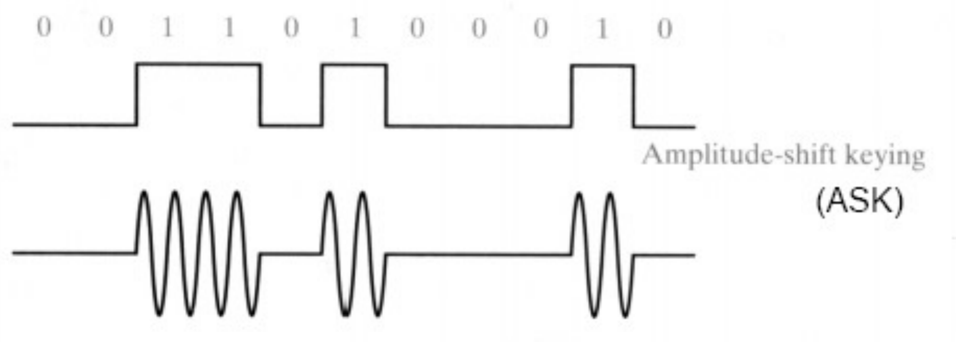
Modulation of digital data to analog signal

- Example: data transmission over telephone line
  - Telephone line accept signal with frequencies between 300Hz - 3400Hz
  - Digital data from the source must be modulated to analog signal to transmit over telephone line.
- 3 modulation techniques:
  - Amplitude-Shift Key
  - Frequency-Shift Key
  - Phase-Shift Key

Amplitude-Shift Key (ASK)

- Varying the amplitude of the carrier wave to represent digital data
  - Carrier original wave function:
    $A\cos(2\pi f t)$
  - 0 and 1 are represented by signals of two different amplitudes. Ex:
  - Amplitude A for 1
  - Amplitude 0 for 0
- Usually used in optical fiber

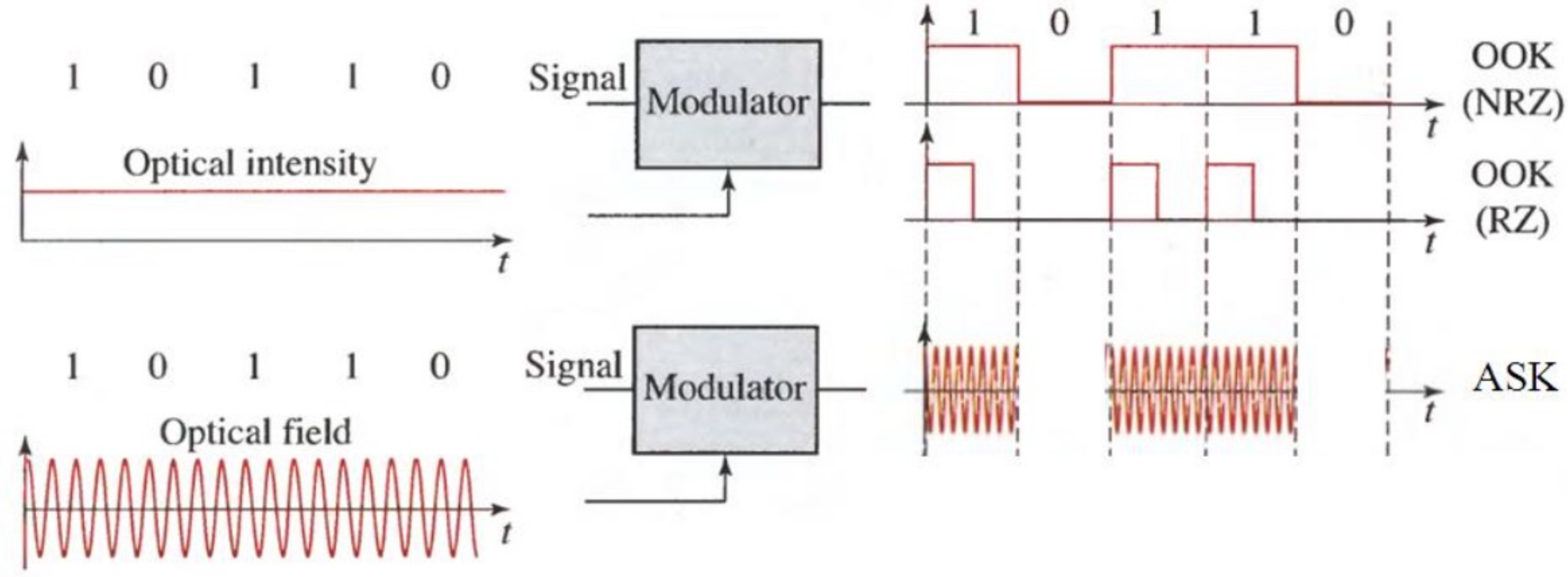
$$s(t) = \begin{cases} A\cos(2\pi f t) & for\ 1 \\ 0 & for\ 0 \end{cases}$$



On-Off Keying (OOK)

- Used in optical fiber
- A kind of ASK.
  - 1: having light during the bit time (turn on the light source).
  - 0: no light during the bit time (turn off light source).
- OOK may be realized in two forms:
  - NRZ: light is on during all bit time of bit 1.
  - RZ (return-to-zero): light is on only in a part of 1.

On-Off Keying (OOK)

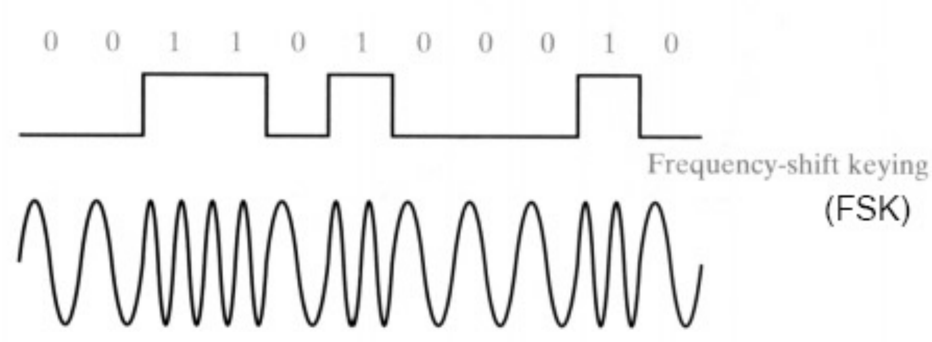


On off key observed from optical intensity (upper figure)
And optical field (lower figure)

Frequency-shift key (FSK)

- Varying the frequency of the carrier wave to represent digital data
- Two symbols to represent bit 0 and 1 are two carrier signals of different frequencies.
- Lower error rate
- Used for transmiting data over telephone line (low frequency) or wireless network (high frequency)

$$s(t) = \begin{cases} A\cos(2\pi f_1 t) \\ A\cos(2\pi f_2 t) \end{cases}$$



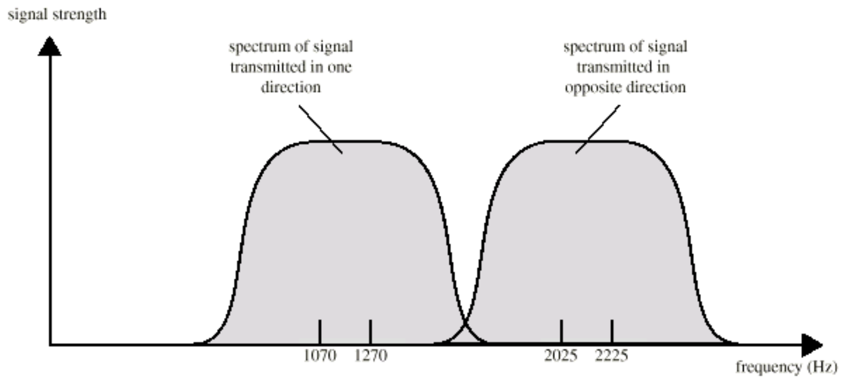
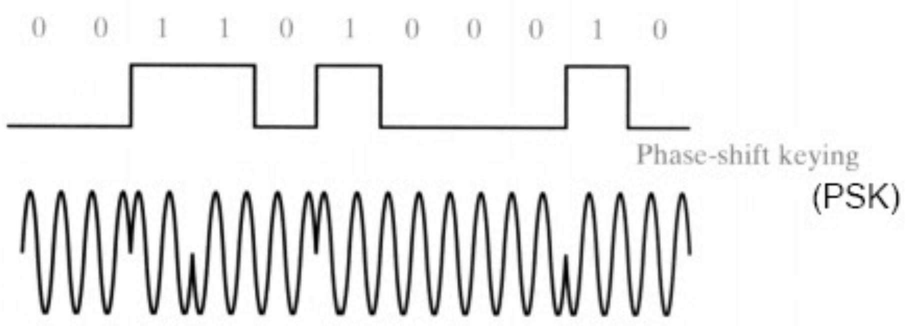


Figure 5.8 Full-Duplex FSK Transmission on a Voice-Grade Line

Phase-shift key (PSK)

- Carrier signal at different phases to represent bit 0 and 1
- A symbol is a signal with one phase

$$s(t) = \begin{cases} A\cos(2\pi f_c t + \pi) & \text{binary 1} \\ A\cos(2\pi f_c t) & \text{binary 0} \end{cases}$$



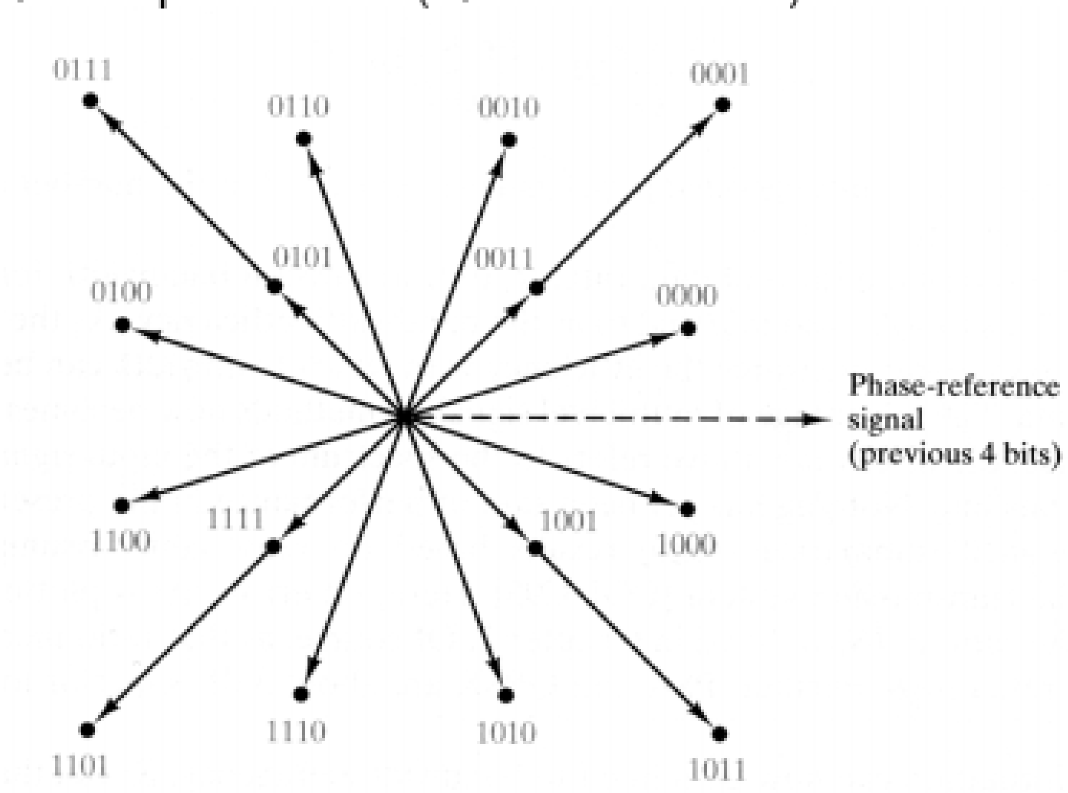
- By using more than 2 phases, more than two symbols can be generated.
  - A symbol may be used to represent more than one bits.
- May be combined with other modulation methods.

$$s(t) = \begin{cases} A\cos(2\pi f_c t + 45°) & 11 \\ A\cos(2\pi f_c t + 135°) & 10 \\ A\cos(2\pi f_c t + 225°) & 00 \\ A\cos(2\pi f_c t + 315°) & 01 \end{cases}$$

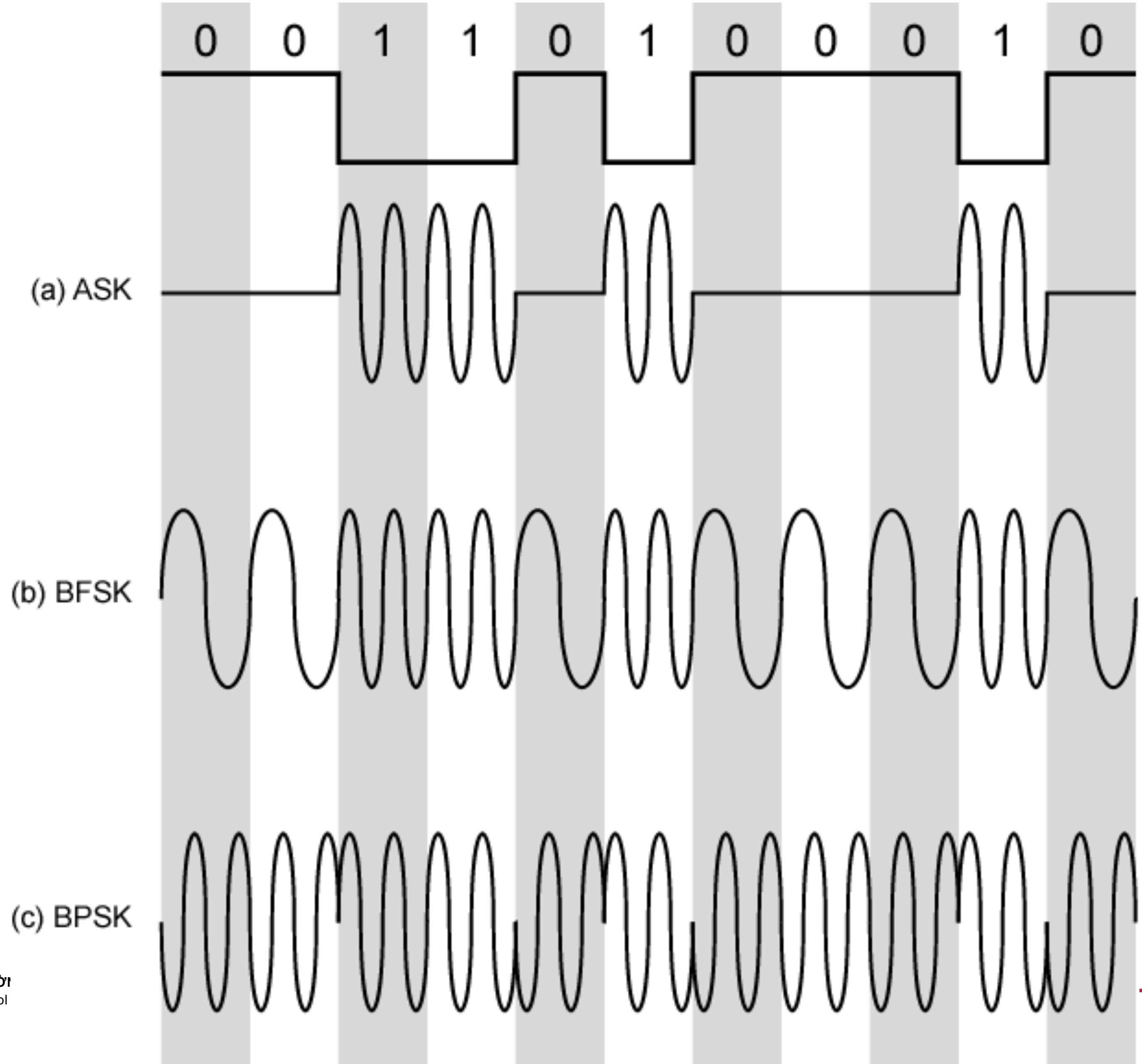
PSK is used in combination with ASK

Constellation diagram

– 9,600 bps modem (2,400 baud x 4)



Digital to analog modulation recaptulation

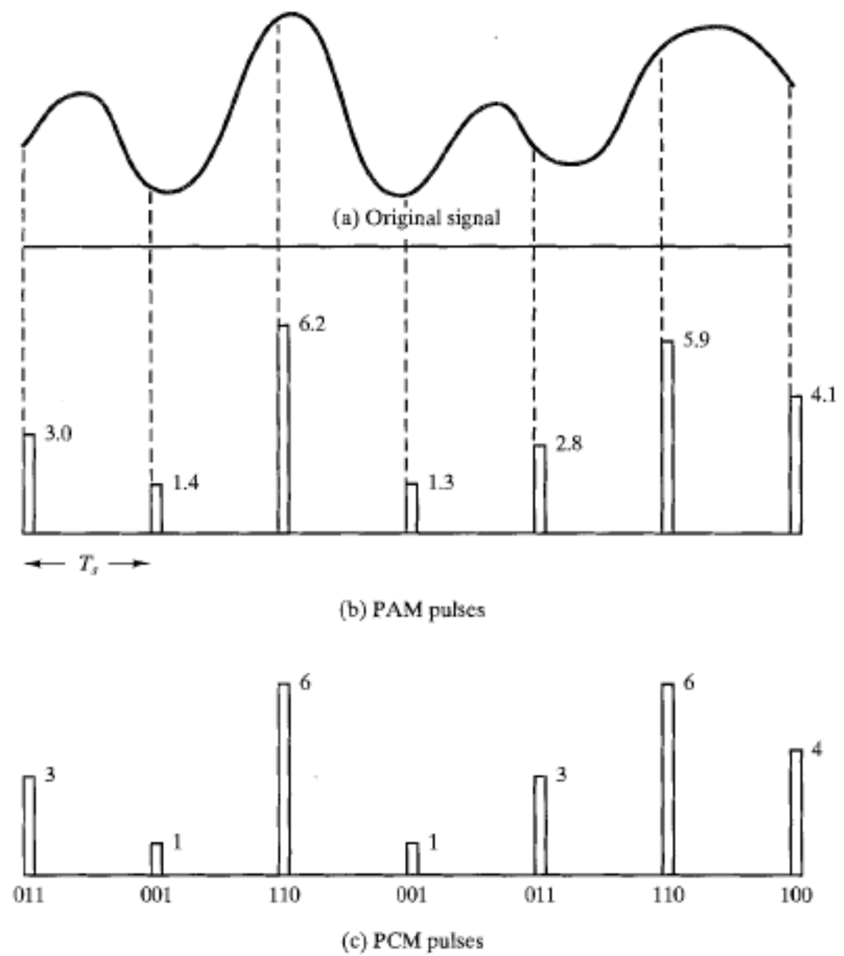


Analog signal to digital data

- Used to digitalize real life analog signal, for example voice signal.
- Converting the analog signal to digital data then
  - Encode digital data to digital signal for transmission.
    - Using line codes: NRZ-L, Manchester etc…
- Two methods for converting analog signal to digital data
  - Pulse Code Modulation
  - Delta Modulation

Pulse Code Modulation (PCM)

- Pulse Code Modulation
- Sample signal according to Nyquist–Shannon sampling theorem
  - If sample a signal with frequency >= 2 *max frequency, the original signal can be recovered fidely from the samples.
  - Ex: human voice has greatest frequency of 4300Hz, it should be sampled with at least 8600 sample/s.
- Sample are then quantized
  - Approximate the amplitude of the sample by some digital values
    - 4 bit quantization ➔ 16 diffrent possible sample amplitudes.
    - More bits, more precise.

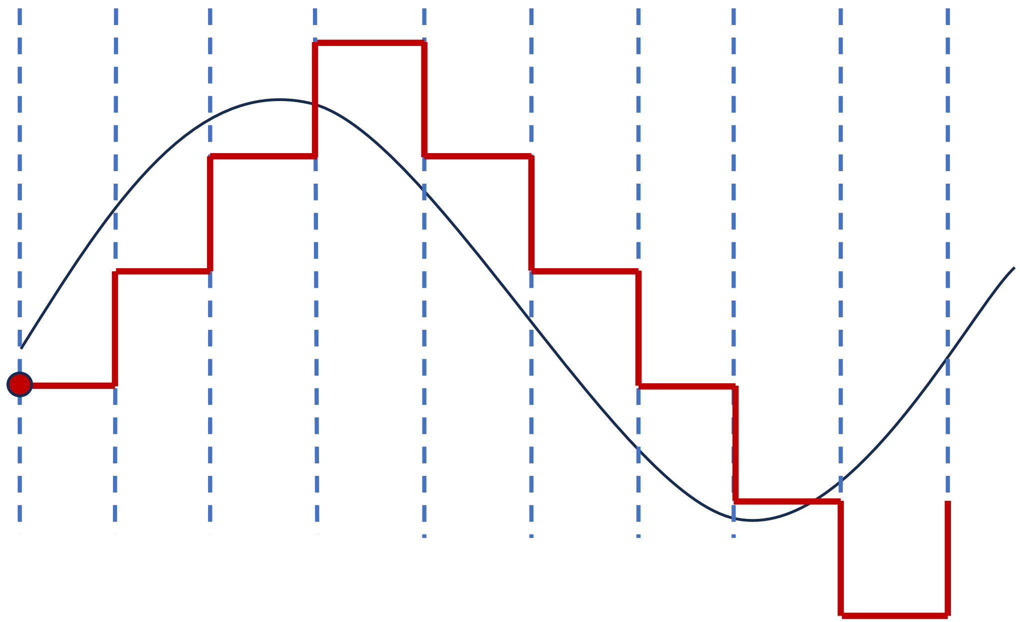


Delta Modulation

- Weakness of PCM: generate a lot of data→
- Delta modulation: Use a single bit for each sample
- Idea: Instead sending the real value of the sample $x(t)$, send the variation in sample value in comparison with the last sample: approximative value $\hat{x}(t)$.
  - If $\mathrm{x(t)} > \hat{x}(t)$: send bit 1
  - If $\mathrm{x(t)} < \hat{x}(t)$: send bit 0

Delta Modulation

- Nếu $x(t) > \hat{x}(t) \rightarrow \hat{x}(t) \coloneqq \hat{x}(t) + \delta$
  - Output = 1
- Nếu $x(t) < \hat{x}(t) \rightarrow \hat{x}(t) \coloneqq \hat{x}(t) - \delta$
  - Output = 0



$x(t) > \hat{x}(t) + \delta$

Output: 1

$x(t) < \hat{x}(t) - \delta$

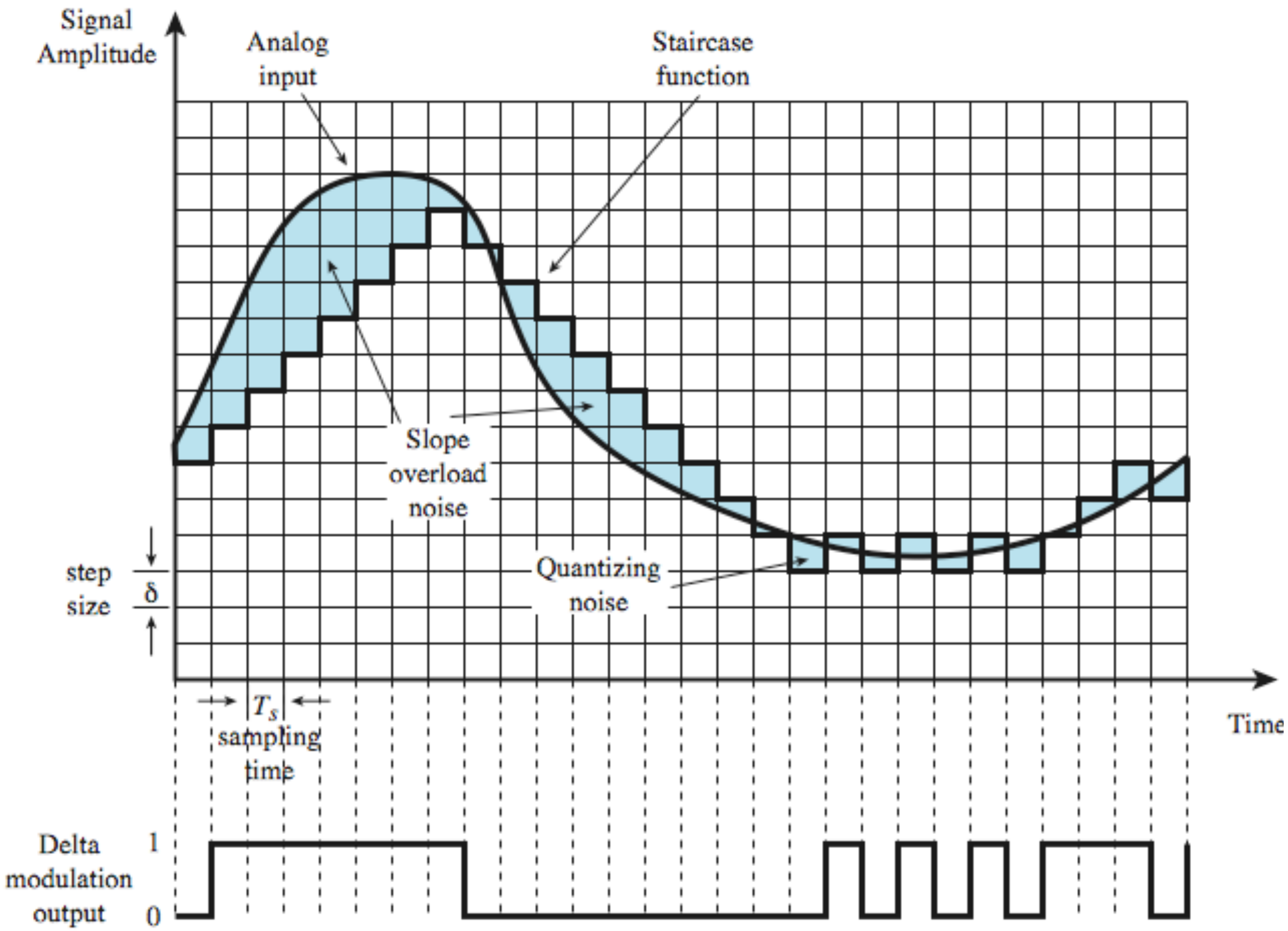
Output: 0

1 1 1 0 0 0 0 0 1 1

Transmitting signal:

Delta Modulation

- Parameters of the modulation
  - Step delta
  - Sampling rate
- Errors:
  - When the signal varies slowly: quantizing noise
  - When the signal varies quickly: overloaded noise



Analog data – analog signal

- Send analog data over a carrier using analog signal
- Integrate signal m(t) to carrier wave with Fc frequency to a signal with frequency around Fc
- Technic is used to shift signal to a frequency appropriate to the frequency of the transmission channel
- 3 methods
  - Amplitude modulation
  - Frequency modulation
  - Phase modulation