Computer Networks

CMP2205

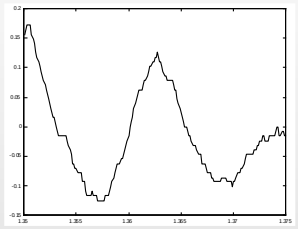
Lecture 3

The Physical (PHY) Layer

- *Transmitting information on wires.*
- *How is information represented?*
  - *Digital systems.*
  - *Analog systems.*

Analog Technology

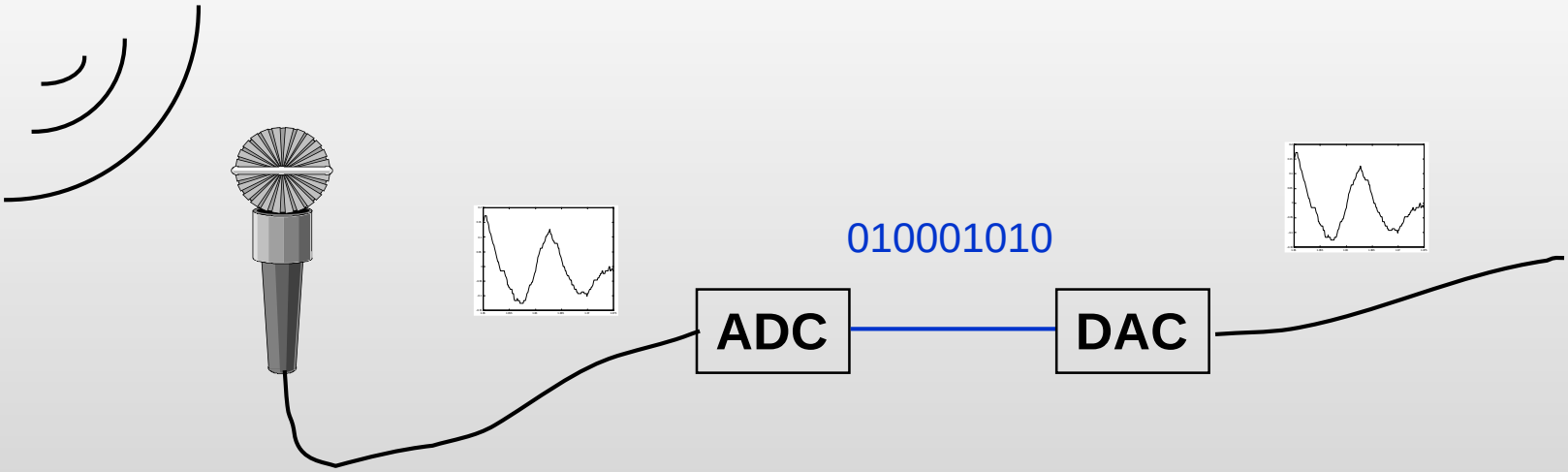
- *Analog devices maintain exact physical analog of information.*
  - *E.g., microphone: the voltage v(t) at the output of the mic is proportional to the sound pressure*



v(t)

Digital Technology

- *It uses **numbers** to record and process information*
  - *Inside a computer, all information is represented by numbers.*
    - *Analog-to-digital conversion: **ADC***
    - *Digital-to-analog conversion: **DAC***



Digital Technology

- *All signals (including multimedia) can be encoded in digital form.*
- *Digital information does not get distorted while being stored, copied or communicated.*

Digital Communication Technology

- *Early example: the **telegraph** (Morse code).*
  - *Uses dots and dashes to transmit letters.*
  - *It is digital even though uses electrical signals.*
- *The telephone has become digital.*
- *CDs and DVDs.*
- *Digital communication networks form the Internet.*
- ***The user is unaware that the signal is encoded in digital form.***

Two Levels are Sufficient

- *Computers encode information using only two levels: 0 and 1.*
- *A **bit** is a digit that can only assume the values 0 and 1 (it is a **bi**nary dig**it**).*
- *A **word** is a set of **bits***
  - *Example: ASCII standard for encoding text*
    - *A = 1000001; B = 1000010; …*
- *A **byte** is a word with **8 bits.***

Definitions

- *1 KB = 1 kilobyte = 1,000 bytes = 8,000 bits*
- *1 MB = 1 megabyte = 1,000 KB*
- *1 GB = 1 gigabyte = 1,000 MB*
- *1 TB = 1 terabyte = 1,000 GB*

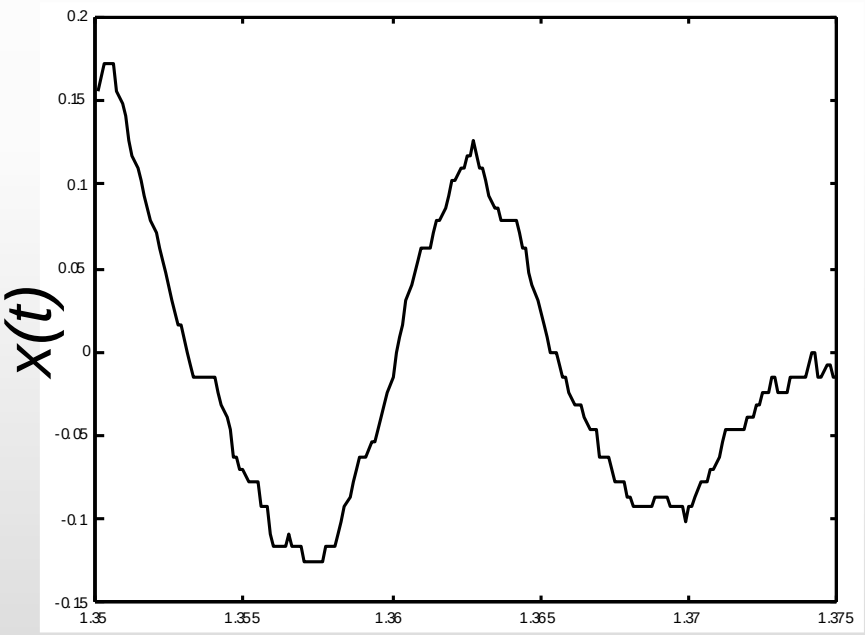
- *1 Kb = 1 kilobit = 1,000 bits*
- *1 Mb = 1 megabit = 1,000 Kb*
- *1 Gb = 1 gigabit = 1,000 Mb*
- *1 Tb = 1 terabit = 1,000 Gb*

Digitization

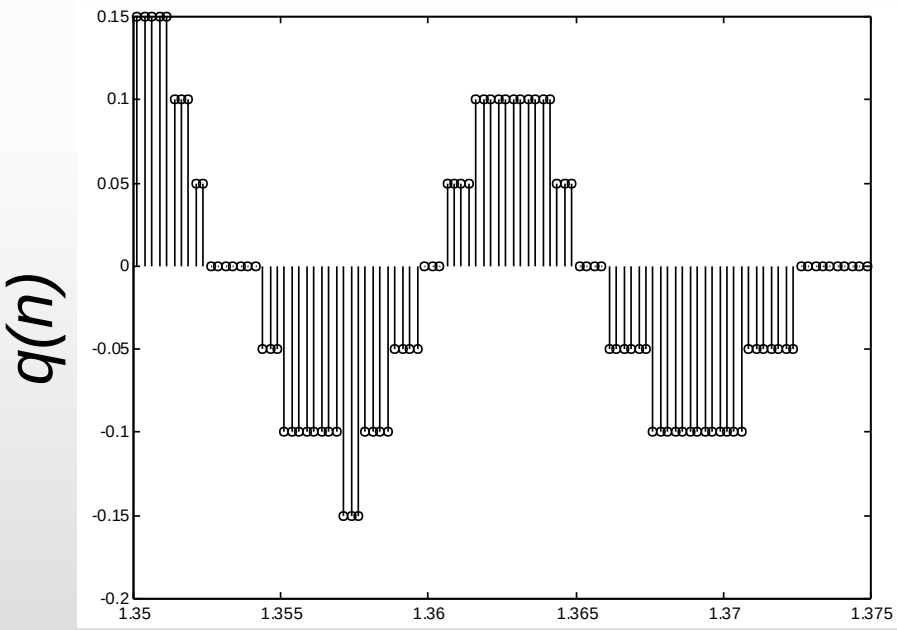
- ***Digitization*** *is the process that allows us to convert analog to digital (implemented by ADC).*
- ***Analog signals****: x(t)*
  - *Defined on continuum (e.g. time).*
  - *Can take on any real value.*
- ***Digital signals****: q(n)*
  - *Sequence of numbers (**samples**) defined by a discrete set (e.g., integers).*

Digitization - Example

Analog signal x(t)



Digitized signal q(n)



Some Definitions

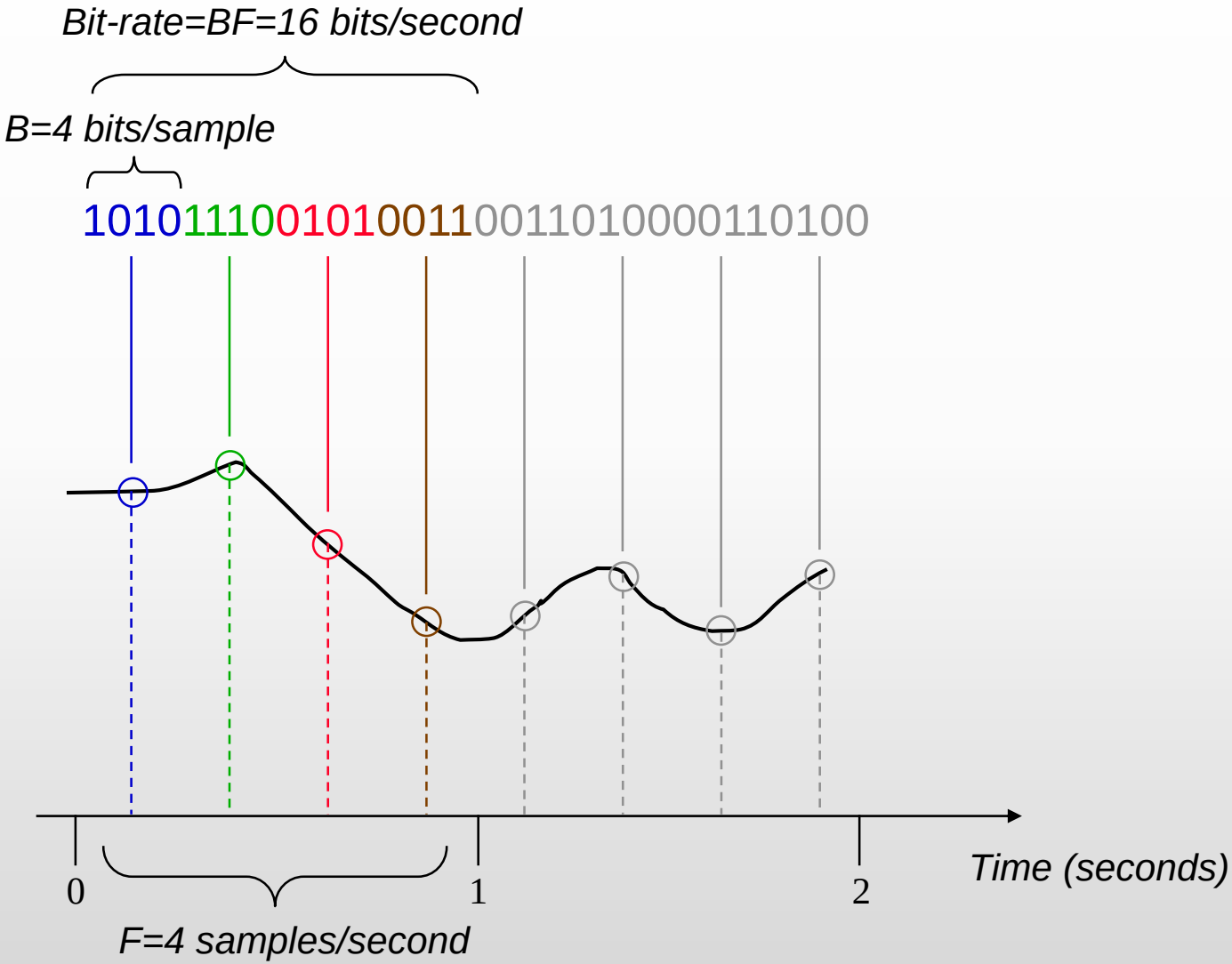
- *Interval of time between two samples:*
  - ***Sampling Interval** (**T**).*
- ***Sampling frequency F=1/T.***
- *E.g.: if the sampling interval is 0.1 seconds, then the sampling frequency is 1/0.1=10.*
  - *Measured in samples/second or Hertz.*
- *Each sample is defined using a **word** of B bits.*
  - *E.g.: we may use 8 bits (1 byte) per sample.*

Bit-rate

- ***Bit-rate** = numbers of bits per second we need to transmit*
  - *For each second we transmit F=1/T samples.*
  - *Each sample is defined with a word of B bits.*
  - ***Bit-rate = F*B.***

- *Example: if F is 10 samples/s and B=8, then the bit rate is 80 bits/s.*

Example of Digitization



Bit-rate - Example 1

- *What is the **bit-rate** of **digitized audio**?*
  - *Sampling rate: F= 44.1 KHz*
  - *Quantization with B=16 bits*
  - ***Bit-rate** = BF= 705.6 Kb/s*
  - *Example: 1 minute of uncompressed stereo music takes more than 10 MB!*

Bit-rate - Example 2

- *What is the bit-rate of **digitized speech?***
  - *Sampling rate: F = 8 KHz*
  - *Quantization with B = 16 bits*
  - ***Bit-rate** = BF = 128 Kb/s*

Data Transmission

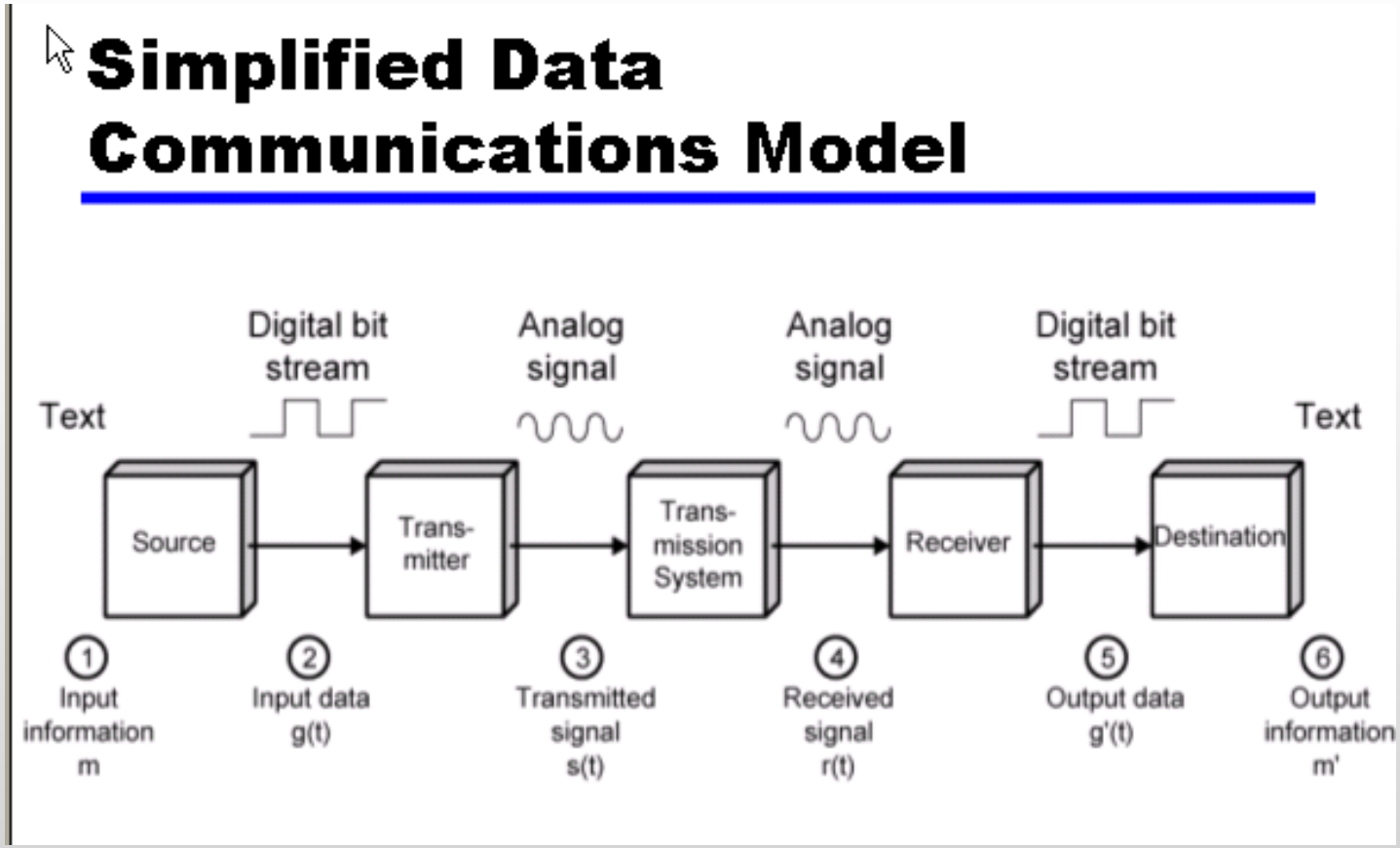
- *Analog and digital transmission.*
  - *Example of analog data: voice and video.*
  - *Example of digital data: character strings*
    - *Use of codes to represent characters as sequence of bits (e.g., ASCII).*
- *Historically, communication infrastructure for analog transmission.*
  - *Digital data needed to be converted: modems (modulator-demodulator).*

Digital Transmission

- *Current trend: digital transmission.*
  - *Cost efficient: advances in digital circuitry. (VLSI).*
- *Advantages:*
  - *Data integrity: better noise immunity.*
  - *Security: easier to integrate encryption algorithms.*
  - *Channel utilization: higher degree of multiplexing (time-division mux'ing).*

Signals and Systems

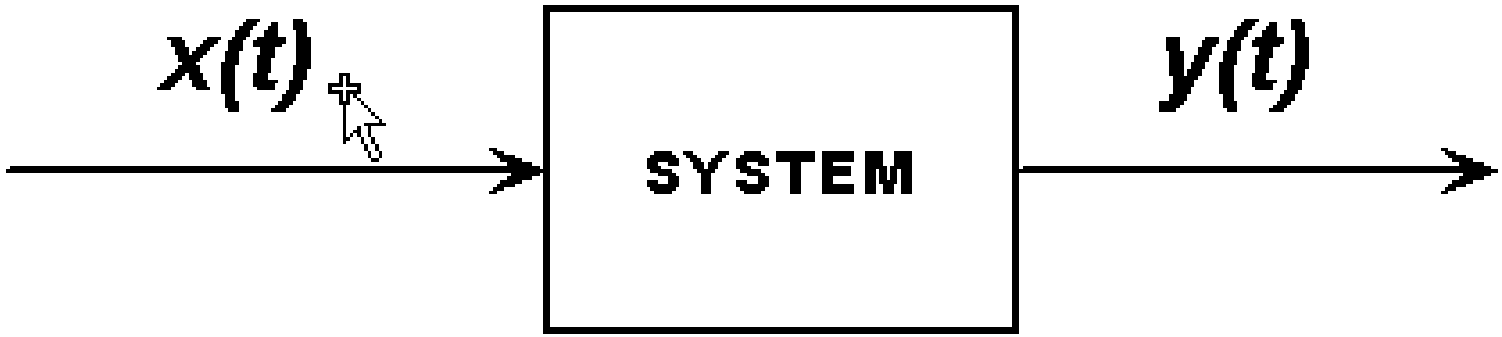
What is a *signal*?
What is a *system*?



Signals and Systems (cont'd)

- *Signal: electro-magnetic wave carrying information.*
  - Time varying function produced by physical device (voltage, current, etc.).
- System: device (or collection thereof) or process (algorithm) having signals as input and output.

Signals and Systems (cont'd)



Signals and Systems (cont'd)

- Periodic signals:
  - $f(t+T) = f(t)$ Period = T (seconds)

- Frequency = 1/ Period
  - "cycles" / sec. = Hertz (Hz)

Fourier Analysis

- *Math tool for studying/designing communication systems.*
- *In the early 19th. Century, Fourier proved that periodic functions can be expressed as sum of sines and cosines.*

Fourier Series

$g(t) = c/2 + \text{sum}\,[a_n \sin(2\,\pi\,n\,f\,t)] + \text{sum}\,[b_n \cos(2\,\pi\,f\,t)]$,

Where :

. $f = 1/T$ is the fundamental frequency.

. a_n and b_n are the sine and cosine amplitudes of the n^{th} harmonics.

Fourier Analysis

- *From the Fourier series, function can be reconstructed.*
- *I.e., if period T and amplitudes are known, original signal can be reconstructed using the corresponding Fourier series.*

Theoretical Basis for Data Communication

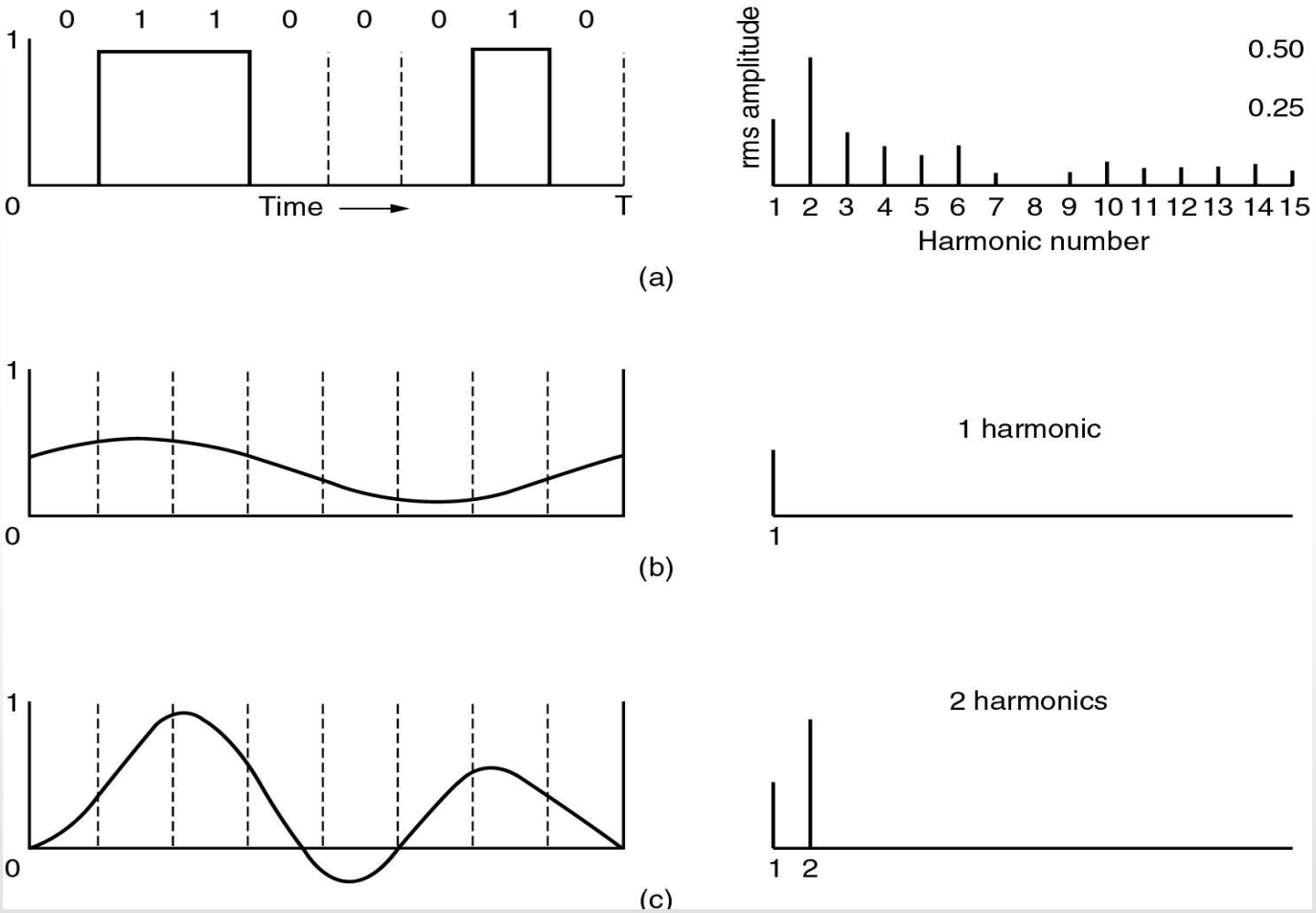
- *Fourier Analysis*
- *Bandwidth-Limited Signals*
- *Maximum Data Rate of a Channel*

Bandwidth-Limited Signals

Example

- *Transmissionn of ASCII “b”: 01100010.*
- *Root-mean-square amplitudes:*
  - $(a_n^2 + b_n^2)^{1/2}$
  - *Proportional to energy transmitted at corresponding frequency.*

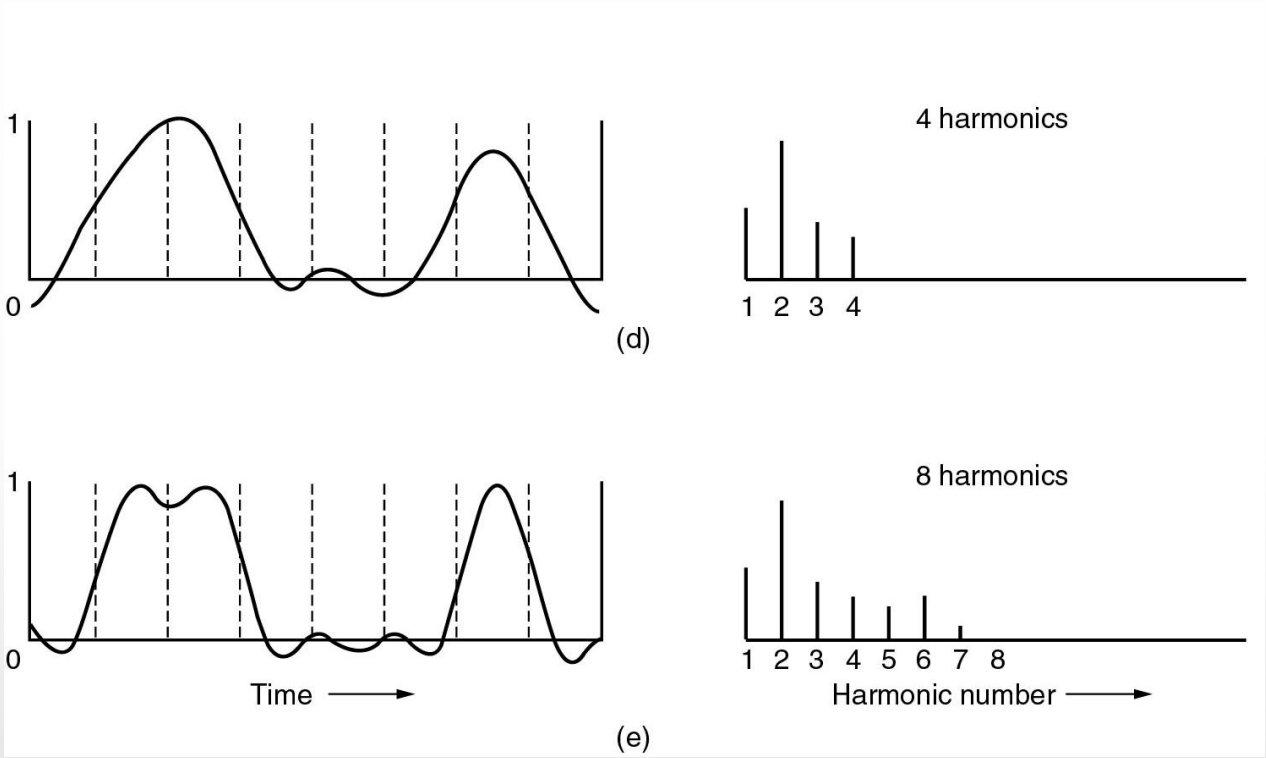
Bandwidth-Limited Signals



(a) Binary signal and its root-mean-square Fourier amplitudes.

(b) – (c) Successive approximations to the original signal.

Bandwidth-Limited Signals (2)



(d) – (e) Successive approximations to original signal.

Transmission Distortion

- *No transmission medium can transmit all Fourier components.*
- *Range of frequency transmitted without severe attenuation is called* **bandwidth**,
  - *Frequently, bandwidth is from 0 to frequency transmitted at half the power.*
- *Bandwidth is physical property of medium.*
  - *Depends on material, length, thickness.*

Data rates and Bandwidth

- *Example: bit rate of* **b** *bits/sec.*
- *Time to send 8 bits is 8/b sec.*
- *First harmonic frequency is b/8 Hz.*
- *If information transmitted over regular phone line, cutoff frequency or bandwidth is 3KHz.*
- *I.e., highest harmonic transmitted is 3000/(b/8) or 24,000/b.*

Bandwidth-Limited Signals (3)

Bps	T (msec)	First harmonic (Hz)	# Harmonics sent
300	26.67	37.5	80
600	13.33	75	40
1200	6.67	150	20
2400	3.33	300	10
4800	1.67	600	5
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

Relation between data rate and harmonics.

Noiseless Channel Capacity

- *Transmission channels have finite capacity.*
- *In perfect (i.e., noiseless) channels, Nyquist (Nyquist, 1924) proved that:*
  - *Capacity (bps) = 2 H V (bps),*
    - *where H is channel bandwdith (Hz) and V is number of discrete levels.*

Noise-Prone Channels

- *Random (thermal) noise is due to molecule motion.*
- *Amount of thermal noise measured by signa-to-noise ratio (SNR).*
  - *SNR = S/N, where S is signal power and N is noise power.*
  - *SNR usually given in decibels (dB).*
  - *SNR in dB is 10 log $_{10}$ S/N.*
  - *If S/N is 10, SNR is 10dB; S/N is 100, SNR is 20dB.*

Shannon's Theorem

- *C (bps) = H log 2 (1+ S/N).*
- *Example: If channel's bandwidth is 3KHz and SNR is 30 dB (analog telephone system), cannot transmit over 30,000 bps.*

Guided Transmission Data

- *Magnetic Media*
- *Twisted Pair*
- *Coaxial Cable*
- *Fiber Optics*

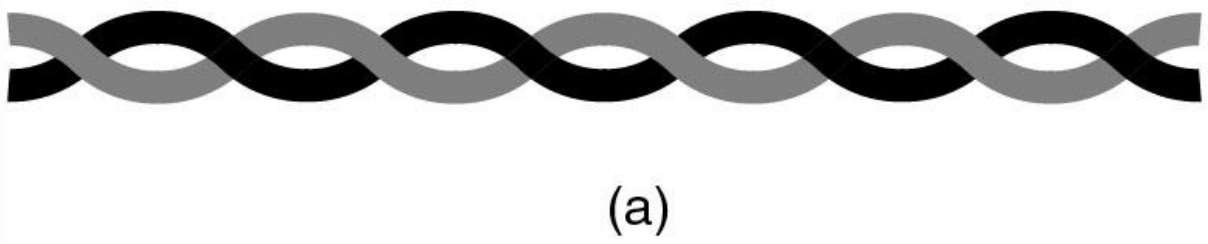
Magnetic Media

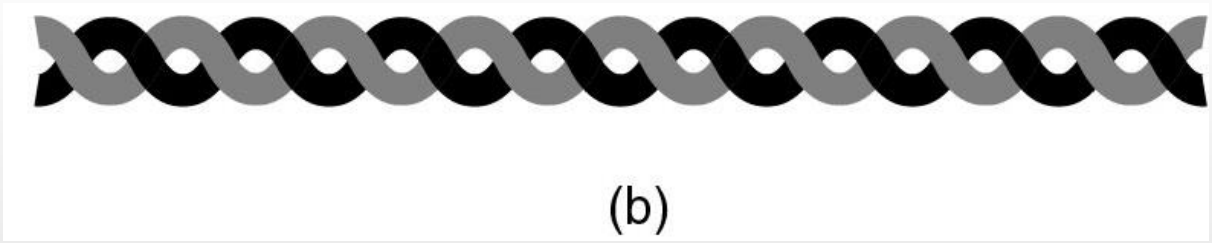
- *Examples?*
- *Advantages?*
- *Disadvantages?*

Twisted Pair

- *Oldest but still very common.*
- *Telephone system.*
- *Cheap and effective for long ranges.*
- *Bundles of twisted pairs.*
- *Can transmit both analog and digital signals.*
- *Bandwidth depends on thickness of wire and distance traveled.*
  - *Mb/s for few kilometers.*

Twisted Pair





- *(a) Category 3 UTP.*
- *(b) Category 5 UTP.*

Twisted Pair

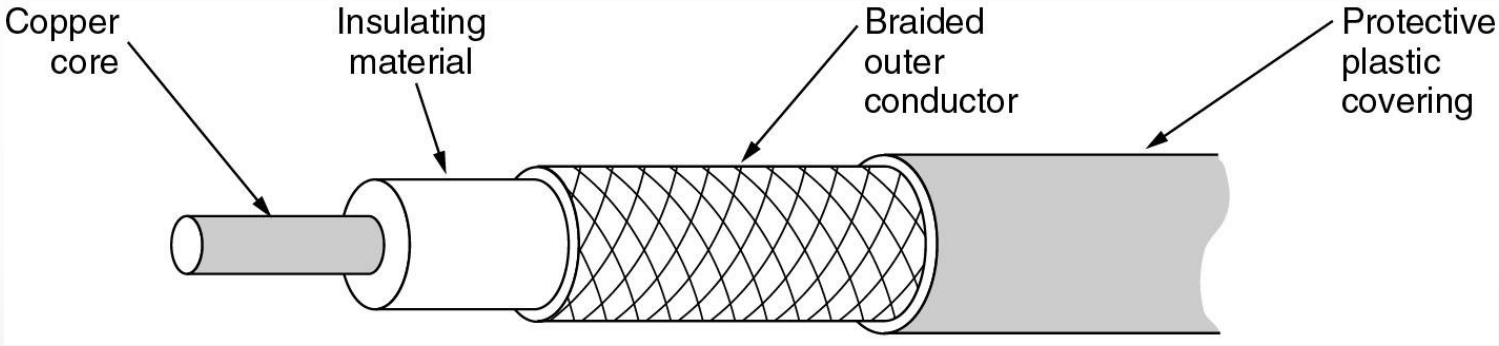
Category	Maximum data rate	Usual application
CAT 1	Up to 1 Mbps (1 MHz)	analog voice (POTS) Integrated Services Digital Network Basic Rate Interface in ISDN Doorbell wiring
CAT 2	4 Mbps	Mainly used in the IBM Cabling System for Token Ring networks
CAT 3	16 Mbps	Voice and data on 10BASE-T Ethernet
CAT 4	20 Mbps	Used in 16 Mbps Token Ring Otherwise not used much
CAT 5	100 Mbps 1000 Mbps (4 pair)	100 Mbps TPDDI 155 Mbps ATM No longer supported; replaced by 5E
CAT 5E	1000 Mbps (10000 Mbps prototype)	100 Mbps TPDDI 155 Mbps ATM Gigabit Ethernet Offers better near-end crosstalk than CAT 5
CAT 6	Up to 400 MHz	Super-fast broadband applications Most popular cabling for new installs
CAT 6E	Up to 625 MHz (field-tested to 500 MHz)	Support for 10 Gigabit Ethernet (10GBASE-T)
CAT 7 (ISO Class F)	600-700 MHz 1.2 GHz in pairs with Siemon connector	Full-motion video Teleradiology Government and manufacturing environments Shielded system

http://searchnetworking.techtarget.com/sDefinition/0,,sid7_gci211752,00.html

Coaxial Cable

- *Better performance than twisted pair, i.e., higher bandwidth and longer distances.*
  - *Good noise immunity.*
- *But…*
- *Bandwidths close to 1GHz.*
- *Used widely in telephone networks for longer distances; but gradually being replaced by fiber.*
- *Used for CATV!*

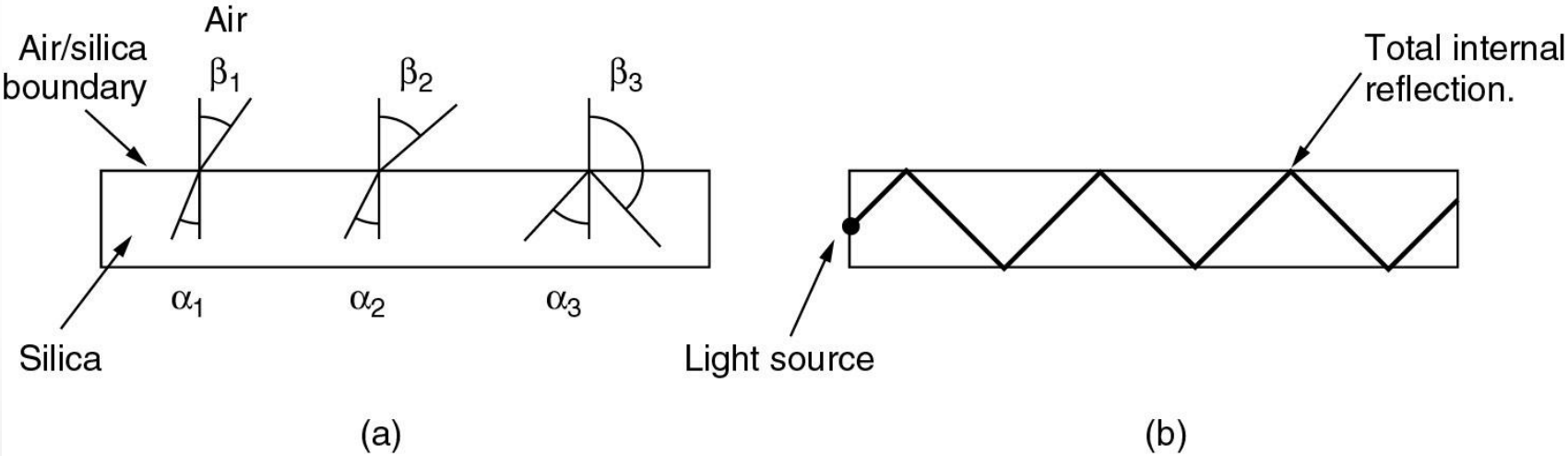
Coaxial Cable



Fiber Optics

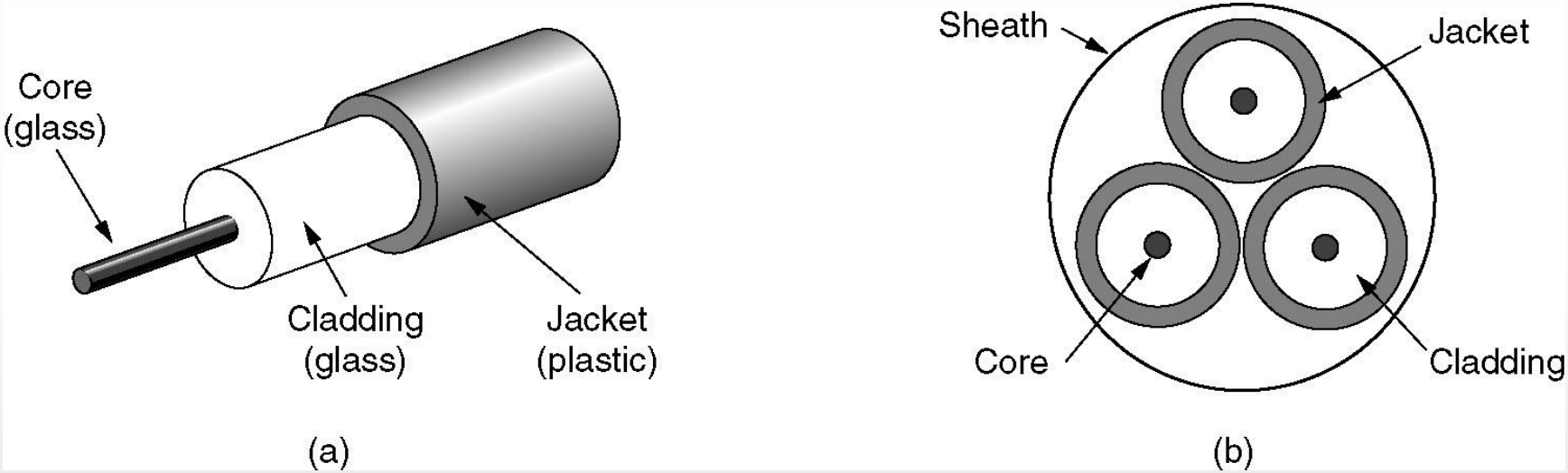
- *Optical transmission.*
- *Optical transmission system: light source, medium, and detector.*
- *Pulse of light = “1”.*
- *No light = “0”.*
- *Transmission medium: ultra thin fiber of glass.*
- *Detector: generates electrical pulse when perceives light.*

Transmitting Light



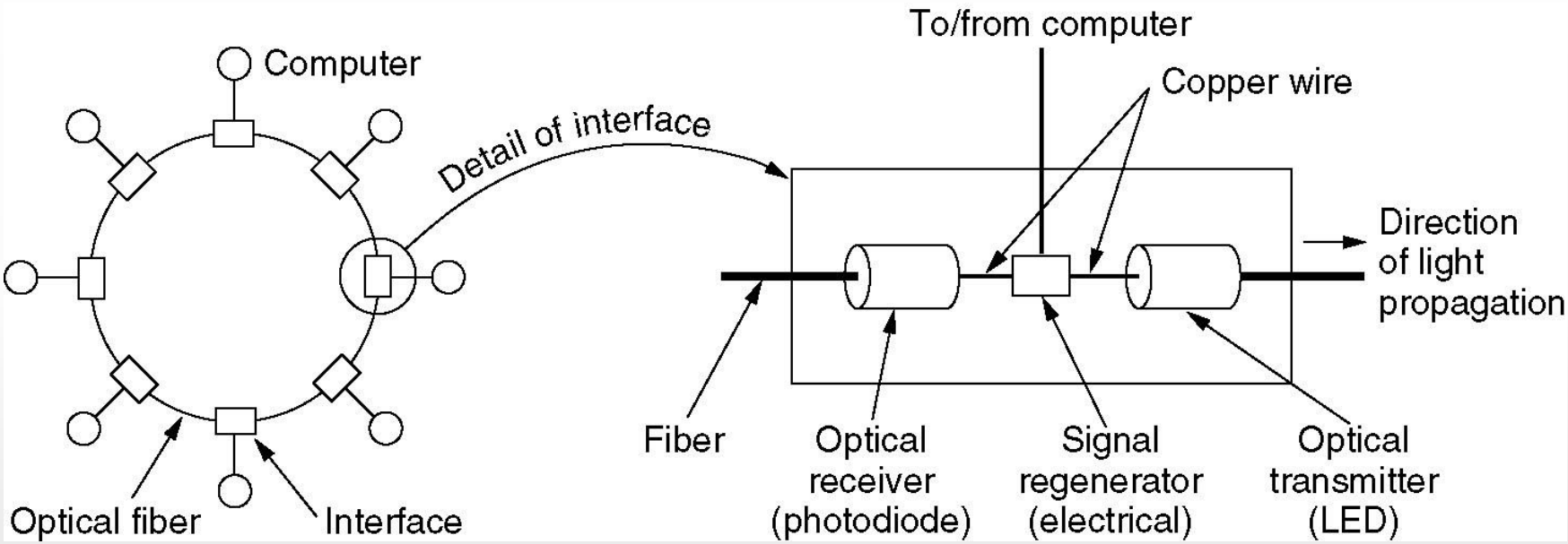
- *(a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.*
- *(b) Light trapped by total internal reflection.*

Fiber Cables



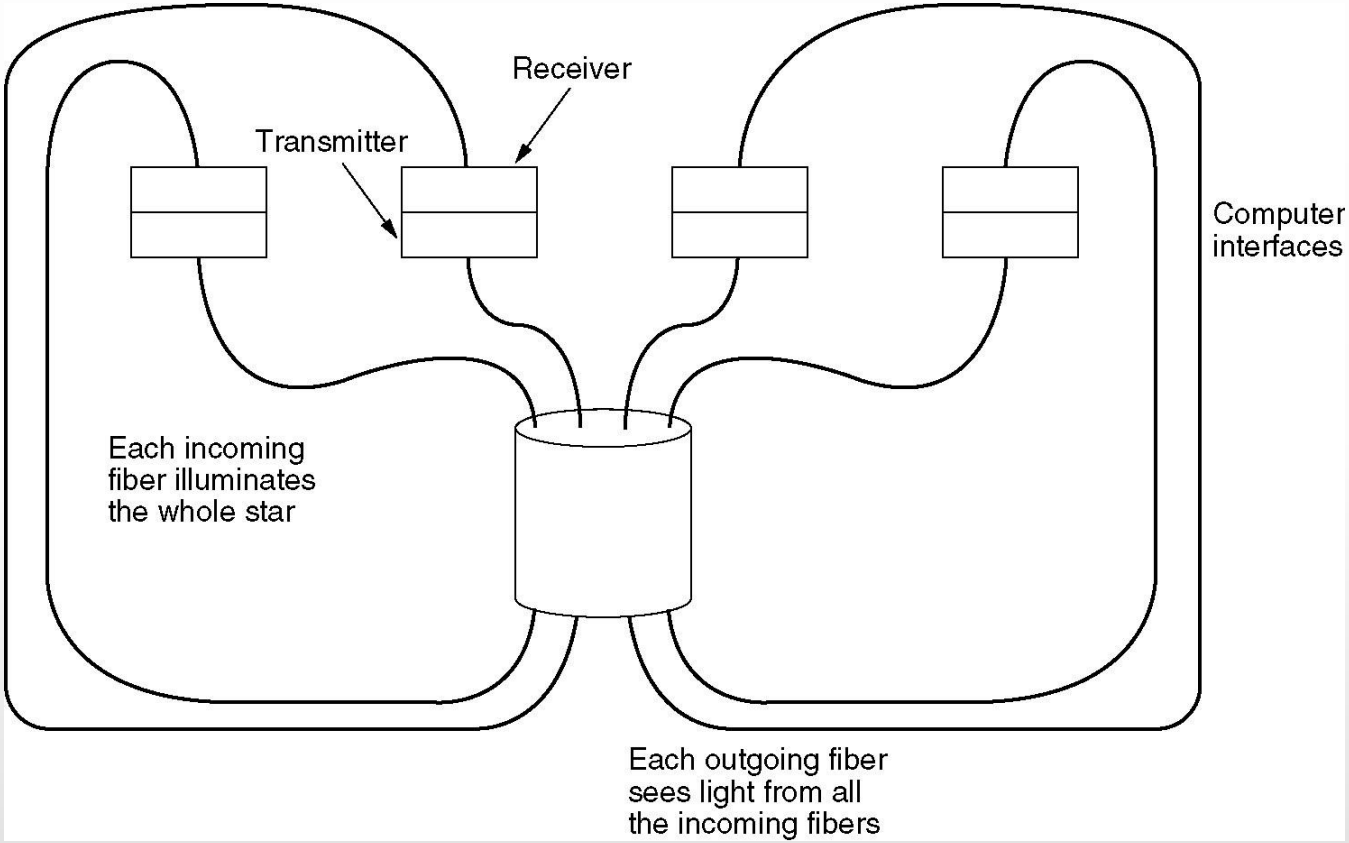
- *(a) Side view of a single fiber.*
- *(b) End view of a sheath with three fibers.*

Fiber Optic Networks



- *A fiber optic ring.*

Fiber Optic Networks (2)



- *A passive star connection in a fiber optics network.*

Fiber versus Copper Wire

- *Fiber can handle much higher bandwidths.*
- *Low attenuation: 50km without repeater.*
- *Unaffected by power surges/outages, and interference.*
- *Fiber is thin and lightweight: easy to deploy and add new capacity.*
- *Difficult to tap.*
- *But…*

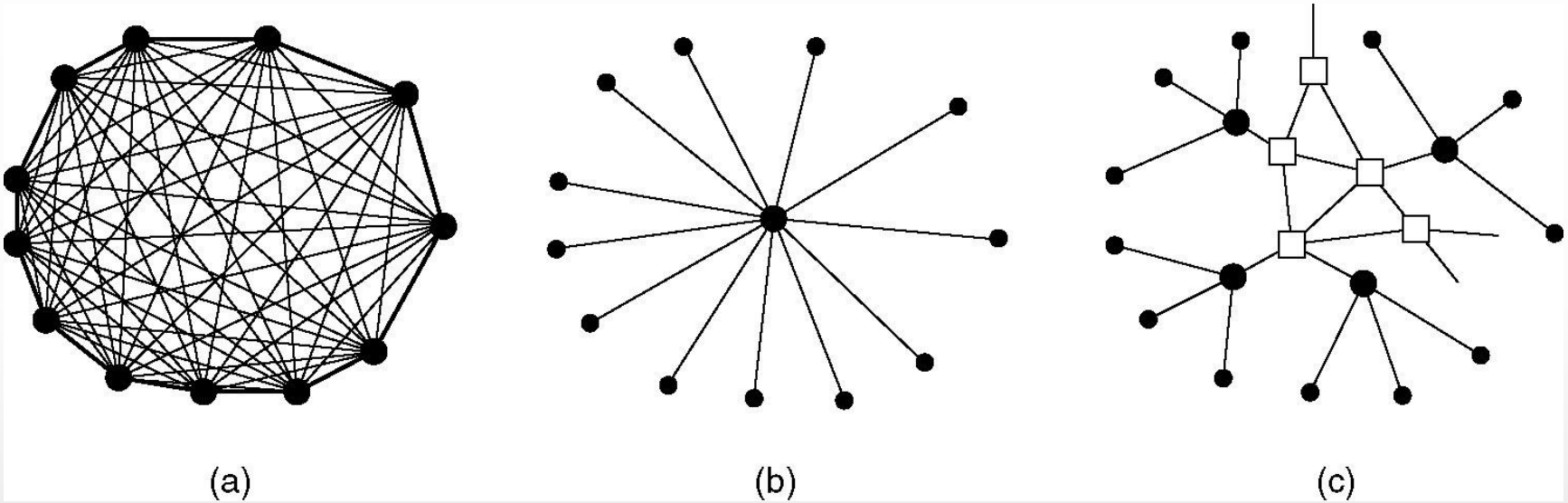
Fiber versus Copper (cont'd)

- *Fiber can be damaged easily.*
- *Optical transmission is unidirectional, so need 2 fibers or 2 frequencies for 2-way communication.*
- *Fiber and fiber interfaces is more expensive.*

Public Switched Telephone System

- *Structure of the Telephone System*
- *The Politics of Telephones*
- *The Local Loop: Modems, ADSL and Wireless*
- *Trunks and Multiplexing*
- *Switching*

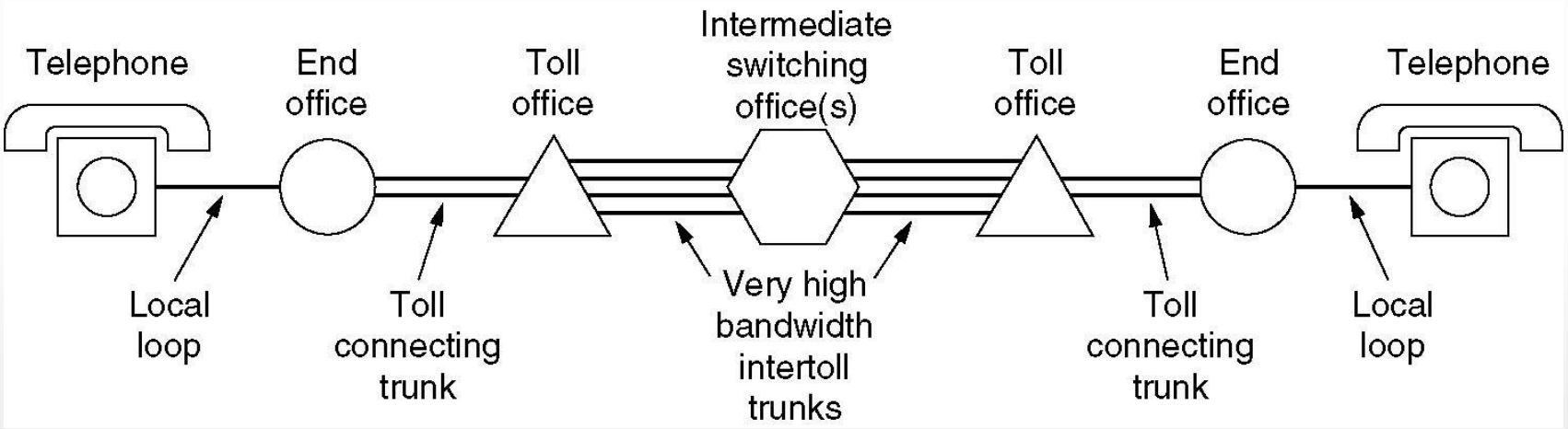
Structure of the Telephone System



- *(a) Fully-interconnected network.*
- *(b) Centralized switch.*
- *(c) Two-level hierarchy.*

Structure of the Telephone System (2)

- *A typical circuit route for a medium-distance call.*



Major Components of the Telephone System

- *Local loops:*
  - *Connection from subscriber to end office.*
- *Trunks*
  - *Outgoing lines connecting offices.*
- *Toll office:*
  - *Connects end offices.*
- *Switching offices*
  - *Where calls are moved from one trunk to another.*