The Physical Layer

Chapter 2

Theoretical Basis for Data Communication

- Fourier analysis
- Bandwidth-limited signals
- Maximum data rate of a channel

Fourier Analysis

- We model the behavior of variation of voltage or current with mathematical functions
- Fourier series is used

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

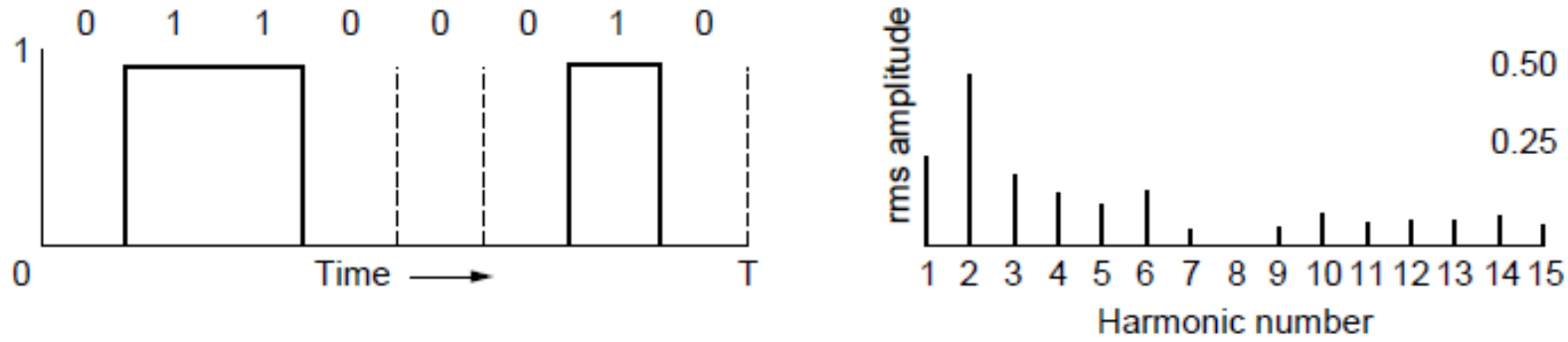
where the *n*th pair of terms is the *n*th harmonic

- Function reconstructed with

$$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi nft)\,dt \qquad b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi nft)\,dt \qquad c = \frac{2}{T}\int_0^T g(t)\,dt$$

Bandwidth-Limited Signals (1)

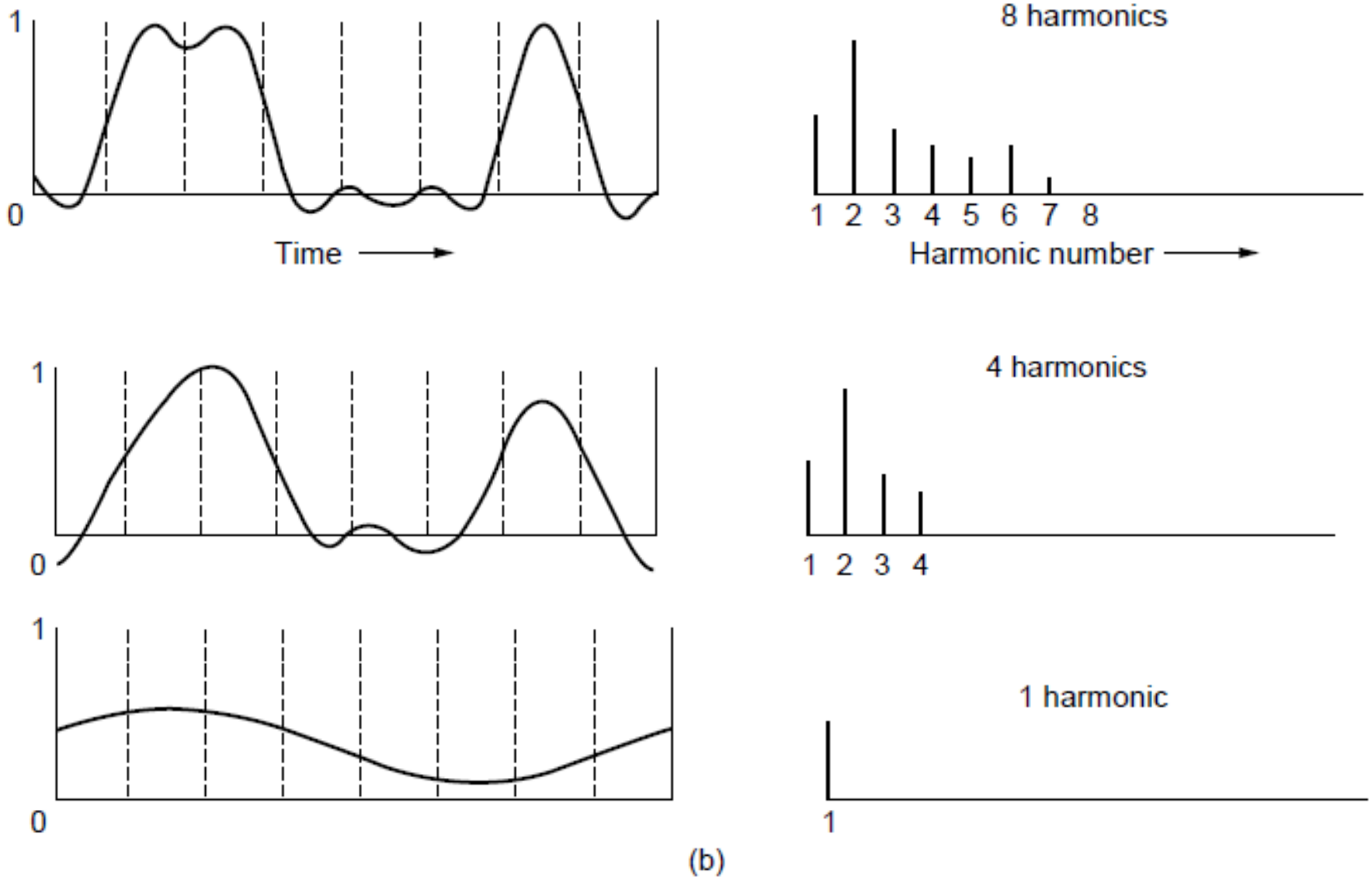
A binary signal and its root-mean-square Fourier amplitudes.



$$rms_n = \sqrt{a_n^2 + b_n^2}$$

- The root-mean-square amplitudes
  - Their square are proportional to the transmitted energy
- Signal transmission reduces harmonics amplitude differently
  - According to their frequencies

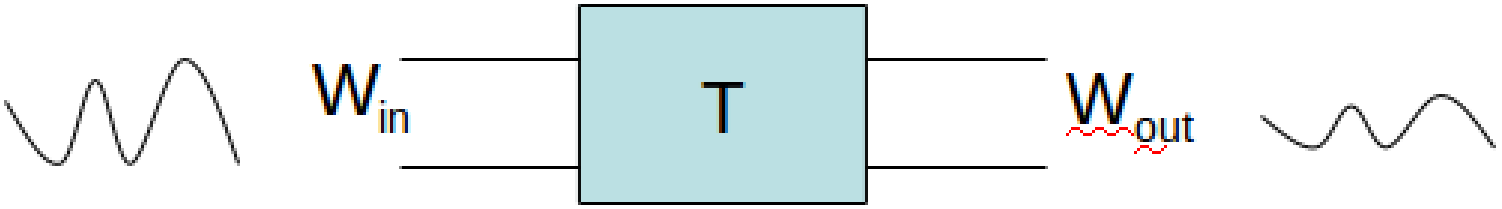
Bandwidth-Limited Signals (2)



Bandwidth-Limited Signals (3)

- Bandwidth: the width of the frequency range transmitted without attenuation
  - Convention: from 0 to the frequency at which the received power has fallen by half
- Bandwidth depends on:
  - material, thickness, and length of a wire or fiber
- Signals types:
  - Baseband signals: bandwidth from 0 to Max
  - Passband signals: bandwidth from Min (≠0) to Max

Gain Index



- Gain (or loss) misured in decibel (dB)

$$W_{dB} = 10 \log_{10} \frac{W}{W_{rif}}$$

- In electrical circuits, since W ∝ V^2

$$V_{dB} = 20 \log_{10} \frac{V}{V_{rif}}$$

The Maximum Data Rate of a Channel

- Nyquist's theorem of noiseless channel

  $$\text{maximum data rate} = 2B \log_2 V \text{ bits/sec}$$

  V: number of signal discrete levels
- Shannon's formula for capacity of noisy channel

  $$\text{maximum number of bits/sec} = B \log_2 (1 + S/N)$$

  S/N: *signal to noise ratio (SNR)*
- *An S /N ratio of:*
  - *0.5 is -3dB, 10 is 10 dB, 100 is 20 dB, 1000 is 30 dB*

Bandwidth-Limited Signals (6)

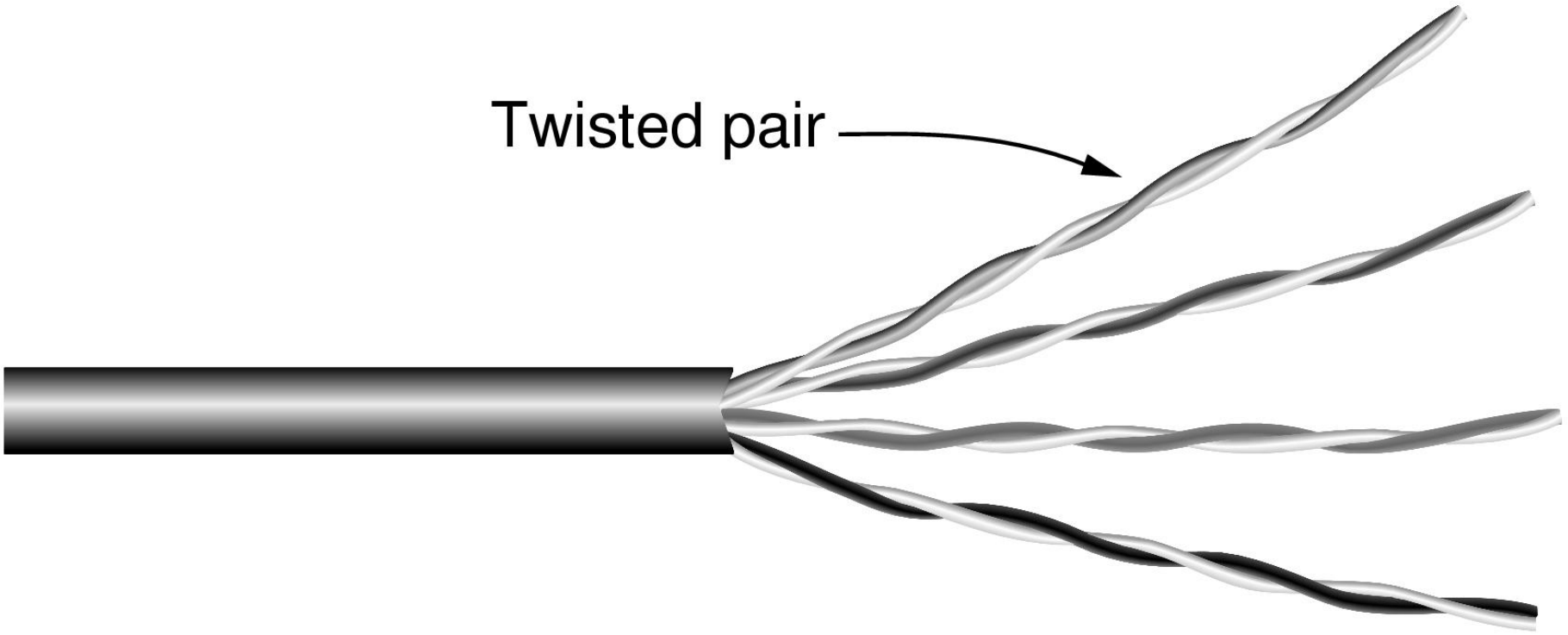
bps	T of Byte (msec)	First harmonic (Hz)	# Harmonics sent
300	26.67	37.5	80
600	13.33	75	40
1200	6.67	150	20
2400	3.33	300	10
4800	1.67	600	5
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

Relation between data rate and harmonics in a 3KHz bandwidth channel

Guided Transmission Media

- Twisted pairs
- Coaxial cable
- Power lines
- Fiber optics

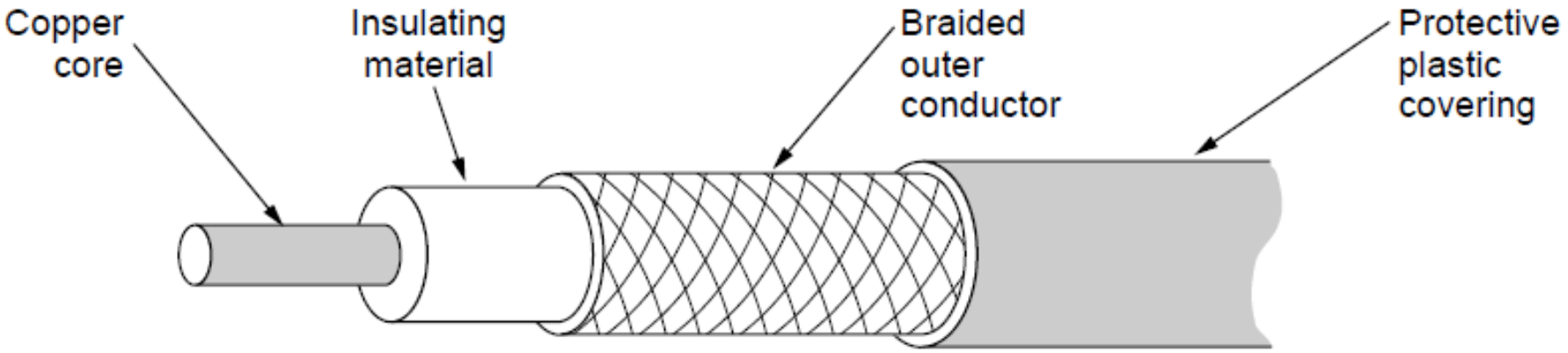
Twisted Pairs



Category 5 UTP cable with four twisted pairs

Category 6 UTP up to 500 MHz bandwidth signals

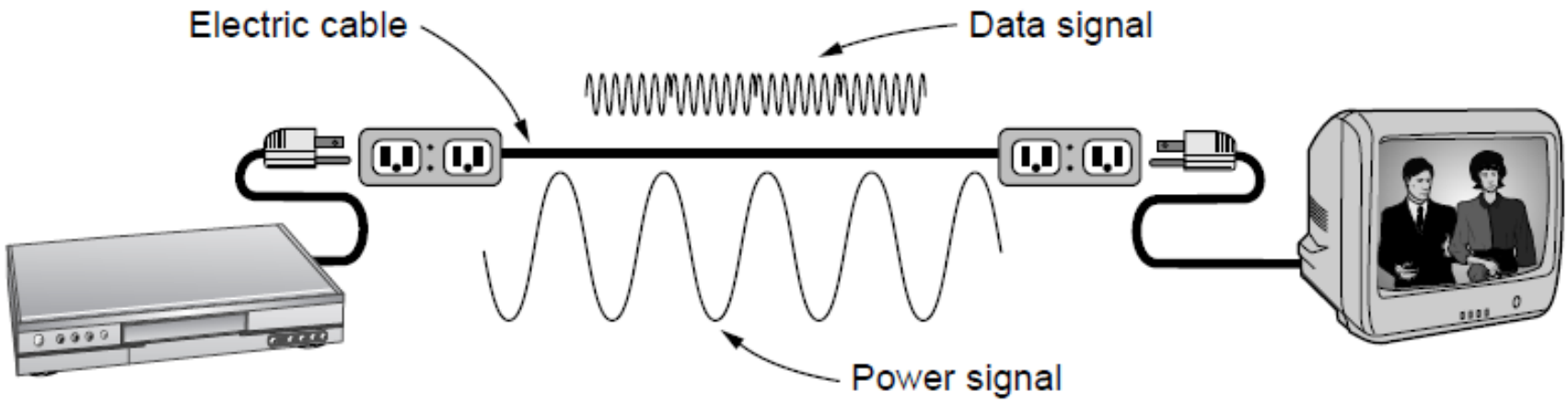
Coaxial Cable



A coaxial cable

Modern cable up to few GHz bandwidth signals

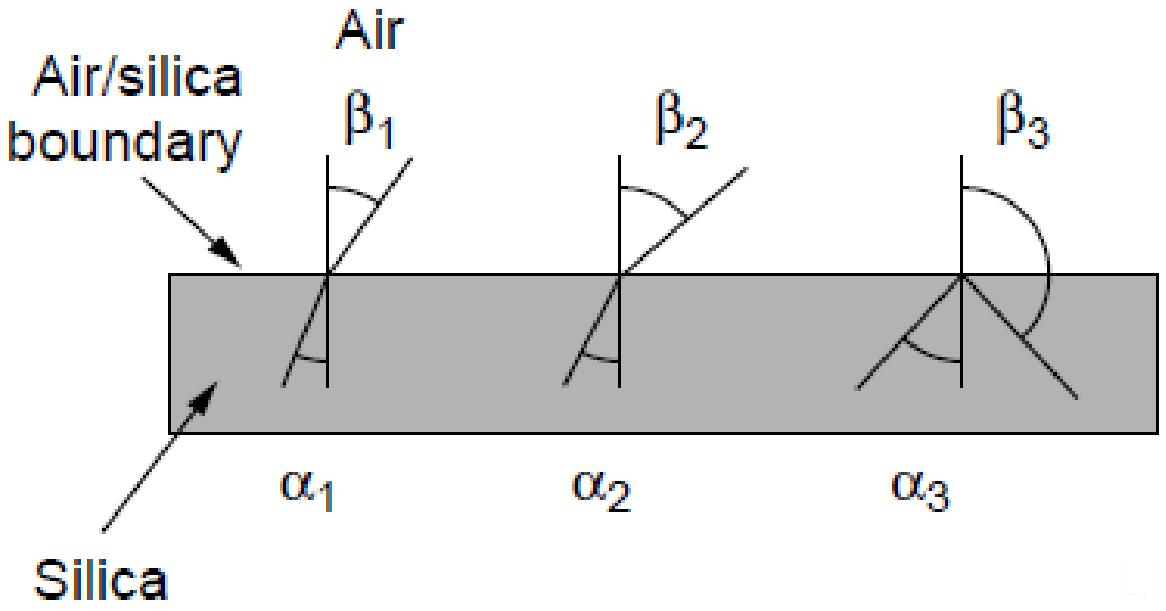
Power Lines



A network that uses household electrical wiring.

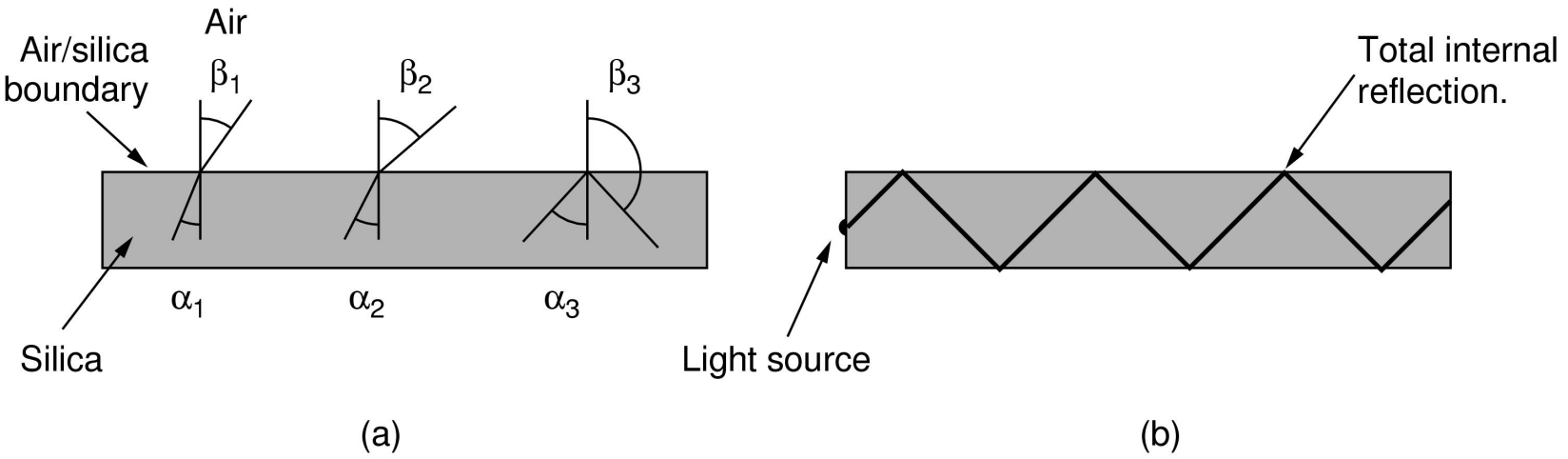
Limited bandwidth up to 1 MHz

Fiber Optics (1)



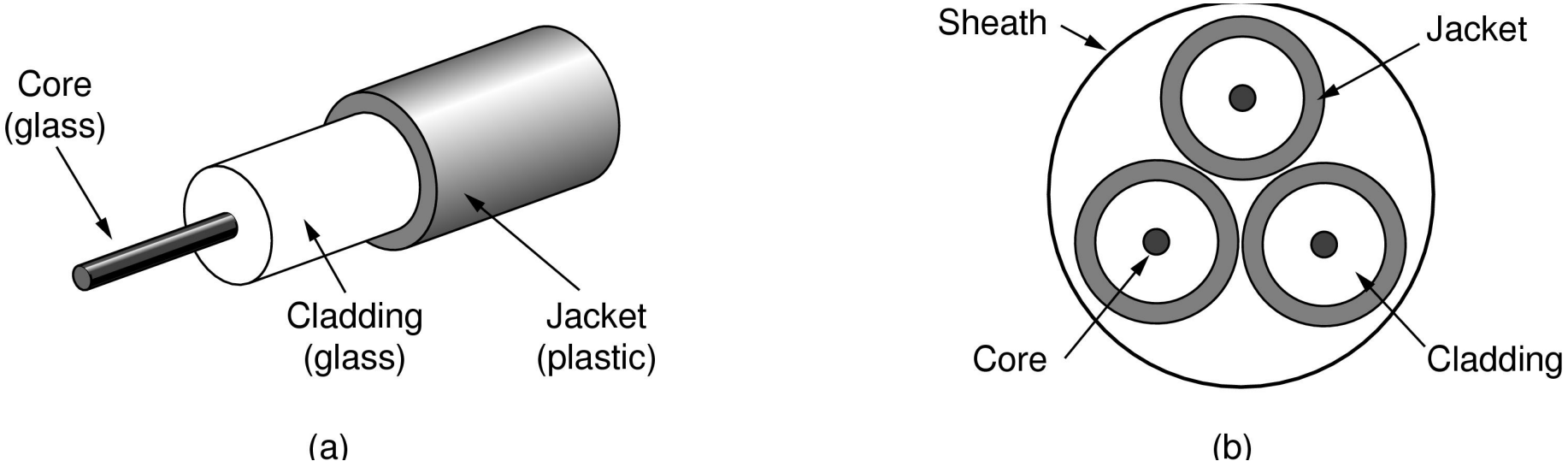
Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.

Fiber Optics (2)



Light trapped by total internal reflection.

Fiber Cables (1)



Views of a fiber cable

Fiber Cables (2)

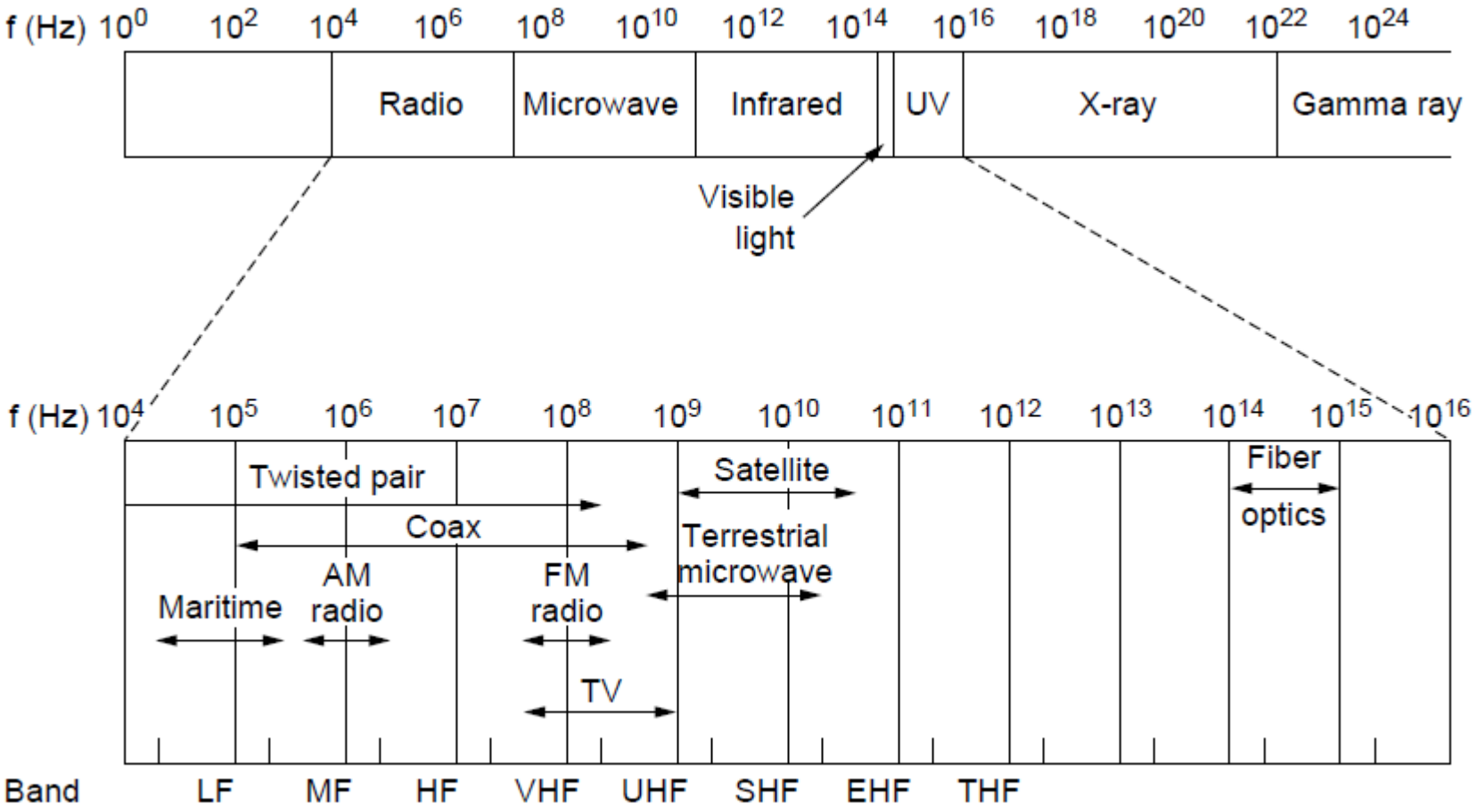
Item	LED	Semiconductor laser
Data rate	Low	High
Fiber type	Multi-mode	Multi-mode or single-mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

A comparison of semiconductor lasers and LEDs as light sources

Wireless Transmission

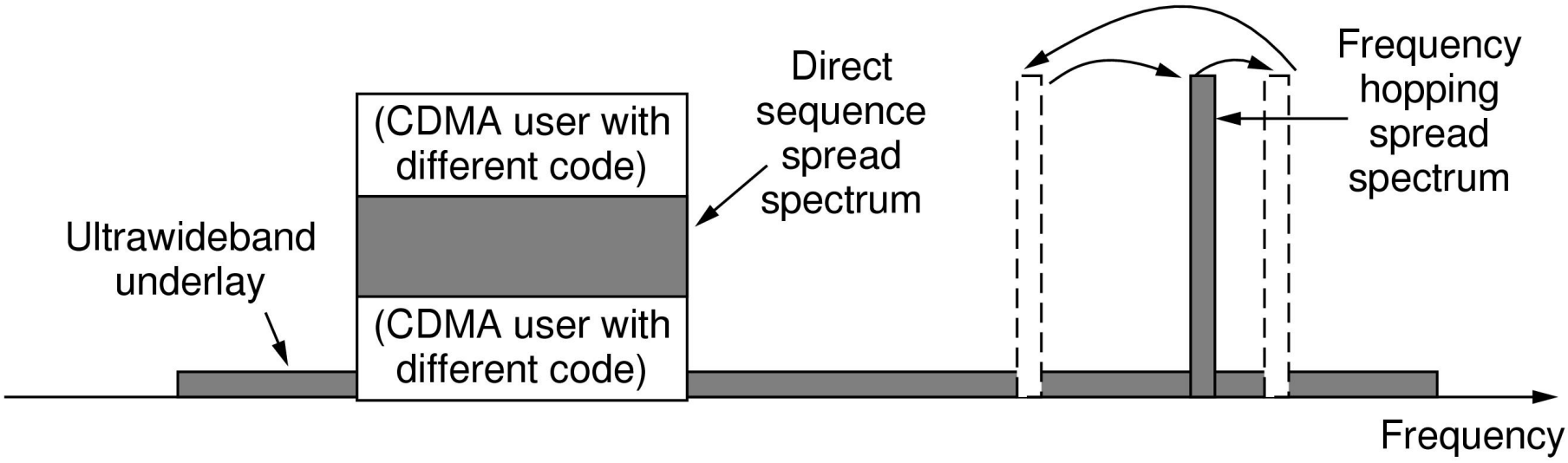
- The Electromagnetic Spectrum
- Radio Transmission
- Microwave Transmission
- Infrared Transmission

The Electromagnetic Spectrum (1)



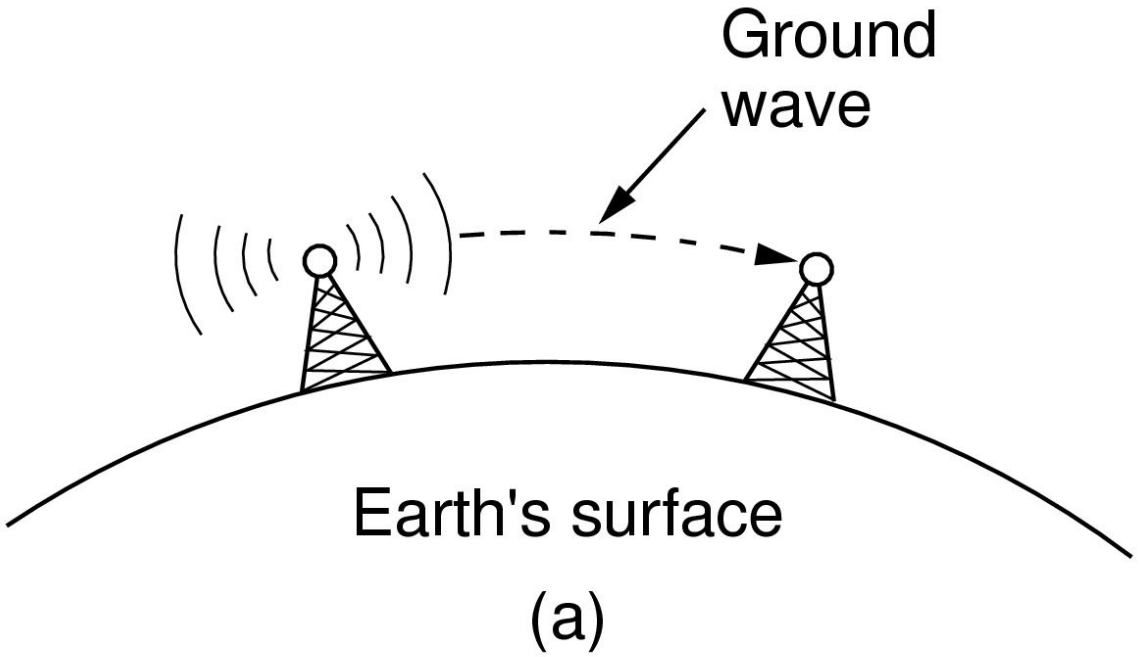
The electromagnetic spectrum and its uses for communication

The Electromagnetic Spectrum (2)



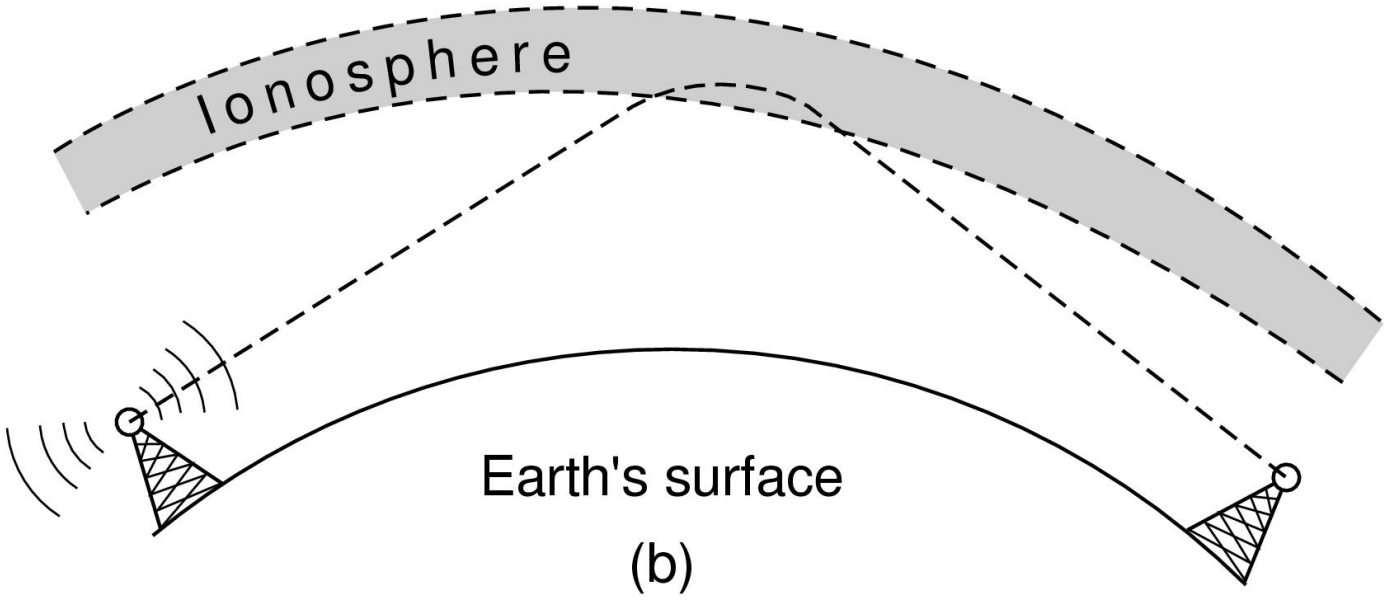
Spread spectrum and ultra-wideband (UWB) communication

Radio Transmission (1)



In the VLF, LF, and MF bands, radio waves follow the curvature of the earth

Radio Transmission (2)

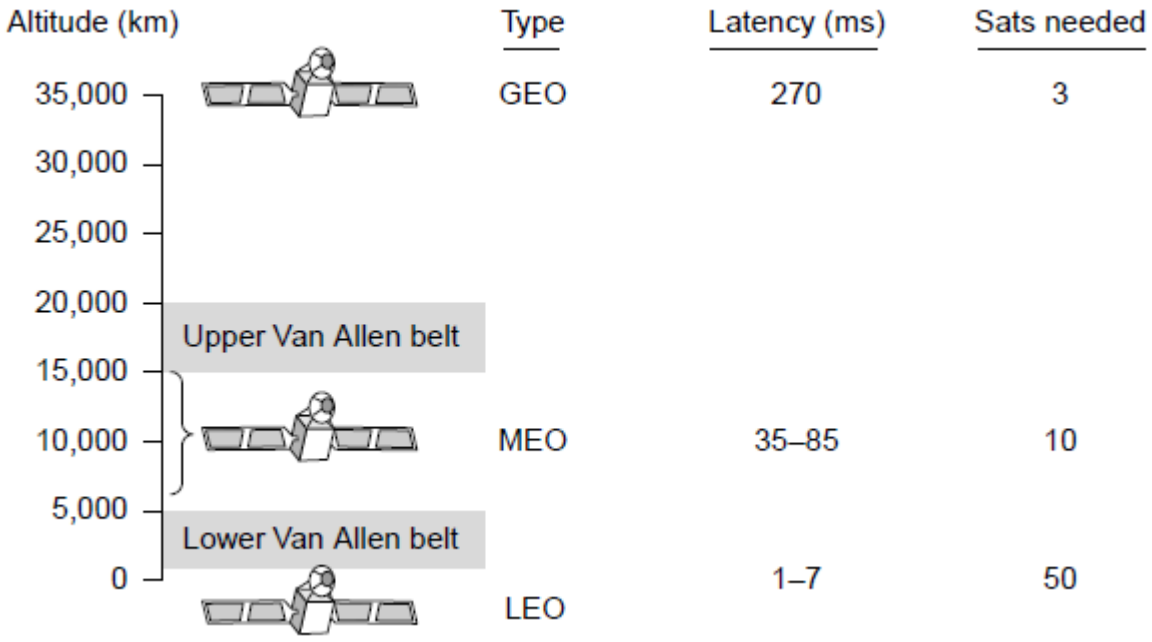


In the HF band, they bounce off the ionosphere.

Communication Satellites

- Geostationary Satellites
- Medium-Earth Orbit Satellites
- Low-Earth Orbit Satellites

Communication Satellites



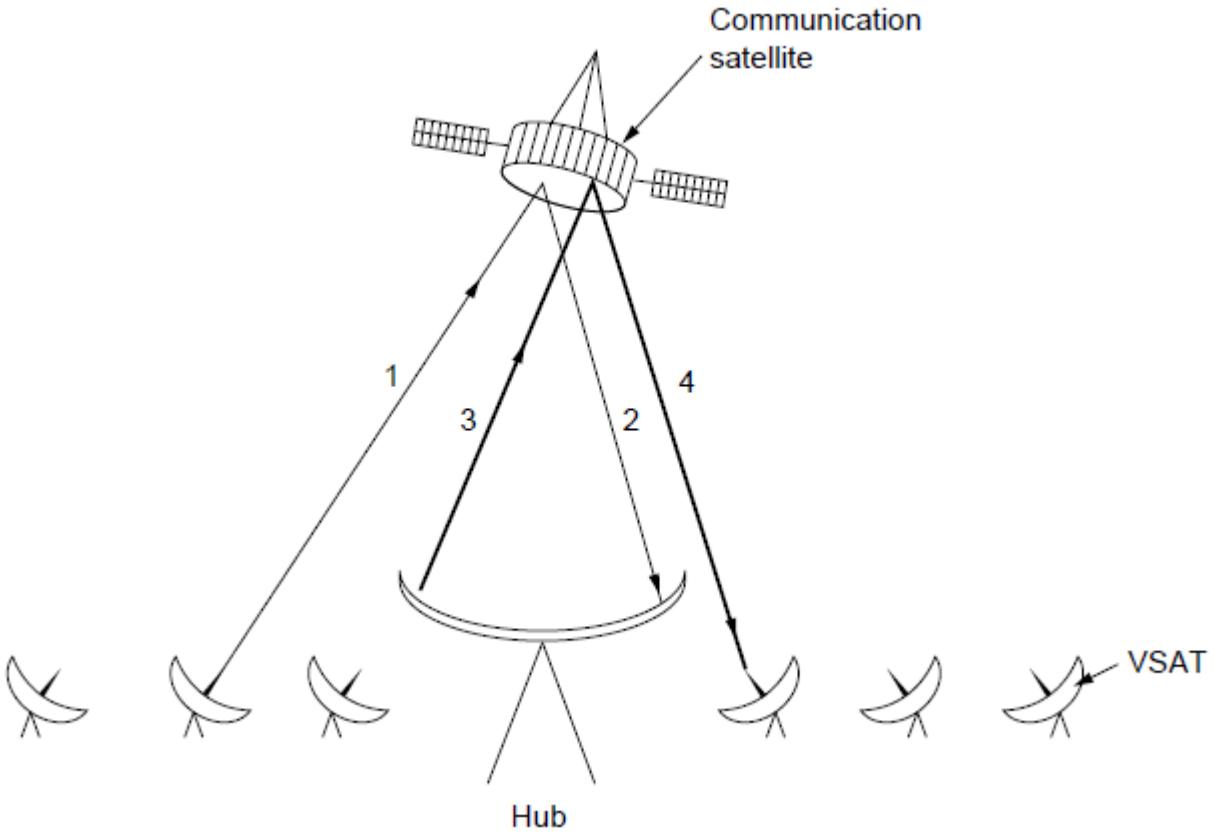
Communication satellites, some properties, including: altitude above earth, round-trip delay time, number of satellites for global coverage.

Geostationary Satellites (1)

Band	Downlink	Uplink	Bandwidth	Problems
L	1.5 GHz	1.6 GHz	15 MHz	Low bandwidth; crowded
S	1.9 GHz	2.2 GHz	70 MHz	Low bandwidth; crowded
C	4.0 GHz	6.0 GHz	500 MHz	Terrestrial interference
Ku	11 GHz	14 GHz	500 MHz	Rain
Ka	20 GHz	30 GHz	3500 MHz	Rain, equipment cost

The principal satellite bands

Geostationary Satellites (2)

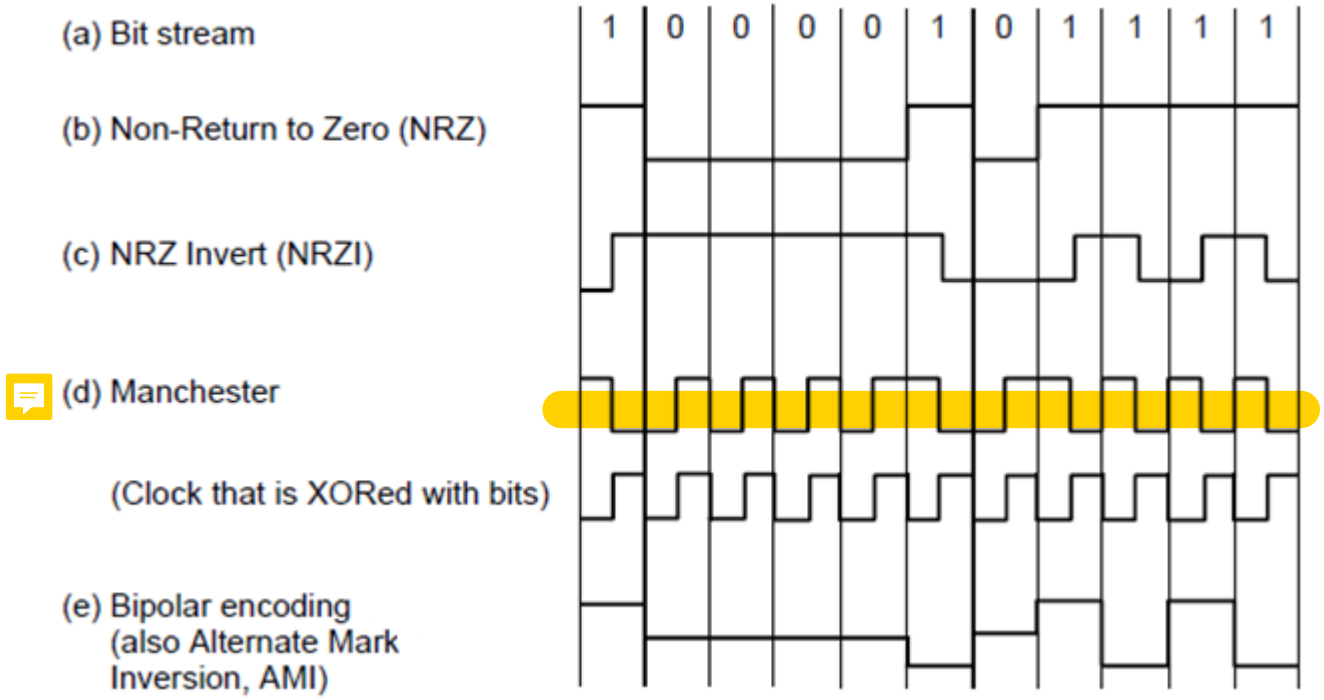


VSATs using a hub.

Digital Modulation and Multiplexing

- Baseband Transmission
- Passband Transmission
- Frequency Division Multiplexing
- Time Division Multiplexing
- Code Division Multiplexing

Baseband Transmission



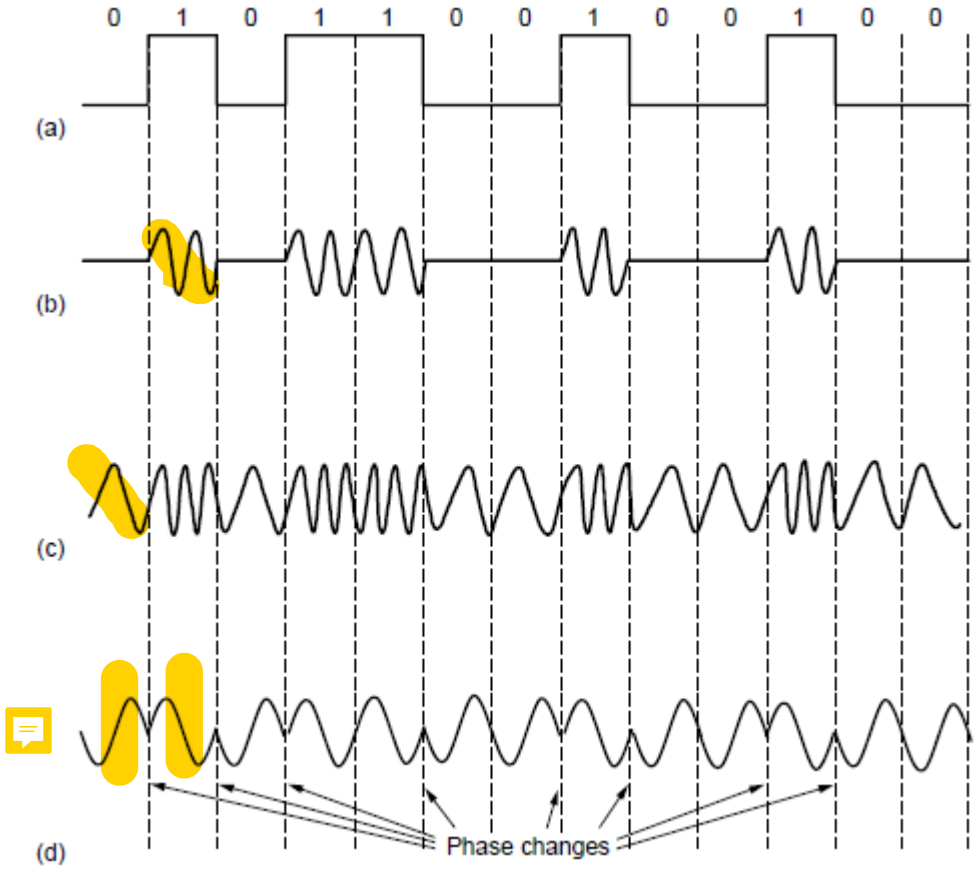
Line codes: (a) Bits, (b) NRZ, (c) NRZI, (d) Manchester, (e) Bipolar or AMI.

Clock Recovery

Data (4B)	Codeword (5B)	Data (4B)	Codeword (5B)
0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
0110	01110	1110	11100
0111	01111	1111	11101

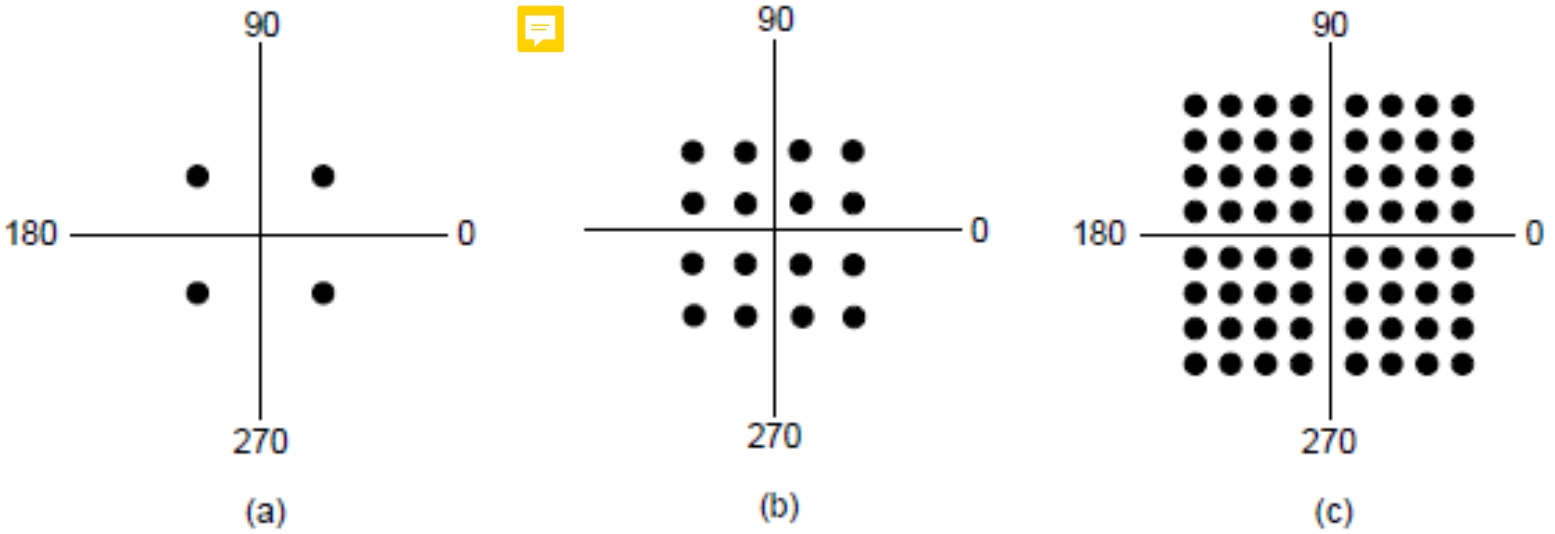
4B/5B mapping.

Passband Transmission (1)



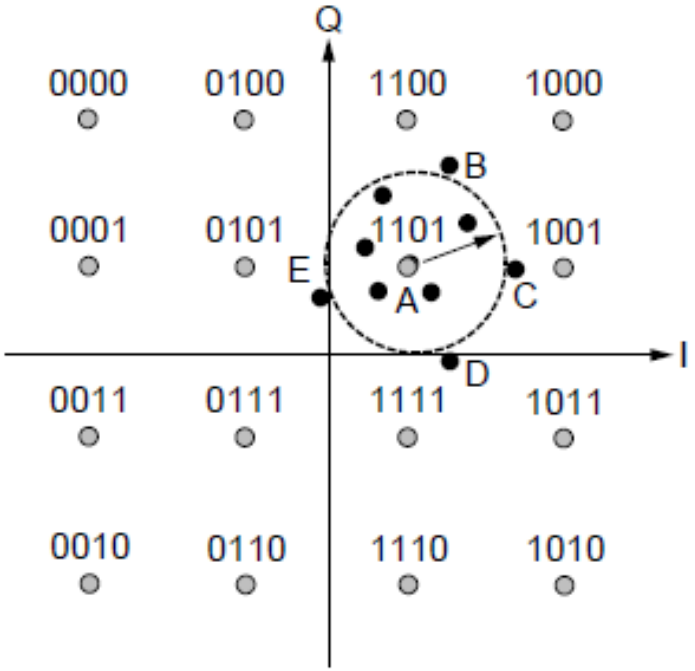
(a) A binary signal. (b) Amplitude shift keying. (c) Frequency shift keying. (d) Phase shift keying (BPSK).

Passband Transmission (2)



(a) QPSK. (b) QAM-16. (c) QAM-64.

Frequency Division Multiplexing (1)

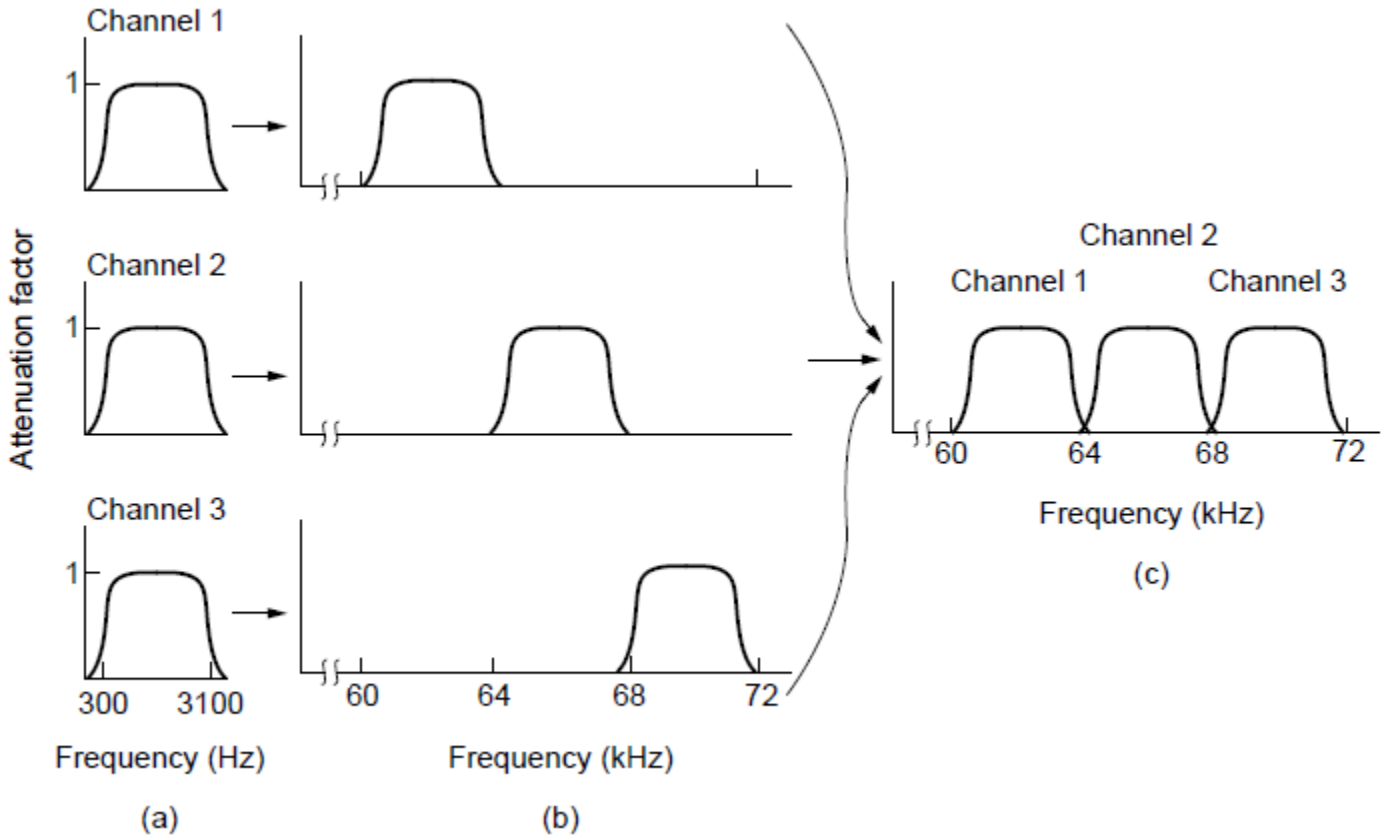


When 1101 is sent:

Point	Decodes as	Bit errors
A	1101	0
B	1100	1
C	1001	1
D	1111	1
E	0101	1

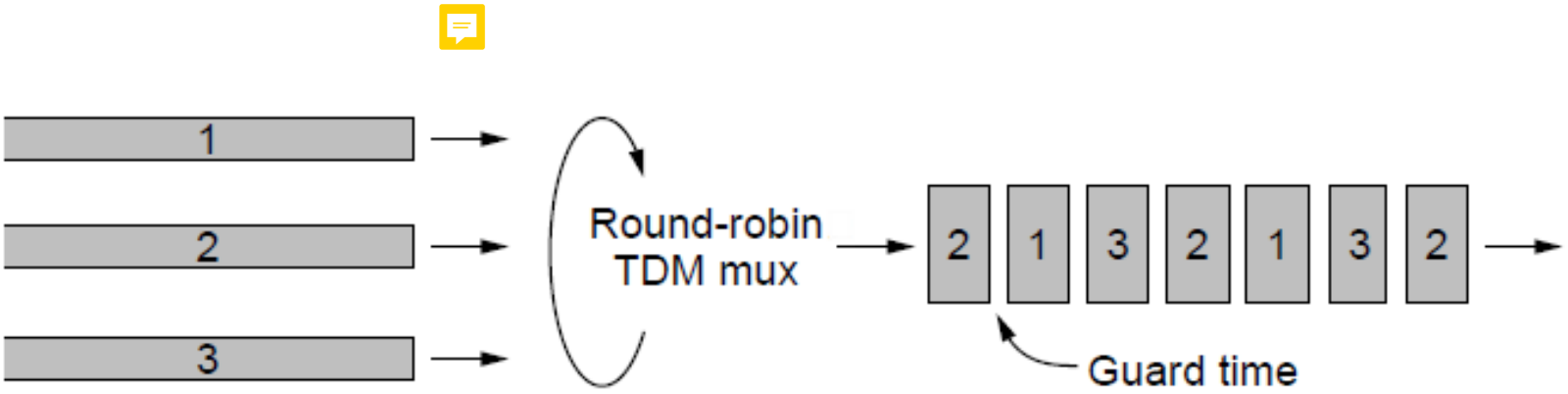
Gray-coded QAM-16.

Frequency Division Multiplexing (2)



Frequency division multiplexing. (a) The original bandwidths. (b) The bandwidths raised in frequency. (c) The multiplexed channel.

Time Division Multiplexing

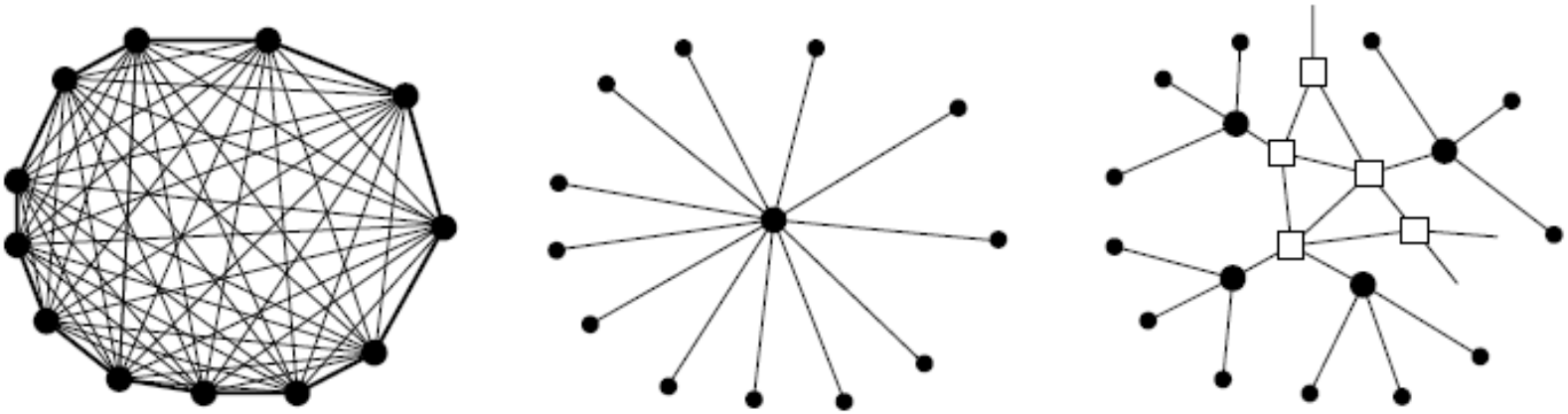


Time Division Multiplexing (TDM).

The Public Switched Telephone Network

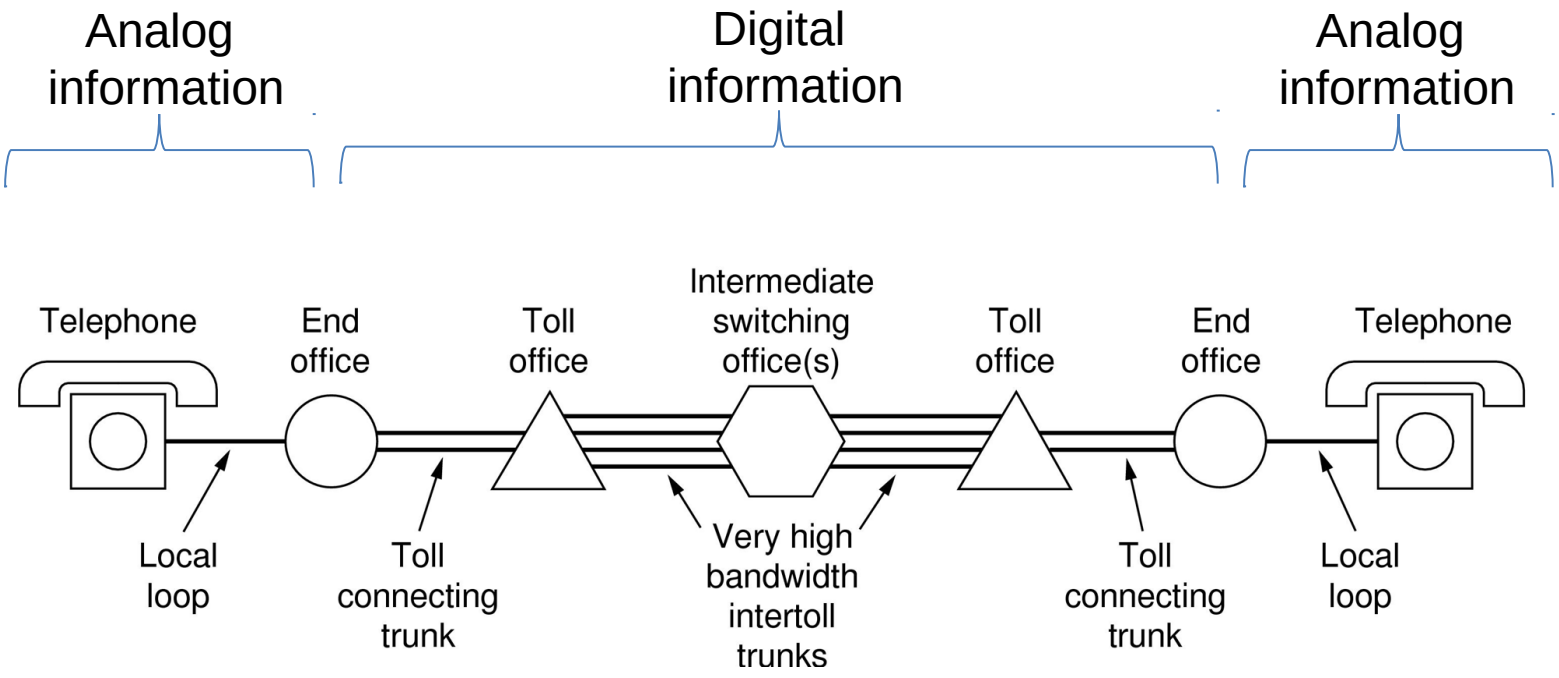
- Structure of the telephone system
- Politics of telephones
- Local loop: modems, ADSL, and fiber
- Trunks and multiplexing
- Switching

Structure of the Telephone System (1)



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

Structure of the Telephone System (2)



A typical circuit route for a long-distance call.

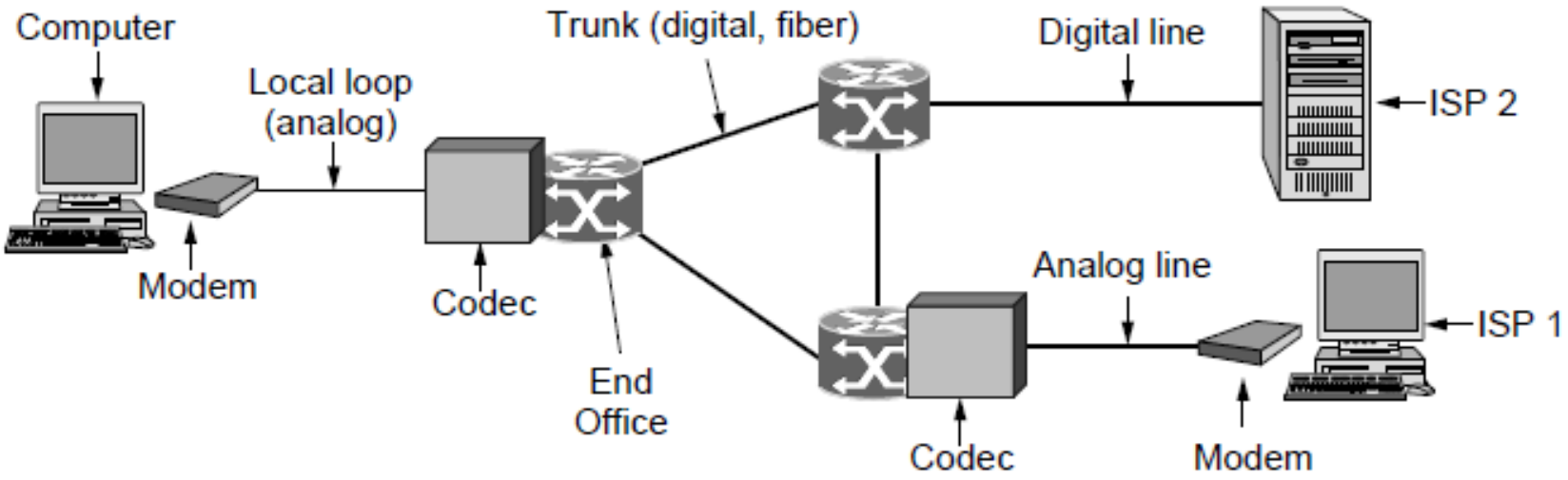
Local loop optimized for voice call (about 4KHz bandwidth)

Structure of the Telephone System (3)

Major Components

1. Local loops analog twisted pairs to houses, businesses).
2. Trunks (digital fiber optic links between switching offices).
3. Switching offices (calls are moved from one trunk to another).

Telephone Modems



Use of both analog and digital transmission for computer -to-computer call. Conversion done by modems and codecs.

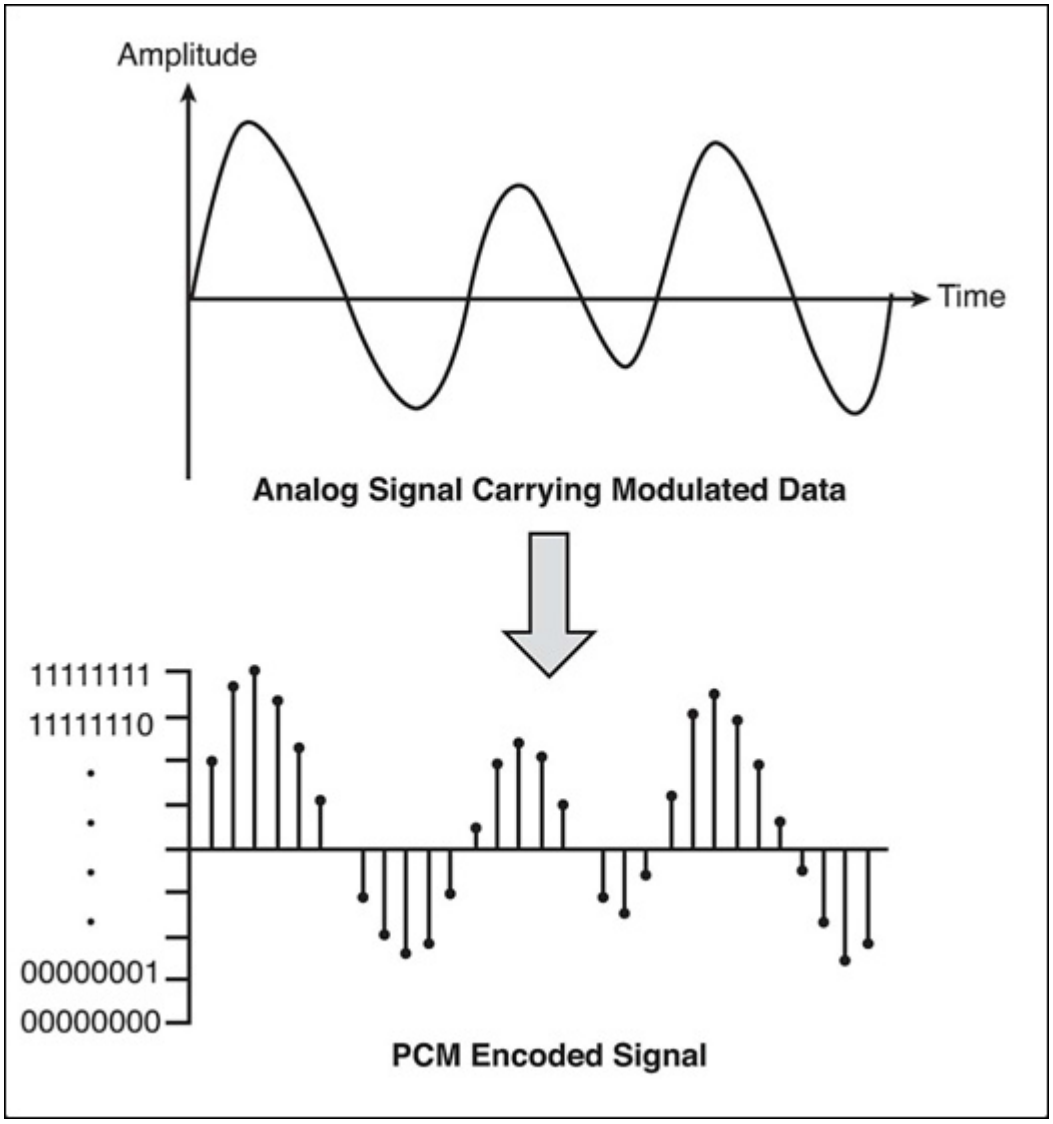
MODEM

- Modem
  - *Mod*ulator-*Dem*odulator
  - Send bits between two hosts over a voice-grade telephone line
  - Use modulation techniques (QPSK, QAM*) to transport bits through an analog signal

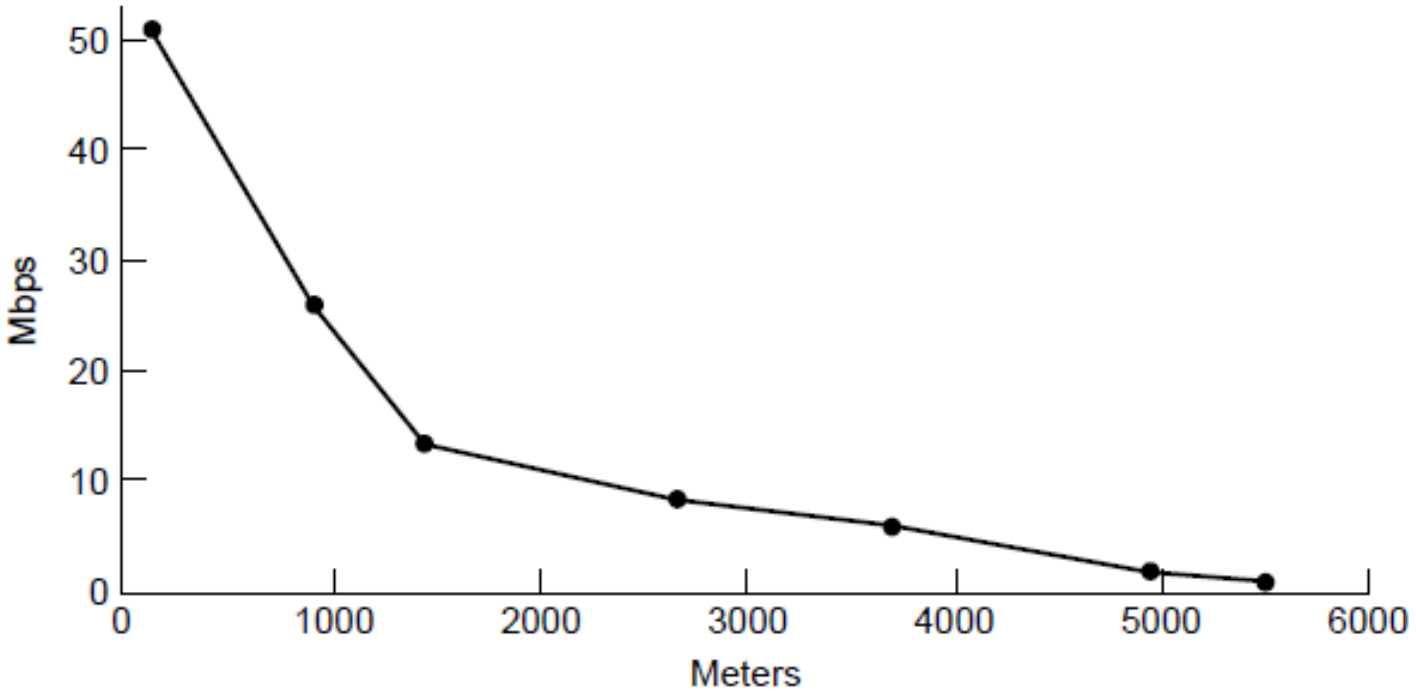
CODEC

- Codec
  - *Cod*er-*Dec*oder
  - Change an analog signal in a discrete one (and viceversa)
  - Use PCM

Pulse Code Modulation (PCM)

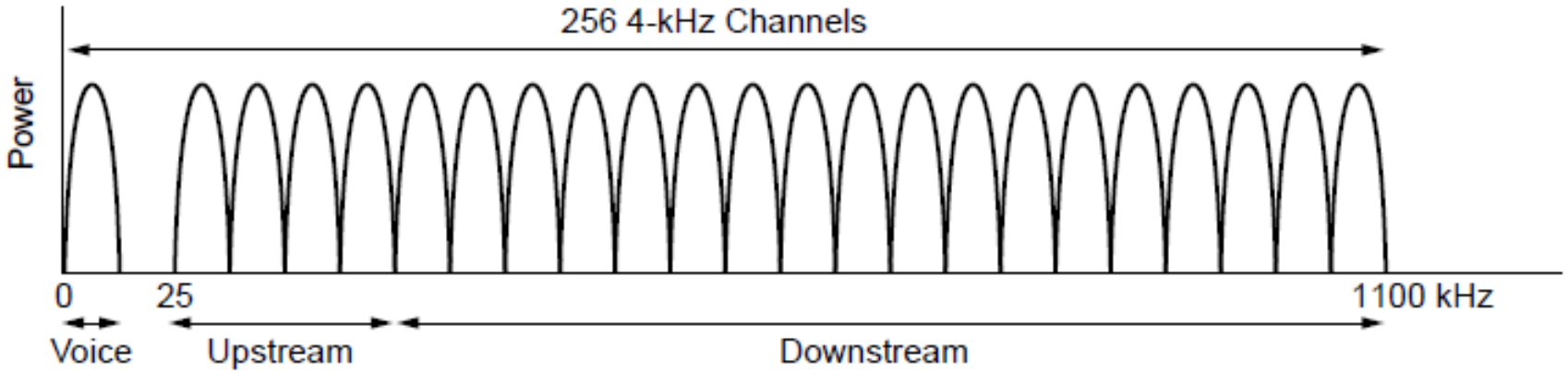


Digital Subscriber Lines (1)



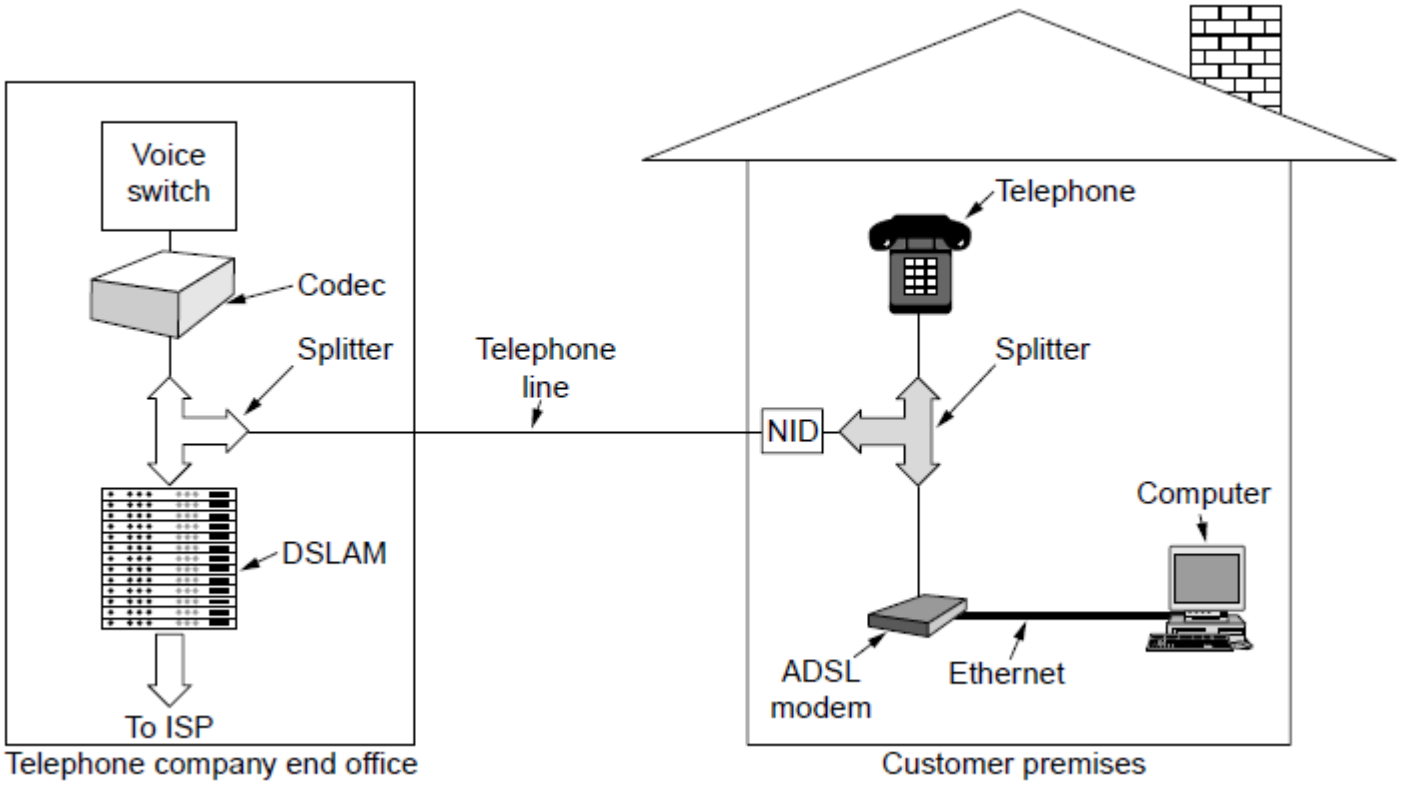
Bandwidth versus distance over Category 3 UTP for DSL.

Digital Subscriber Lines (2)



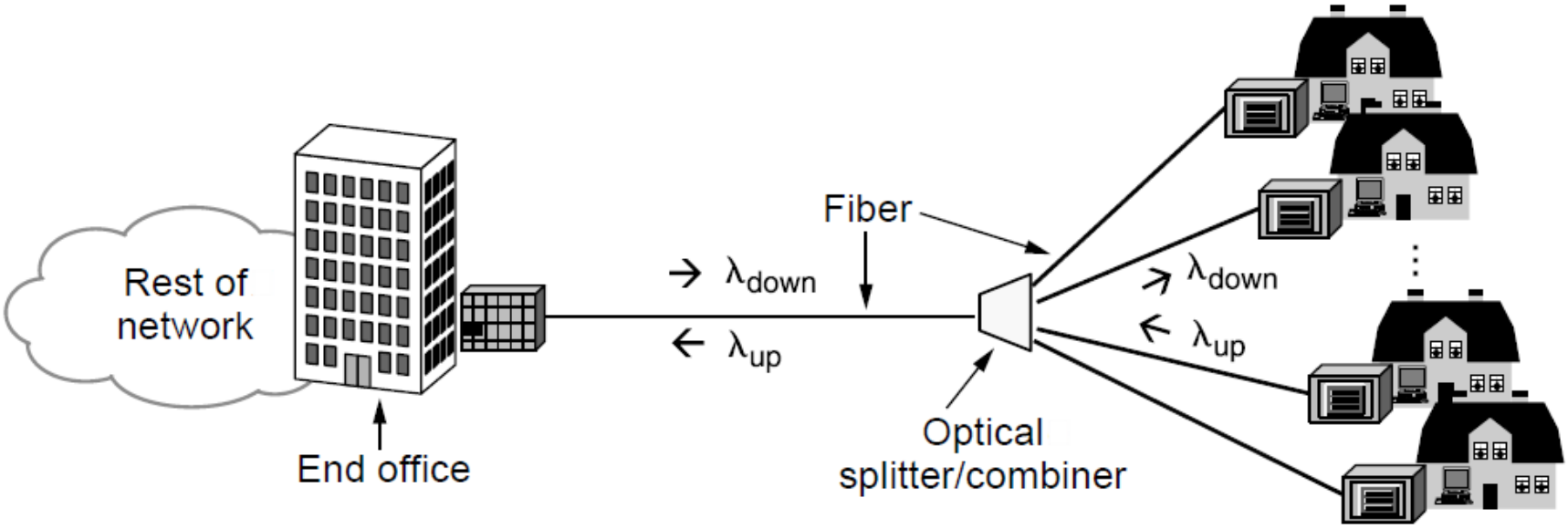
Operation of ADSL using discrete multitone modulation (a special type of FDM).

Digital Subscriber Lines (3)



A typical ADSL equipment configuration.

Fiber To The Home



Passive optical network for Fiber To The Home.

End

Chapter 2