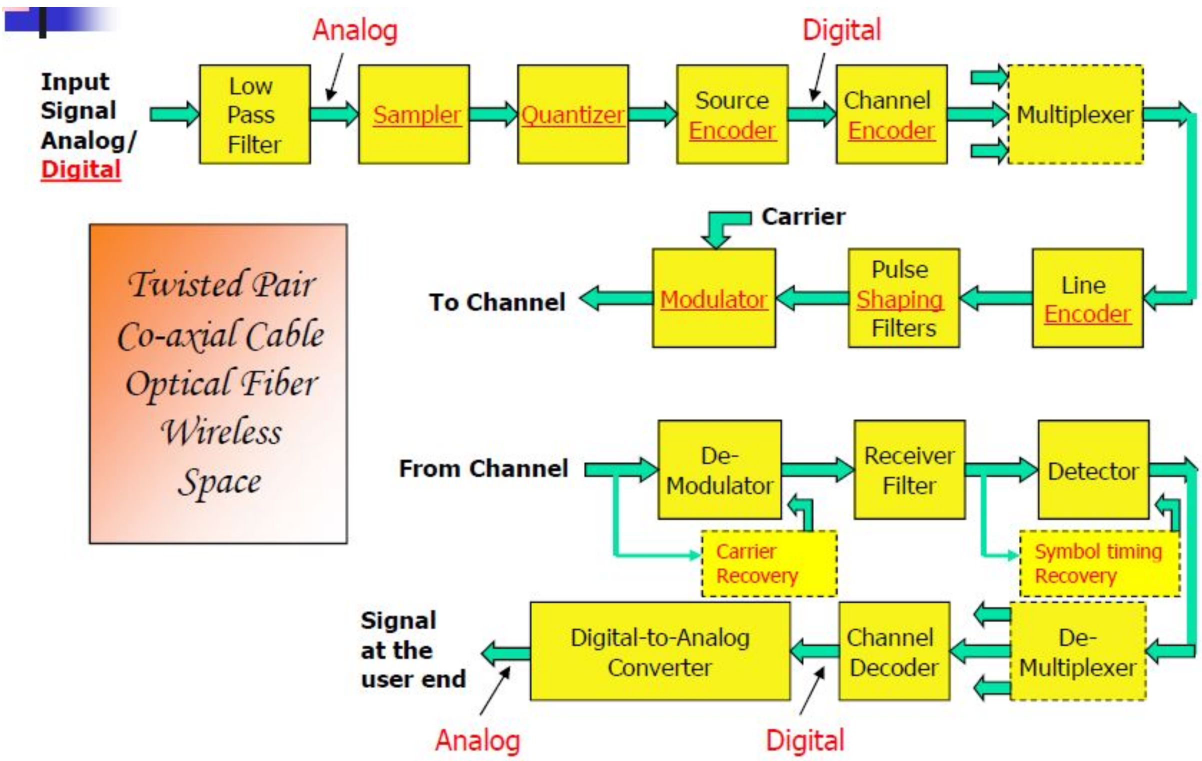
1. Transmission Fundamentals



1.1 Signals

Time Domain Concepts

Electromagnetic: function of time

$$s(t) = A_t \sin(2\pi f_t t + \varphi_t)$$

Analog: A continuously varying electromagnetic wave that may be propagated over a variety of media, depending on frequency; can propagate analog and digital data

Digital: maintains a constant level for some period of time and then to another constant; A sequence of voltage pulses that may be transmitted over a copper wire medium; cheaper, less susceptible, suffer more from attenuation; can propagate analog and digital data

Periodic: signal that repeats over time periodically

$$s(t+T) = s(t) \quad -\infty < t < +\infty$$

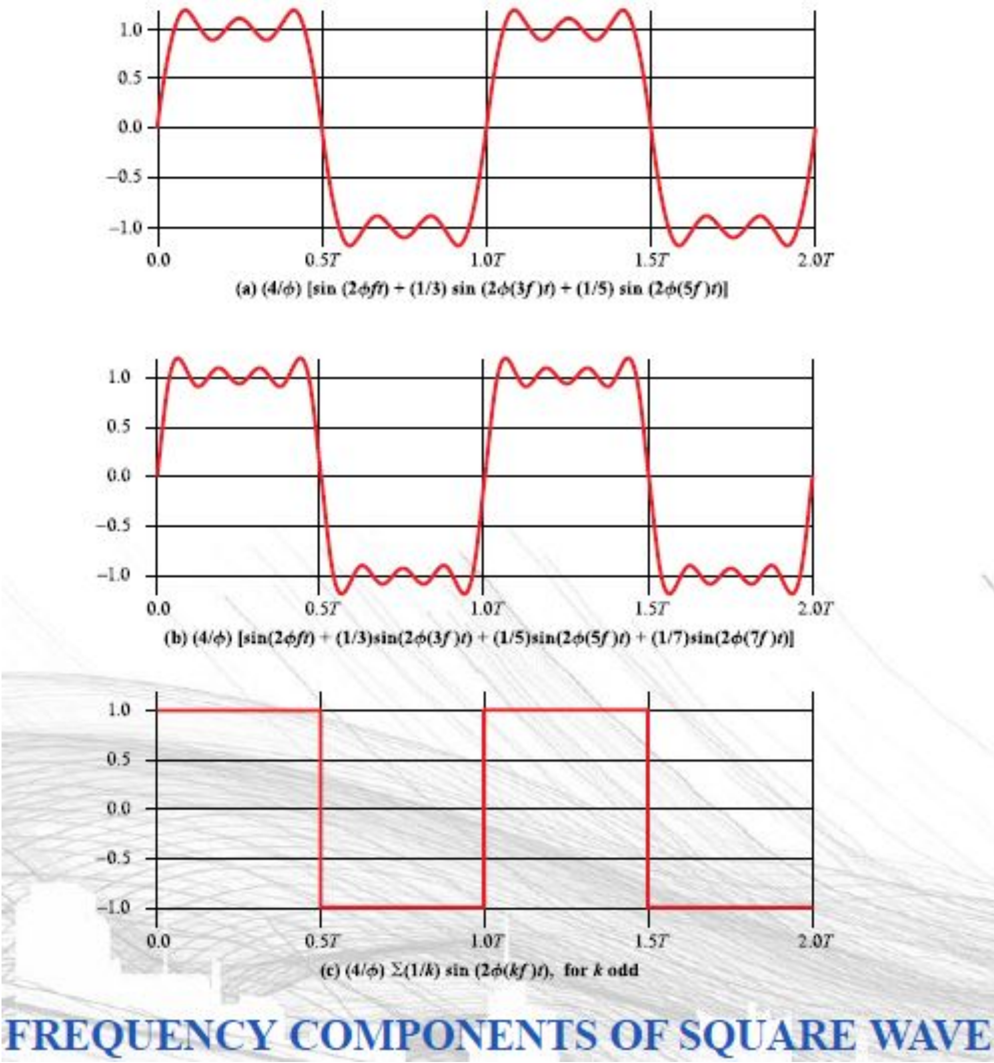
Frequency-Domain Concepts

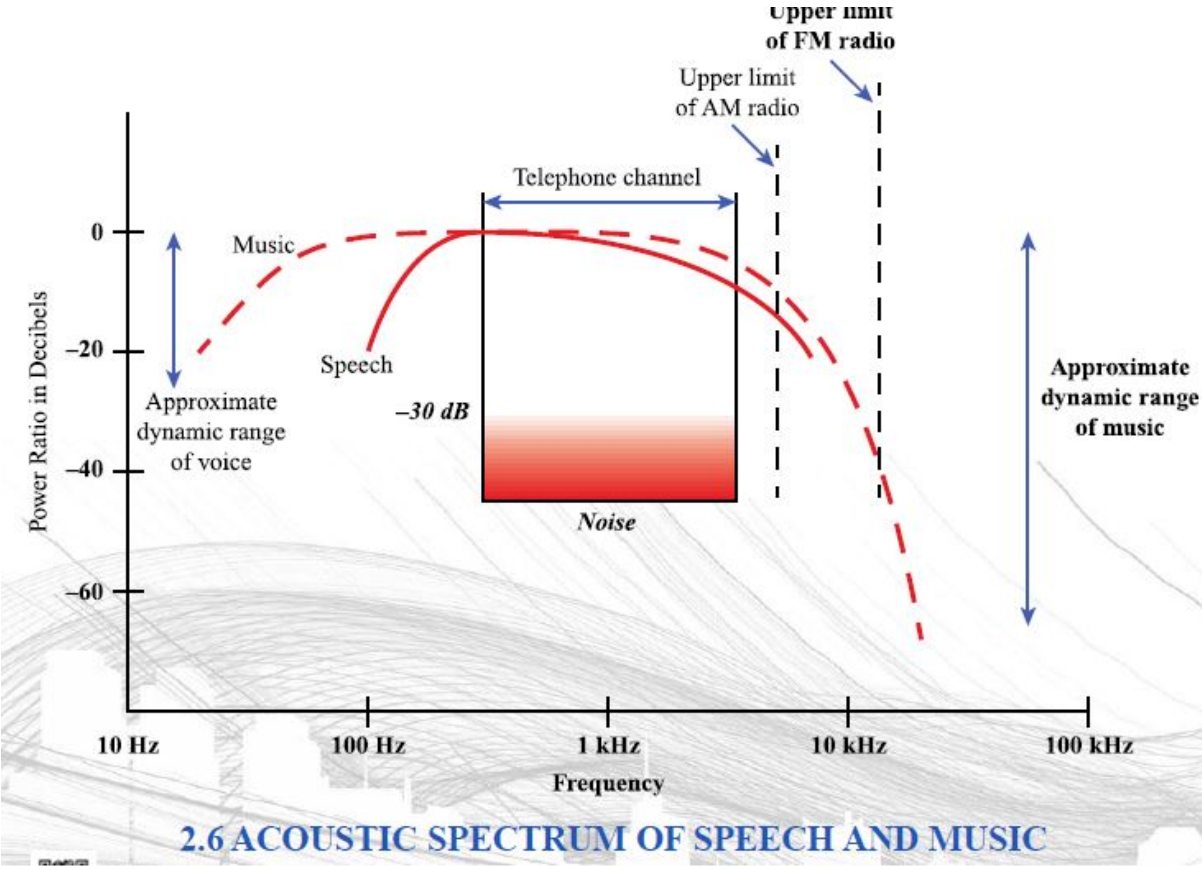
Fundamental frequency: when every frequency is multiple of one frequency

Spectrum: range of frequencies

Absolute bandwidth: width of the spectrum

Effective bandwidth: band of frequencies

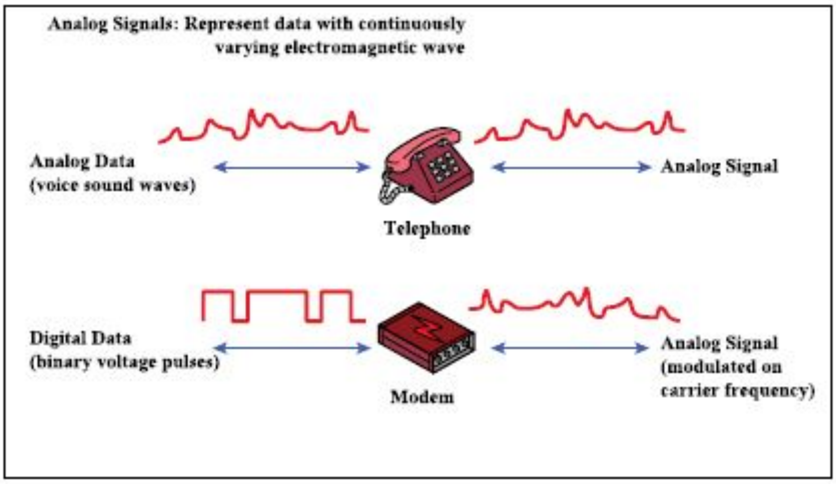


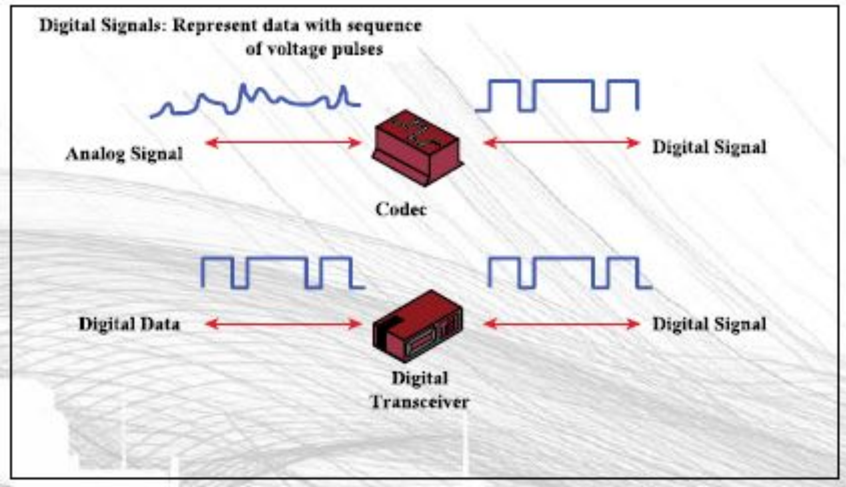


The greater the bandwidth, the higher the
information-carrying capacity

- **Conclusions**
  - – Any digital waveform will have infinite bandwidth
  - – BUT the transmission system will limit the bandwidth that can be transmitted
  - – AND, for any given medium, the greater the bandwidth transmitted, more cost
  - – HOWEVER, limiting the bandwidth creates distortions

REASONS FOR CHOOSING DATA AND SIGNAL COMBINATIONS





1.2 ANALOG AND DIGITAL TRANSMISSION

Analog

transmit without regard to content; can be amplified but distorted (errors)

Digital

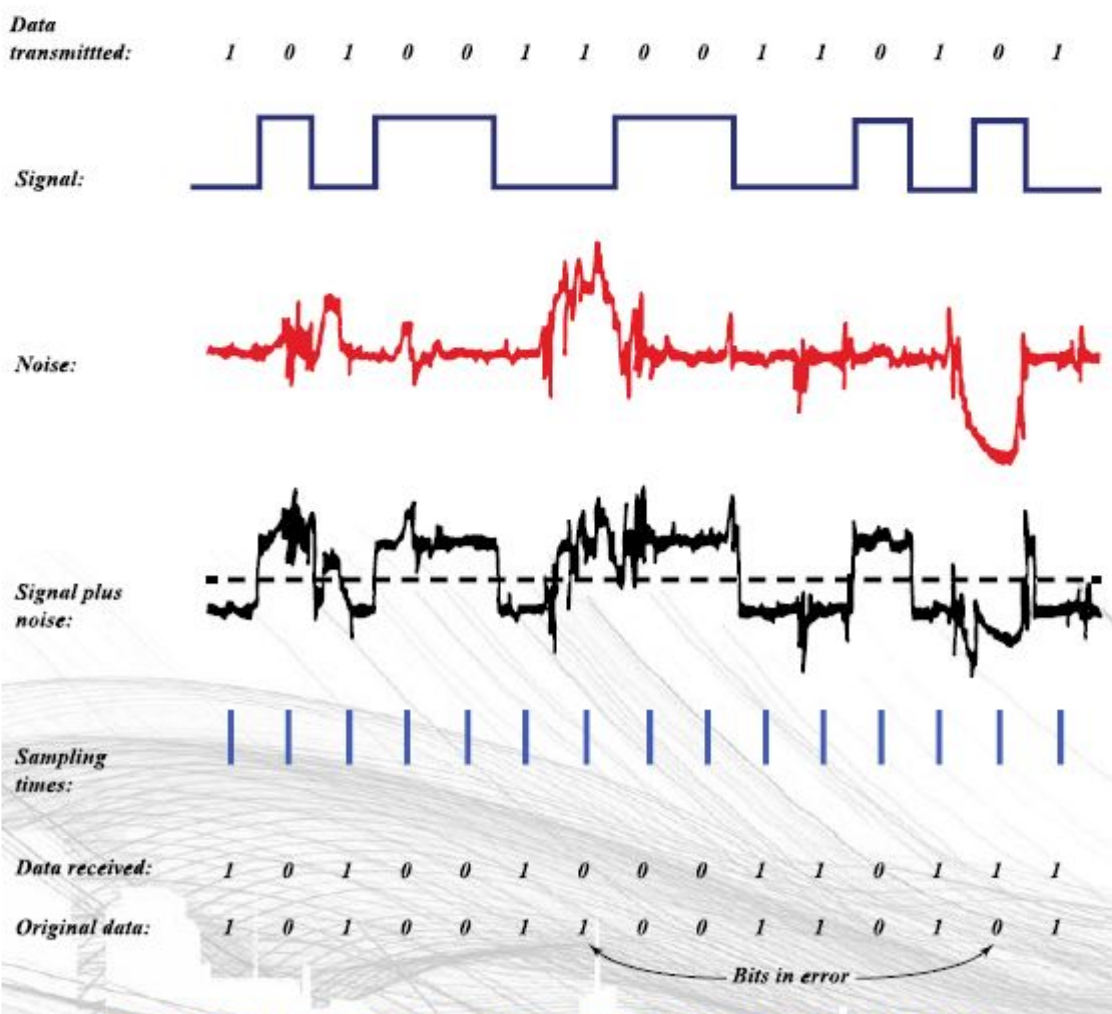
Attenuation endangers integrity of data:

- **Digital signal**: repeaters achieve greater distance and recover signal and retransmit
- **Analog signal**: retransmission device recovers digital data from analog signal; generates new, clean

Noise: limit data rate

1.3 Channel Capacity

The maximum rate at which data can be transmitted



2.9 EFFECT OF NOISE ON DIGITAL SIGNAL

NYQUIST BANDWIDTH

- For binary signals (two voltage levels)
  - $C = 2B$
- With multilevel signaling
  - $C = 2B \log_2 M$
  - M = number of discrete signal or voltage levels

SIGNAL-TO-NOISE Ratio

Ratio of the power in a signal to the power contained in the noise

$$(SNR)_{dB} = 10\log_{10}\frac{\text{signal power}}{\text{noise power}}$$

SHANNON CAPACITY FORMULA

- Equation:

$$C = B\log_2(1+\text{SNR})$$

- Represents theoretical maximum that can be achieved; in practice only lower rates achieved

EXAMPLE OF NYQUIST AND SHANNON FORMULATIONS

Spectrum of a channel between 3 MHz and 4 MHz ; $\text{SNR}_{\text{dB}} = 24$ dB

$$B = 4\,\text{MHz} - 3\,\text{MHz} = 1\,\text{MHz}$$

$$\text{SNR}_{\text{dB}} = 24\,\text{dB} = 10\log_{10}(\text{SNR})$$

$$\text{SNR} = 251$$

Using Shannon's formula

$$C = 10^6 \times \log_2(1+251) \approx 10^6 \times 8 = 8\text{Mbps}$$

How many signaling levels are required?

$$C = 2B\log_2 M$$

$$8\times10^6 = 2\times\left(10^6\right)\times\log_2 M$$

$$4 = \log_2 M$$

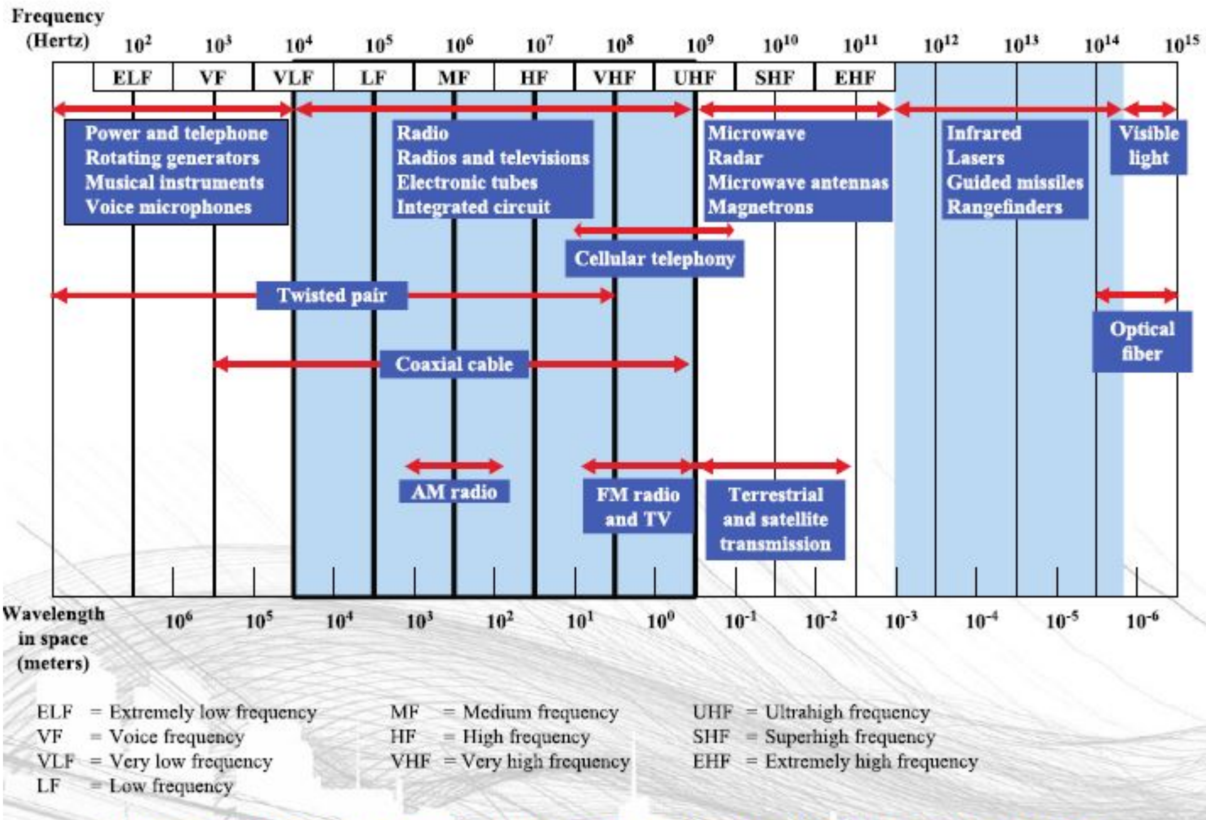
$$M = 16$$

1.4 TRANSMISSION MEDIA

Trans. medium: physical path

Guided media: waves are guided along a solid medium

Unguided media: does not guide electromagnetic signals (wireless), use of antennas



2.10 ELECTROMAGNETIC SPECTRUM OF TELECOMMUNICATIONS

TERRESTRIAL MICROWAVE

LUNGO TIRO

Parabolic "dish", 3m in diameter

- applications: long haul TLCs; ptp links between buildings

SATELLITE MICROWAVE

link ground-based microwave transmitter/receivers;

uplink: receiving frequency

downlink: transmitting frequency

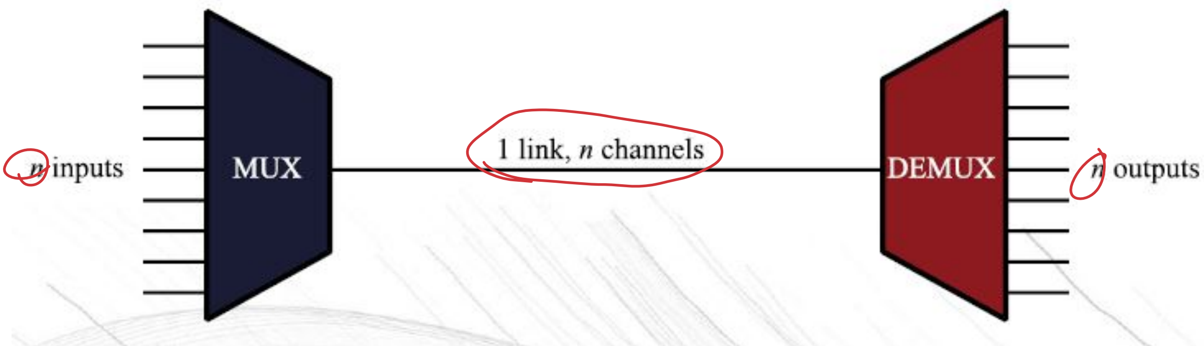
BROADCAST RADIO

Omnidirectional, rigidly mounted alignment antennas

- applications: broadcast radio

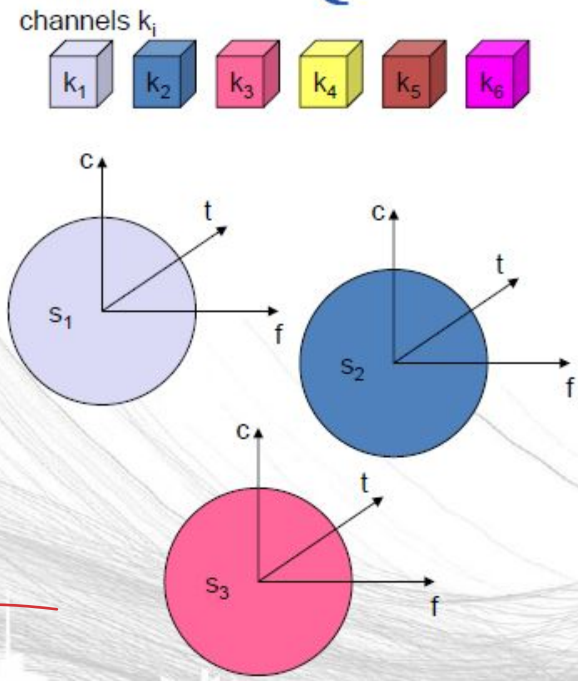
1.5 MULTIPLEXING

Carry multiple signals on a single medium; more efficient use of transmission medium



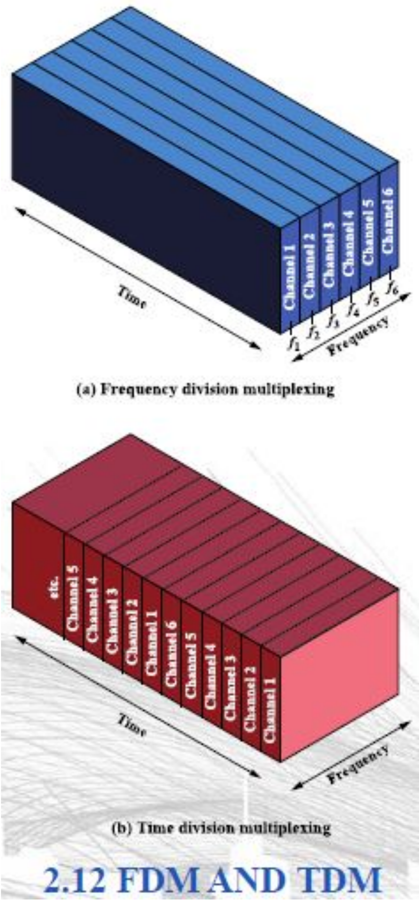
multiplexing widespread because with an increase of data rate, decline cost per kbps

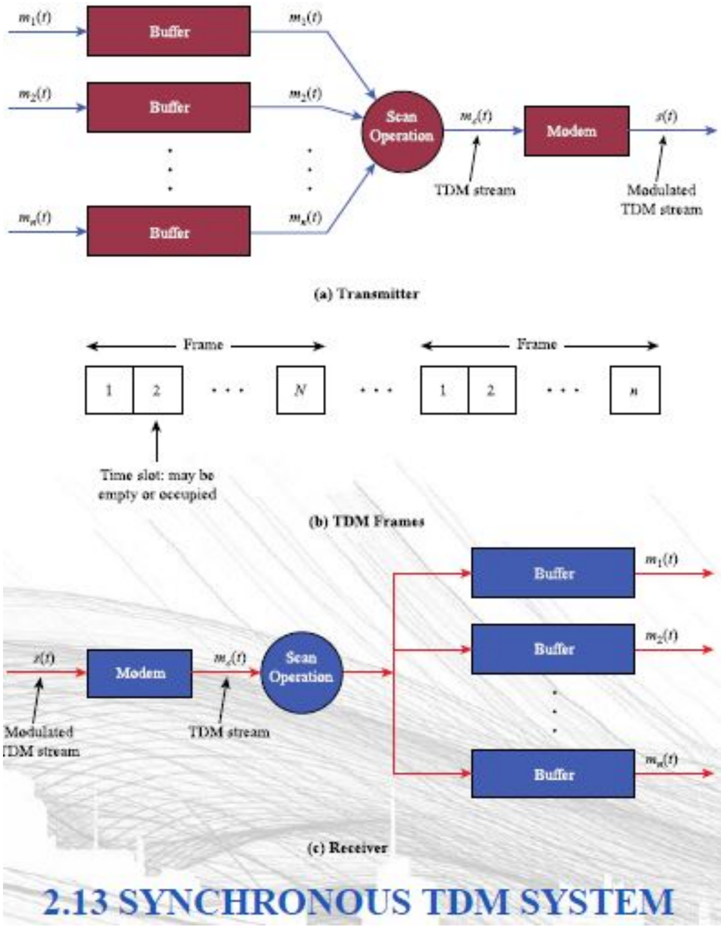
MULTIPLEXING TECHNIQUES



- Multiplexing in 4 dimensions
  - space (s_i)
  - time (t)
  - frequency (f)
  - code (c)
- Goal: multiple use of a shared medium
- Important: guard spaces needed!

- **Frequency-division multiplexing (FDM)**
  - Takes advantage that the useful bandwidth of the medium exceeds the required.
- **Time-division multiplexing (TDM)**
  - Takes advantage that the achievable bit rate of the medium exceeds the required data


Channel 1
Channel 2
Channel 3
Channel 4
Channel 5
Channel 6
Time
Frequency
(a) Frequency division multiplexing
etc.
Channel 5
Channel 4
Channel 3
Channel 2
Channel 1
Channel 6
Channel 5
Channel 4
Channel 3
Channel 2
Channel 1
Time
Frequency
(b) Time division multiplexing
2.12 FDM AND TDM


Buffer
Buffer
Buffer
Scan Operation
Modem
TDM stream
Modulated TDM stream
(a) Transmitter
Frame
Frame
Time slot: may be empty or occupied
(b) TDM Frames
Modem
Scan Operation
Buffer
Buffer
Buffer
Modulated TDM stream
TDM stream
(c) Receiver
2.13 SYNCHRONOUS TDM SYSTEM