Redes de Computadores

The Physical Layer

Manuel P. Ricardo

Faculdade de Engenharia da Universidade do Porto

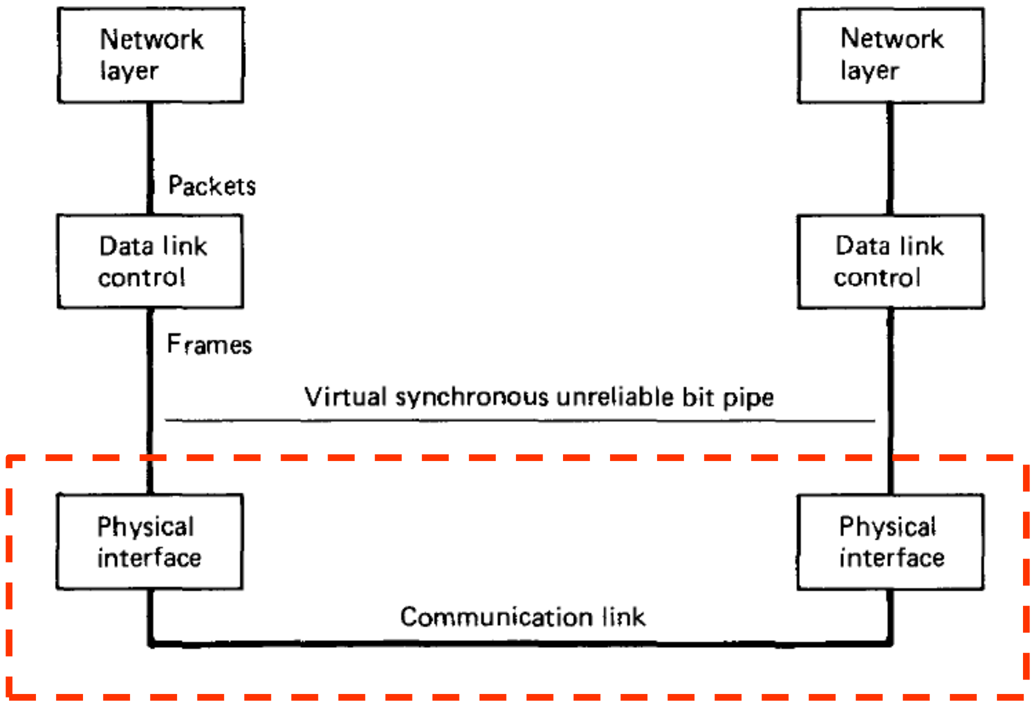
- *What service does the Physical Layer offer to Data Link Layer?*
- *How to encode a sequence of bits into an analogue signal?*
- *Why does the received signal r(t) differ from the transmitted signal s(t)?*
- *What is the difference between baudrate and bitrate?*
- *What are the advantages of the Manchester code over the NRZ code?*
- *What are the common digital modulations?*
- *What is the maximum capacity of a communications channel?*
- *What types of media exist and what are their main characteristics?*
- *What is dB, dBW, dBm, Gain, and Attenuation?*
- *How does the attenuation of a wireless channel vary with distance and wavelength?*

Service Provided by the Physical Layer

Physical layer → aqui vai estar o canal rádio/cabo
→ canal real que serve para fazer comunicação de um lado para o outro

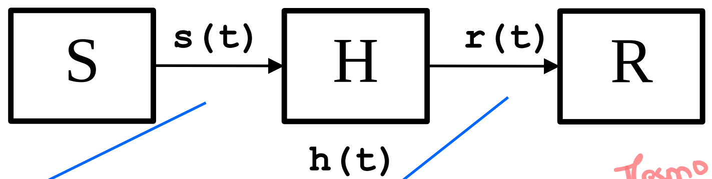
- » real communication channels used by the network
- » interfaces required to transmit and receive digital data
- » appears to higher layers as an unreliable virtual bit pipe

Para o canal superior vai ser um tubo que pode perder informação



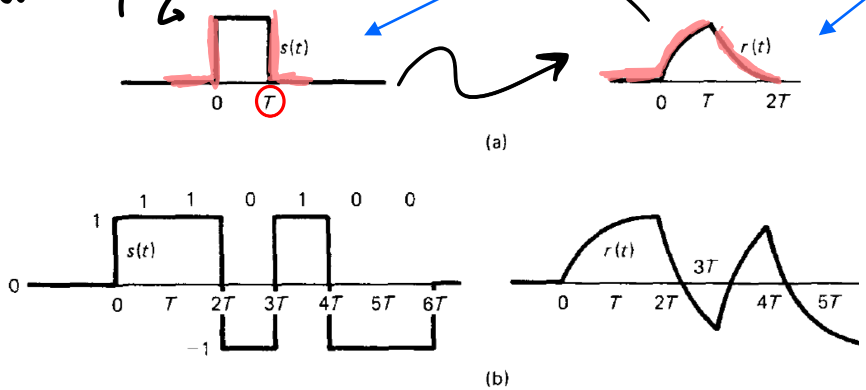
Transmission Channel Modifies Input Signal **s(t)**

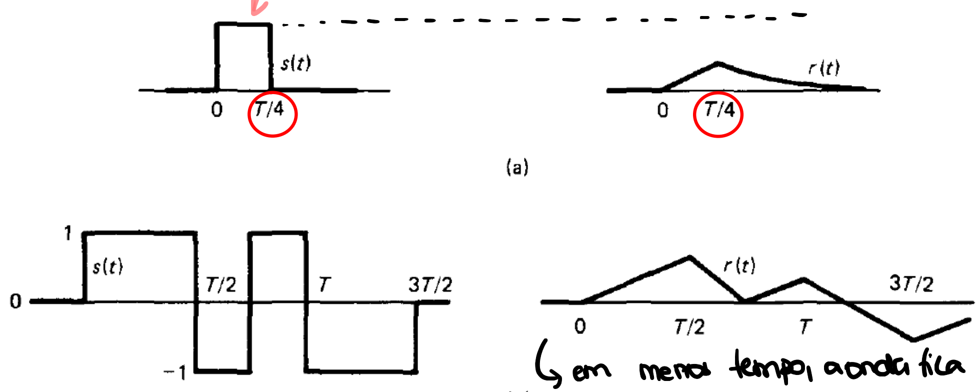
Vai levar algum tempo a mudar de níveis.
Não é instantâneo como aqui



Mesmo sistema
Transição + rápida

O canal pode não ter tempo para atingir o nível desejado





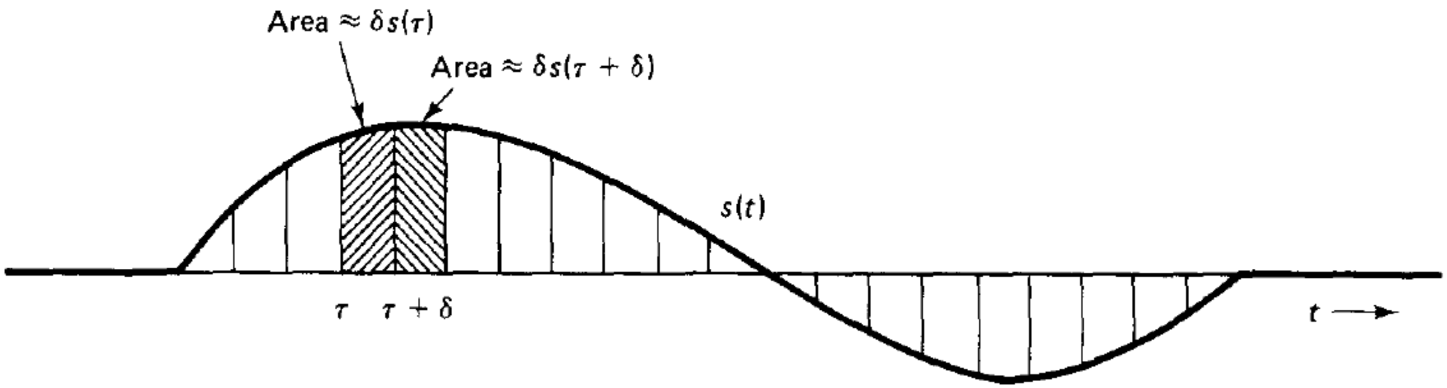
↳ em menos tempo, a onda fica + diferente da onda transmitida

Figure 2.3 Relation of input and output waveforms for a communication channel with filtering. Part (a) shows the response $r(t)$ to an input $s(t)$ consisting of a rectangular pulse, and part (b) shows the response to a sequence of pulses. Part (b) also illustrates the NRZ code in which a sequence of binary inputs (1 1 0 1 0 0) is mapped into rectangular pulses. The duration of each pulse is equal to the time between binary inputs.

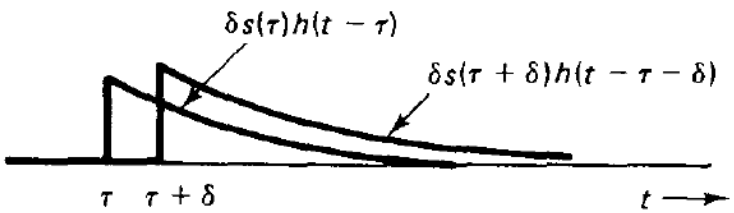
Figure 2.4 Relation of input and output waveforms for the same channel as in Fig. 2.3. Here the binary digits enter at 4 times the rate of Fig. 2.3, and the rectangular pulses last one-fourth as long. Note that the output $r(t)$ is more distorted and more attenuated than that in Fig. 2.3.

Há sistemas que reagem mais Rapidamente

$\mathtt{r(t)}$ *is the convolution of* $\mathtt{s(t)}$ *and* $\mathtt{h(t)}$



Impulso que vamos, instantaneā
mente colocado no canal h(t)



$$r(t) = \int_{-\infty}^{+\infty} s(\tau) h(t - \tau) d\tau$$

Sinal recebido é a convulsão do sinal enviado

The Fourier Transform

- Using Fourier transforms

Canal de transmissão

sinais enviados

$$S(f) = \int_{-\infty}^{+\infty} s(\tau) e^{-j2\pi f\tau} d\tau \qquad H(f) = \int_{-\infty}^{+\infty} h(\tau) e^{-j2\pi f\tau} d\tau$$

$t \rightarrow f$

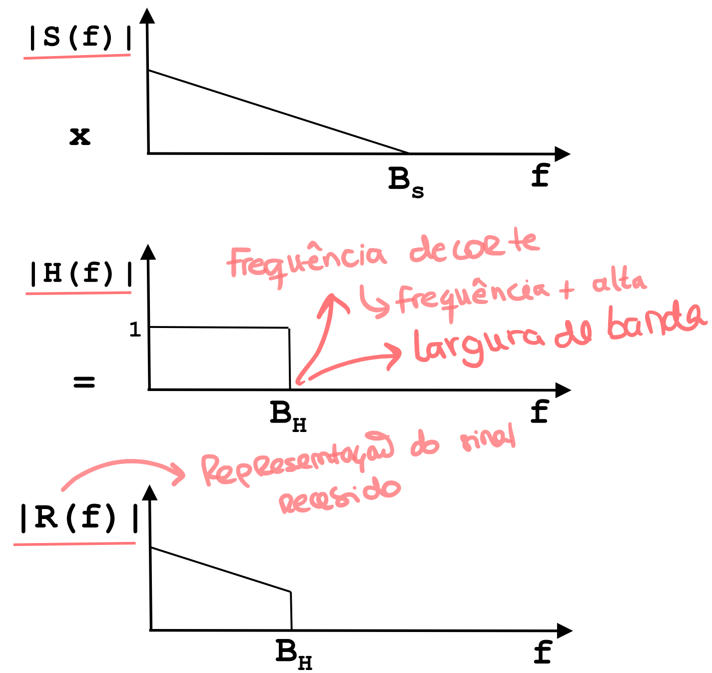
and, in the frequency domain

Resposta e frequência do canal de transmissão

$$R(f) = S(f) \times H(f)$$

sinal recebido

↳ sinal enviado

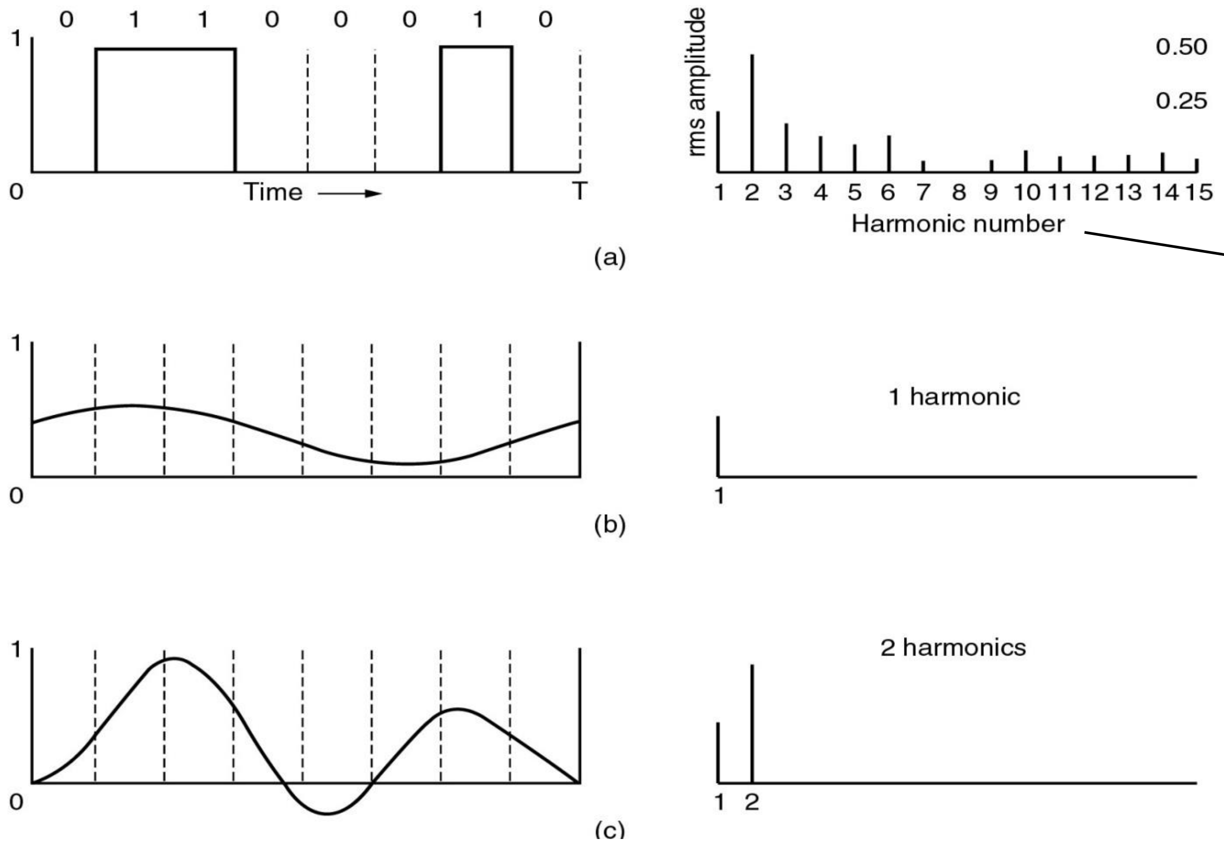


- Thus, **`r(t)`** depends on $\mathbf{B_H}$

$$\underbrace{r(t) = \int_{-\infty}^{+\infty} R(f) e^{j2\pi ft}}_{\text{transformada inversa}} df = \int_{-B_H}^{+B_H} R(f) e^{j2\pi ft} df$$

$f \rightarrow t$

Bandwidth-Limited Signals

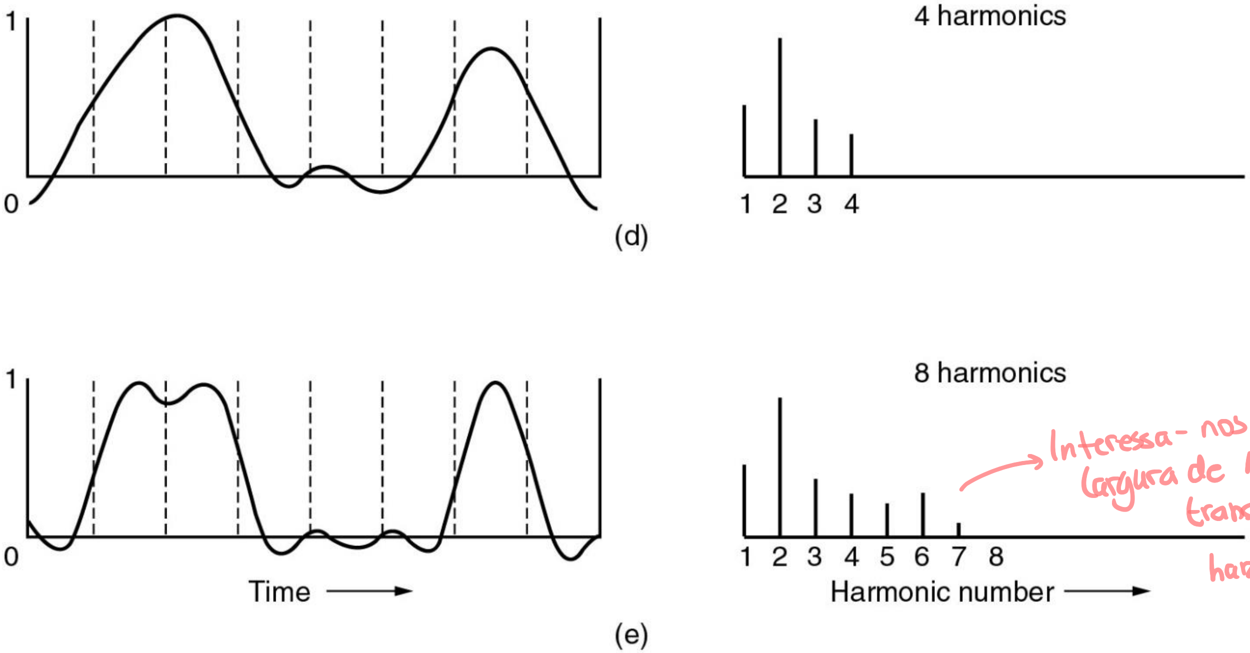


$\frac{i}{T}$ *Hz*

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

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

Bandwidth-Limited Signals



Interessa-nos uma boa largura de banda para transmitir vários harmónicos

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

Reconstructing de Signal the Receiver

- In digital communications, the receiver
  - » samples r(t) in order to decide about the bits transmitted
- Nyquist showed that
  - » a signal r(t) having a bandwidth B Hz
  - » can be fully reconstructed
  - » if sampled at rate 2B sample/s
  - » sampling at higher rate does not provide additional information

Transmitting Information

Onda de tensão que varia entre

2 níveis

- Let us assume
  - » a square ware v(t) alternating between -5 V (bit 0) and 5 V (bit 1),
  - » passing through a lowpass channel B_H=3 kHz

freq. de corte → sinal recebido não pode ter frequência superior a essa

- If receiver samples the signal at $2B_H$ = 6 ksample/s, it receives
  - » a bitrate of $C=2.B_H$ = 6 kbit/s (1 sample - 1 bit of information)

Aproximação inicial ao débito

Por cada amostra quantos bits são transmitidos

$$\overbrace{C = 2B\log_2(M)}$$

- However,
  - » if M=4 levels are used to encode information
    - – -5V(00) , -2V(01) , 2V(10), 5V(11)

A cada nível transmitem-se 2 bits

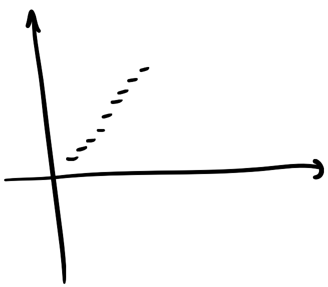
  - » Then, the channel capacity becomes $C = 2B\log_2(M) = 2\times 3k \times 2 = 12kbit/s$

4 canais → 2 bits por sinal

  - » **2B expresses the channel baudrate in symbol/s or baud**

To Think

- Can we transmit an infinite number of bit/s in a channel of bandwidth B= 3 kHz by increasing the number of levels M?

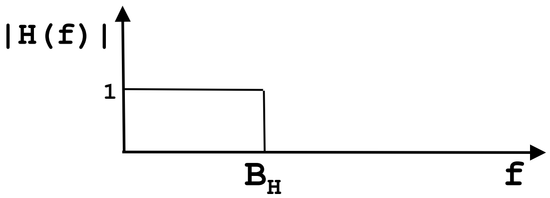


$$C = 2B\log_2(M)$$

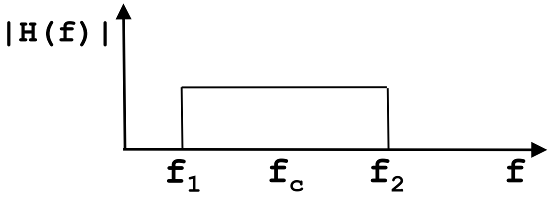
Não é possível, pois se tivermos um número muito grande de níveis, quando fazemos a transmissão para o receptor, pode haver ruído (sinal um pouco + a cima ou + baixo) e como com muitos canais, os níveis são muito pequenos, o sinal pode ser mal interpretado → Probabilidade de erro aumenta

Baseband / Passband Transmission

- Baseband transmission
  - signal has frequencies from zero up to a maximum B_H
  - common for wires

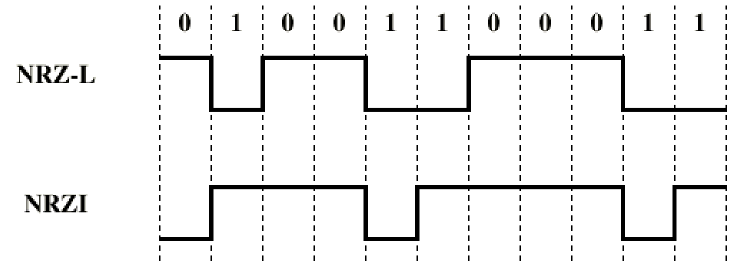


- Passband transmission
  - signal uses band of frequencies around the **frequency of the carrier f_c**
  - common for wireless and optical channels



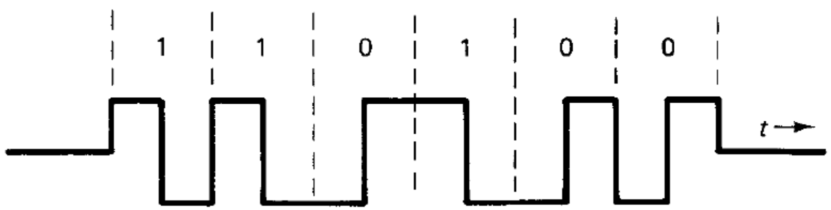
Baseband Transmission - Common Codes

- NRZ-L (Non Return to Zero - Level)
  - » Two levels representing 0 and 1



- NRZ-I (Non Return to Zero - Inverted)
  - » Change of level represents a 1

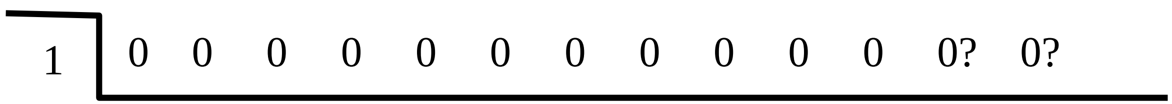
- **Manchester**
  - » Transition in the middle of the bit
  - » 1: positive → negative
  - » 0: negative → positive
  - » Used in Ethernet (IEEE 802.3)



- There are many codes …

Clock Recovery

- To decode the symbols, signals need sufficient transitions
  - Otherwise long runs of 0s (or 1s) are confusing, e.g.:

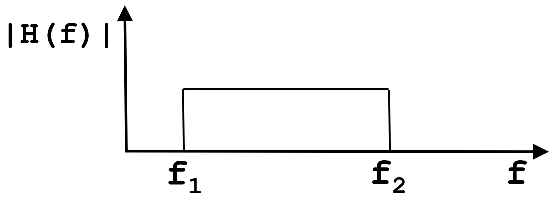


- Strategies:
  - Manchester coding, mixes clock signal in every symbol
  - 4B/5B maps 4 data bits to 5 coded bits with 1s and 0s:

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

Bandpass Transmission

- Some physical channels are bandpass

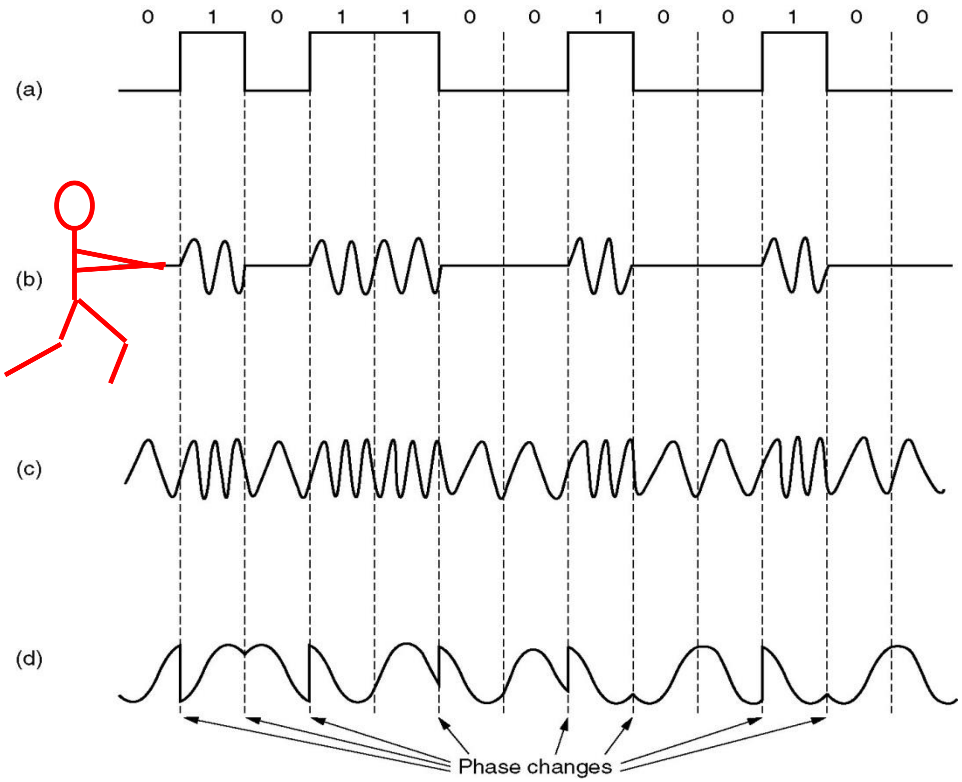


- Technique used to enable **`s(t)`** to pass through **`h(t)`**
  - » Modulation

To Think

- How to transmit bits using a continuous carrier?

Types of Modulations



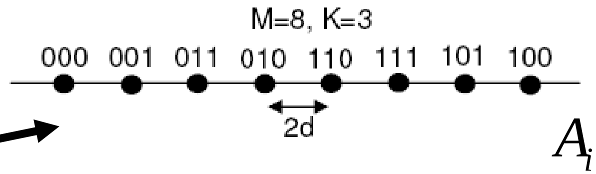
(a) A binary signal

(b) Amplitude modulation

(c) Frequency modulation

(d) Phase modulation

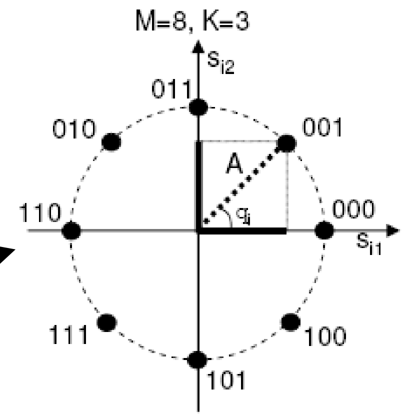
Amplitude and Phase Modulations



- Amplitude Modulation

  information coded in the carrier's amplitude

  $$s(t) = A_i \cos(2\pi f_c t)$$

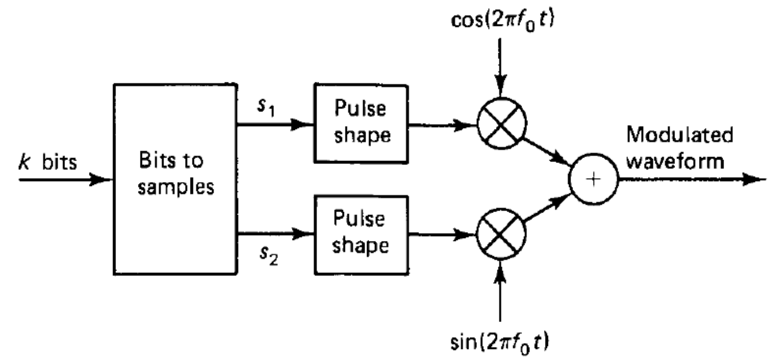


- Phase Modulation

  information coded in carrier's phase

  $$s(t) = A\cos(\theta_i + 2\pi f_c t)$$

$$\begin{aligned} s(t) &= A\cos(\theta_i + 2\pi f_c t) = \\ &= A\cos(\theta_i)\cos(2\pi f_c t) - A sen(\theta_i) sen(2\pi f_c t) = \\ &= s_1(t)\cos(2\pi f_c t) + s_2(t) sen(2\pi f_c t) \end{aligned}$$



(a) Modulator

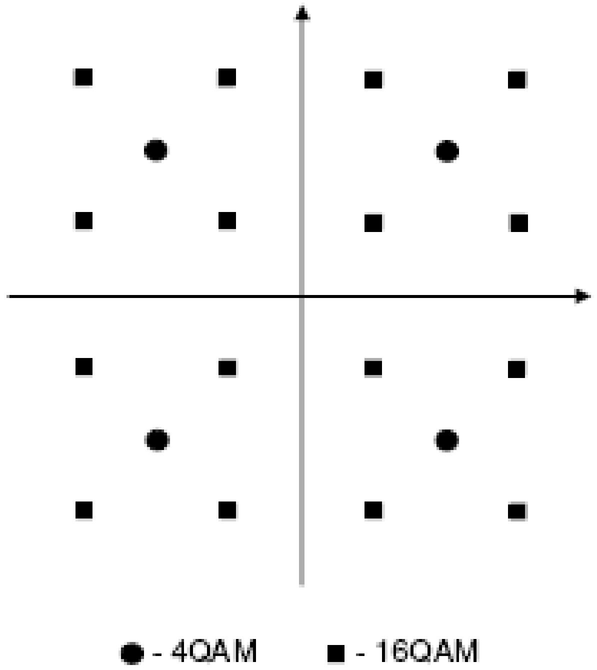
- $K = log_2 M$ bits sent over a time symbol interval

Quadrature Amplitude Modulation

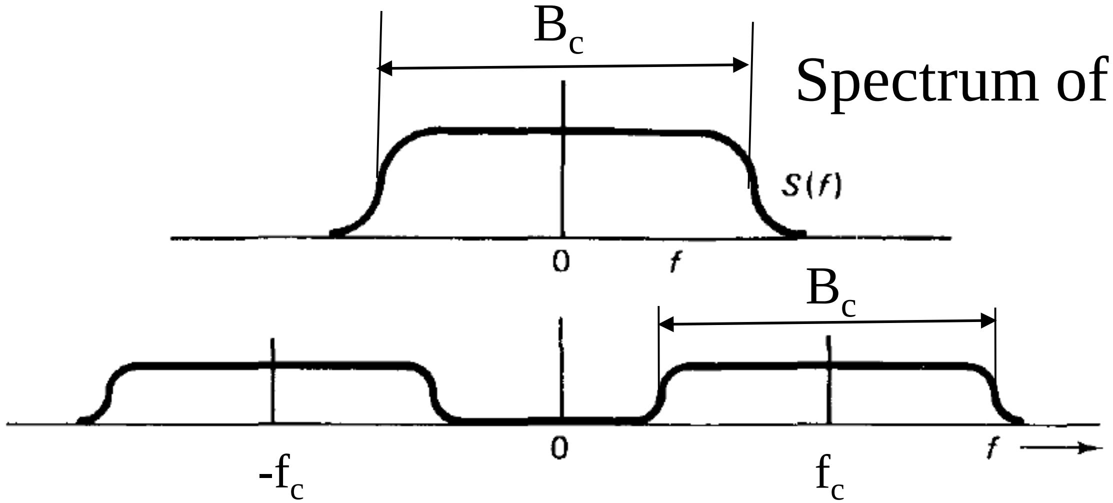
- Quadrature Amplitude Modulation (M-QAM)

  information coded both in amplitude and phase

$$s(t) = A_i \cos\left(\theta_i + 2\pi f_c t\right)$$



Amplitude Modulation - Representation in the Frequency domain



Spectrum of original signal A(t)

Spectrum of the modulated signal

Shannon's Law

- Noise imposes the limit on the number levels M (bit/symbol)
  - » Noise high ➔ low M
  - » or, high Signal to Noise Ratio (SNR) ➔ high M

- Maximum theoretical capacity of a channel, C (bit/s)

$$C = B_c \log_2\left(1 + \frac{P_r}{N_0 B_c}\right)$$

  - » B_c – bandwidth of the channel (Hz) (see last slide)

    B_c = sampling rate
  - » P_r – signal power as seen by receiver (W)
  - » N_0B_c - noise power within the bandwidth B_c, as seen by receiver (W)
  - » N_0 – White noise; noise power per unit bandwidth (W/Hz)

Example

- If a bandpass channel has a bandwidth B_c= 100 kHz and Signal to Noise ratio (SNR) at the receiver is
  - $P_r/(N_0B_c)=7$ ➔ $C = 100k \log_2(1+7) = 300 kbit/s$
  - $P_r/(N_0B_c)=255$ ➔ $C = 100k \log_2(1+255) = 800 kbit/s$
- Power expressed in **W**, **dBW**, or **dBm**
  - $P_{dBW}=10 \log_{10}P$: P=100mW ➔ $P_{dBW}=10 \log_{10}(100*10^{-3})=$ -10 dBW
  - $P_{dBm}=10 \log_{10}(P/1mW)$: P=100mW ➔ $P_{dBm}=10 \log_{10}(100)=$ 20 dBm

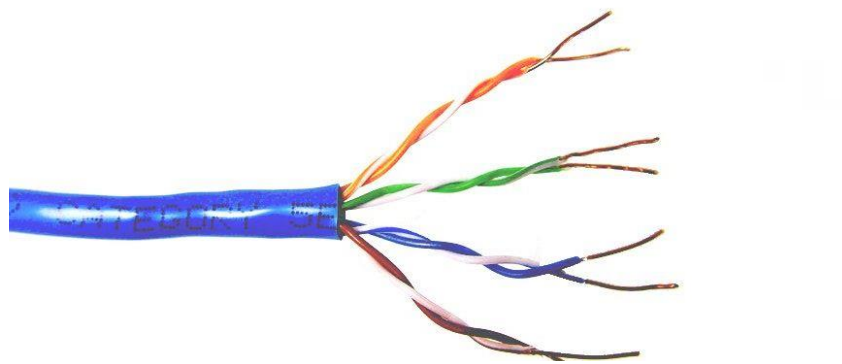
Guided Transmission

- Twisted Pair
- Coaxial Cable
- Fiber Optics

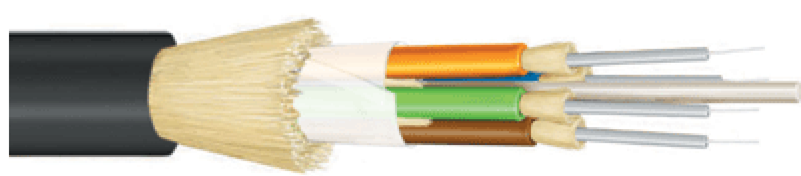
Guided Transmission

- Coaxial cable

- Unshielded twisted pair



- Fiber optic



Twisted Pair

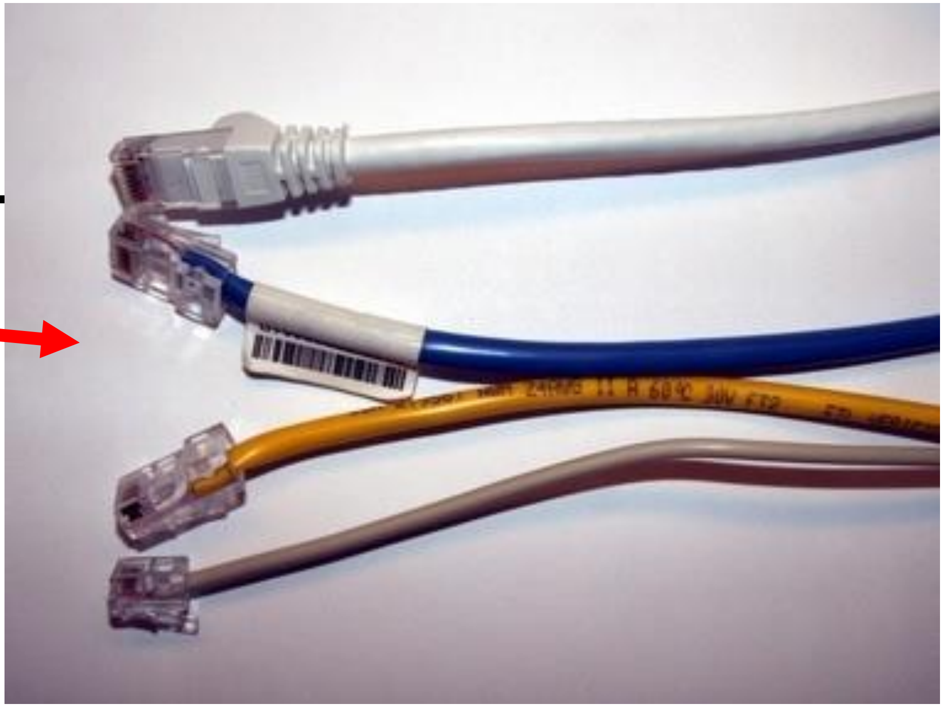
(a)

(b)

(a) Category 3 UTP.

(b) Category 5 UTP.

UTP Cables



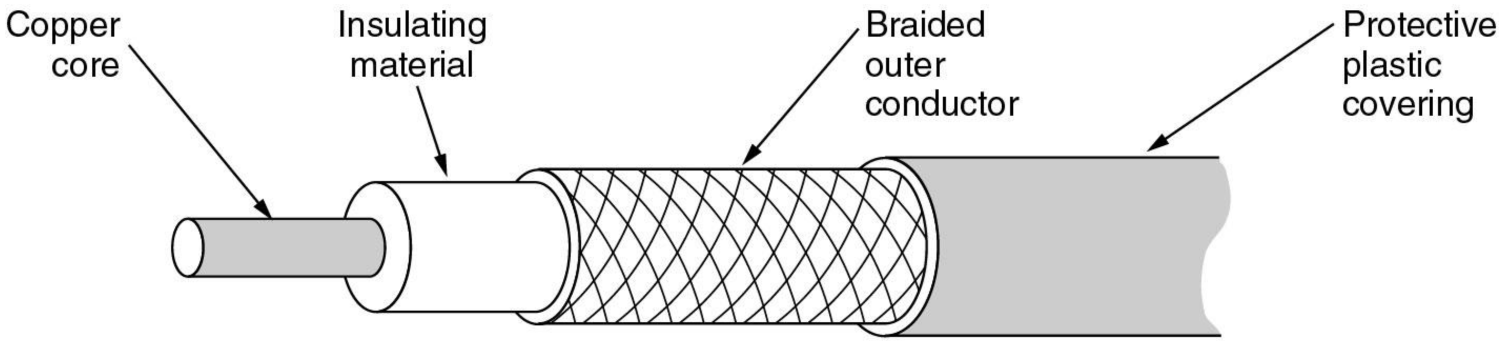
- From top to bottom:
  Cat. 6, Cat. 5e, Cat. 5, Cat. 3
- Cat 3, 16 MHz bandwidth
- Cat. 5 / 5e, 100MHz
- Cat. 6, 250MHz
- Cat. 6a, 500MHz
- Cat. 7, 600MHz
- Typical attenuations 2 – 25 dB/100 m

dB, dBm, Gain, Attenuation

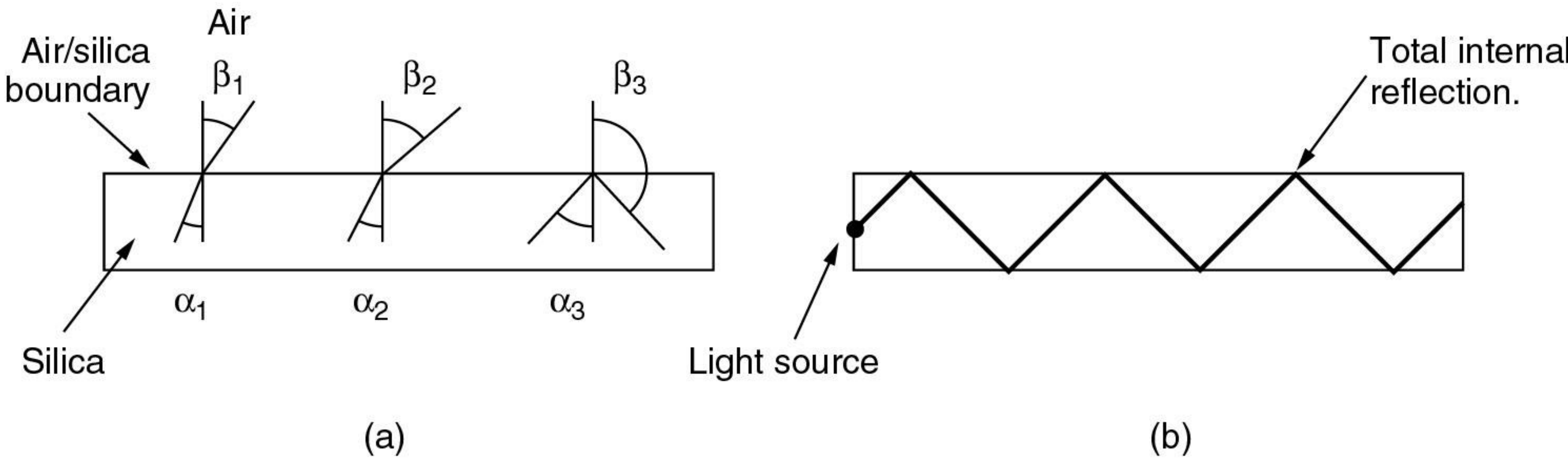
- Attenuation and Gain of the channel are related issues
- In Watts ➔ $P_r = P_t * \text{Gain}$
- In dB,
  - » $10\log_{10}(P_r) = 10\log_{10}(P_t * \text{Gain}) = 10\log_{10}(P_t) + 10\log_{10}(\text{Gain})$
  - » $P_{r_{dBW}} = P_{t_{dBW}} + \text{Gain}_{dB}$ or $P_{r_{dBm}} = P_{t_{dBm}} + \text{Gain}_{dB}$
  - » If Gain= 0.01 and $P_{t_{dBm}}$ = 30 dBm (1W)
    - – $\text{Gain}_{dB} = 10\log_{10}(0.01) = -20\text{dB}$
    - – $P_{r_{dBm}} = P_{t_{dBm}} + \text{Gain}_{dB} = 30-20 = 10\text{dBm} = 10\text{mW}$
- Gain = -20dB ⇔ Attenuation=20dB

Coaxial Cable

- High bandwidth, good immunity to noise
- High bandwidths (e.g. 1 GHz)
- Low attenuations



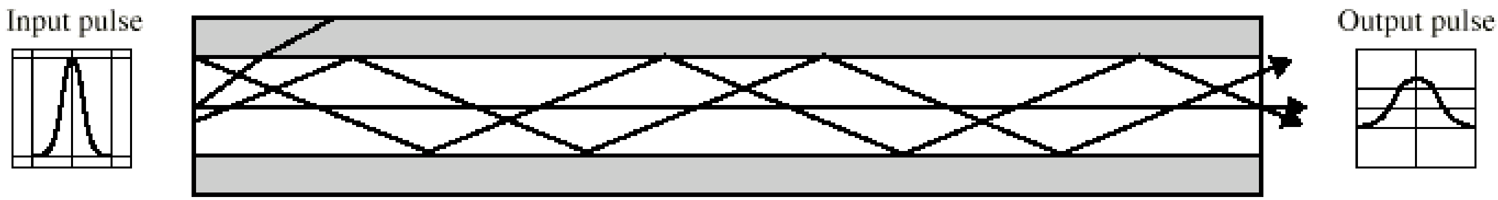
Fiber Optics



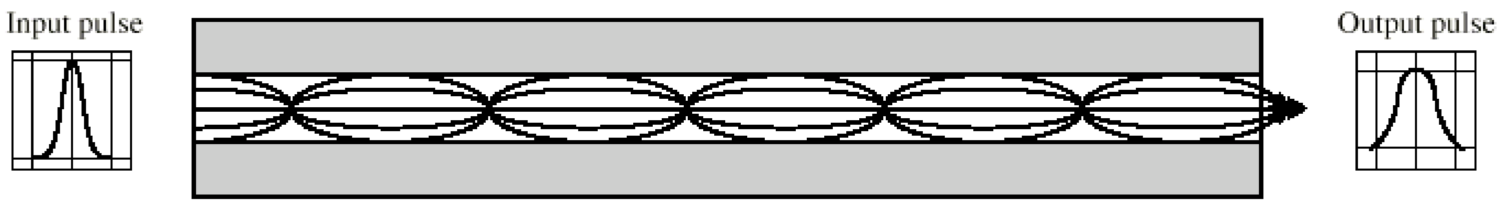
(a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.

(b) Light trapped by total internal reflection.

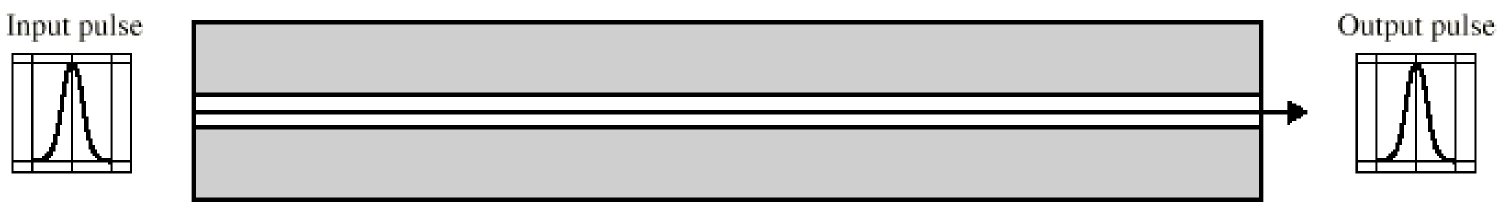
Fiber Optical – Multimode vs Monomode



(a) Step-index multimode



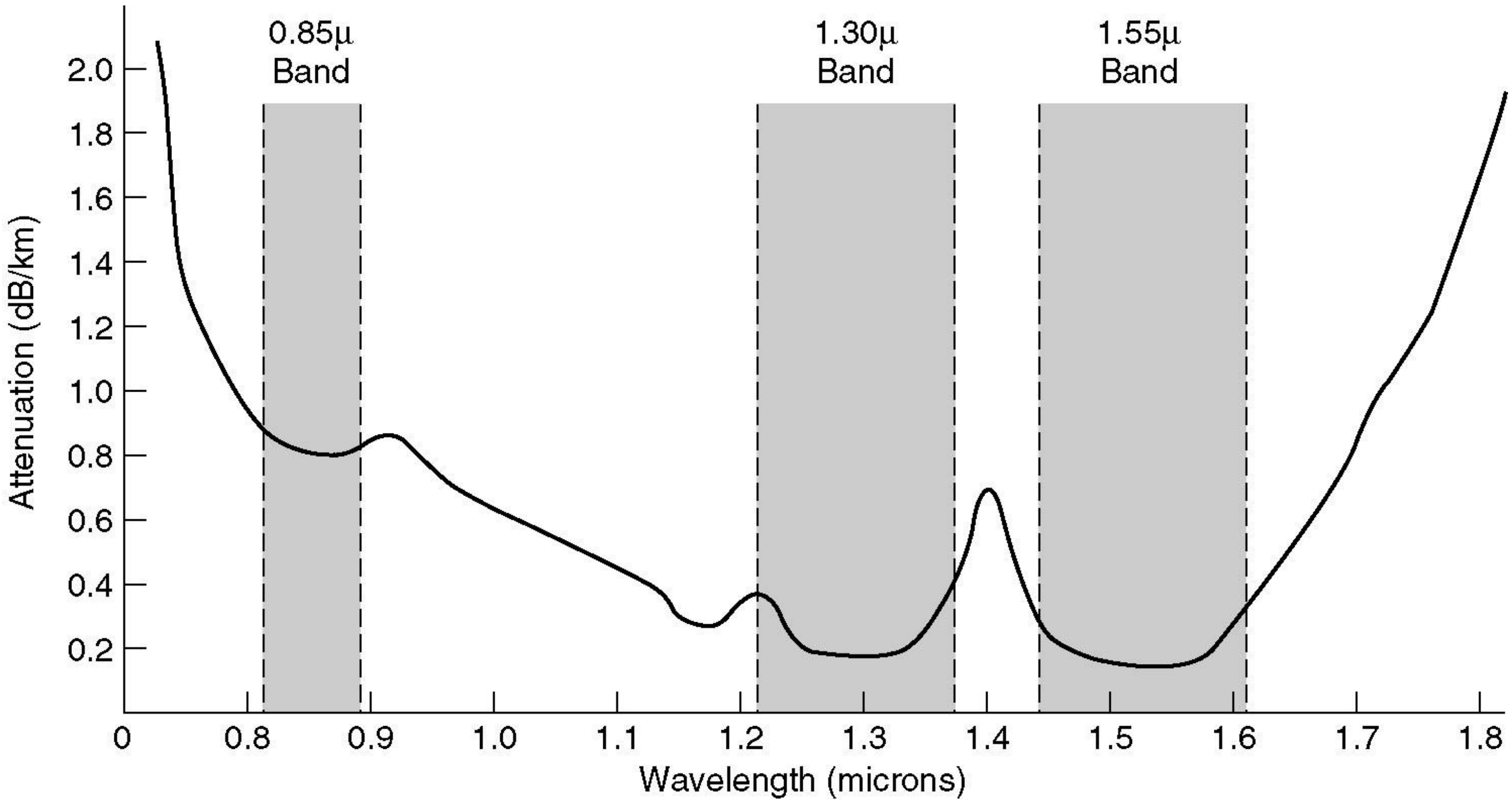
(b) Graded-index multimode



(c) Single mode

Optical Fiber

- Attenuation of light through fiber in the infrared region
- Bandwidths of 30 000 GHz ! Very low attenuations < 1dB/km
- Data transmission: Light (1) / No light (0) ➔ NRZ



Wavelength(λ), Propagation Delay

$$\lambda = vT \qquad \lambda f = v$$

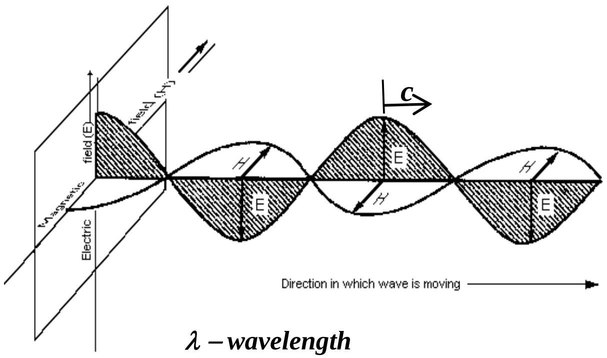
- λ : *wavelength*
- *v: velocity of the wave*
- *f : frequency*

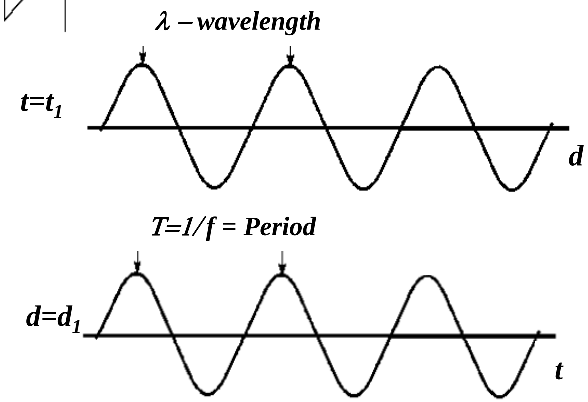
» Speed of ligth in free space c = 3 * 10 [8] m/s

» Propagation delays ($\mu s / km$)

- Free space (1/c): $3.3\mu s / km$
- Coaxial cable: $4\mu s / km$
- UTP: $5\mu s / km$
- Optical fiber: $5\mu s / km$

speed decreases



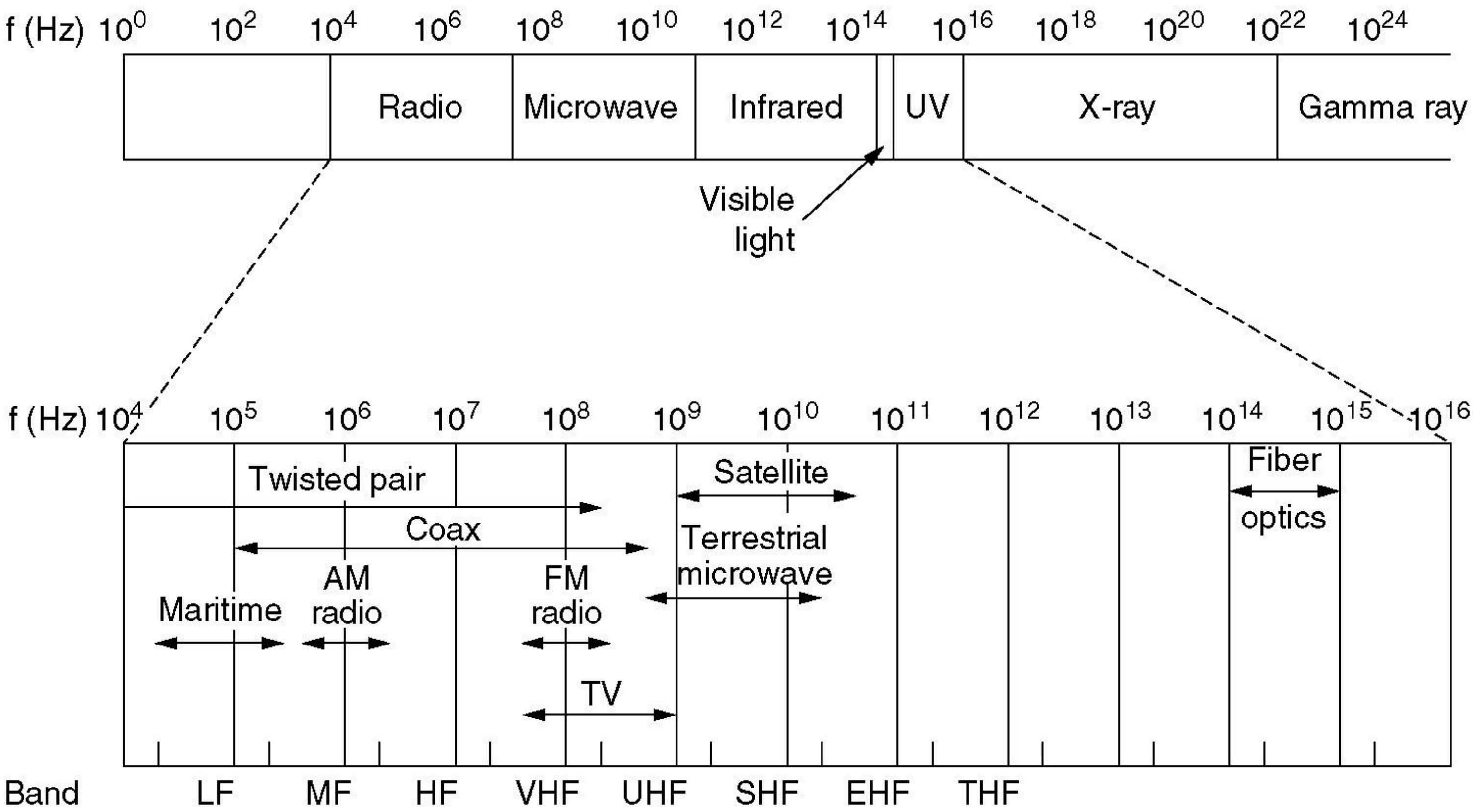


Wireless Transmission

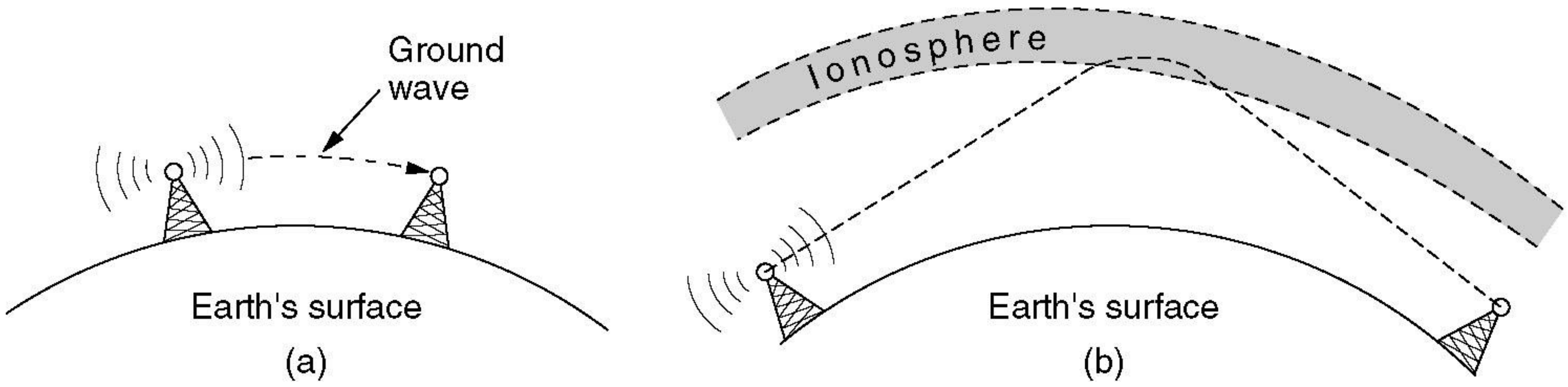
- The Electromagnetic Spectrum
- Radio Transmission

The Electromagnetic Spectrum

The electromagnetic spectrum and its uses for communication



Radio Transmission



(a) In the LF and MF bands, radio waves follow earth curvature

(b) In the HF band, they bounce off the ionosphere.

To Think

- How does the attenuation of an wireless channel vary with the distance?

Free Space Loss

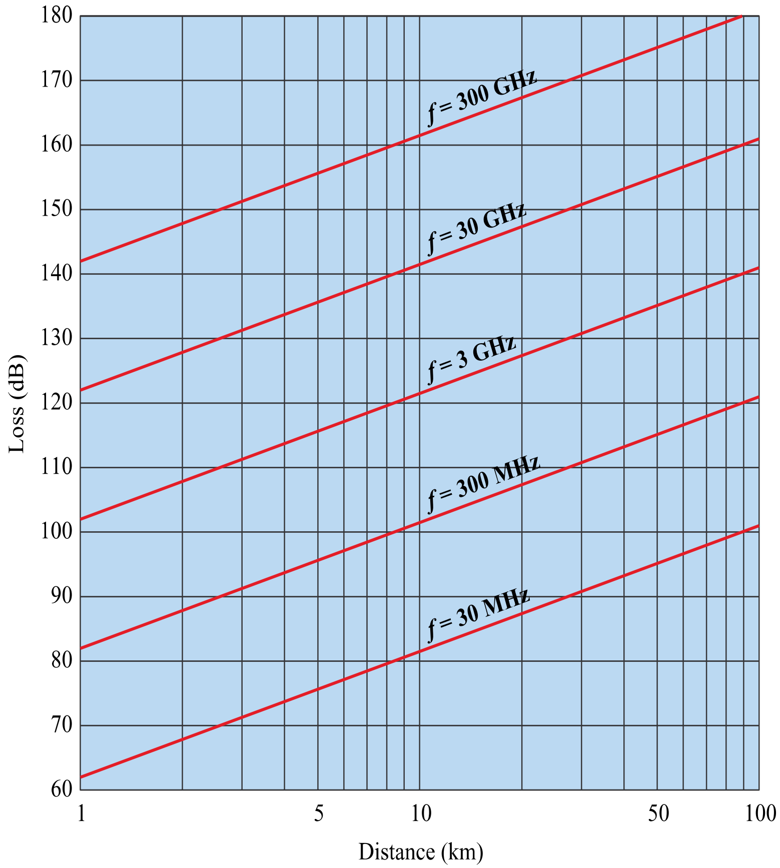
- Free space loss, ideal isotropic antenna

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2} \qquad \lambda f = c$$

  - P_t = signal power at transmitting antenna
  - P_r = signal power at receiving antenna
  - λ = carrier wavelength
  - d = propagation distance between antennas
  - c = speed of light (3×10^8 m/s)

Free Space Loss, in dB

$$L_{dB} = 10\log\left(\frac{P_t}{P_r}\right) = 20\log\left(\frac{4\pi f d}{c}\right) = 20\log(f) + 20\log(d) - 147.56\,dB$$



Homework

1. Review slides

   Important: slides do not address details (no time!). Book(s) must be read!

2. Read from Tanenbaum
   - » Sections 2.1, 2.2, 2.3, 2.5, 2.6, 2.8, 2.9

3. Read from Bertsekas&Gallager
   - » Sections 2.1, 2.2

4. Answer questions at moodle