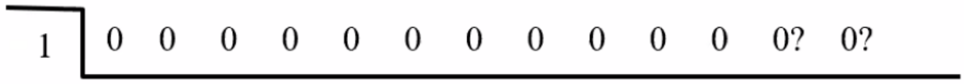
# Clock Recovery

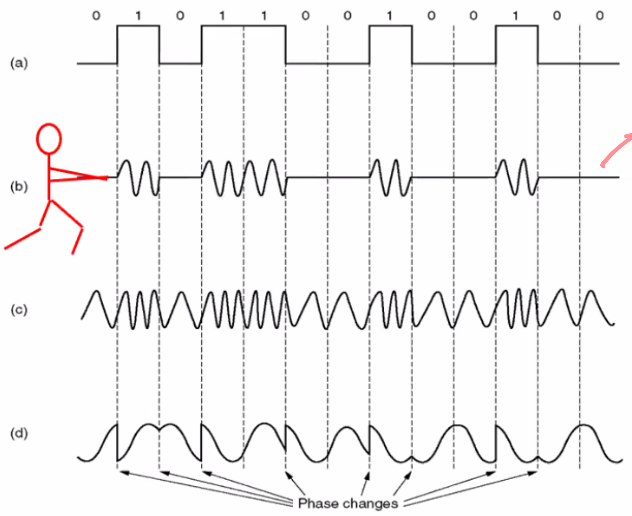
- To decode the symbols, signals need sufficient transitions
  - » Otherwise long runs of 0s (or 1s) are confusing, e.g.:




- 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 |

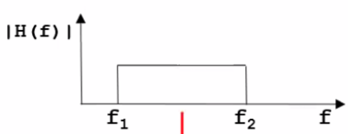
# Types of Modulations




frequência da portadora

(a) A binary signal
(b) Amplitude modulation
(c) Frequency modulation
(d) Phase modulation

- Some physical channels are bandpass




frequência do sinal em que vamos trabalhar

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

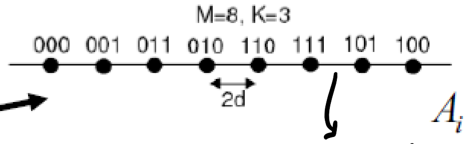
# Amplitude and Phase Modulations

8 amplitudes

- Amplitude Modulation

  information coded in the carrier's amplitude

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

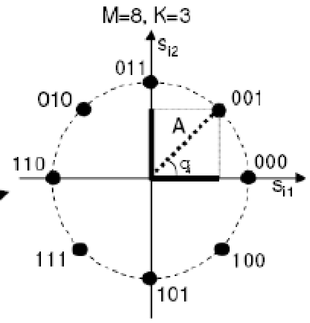



$\log_2 M$

- Phase Modulation

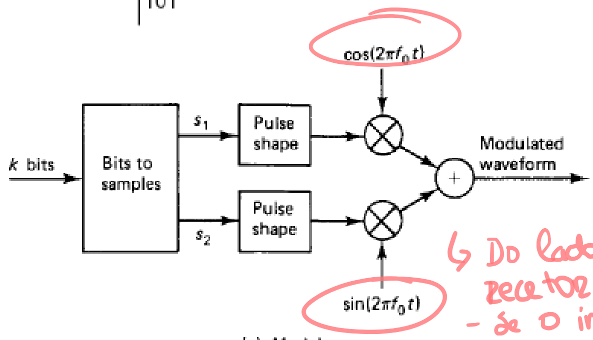
  information coded in carrier's phase

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




Consiste em enviar um cos e um sen

$$s(t) = A\cos(\theta_i + 2\pi f_c t) =$$
$$= A\cos(\theta_i)\cos(2\pi f_c t) - A sen(\theta_i) sen(2\pi f_c t) =$$
$$= s_1(t)\cos(2\pi f_c t) + s_2(t) sen(2\pi f_c t)$$




(a) Modulator

↳ Do lado do receptor faz-se o inverso

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

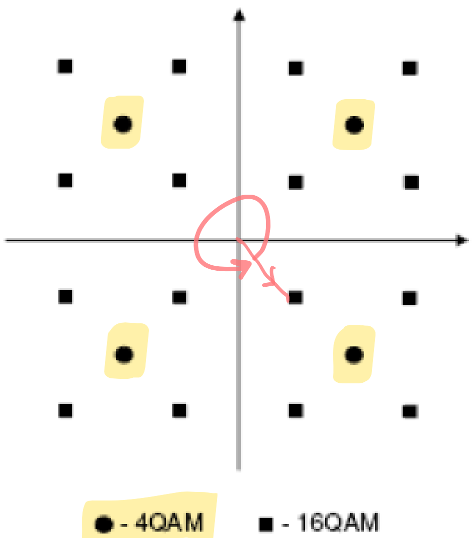


# Quadrature Amplitude Modulation

- Quadrature Amplitude Modulation (M-QAM)

  information coded both in amplitude and phase

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

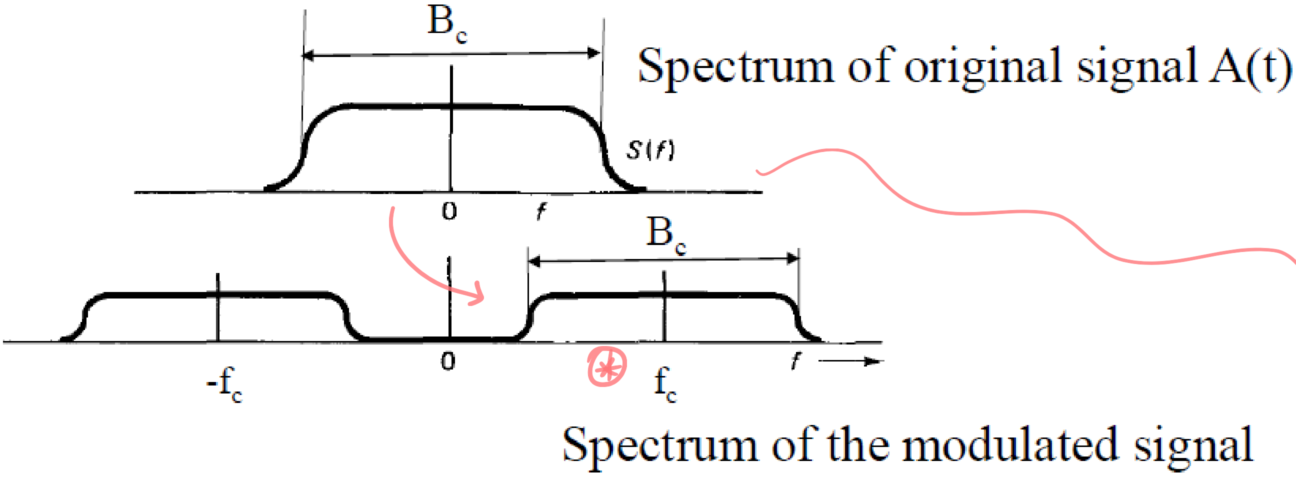



Amplitude constante
Muda fase

↳ $\log_2 16 = 4$ bits

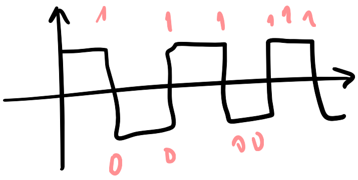
↳ Muda amplitude e fase

# *Amplitude Modulation - Representation in the Frequency domain*




Se o sinal que estamos a transmitir é assim
ele desloca-se ao multiplicar

$M=2 \rightarrow \log_2 2 = 1$



# *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)

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

Potência de sinal Recebido

Potência de Ruído

↳ Quanto maior a largura do canal ↳ maior o ruído

  - » $B_c$ – bandwidth of the channel (Hz) (see last slide)
    $B_c$ = sampling rate
    ↳ largura-banda do canal
  - » $P_r$ – 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)
    Densidade espetral de ruído

O número máximo de bits que transmitimos depende da largura do canal e da relação potência recebida/ruído

# *Example*

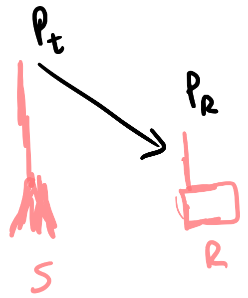
- If a bandpass channel has a bandwidth $B_c$= 100 kHz

  and Signal to Noise ratio (SNR) at the receiver is

  » $P_r/(N_0B_c)=7$ ➔ $C = 100k \log_2(1+7) = 300 kbit/s$ ← No máximo transmite-se

  » $P_r/(N_0B_c)=255$ ➔ $C = 100k \log_2(1+255) = 800 kbit/s$ ← No máximo transmite-se

  Quanto maior ⟶ > taxa de transferência




- 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

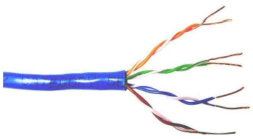
Quanto > a distância ⟶ < Potência recebida

## Guided transmission

- Twisted Pair
- Coaxial Cable
- Fiber Optics

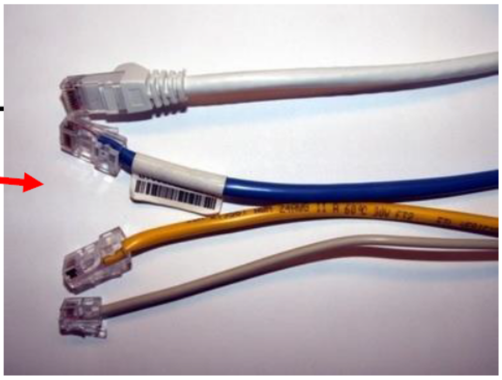
- Coaxial cable

- Unshielded twisted pair



- Fiber optic

### *UTP Cables*



- From top to bottom:
  Cat. 6, Cat. 5e, Cat. 5, Cat. 3

Quanto > a categoria ↓ > largura de banda ↓ + transmissão

- 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 ⟶ Gains ⇒ -25 → -2 dB/100m

# *dB, dBm, Gain, Attenuation*

- Attenuation and Gain of the channel are related issues
- In Watts ➔ $P_r = P_t * Gain$

S — $P_t$ — H (G) — $P_R$ — R

↳ Geralmente $P_t > P_R$, a não ser que H seja um amplificador

- In dB,
  - » $10\log_{10}(P_r) = 10\log_{10}(P_t * Gain) = 10\log_{10}(P_t) + 10\log_{10}(Gain)$
  - » $P_{r_{dBW}} = P_{t_{dBW}} + Gain_{dB}$ or $P_{r_{dBm}} = P_{t_{dBm}} + Gain_{dB}$

↳ geralmente Gain<1

↳ $Gain_{dB} < 0$

  - » If Gain= 0.01 and $P_{t_{dBm}}$ = 30 dBm (1W)

transmito 1W e recebo 0.01 W

    - $Gain_{dB} = 10\log_{10}(0.01) = -20dB$
    - $P_{r_{dBm}} = P_{t_{dBm}} + Gain_{dB} = 30-20 = 10dBm = 10mW$

- Gain = -20dB ⬅➔ Attenuation=20dB

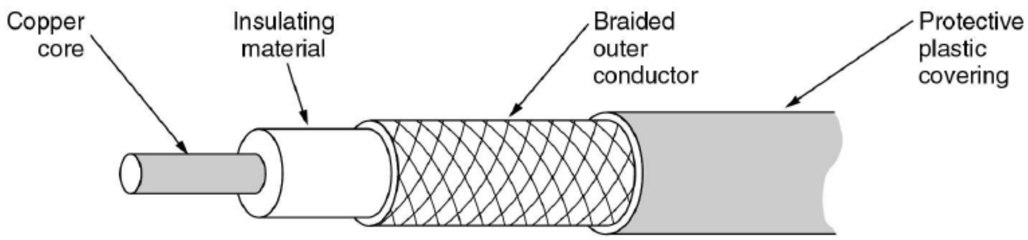
→ Gain = − Attenuation

## *Coaxial Cable*

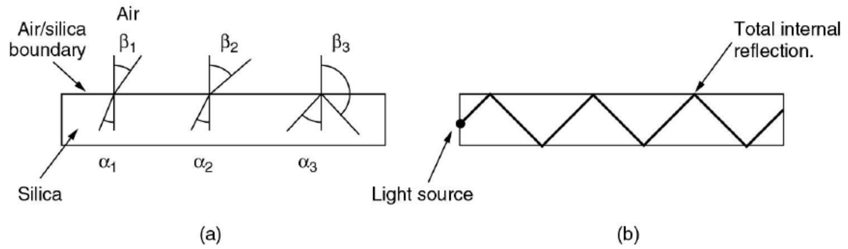
Atenuação → Perda de sinal

Perda de trajeto

- High bandwidth, good immunity to noise
- High bandwidths (e.g. 1 GHz) → Grandes larguras
- Low attenuations ↳ Pequenas perdas




## *Fiber Optics*

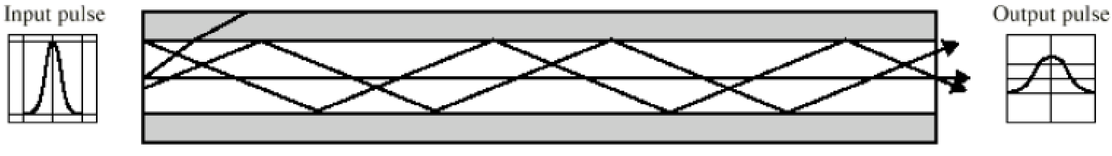



(a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.

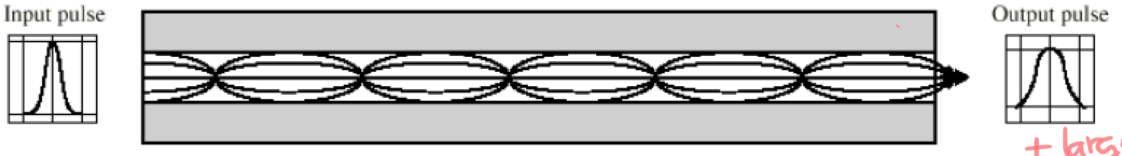
(b) Light trapped by total internal reflection.

# Fiber Optical – Multimode vs Monomode

Percorre caminhos + longos, devido às reflexões




(a) Step-index multimode




+ largo

(b) Graded-index multimode

trajeto direto

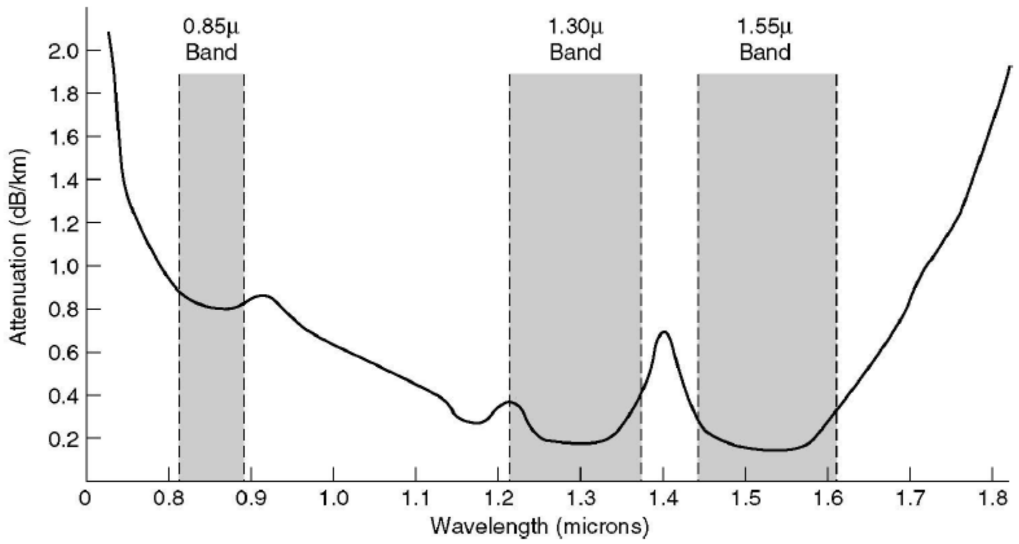

boa representação

(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

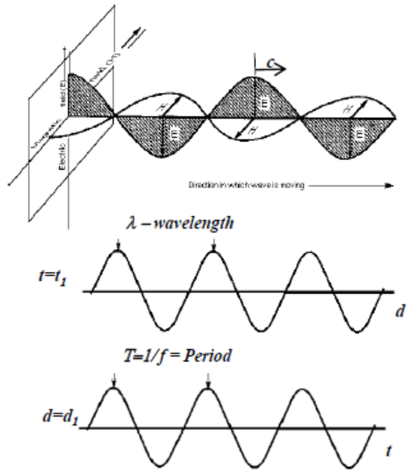
Enorme potencial de transmissão de informação



# *Wavelength($\lambda$), Propagation Delay*

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

- $\lambda$ : *wavelength*
- *v: velocity of the wave*
- *f : frequency*




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

» Propagation delays ($\mu s / km$)

$T_{prop}$

- 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