Redes de Computadores

The Physical Layer

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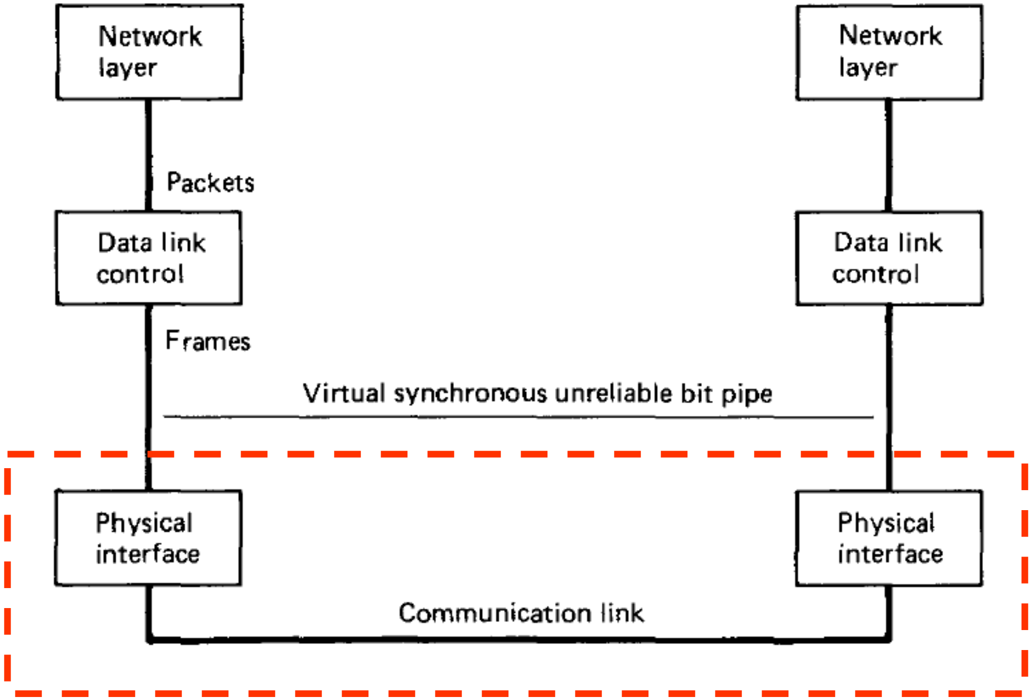
» *What service does the Physical Layer offer to Data Link Layer?*
» ***How to encode a sequence of bits into an analogue signal?***
» *Why does the received signal r(t) differ from the transmitted signal s(t)?*
» *How does the bandwidth of a channel affect the received signal?*
» *How many sample/s are required for the receiver to rebuild an analogue signal?*
» ***What is the difference between baudrate and bitrate?***
» *Why can't an infinite number of bit/s be transmitted in a limited bandwidth channel?*
» ***What is the are the advantages of the Manchester code over the NRZ code?***
» ***What are the common digital modulations? How is the signal s(t) generated?***
» ***What is the maximum capacity of a communications channel?***
» *Why does the SNR affect the maximum capacity of a channel?*
» *What types of guided media exist and what are their main characteristics?*
» *What is dB, dBW, dBm, Gain, and Attenuation?*
» *How to relate transmitted and received powers in Watts and dB?*
» ***How does the attenuation of a wireless channel vary with distance and wavelength?***

Service Provided by the Physical Layer

Physical layer

» 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



To Think

[Sender]══════════ [Receiver]

- How to transmit the sequence of bits

  110100 …

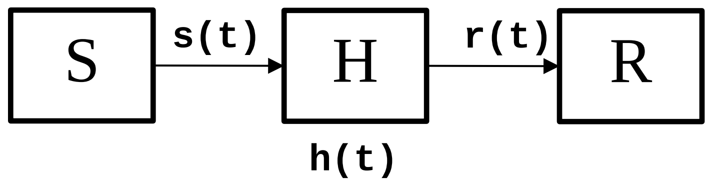
  from Sender to Receiver using two wires?

To Think

- If 1 bit is transmitted every T sec ➔ bitrate = 1/T bit/s

- Why can't we transmit infinite bitrate (bit/s) using a real cable?

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



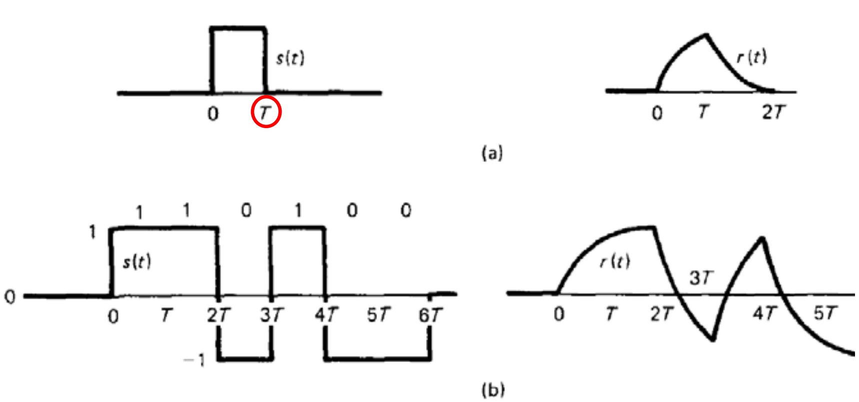


Figure 2.3 Relation of input and output waveforms for a communication channel with filtering. Part (a) shows the response $r(t)$ to an input $s(t)$ consisting of a rectangular pulse, and part (b) shows the response to a sequence of pulses. Part (b) also illustrates the NRZ code in which a sequence of 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.

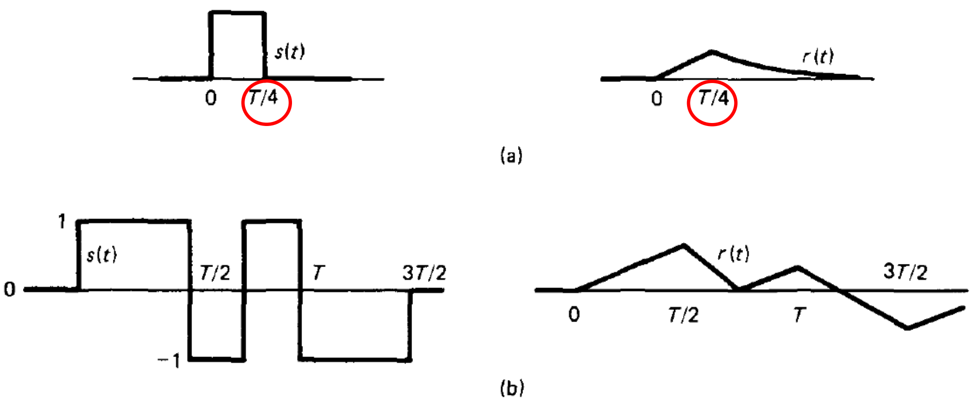
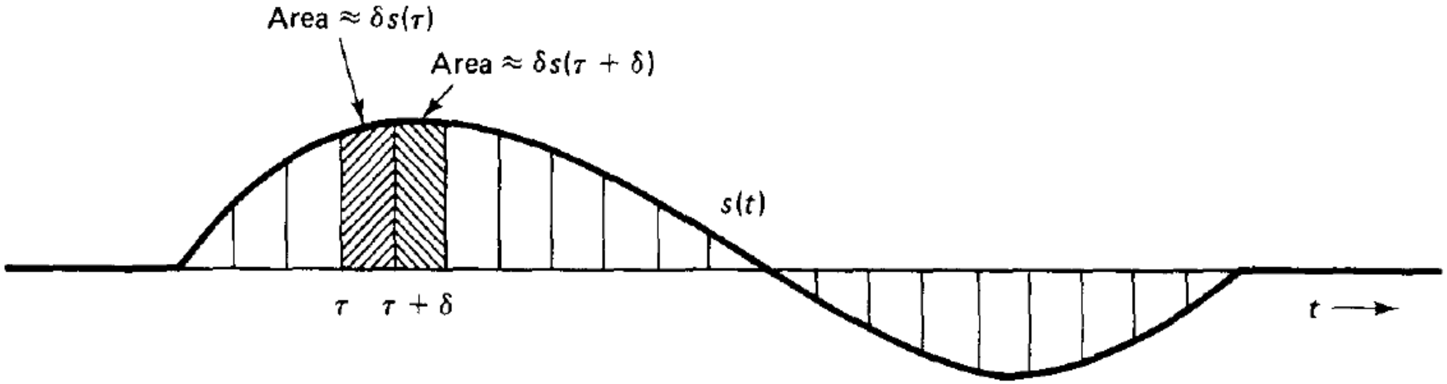
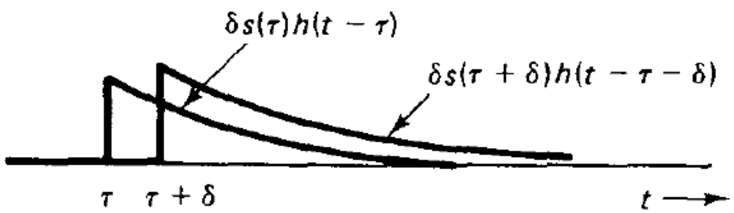


Figure 2.4 Relation of input and output waveforms for the same channel as in Fig. 2.3. Here the binary digits enter at 4 times the rate of Fig. 2.3, and the rectangular pulses last one-fourth as long. Note that the output $r(t)$ is more distorted and more attenuated than that in Fig. 2.3.

r(t) is the convolution of *s(t)* and *h(t)*





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

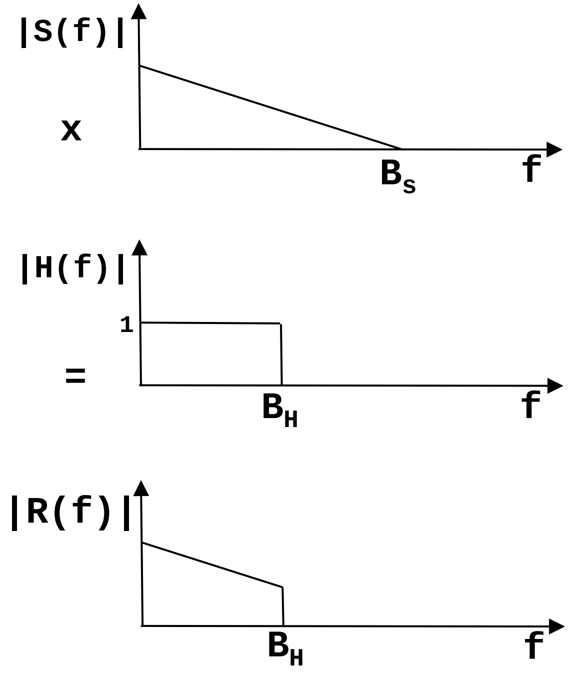
The Fourrier Transform

- Using Fourrier transforms

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

and, in the frequency domain

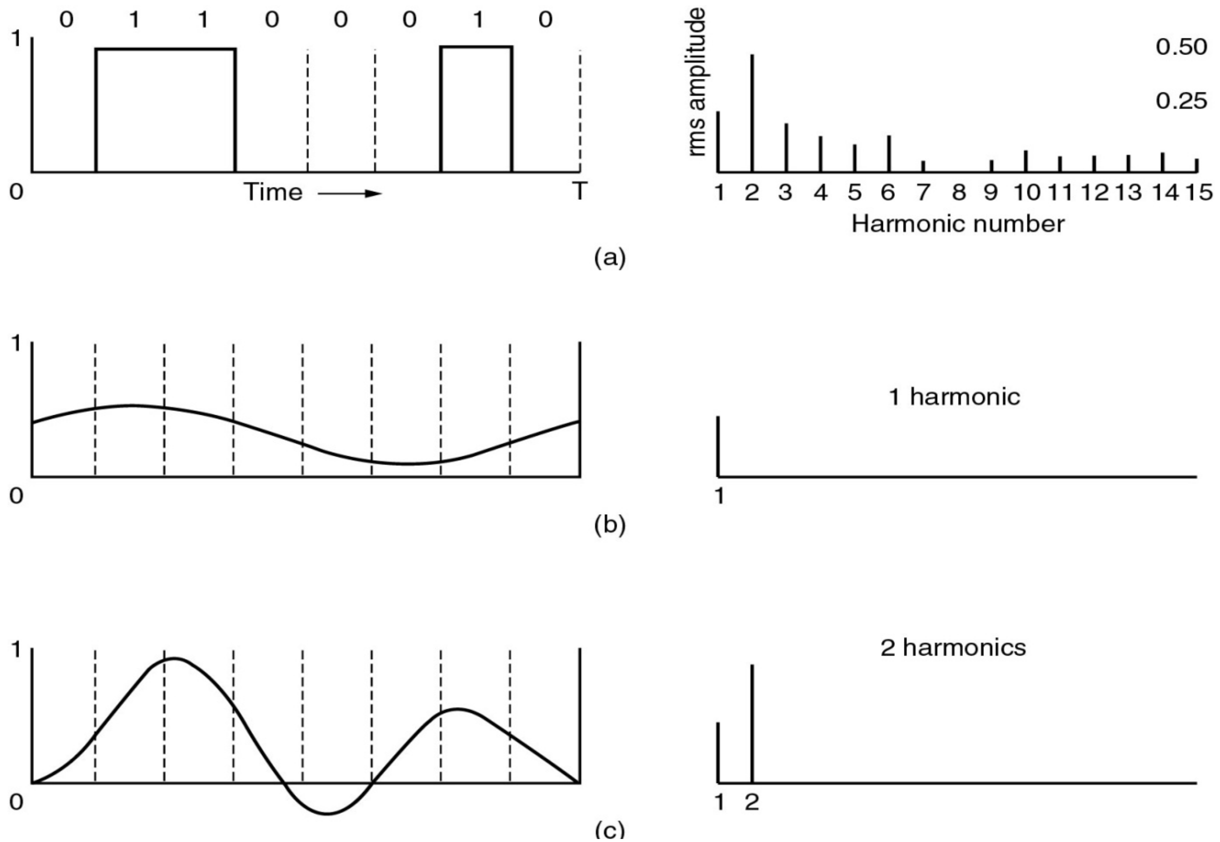
$$R(f) = S(f) \times H(f)$$



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

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

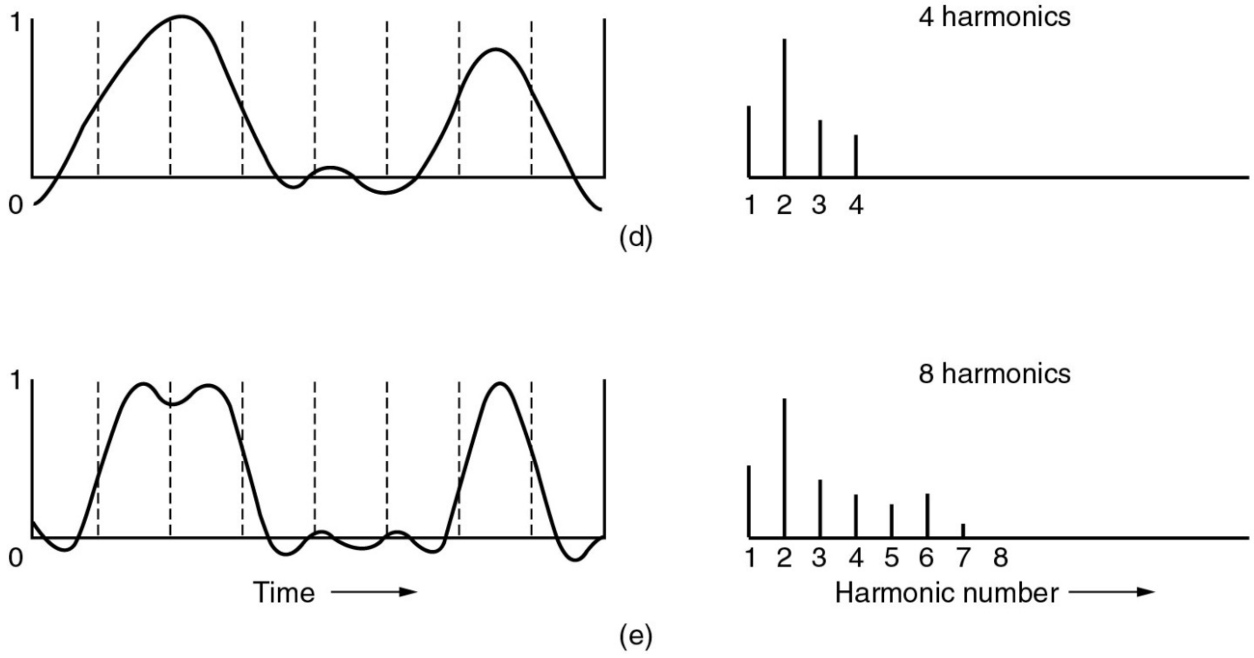
Bandwidth-Limited Signals



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

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

Bandwidth-Limited Signals



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

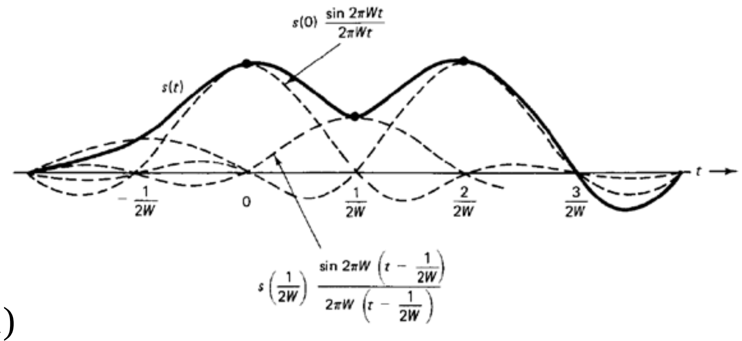
Recovering bits at the Receiver

- Receiver needs to
  - » sample **`r(t)`** in order to decide about the bits transmitted
- Nyquist showed that

  if receiver samples a low pass signal of bandwidth B

  at rate **`2B`** sample/s

  then the original **`r(t)`** signal can be reconstructed



- For instance,
  - » a square ware `v(t)` alternating between -5 V (0) and 5 V (1)
  - » passing through a lowpass channel B_H=3kHz
  - » and sampled at $2B_H$ = 6 ksample/s,
  - » transports C=$2B_H$ = 6 kbit/s

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

- However,
  - » if M=4 levels are used to encode information

    -5V(00) , -2V(01) , 2V(10), 5V(11)
  - » Then, the channel capacity becomes $C = 2B\log_2(M) = 2\times 3k\times 2 = 12kbit/s$
  - » 2B expresses the channel baudrate in **symbol/s** or **baud**

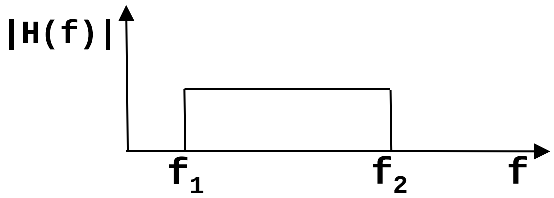
To Think

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

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

Bandpass Channels

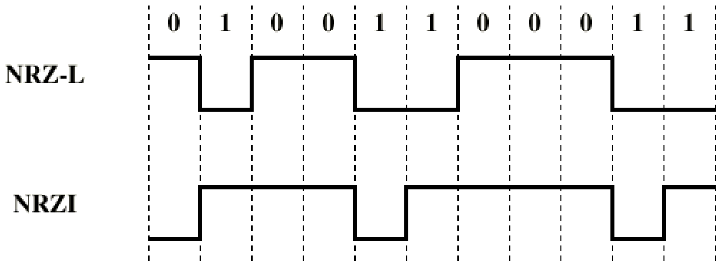
- Most of physical channels are bandpass channels
  - » In particular, $|H(0)|=0$ ➔ dc component does not pass in the channel



- Two main techniques used to enable **s(t)** to pass through **h(t)**
  - » Coding
  - » Modulation

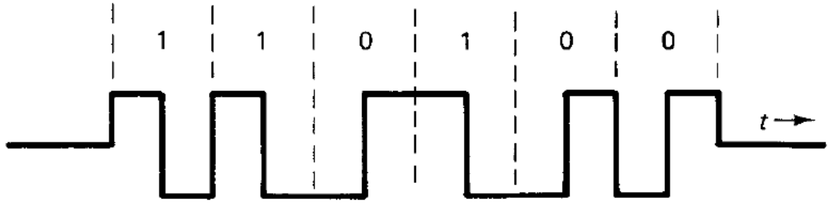
Common Codes

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



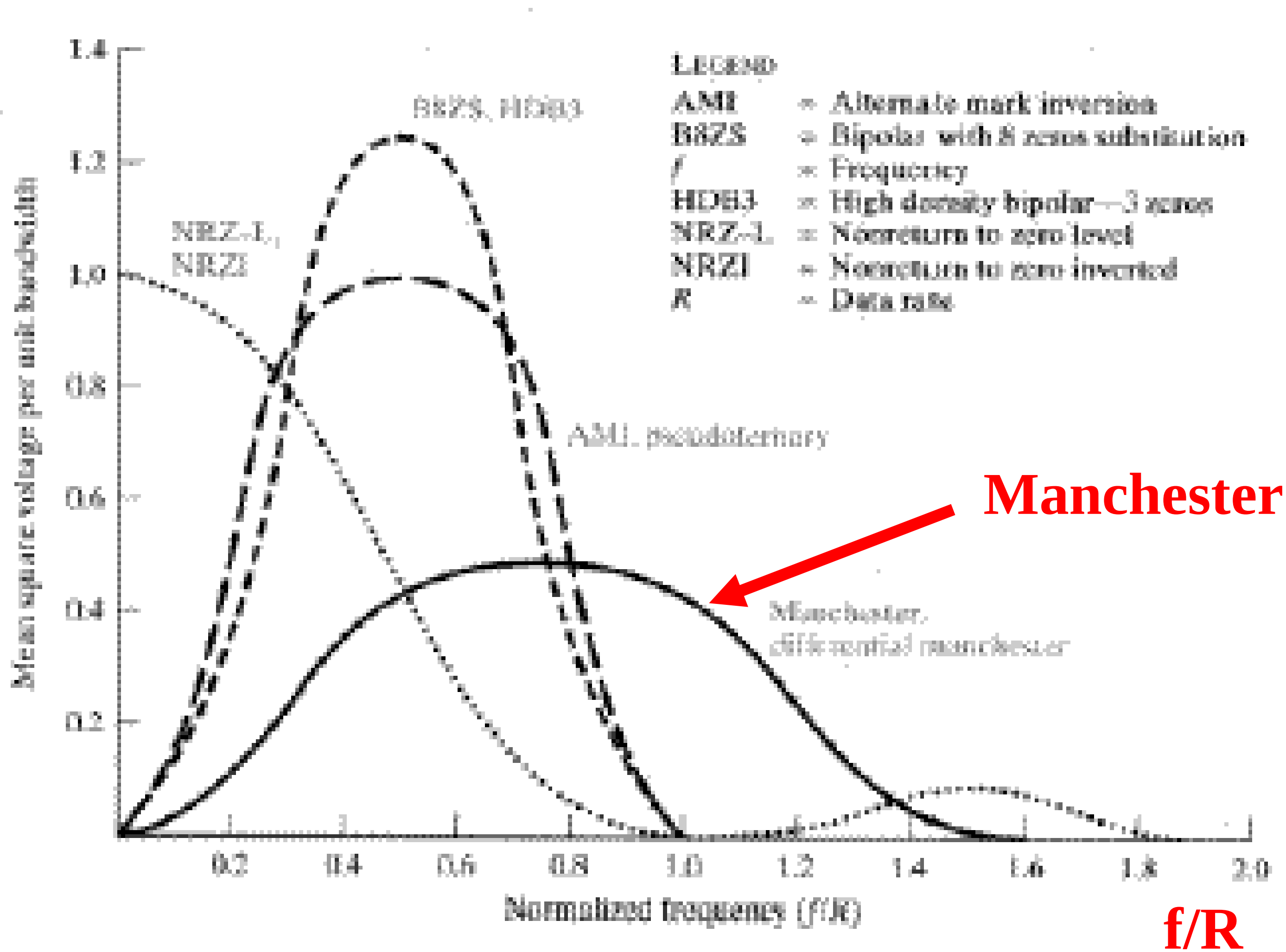
- NRZ-I (Non Return to Zero - Inverted)
  - » Change of level represents a 1

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



- There are many codes …

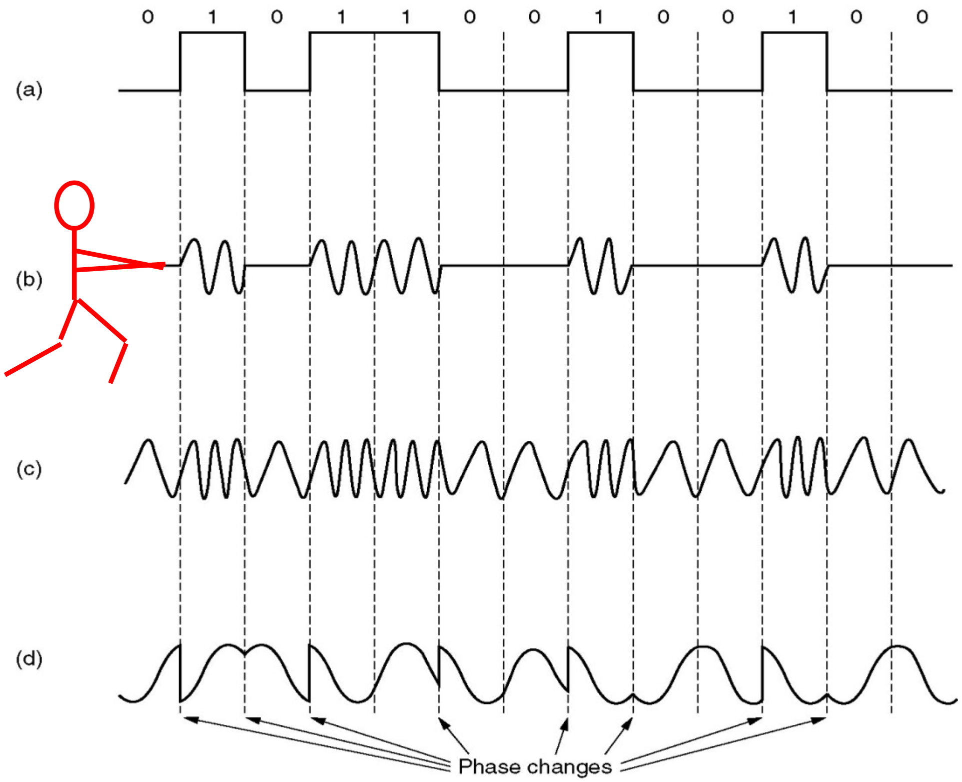
Spectral PowerDensity



To Think

- How to transmit bits using a continuous carrier?

Types of Modulations



(a) A binary signal

(b) Amplitude modulation

(c) Frequency modulation

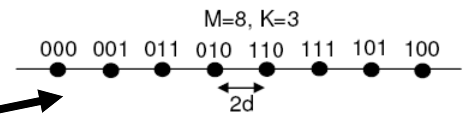
(d) Phase modulation

Amplitude and Phase Modulations

- Pulse Amplitude Modulation (M-PAM)

  information coded in the carrier's amplitude

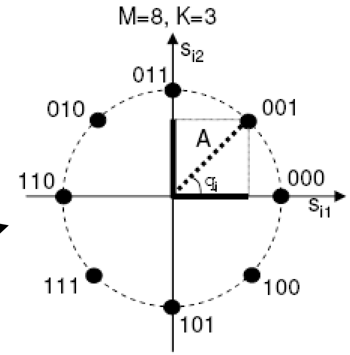
  $$s(t) = A_i \cos(2\pi f_c t)$$



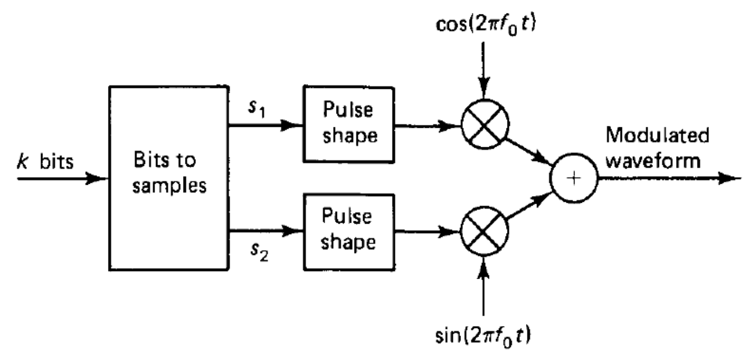
- Phase Shift Keying (M-PSK)

  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

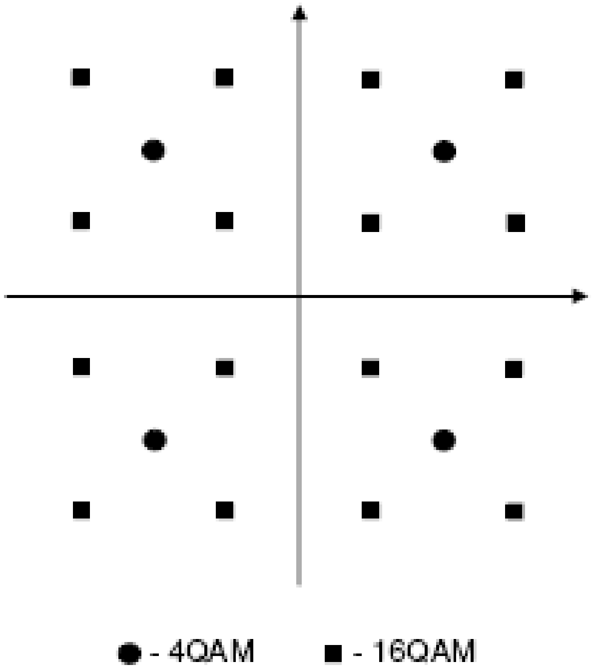
- $K = log_2 M$ bits sent over a time symbol interval

Quadrature Amplitude Modulation

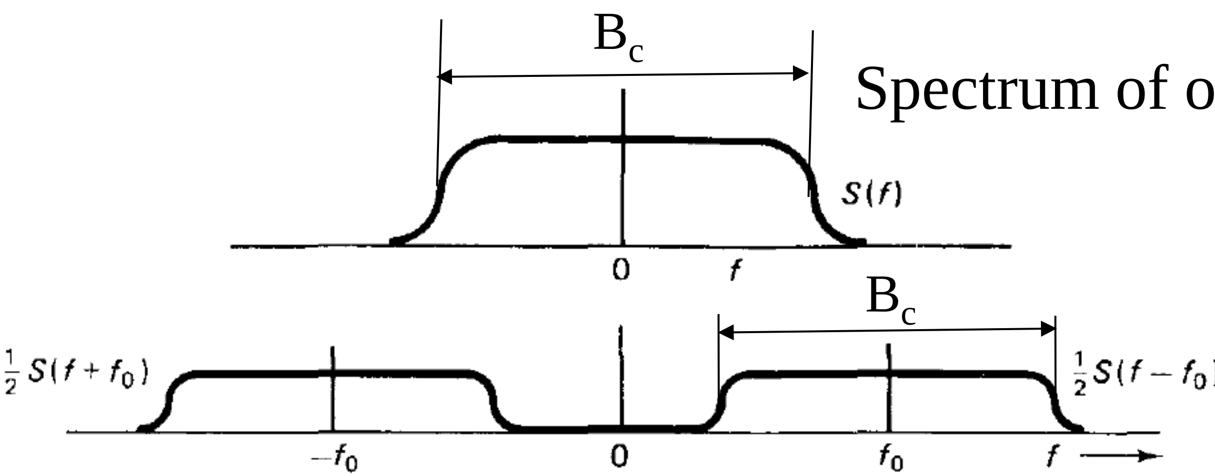
- Quadrature Amplitude Modulation (M-QAM)

  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

($f_0=f_c$)

Shannon's Law

- Noise imposes the limit on the number levels M (bit/symbol)
  - » Noise high ➔ low M
  - » or, high Signal to Noise Ratio (high 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, f_2-f_1, (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: $N_0 = 10^{-9}$ W/Hz

Example

- If a bandpass channel has a bandwidth B_c= 100 kHz and Signal to Noise ratio (SNR) at the receiver is
  - » $P_r/(N_0B_c)=7$ ➔ $C = 100k\log_2(1+7) = 300kbit/s$
  - » $P_r/(N_0B_c)=255$ ➔ $C = 100k\log_2(1+255) = 800kbit/s$
- Note
  - » $P_{dBW}=10\log_{10}P$: 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

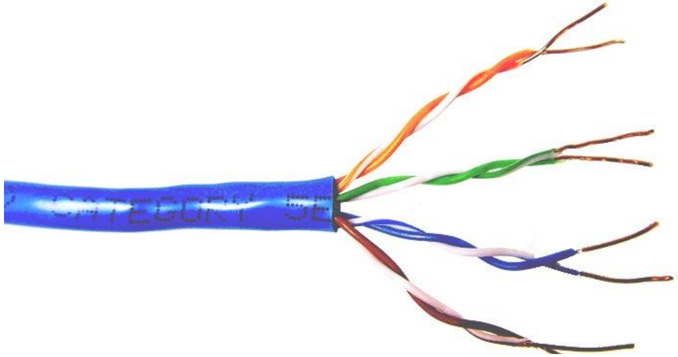
Guided Transmission

- Twisted Pair
- Coaxial Cable
- Fiber Optics

Guided Transmission

- Coaxial cable

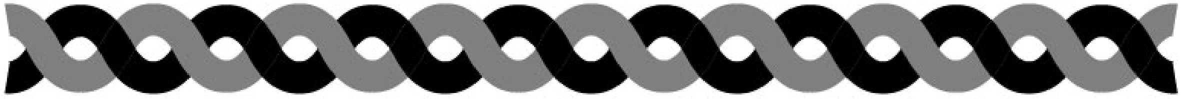
- Unshielded twisted pair



- Fiber optic

Twisted Pair

(a)

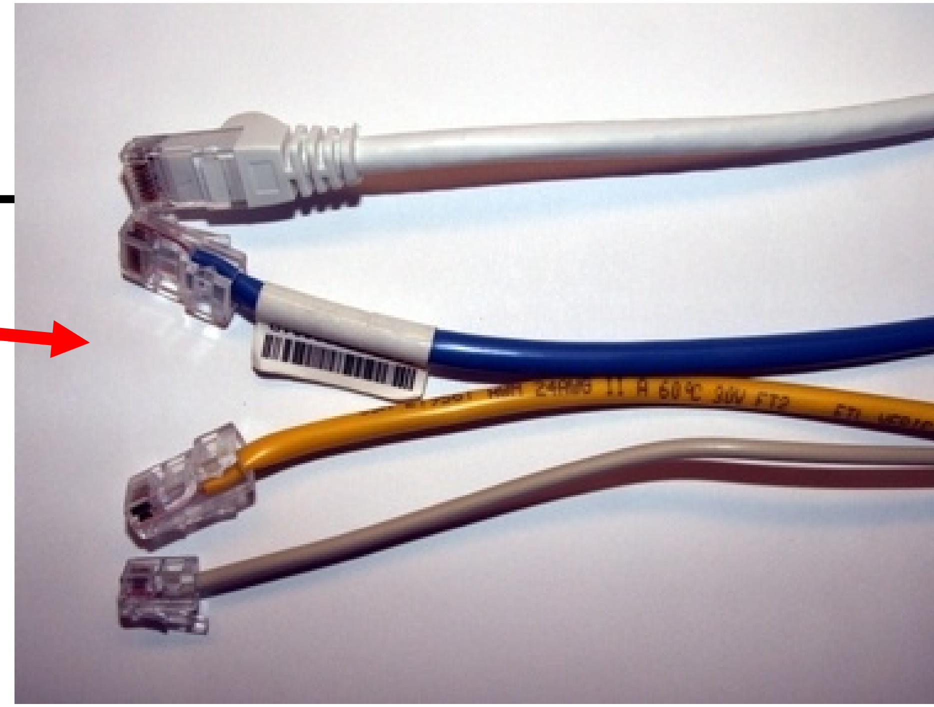


(b)

(a) Category 3 UTP.

(b) Category 5 UTP.

UTP Cables



- From top to bottom:

  Cat. 6, Cat. 5e, Cat. 5, Cat. 3

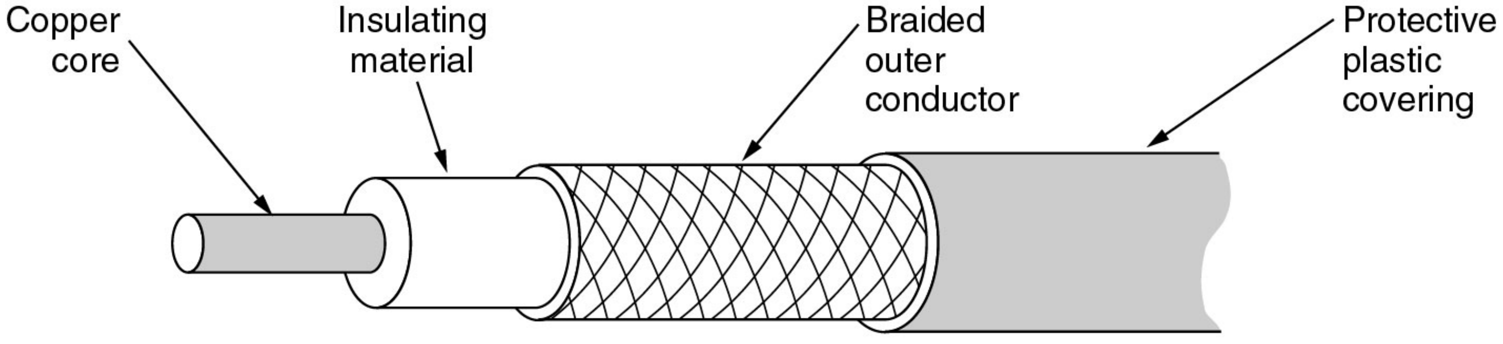
- Cat 3, 16 MHz bandwidth
- Cat. 5 / 5e, 100MHz
- Cat. 6, 250MHz
- Cat. 6a, 500MHz
- Cat. 7, 600MHz
- Typical attenuations 2 – 25 dB/100 m

dB, dBm, Gain, Attenuation

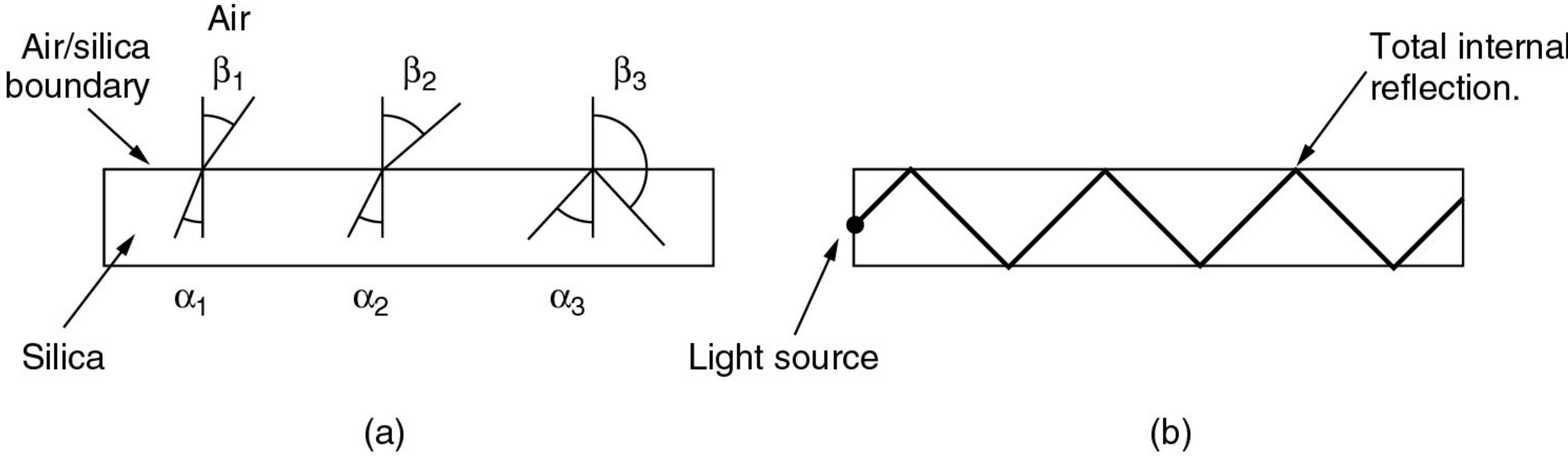
- Attenuation and Gain of the channel are related issues
- In Watts ➔ $P_r = P_t * \text{Gain}$
- In dB,
  - » $10\log_{10}(P_r) = 10\log_{10}(P_t * \text{Gain}) = 10\log_{10}(P_t) + 10\log_{10}(\text{Gain})$
  - » $P_{r_{dBW}} = P_{t_{dBW}} + \text{Gain}_{dB}$ or $P_{r_{dBm}} = P_{t_{dBm}} + \text{Gain}_{dB}$
  - » 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. 1GHz)
- Low attenuations



Fiber Optics



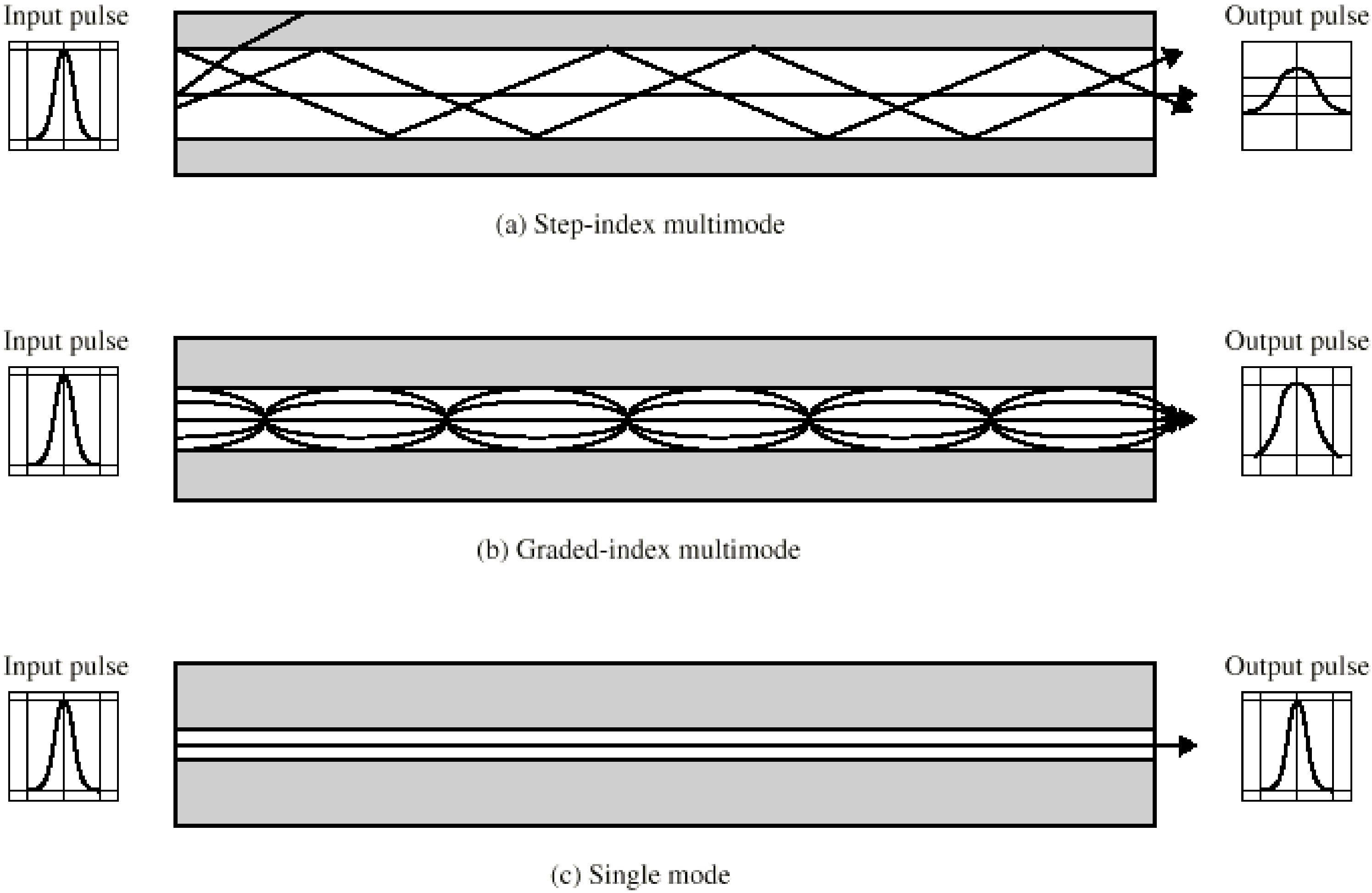
(a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.

(b) Light trapped by total internal reflection.

To Think

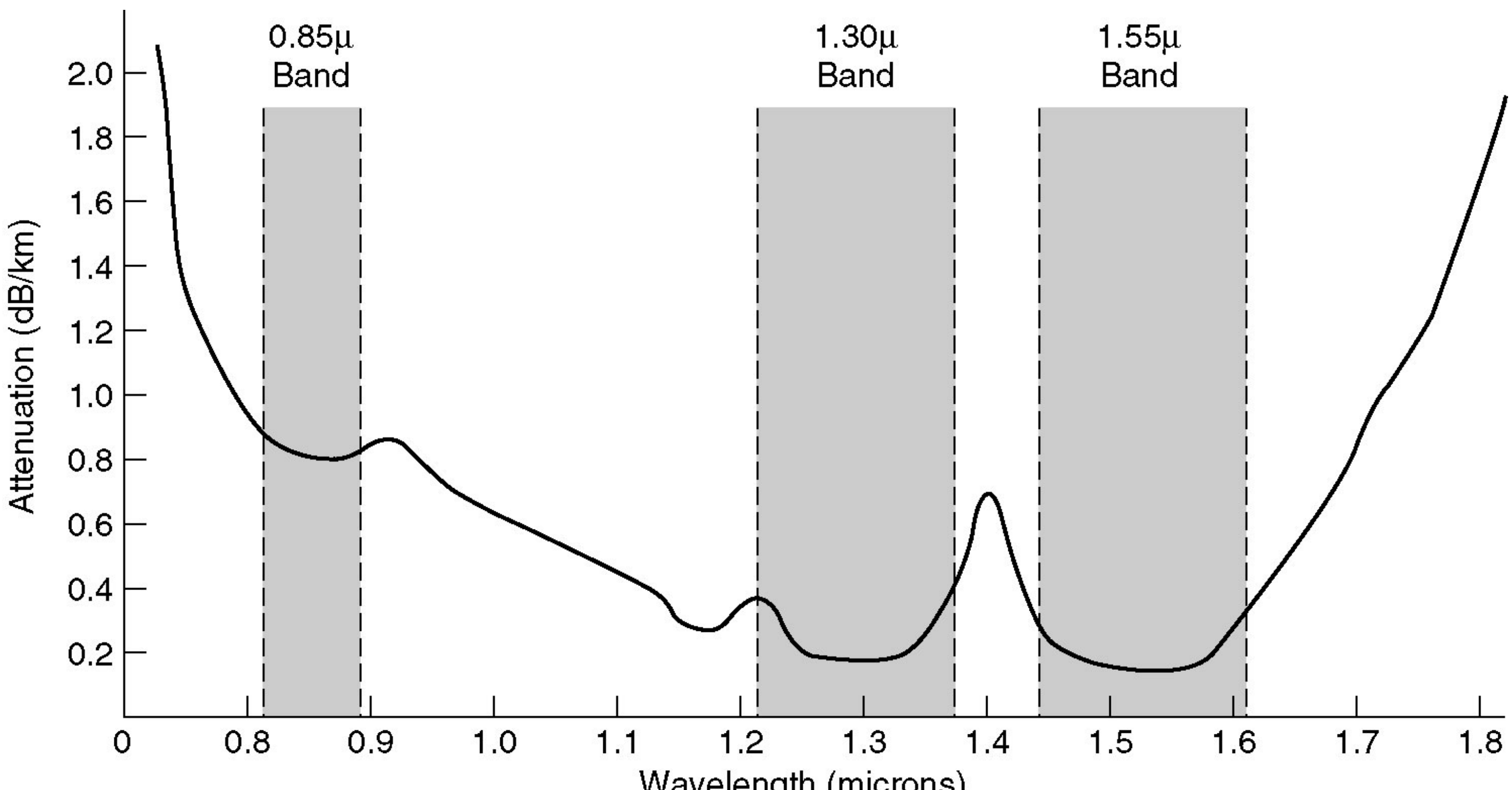
- How to transmit bits through an optical fiber?

Fiber Optical – Multimode vs Monomode



Optical Fiber

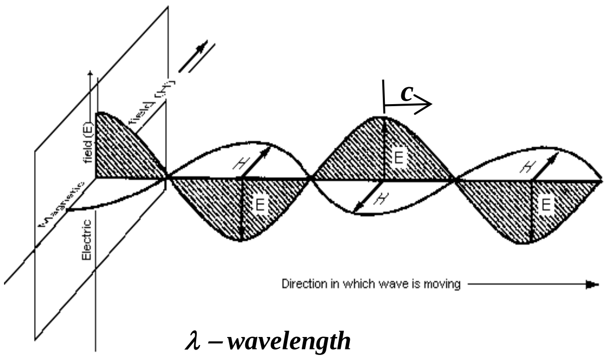
- Attenuation of light through fiber in the infrared region
- Bandwidths of 30 000 GHz ! Very low attenuations < 1dB/km
- Data transmission: Light (1) / No light (0) ➔ NRZ

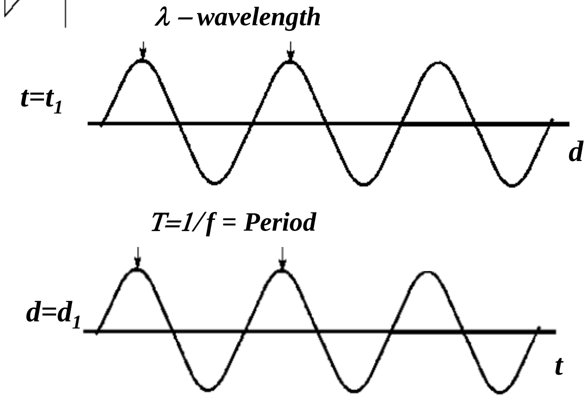


Wavelength(λ), Propagation Delay

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

- 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: $5 \mu s / km$

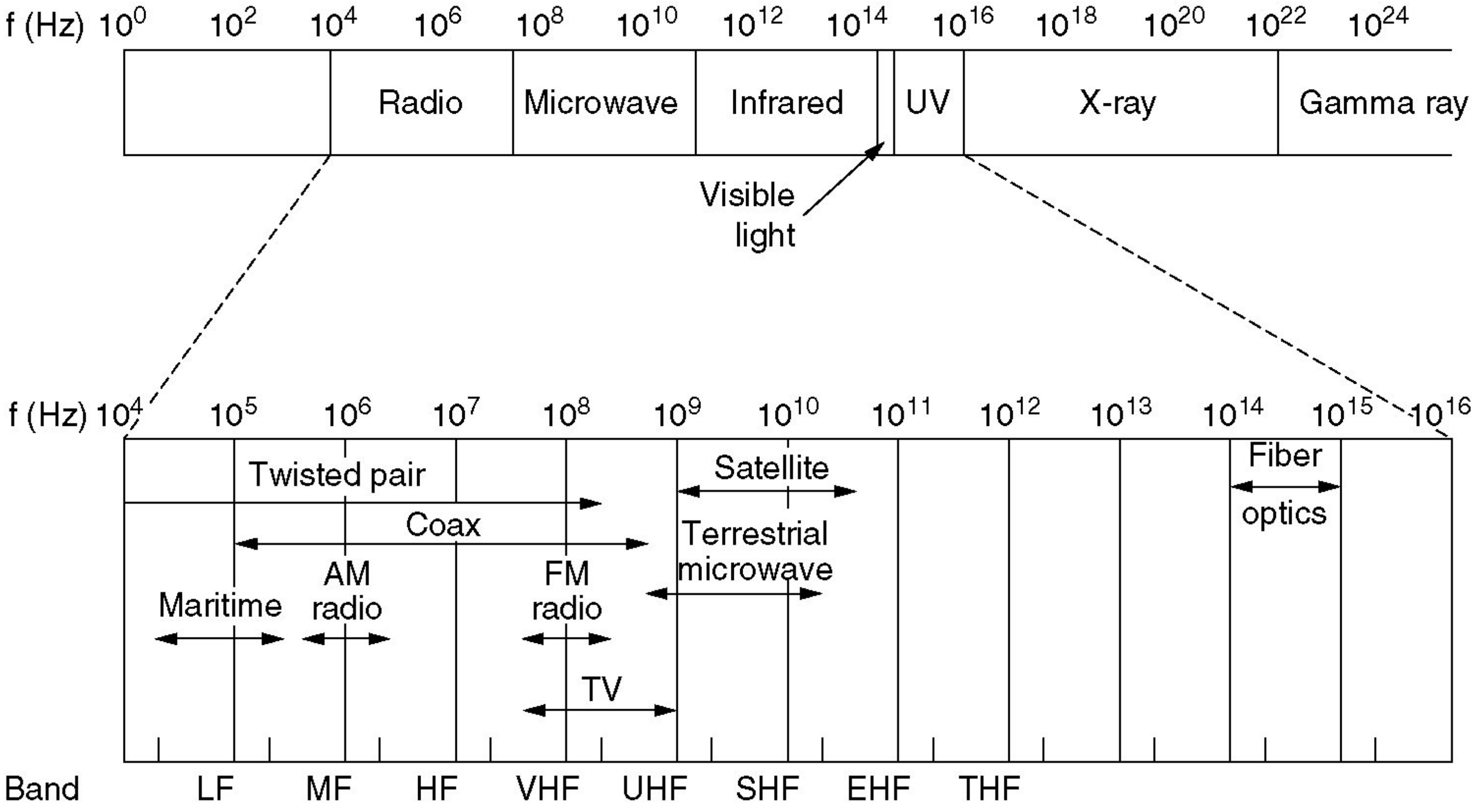
speed decreases

Wireless Transmission

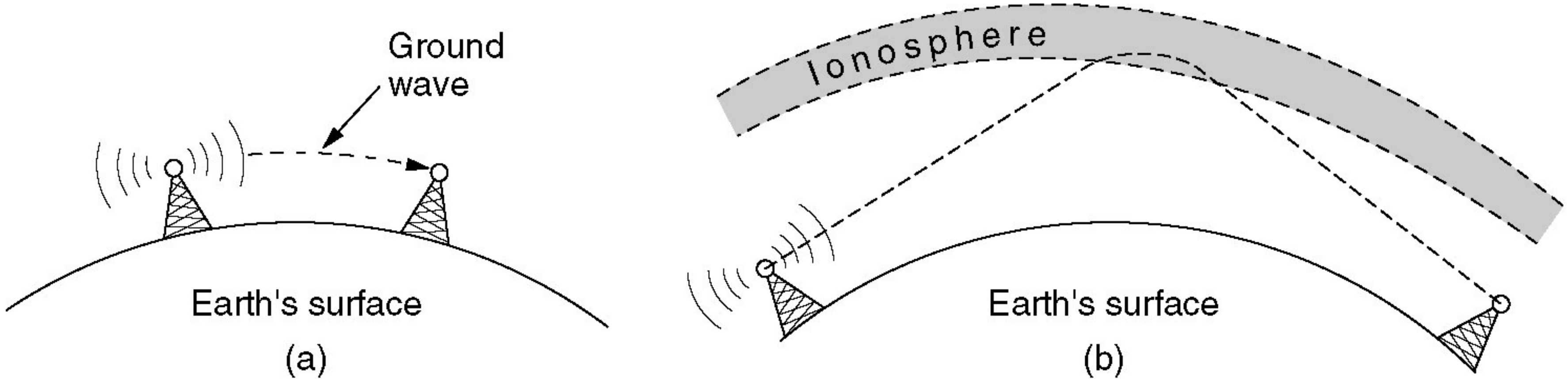
- The Electromagnetic Spectrum
- Radio Transmission

The Electromagnetic Spectrum

The electromagnetic spectrum and its uses for communication



Radio Transmission



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

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

To Think

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

$$f_c = c / \lambda$$

Path Loss – Free Space Model

- Channel gain in free space → $P_r/P_s = \left[\frac{\lambda\sqrt{G_l}}{4\pi d}\right]^2$
  - » $\lambda = c / f_c$, the wavelength of the carrier
  - » G_l, antennas Gain
  - » d, distance sender – receiver

$$\downarrow$$

$$\boxed{PG_{dB} = 10\ log(Pr/Ps)}$$

$$\downarrow$$

$$\boxed{PL_{dB} = -PG_{dB} = P_{s_{dB}} - P_{r_{dB}}}$$

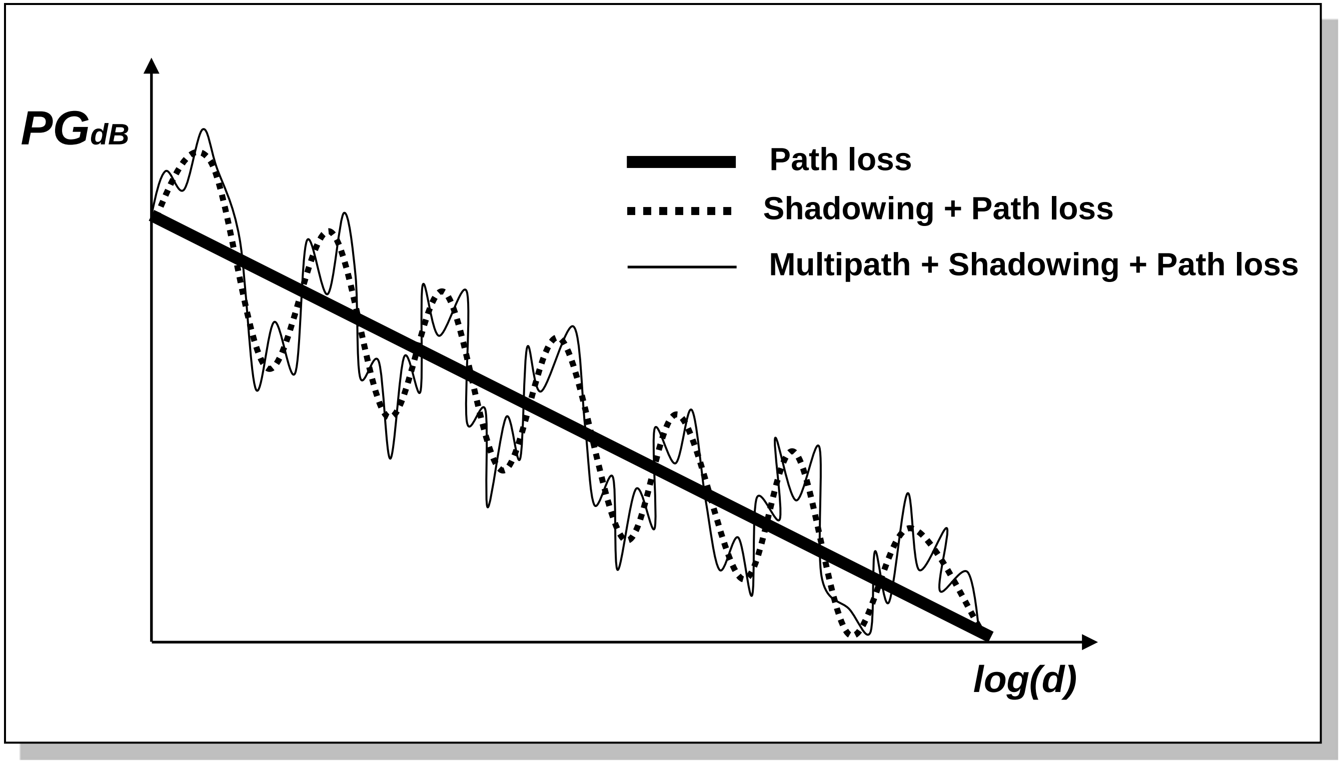
$$\downarrow$$

$$\boxed{PL_{dB} = -10\ log\frac{\lambda^2 G_l}{(4\pi d)^2}}$$

$$PG_{dB} = 20.\log\left(\frac{\lambda\sqrt{G_l}}{4\pi}\right) - 20.\log(d) = b - 20x$$

Signal Propagation and Wireless Channels

$$PG_{dB} = 10\ log(Pr/Ps)$$



Path Loss – Free Space Model

Assume a receiver needs to receive, at least, 0.1 μW ➔ $\boxed{P_r = 0.1\ \mu W}$

$$\boxed{P_{r_{dBW}} = 10\ log\left(\frac{P_{r_W}}{1\ W}\right) = 10\ log\left(\frac{10^{-7}\ W}{1\ W}\right) = -70\ dBW}$$

$$\boxed{P_{r_{dBm}} = 10\ log\left(\frac{P_{r_W}}{1\ mW}\right) = 10\ log\left(\frac{10^{-7}\ W}{10^{-3}\ W}\right) = -40\ dBm}$$

f_c (MHz)	λ $\left(\frac{c}{f_c}\right)$ (cm)	d (m)	PL_{dB} $\left(-10\ log\frac{\lambda^2 G_l}{(4\pi d)^2}\right)$ (dB)	$P_{s_{dBm}}$ $(P_{r_{dBm}} + PL_{dB})$ (dBm)	P_s $\left(10^{\frac{P_{s_{dBm}}}{10}-3}\right)$ (W)
900	33	10 100 1000	51.5 71.5 91.5	11.5 31.5 51.5	0.014 1.42 142
3000	10	10 100 1000	62 82 102	22 42 62	0.158 15.8 1579

P_L increases 20 db per logd

Capacity of an Wireless Channel

$P_r(d) = (d_0/d)^3 \, P_t$, for $d_0 = \ 10m$

d (m)	$\gamma = P_r(d)/(N_0 B)$	$SNR = \gamma_{dB} = 10 \ log \gamma$ (dB)	$C = B \ log_2(1+\gamma)$ $(kbit/s)$	Efficiency (bit/s/Hz)
50	267	24	242	8
100	33	15	153	5.1
500	0.27	-6	10	0.3
1000	0.033	-15	1.4	0.05

Table 2.6: Shannon capacities for wireless channels. The limiting capacities of wireless channels depend on the channel bandwidth and on the power received. The capacity C of the channel and its efficiency are given for a transmitted power $P_s = 1\,W$, $d_0 = 10\ m$, a narrow bandwidth of $30\ kHz$ and a noise power spectral density $N_0 = 10^{-9}\ W/Hz$. The capacity decreases significantly as the distance between the sender and the receiver increases

To Think

- How to transmit in both directions,

  a→b and a ← b,

  using the transmission media studied?

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