Physical Layer

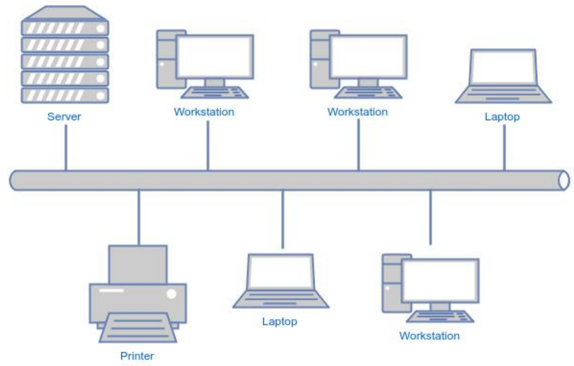
Responsibilities and Services

Provide following services to upper layer protocols:

- Define network topology
- Converts bit into signal and vice versa.
- Defining the medium of communication
  - Guided Medium (Wired)
  - Unguided Medium (Wireless)
- Defining interface type
  - RS232
  - RJ45 etc.
- Facilitate parallel as well as serial communication

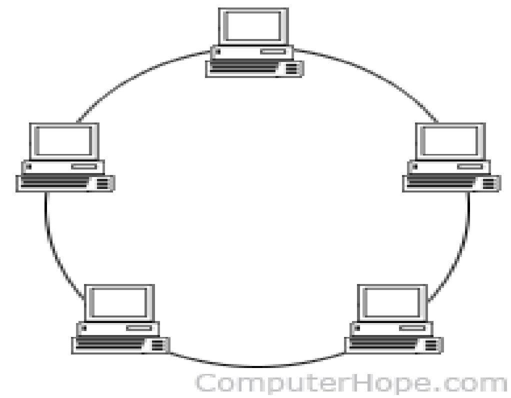
Network Topology

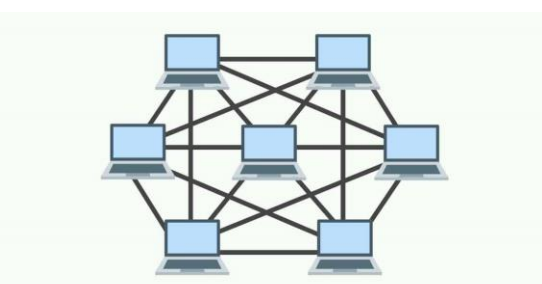
- Bus
- Ring
- Star
- tree
- Mesh
- Combination of above all

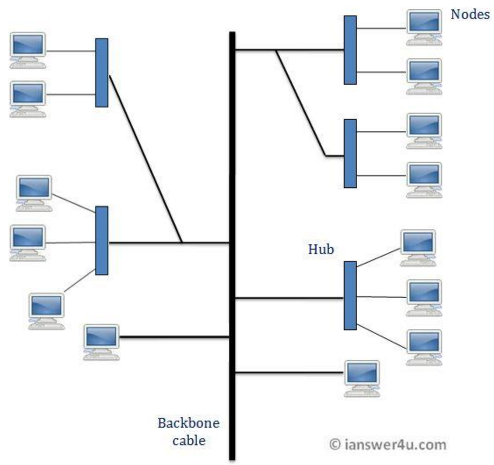


Bus Topology Network

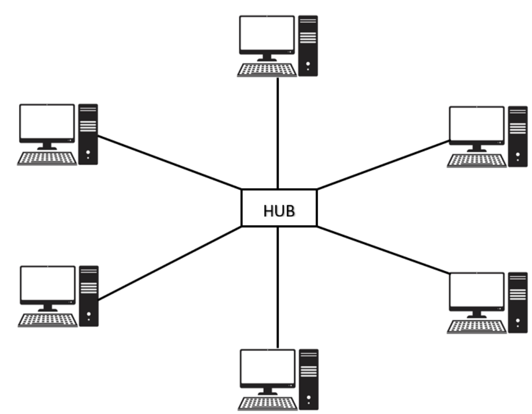
Ring Topology



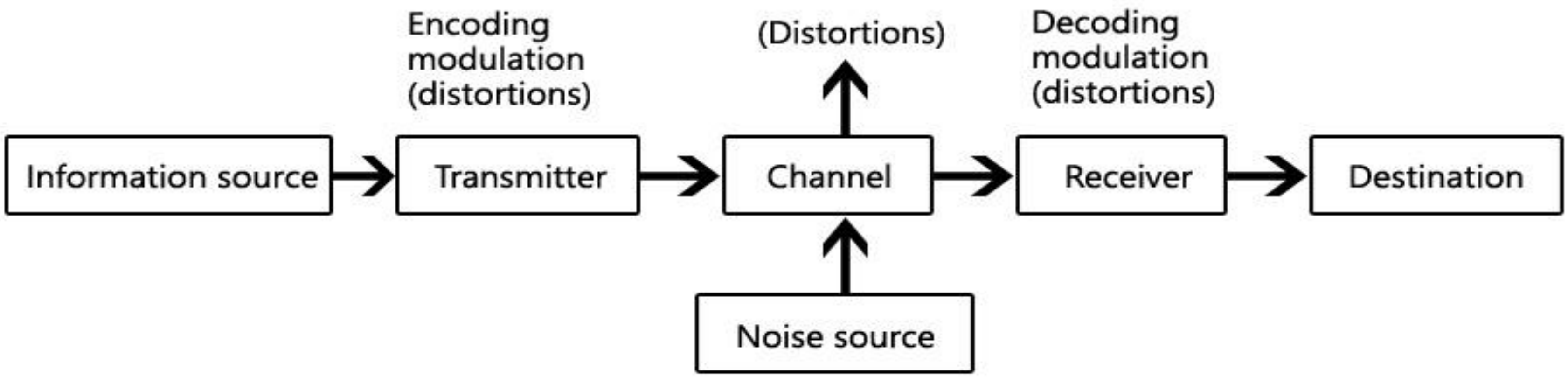




Star Topology

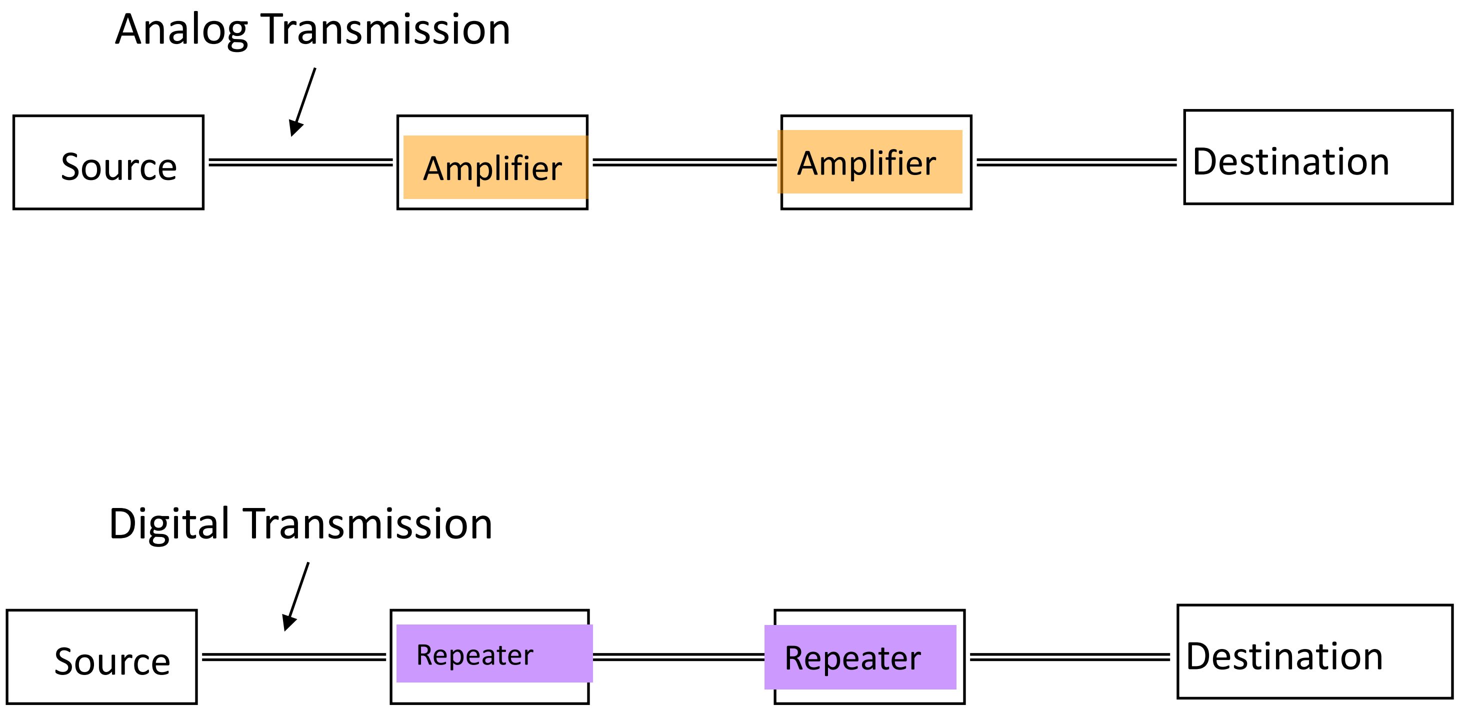


Communication Basics



- Communication means transfer of data from one place to another.
- To transfer the data, signals are sent from one place to another over either wired medium or wireless medium.
- A signal is a physical representation of data which will be a function of time and space.

Communication Basics



Communication Channel

- A logical point to point connection between source and destination.
- So far we have assumed one channel per connection.
- What if there is more bandwidth available than that required by a single user then we can create more than one channel from the available bandwidth by the use of multiplexing techniques for example:
  - Frequency division multiplexing (FDM)
  - Time division multiplexing (TDM)
  - Code division multiplexing (CDMA)
  - Orthogonal frequency division multiplexing (OFDM) etc.

Type of communication

- Digital data and analog signal (Computer to internet communication through modem, mobile communication)
- Digital data and digital signal (LAN)
- Analog data and analog signal (Telephone)
- Analog data and digital signal (Voice over internet)

Bandwidth vs. Spectrum

Bandwidth: it is defined for the wired medium and depends upon the number of frequencies that the medium allows to pass through it. (f_{max}-f_{min} Hz)

Spectrum: Part of electromagnetic spectrum allowed by the regulatory bodies to use.

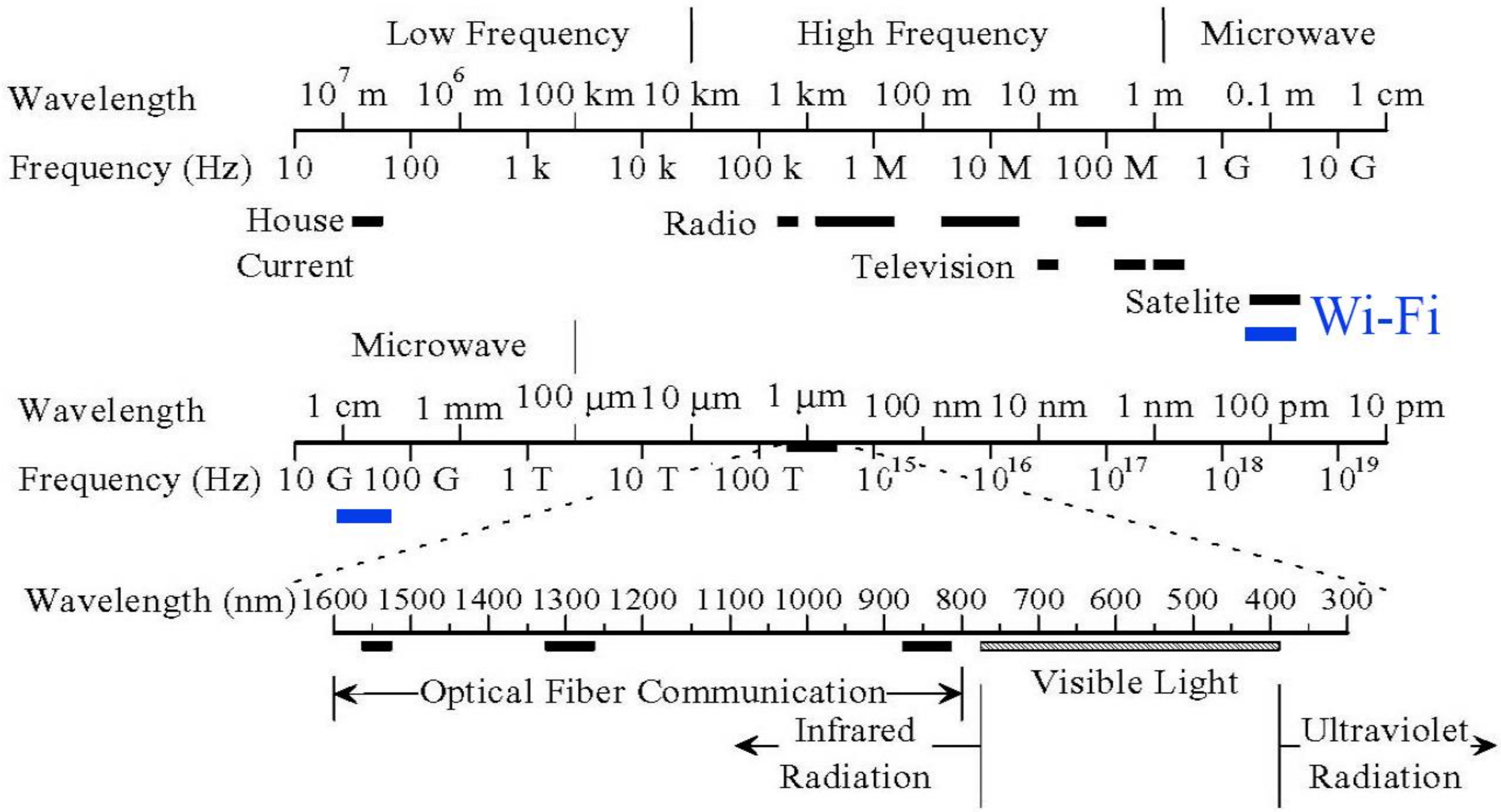
Physical Layer definitions

- the time required to transmit a character depends on both the encoding method and the signaling speed (i.e., the modulation rate - the number of times/sec the signal changes its voltage)
- baud (D) - the number of changes per second
- bandwidth (H) - the range of frequencies that is passed by a channel. The transmitted signal is constrained by the transmitter and the nature of the transmission medium in cycles/sec (hertz)
- channel capacity (C) – the rate at which data can be transmitted over a given channel under given conditions.{This is also referred to as **data rate (R)** .}

Transmission Medium

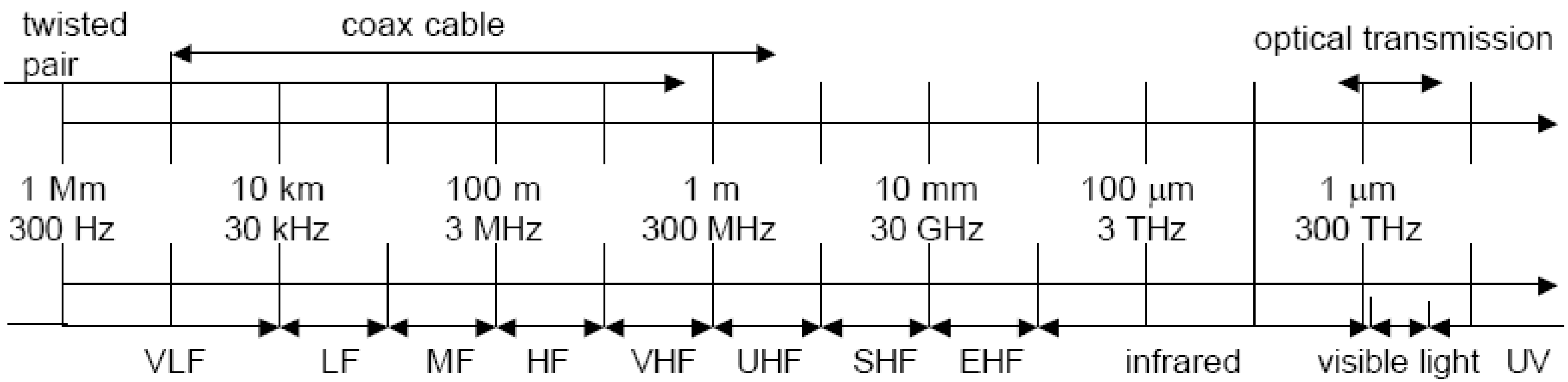
- Wired (Guided Medium)
  - Twisted pairs ($10^4 to 10^8 Hz$) ($10\ KHz\ to\ 100\ MHz$) (Mbps) (~10 Kms)
  - Unshielded Twisted Pair ($10^4 to 10^8 Hz$) ($10\ KHz\ to\ 100\ MHz$) ($Gbps$)(~10 Kms)
  - Coaxial cables ($10^5 to 10^9 Hz$) ($100\ KHz\ to\ 1\ GHz$) ($Gbps$)(~10 Kms)
  - Fiber LinesCoaxial cables ($10^{14} to 10^{15} Hz$) ($100\ THz\ to\ 1000\ THz$)($> Gbps$) (~100 Kms)
- Wireless (Part of electromagnetic spectrum) (Unguided Medium)
  - Radio waves ($10^4 to 10^8 Hz$) ($10\ KHz\ to\ 100\ MHz$)
  - Microwaves ($10^8 to 10^{10} Hz$) ($100\ MHz\ to\ 10\ GHz$)
  - Infrared ($10^{11} to 10^{14} Hz$) ($100\ GHz\ to\ 100\ THz$)
  - Visible Light

Frequencies for Communication



- Wireless communication uses 100 kHz to 60 GHz

Frequencies for Communication



VLF = Very Low Frequency
LF = Low Frequency
MF = Medium Frequency
HF = High Frequency
VHF = Very High Frequency

UHF = Ultra High Frequency
SHF = Super High Frequency
EHF = Extra High Frequency
UV = Ultraviolet Light

Frequency and wave length:

$$\lambda = c/f$$

wave length λ, speed of light $c \cong 3\text{x}10^8$m/s, frequency f

Frequencies for Communication

- VLF, LF, MF HF not used for wireless
- VHF-/UHF-ranges for mobile radio
  - simple, small antenna for cars
  - deterministic propagation characteristics, reliable connections
- SHF and higher for directed radio links, satellite communication
  - small antenna, beam forming
  - large bandwidth available
- Wireless LANs use frequencies in UHF to SHF range
  - some systems planned up to EHF
  - limitations due to absorption by water and oxygen molecules (resonance frequencies)
  - weather dependent fading. (E.g. signal loss caused by heavy rain)

What is a signal

- A signal is an electrical and electromagnetic encoding of data.
- Signal can be of two types:
  - Digital Signal (discrete time and discrete values)
  - Analog Signal (continuous time and continuous values)
- Digital signals are generated by the use of encoding techniques.
- Analog signals are generated by the use of modulation techniques.

Analog and Digital Signaling Comparison

- Digital signaling is:
  - Cheaper
  - Less susceptible to noise interference
  - Suffers more attenuation.

Analog Transmissions

Analog transmission :: a means of transmitting analog signals *without regard to their content* (i.e., the signals may represent analog data or digital data).

transmissions are attenuated over distance.

Analog signal – the analog transmission system uses amplifiers to boost the energy in the signal.

Digital Transmissions

Digital transmissions are concerned with the content of the signal. Attenuation is overcome without amplifying the noise.

Analog signals {*assumes digital data*}:

With retransmission devices [analog repeater] at appropriate points the device recovers the digital data from the analog signal and generates a <u>new</u> clean analog signal.

the noise is not cumulative!!

Digital Transmissions

digital signals – **digital repeaters** are used to attain greater distances.

The **digital repeater** receives the digital signal, recovers the patterns of 0's and 1's and retransmits a <u>new</u> digital signal.

The treatment is the same for analog and digital data.

Signal Parameter

- Parameters of periodic signals:
  - period T,
  - frequency f=1/T,
  - amplitude A,
  - phase shift θ

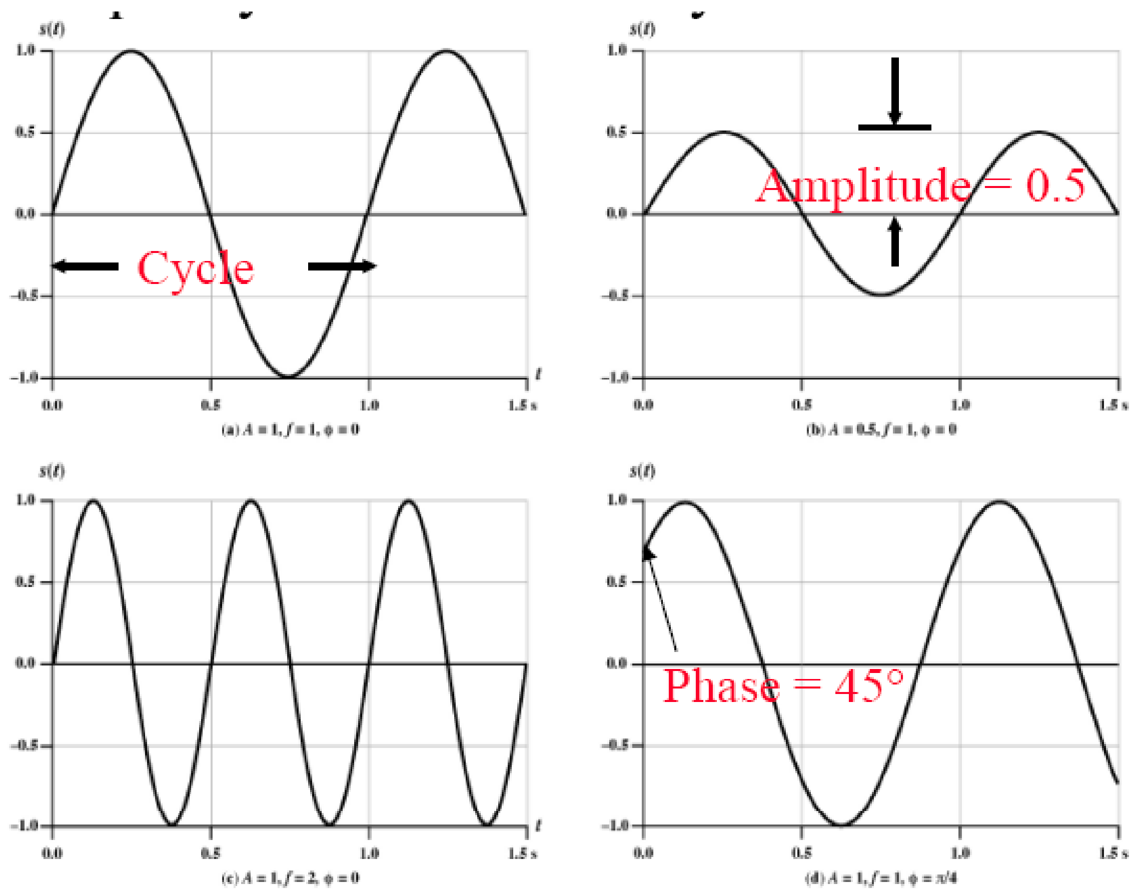
Signal Parameter (contd.)

A sine wave as special periodic signal for a carrier can be represented as:

$$A \, \mathrm{Sin}(2\pi f t + \theta)$$

A = Amplitude, f=Frequency, θ= Phase, Period T = 1/f,

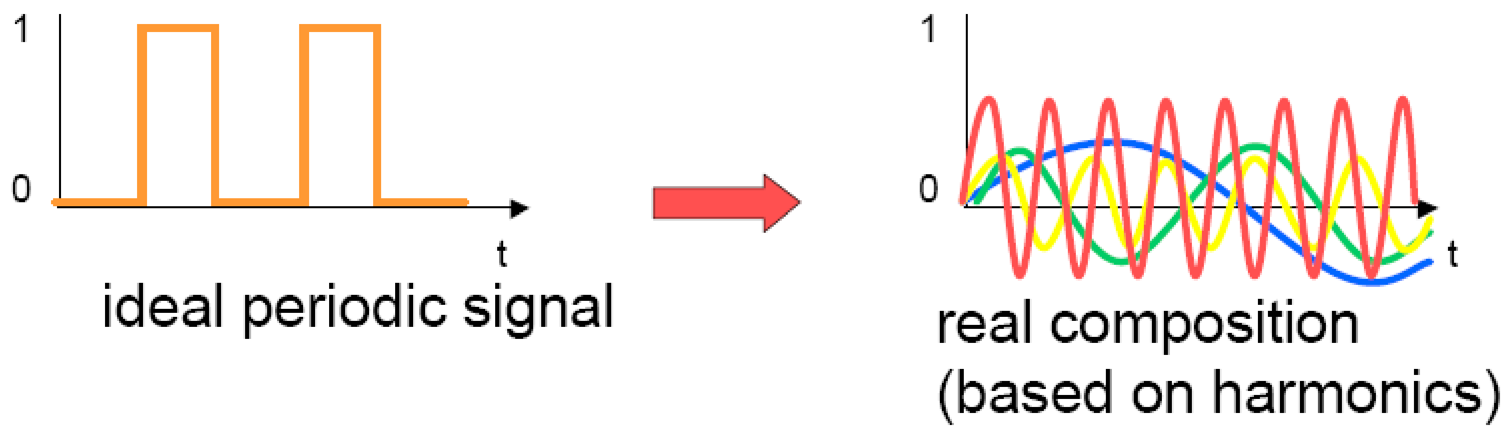
- Frequency is measured in Cycles/sec or **Hertz**



Signal Parameter (contd.)

Fourier representation of a periodic signal:

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



Signal Parameter (contd.)

Wavelength:

- Distance occupied by one cycle
- Distance between two points of corresponding phase in two consecutive cycles
  - Wavelength = λ
  - Assuming signal velocity *v*

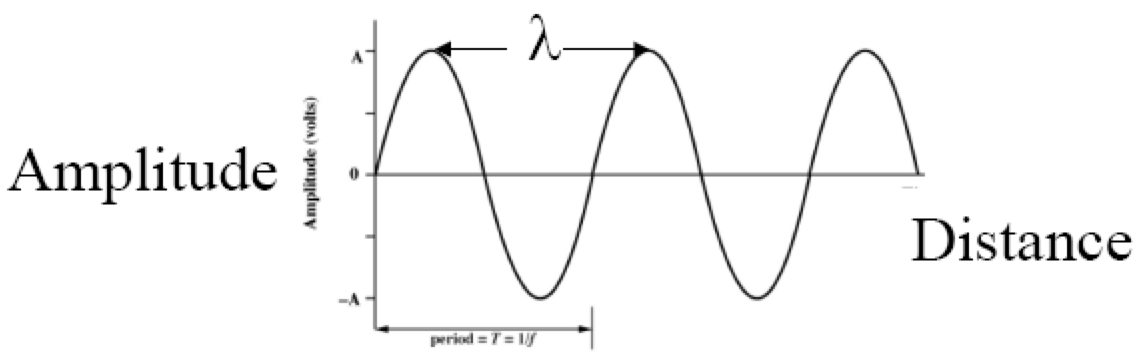
    (Wavelength) $\lambda = vT$

    $T=1/f$

    $\lambda f = v$

    $\lambda = v/f$ *=> higher the frequency, lower the wavelength*

    v=c = 3×108 m/s(speed of light in free space) = *300 m/µs*

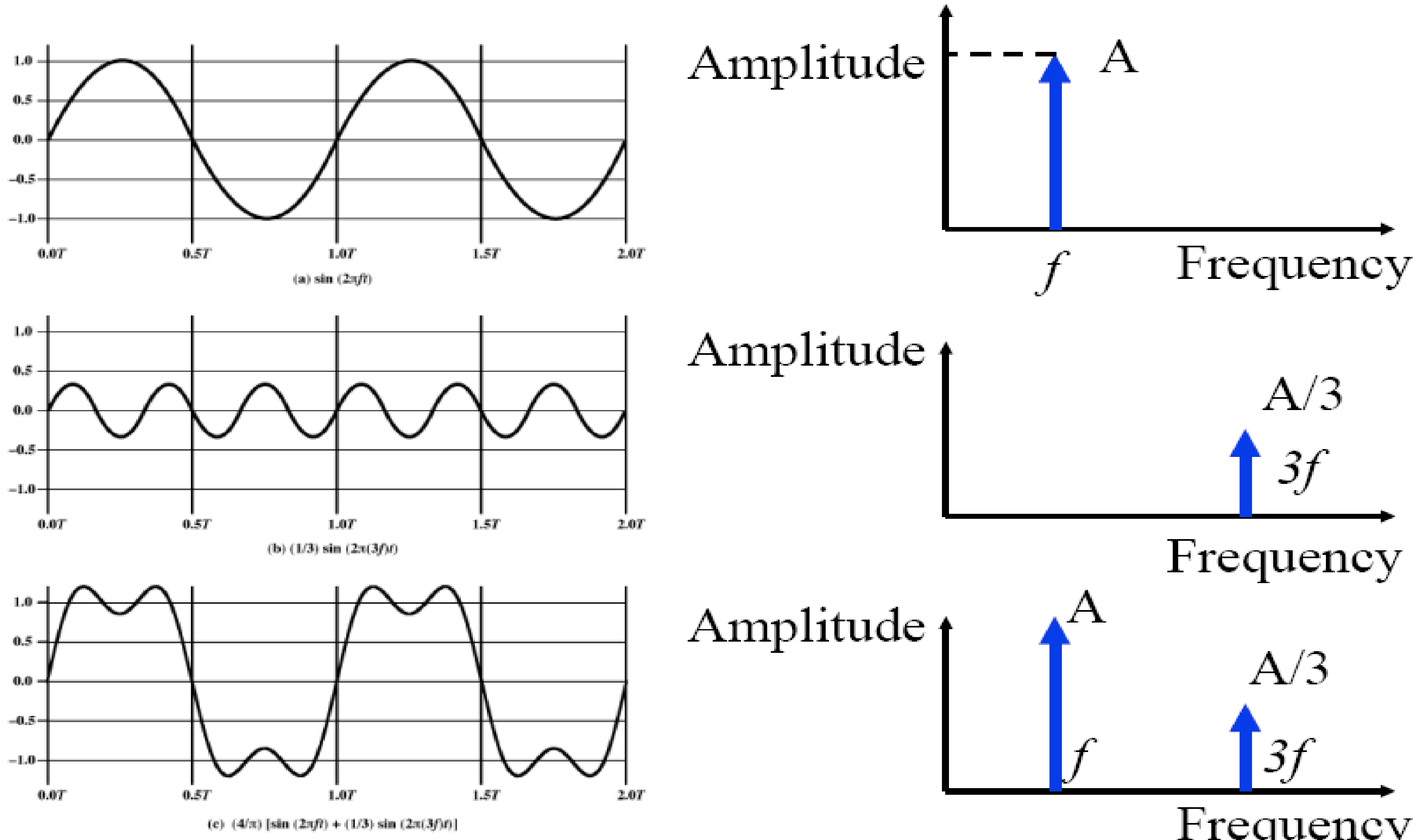


Example

- Frequency = 2.5 GHz

$$
\begin{aligned}
\text{Wavelength } = \lambda &= \frac{c}{f} \\
&= \frac{300 \text{ m}/\mu\text{s}}{2.5 \times 10^9} \\
&= 120 \times 10^{-3} = 120 \text{ mm} = 12 \text{ cm}
\end{aligned}
$$

Time and Frequency Domain Representations



Transmission Impairments

- Attenuation
- Delay distortions (Delay spread)
- Noise
- Interference
- Multipath Fading

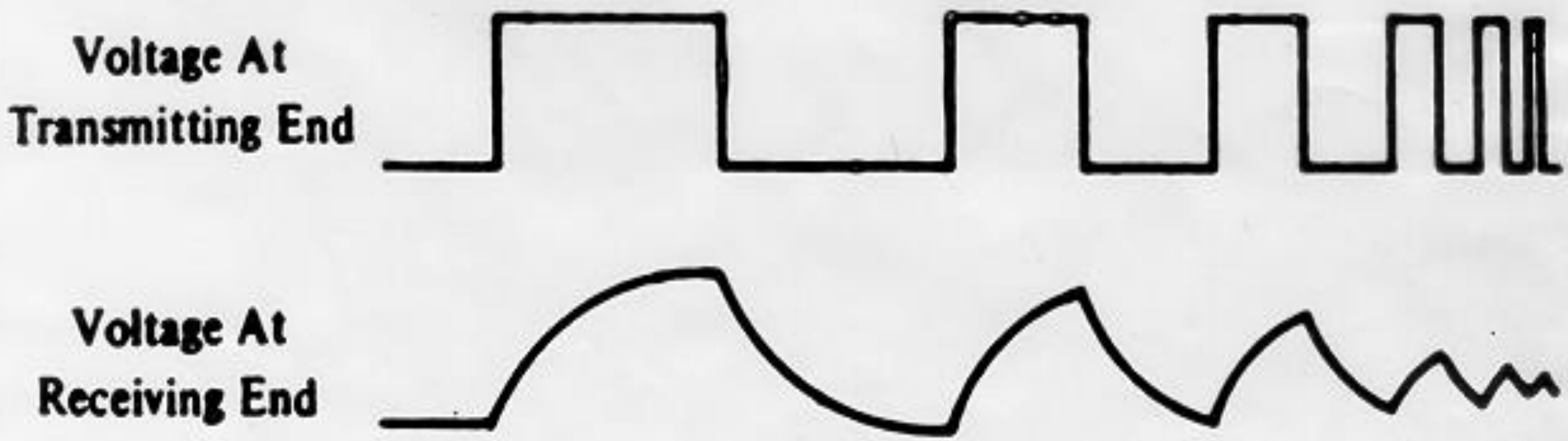
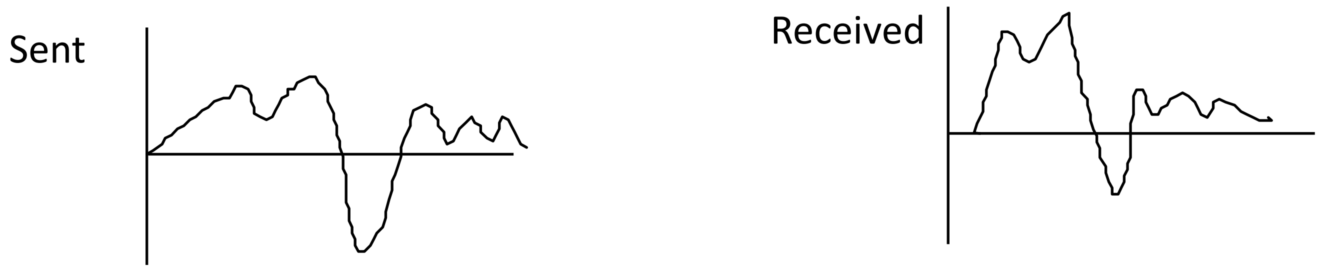


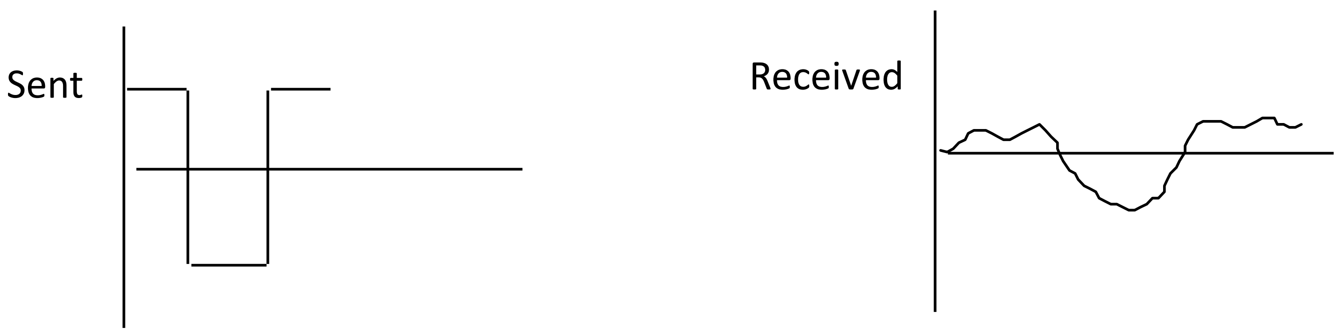
FIGURE 2.1 Attenuation of Digital Signals

(a) Analog transmission: all details must be reproduced accurately



- e.g. AM, FM, TV transmission

(b) Digital transmission: only discrete levels need to be reproduced



- e.g digital telephone, CD Audio

Leon-Garcia & Widjaja: *Communication Networks*
Figure 3.6

Nyquist Theorem

{assume a noiseless channel}

If an arbitrary signal is run through a channel of bandwidth **H, the** signal occupy **V** discrete levels, then the maximum data rate obtained over the channel can be computed as

$$\text{Max. data rate} :: \ \mathbf{C} = 2\mathbf{H} \log_2 (\mathbf{V}) \ \text{bits/sec.}$$

The Nyquist theorem says that the signal can be *completely* reconstructed by making **2H** samples/sec.

Note – a higher sampling rate is pointless because higher frequency signals have been filtered out.

Voice-grade phone line

Example 1. {sampling rate}

H = 4000 Hz

2H = 8000 samples/sec.

→ sample every 125 microseconds!!

Example 2. {noiseless capacity}

D = 2400 baud {note D = 2H}

V = each pulse encodes 16 levels

C = $2H \log_2 (V) = D \times \log_2 (V)$

$= 2400 \times 4 = 9600$ bps.

Shannon's Channel Capacity Result

{assuming only thermal noise}

For a noisy channel of bandwidth **H** Hz. and a signal-to-noise ratio **SNR**, the max. data rate:

$$\mathbf{C} = \mathbf{H} \log_2 (1 + \mathbf{SNR})$$

Regardless of the number of signal levels used and the frequency of the sampling.

Signal to Noise Ratio

$$SNR_{dB} = 10\log_{10}\frac{SignalPower}{NoisePower}$$

Shannon Example – Noisy Channel

[LG&W p. 110]

Telephone channel (3400 Hz) at 40 dB SNR

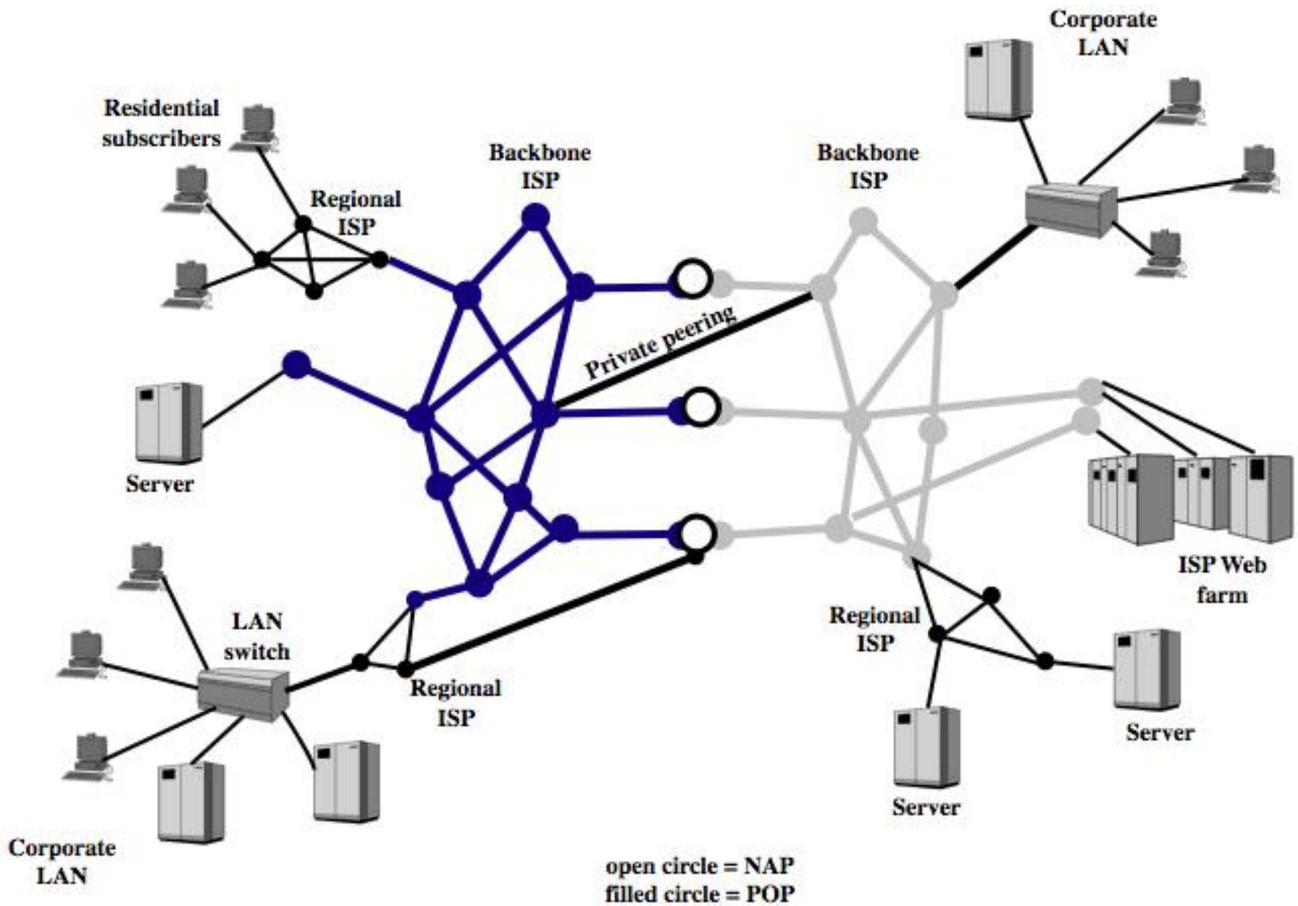
$C = H \log_2 (1+SNR)$ b/s

$SNR = 40$ dB ; $40 = 10 \log_{10} (SNR)$;

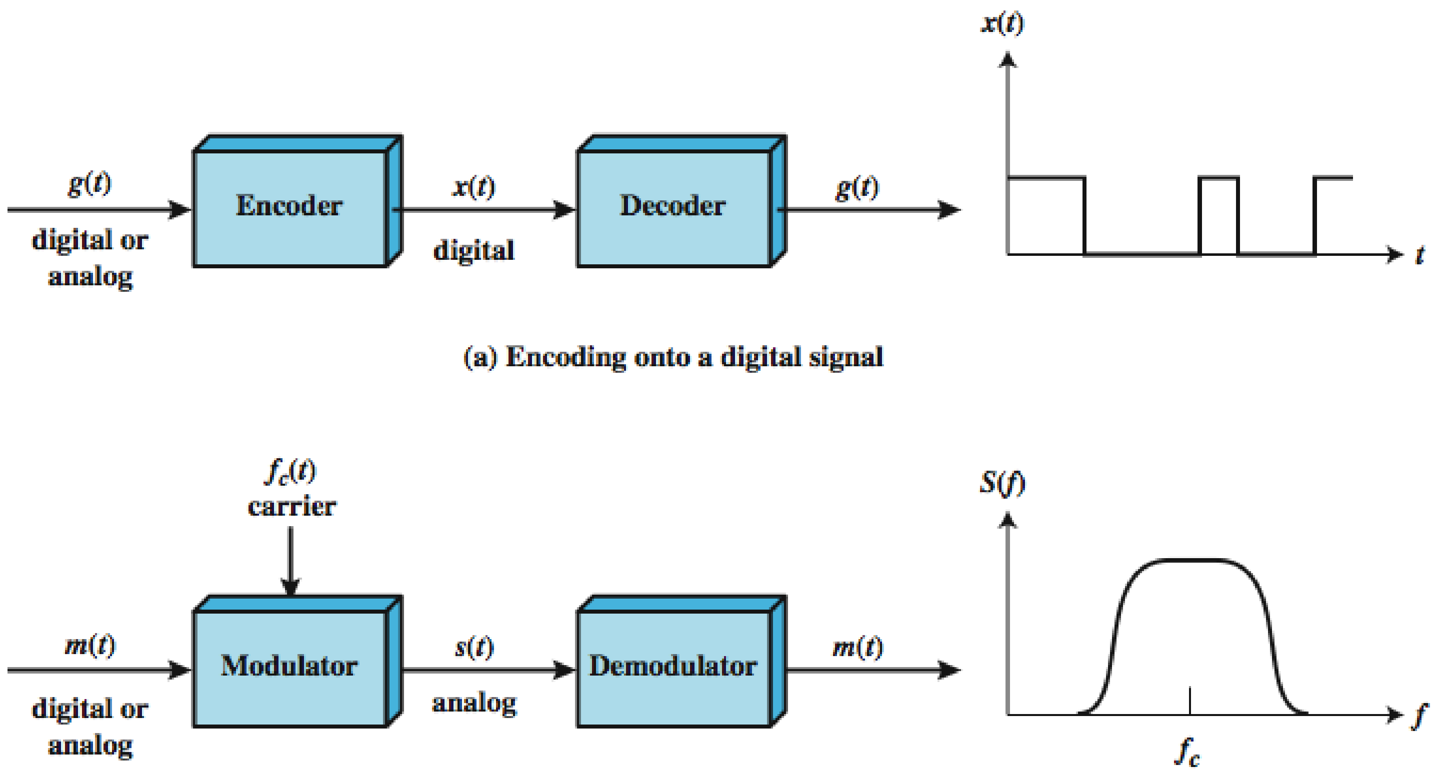
$4 = \log_{10} (SNR)$; $SNR = 10{,}000$

$C = 3400 \log_2 (10001) = 44.8$ kbps

Internet Architecture



Signal Encoding Techniques



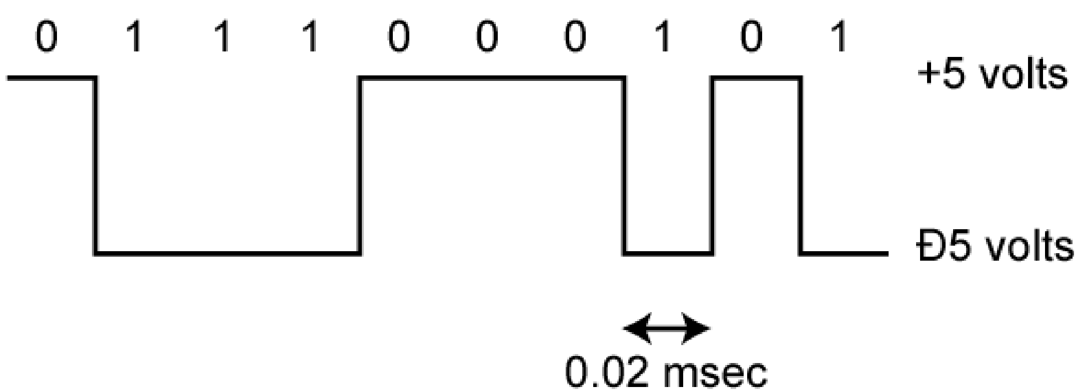
(a) Encoding onto a digital signal

(b) Modulation onto an analog signal

Figure 5.1 Encoding and Modulation Techniques

Digital Data, Digital Signal

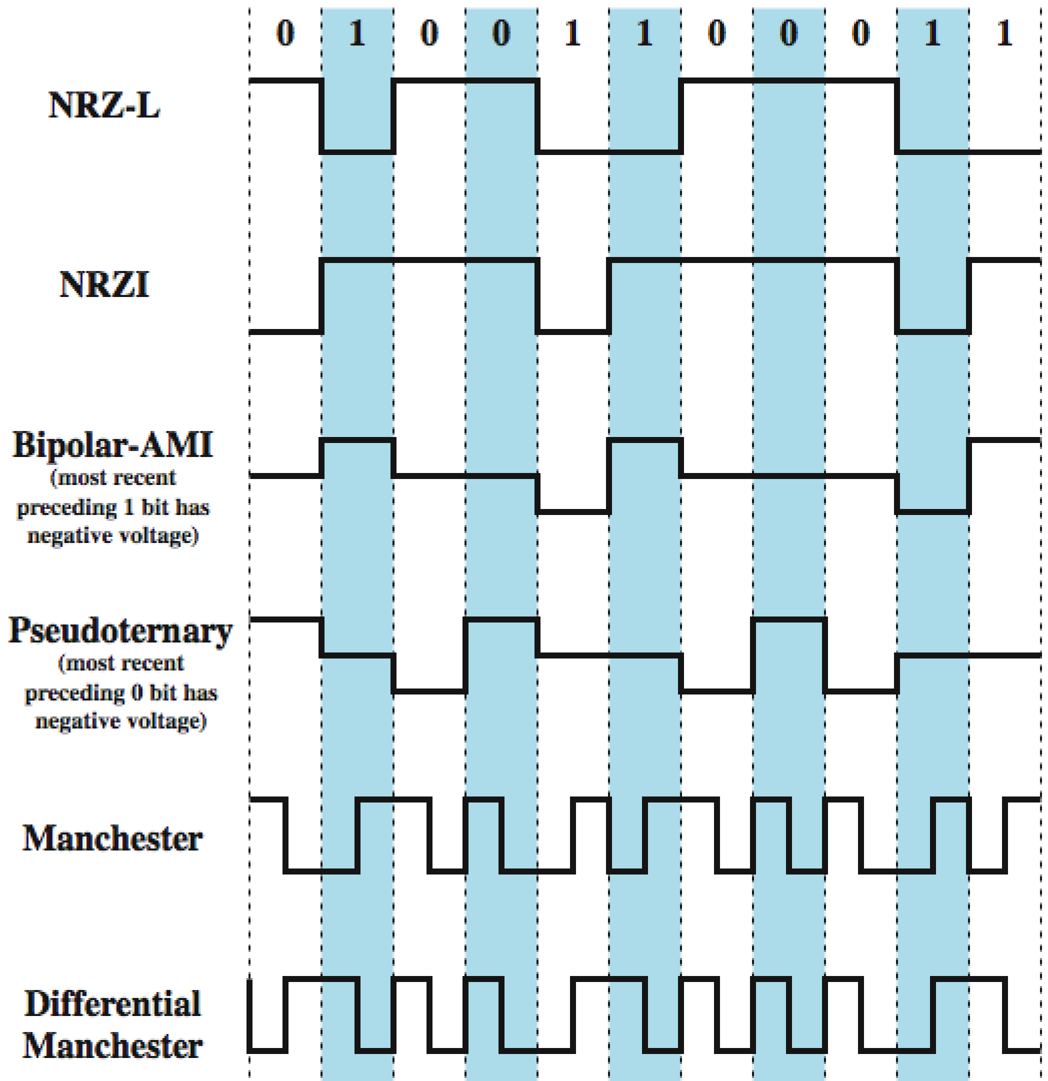
- Digital signal
  - discrete, discontinuous voltage pulses
  - each pulse is a signal element
  - binary data encoded into signal elements



Comparison of Encoding Schemes

- clocking
- error detection
- signal interference and noise immunity (BER)
- cost and complexity (Hardware implementation and no. of signals required to represent 1 bit information)
- Net DC Component present in the signal

Encoding Schemes



Nonreturn to Zero-Level (NRZ-L)

- two different voltages for 0 and 1 bits

Rule

0: High voltage level

1: Low voltage level

Data stream: 0 0 0 0 1 0 1 0 1 1 1 0 1 0

No Return to Zero Inverted (Differential Encoding)

- no return to zero inverted on ones
- constant voltage pulse for duration of bit
- data encoded as presence or absence of signal transition at beginning of bit time

1: transition (low to high or high to low) at the start of the bit interval

0:no transition at the start of the bit interval

Data stream: 0 0 0 0 1 0 1 0 1 1 1 0 1 0

NRZ Pros & Cons

- Pros
  - easy to engineer
  - make good use of bandwidth
- Cons
  - dc component
  - lack of synchronization capability
- used for magnetic recording
- not often used for signal transmission

Multilevel Binary
Bipolar-AMI

- Use more than two levels
- Bipolar-AMI

  0: represented by no line signal (0 Voltage)
  1: one represented by alternate positive and negative pulse

  - Data stream: 0 0 0 0 1 0 1 0 1 1 1 0 0 0 0 0 0 0 0 0 0

- Pros:
  - no loss of sync if a long string of ones
  - long runs of zeros still a problem
  - no net dc component
  - lower bandwidth
  - easy error detection

Multilevel Binary Pseudoternary

- Same as Bipolar – AMI

  1: represented by no line signal (0 Voltage)

  0: one represented by alternate positive and negative pulse

- Data stream: 0 0 0 0 1 0 1 0 1 1 1 0 0 0 0 0 0 0 0 0 0

- Both Bipolar AMI and Pseudoternary used in some applications.

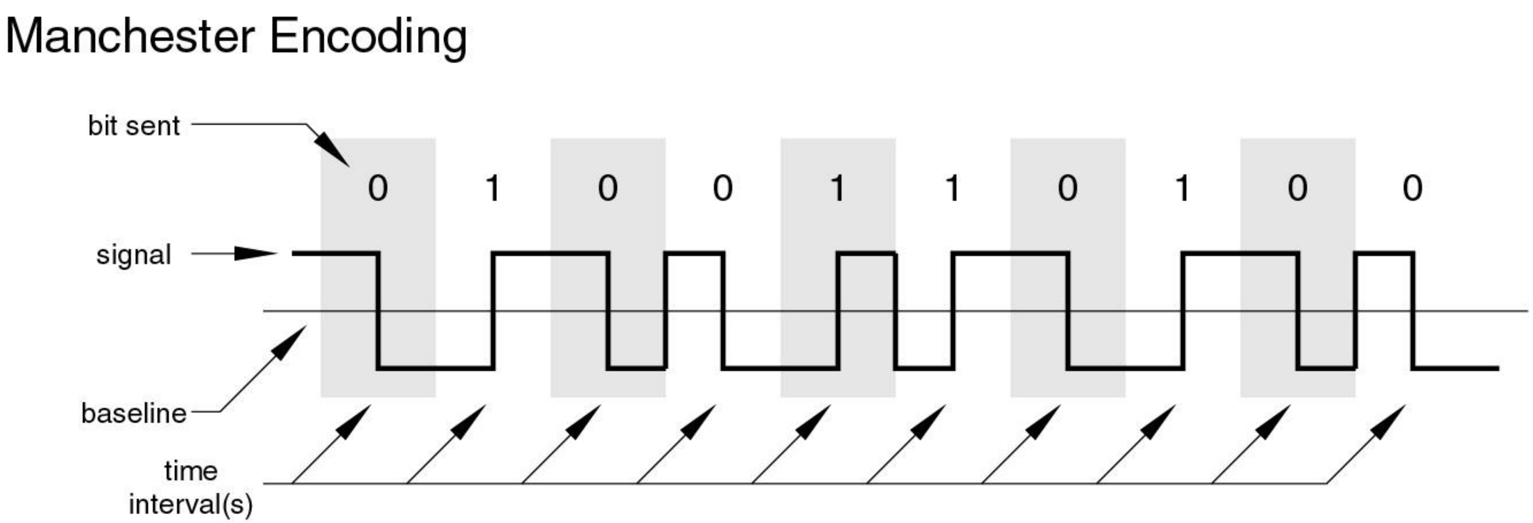
Multilevel Binary Issues

- synchronization with long runs of 0's or 1's
- not as efficient as NRZ
  - each signal element only represents one bit
    - receiver distinguishes between three levels: +A, -A, 0
  - a 3 level system could represent $\log_2 3 = 1.58$ bits
  - requires approx. 3dB more signal power for same probability of bit error
- Examples:
  - Manchester and
  - Differential Manchester Encoding

Manchester Encoding

Rule

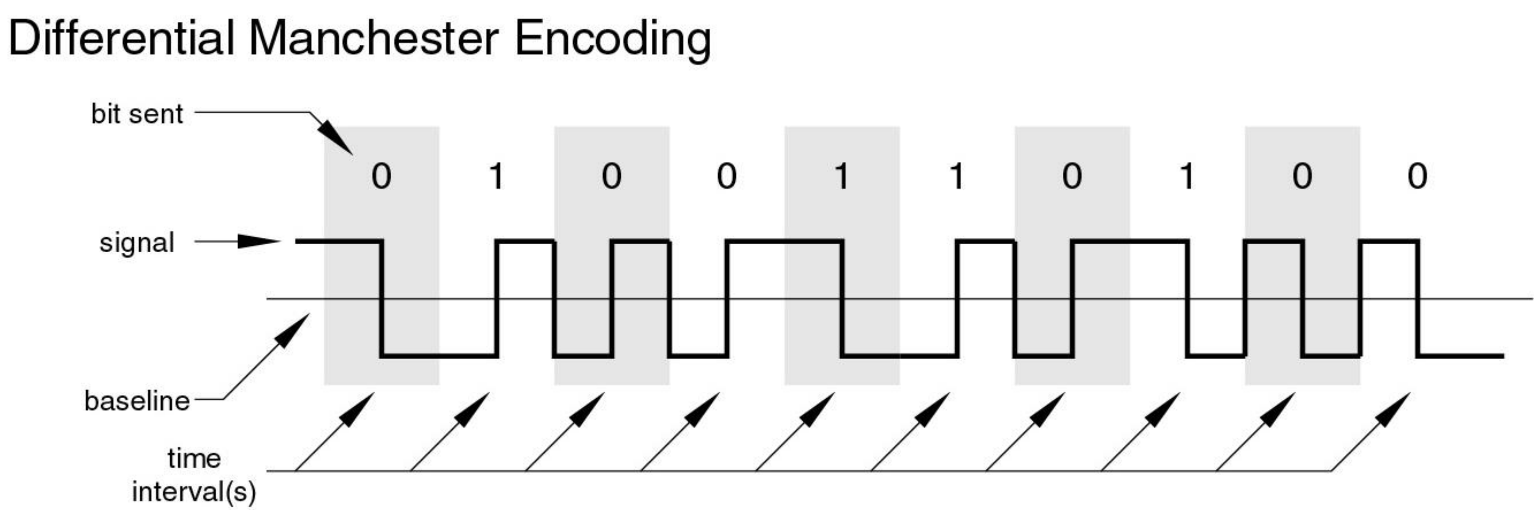
- has transition in middle of each bit period
- transition serves as clock and data
- 1: Low to high transition at the middle of the bit interval
- 0: High to low transition at the middle of the bit interval
- used by IEEE 802.3 (Ethernet)



Differential Manchester Encoding

Rule

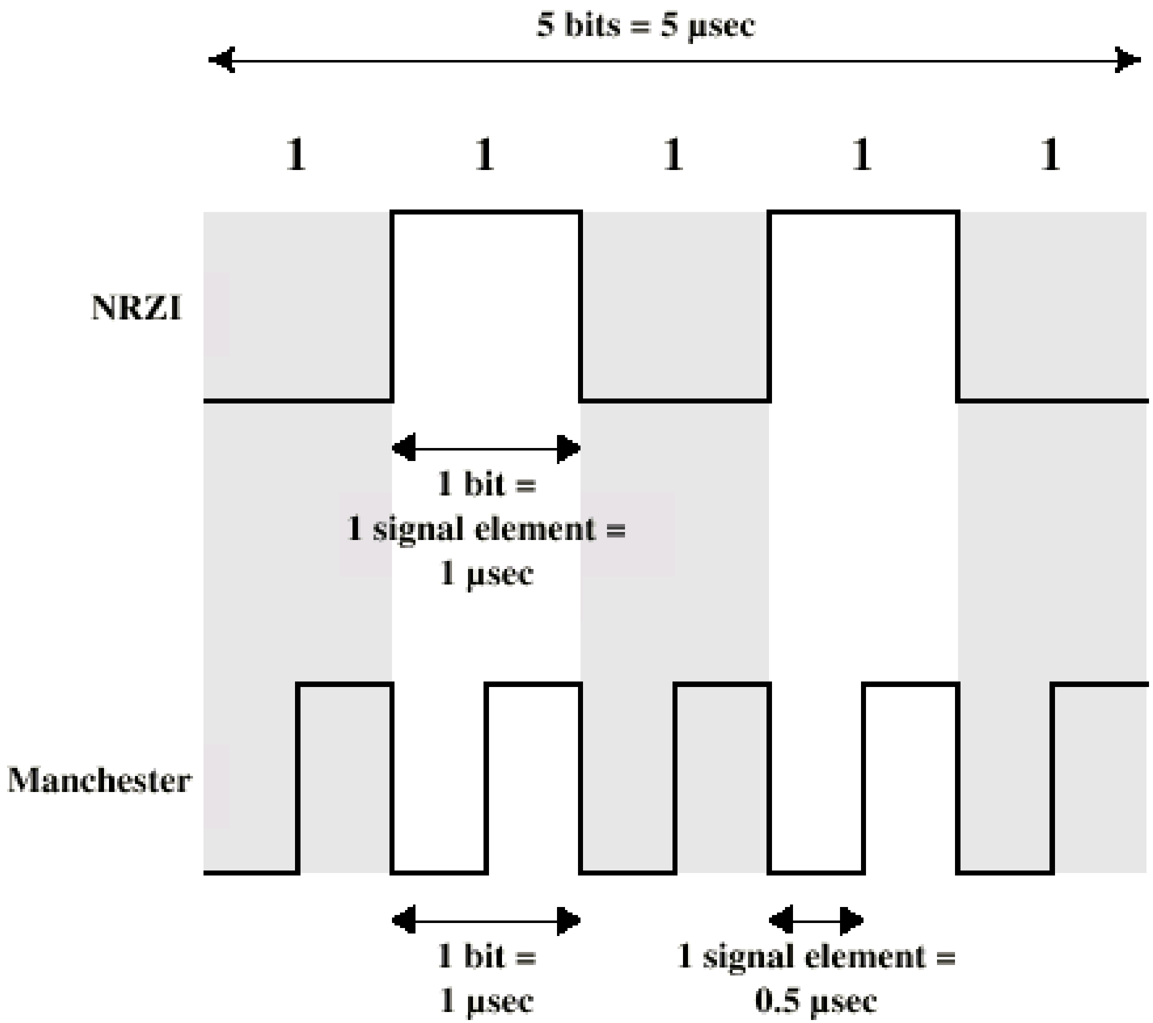
- 0: transition at start of bit period
- 1: no transition at start of bit period
- Always a transition at the middle of bit interval is clocking only
  - this is a differential encoding scheme
  - used by IEEE 802.5



Biphase Pros and Cons

- Con
  - at least one transition per bit time and possibly two
  - maximum modulation rate is twice NRZ
  - requires more bandwidth
- Pros
  - synchronization on mid bit transition (self clocking)
  - has no dc component
  - has error detection

Modulation Rate



For long distance digital transmission

- Bipolar AMI with 8 zero substitution (B8ZS)
- High Density Bipolar with 4 zero substitution (HDB3)

B8ZS

Rule:

- Encoding takes place as per Bipolar –AMI but every sequence of 8 zeros will be replaced by the following rules:
  - If last voltage pulse preceding 8 zeros was positive then
    - $000 + -0 - +$
  - If last voltage pulse preceding 8 zeros was negative then
    - $000 - +0 + -$
- Cause two code violations in Bipolar AMI code.
- Data stream: 0 0 0 0 1 0 1 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0

HDB3

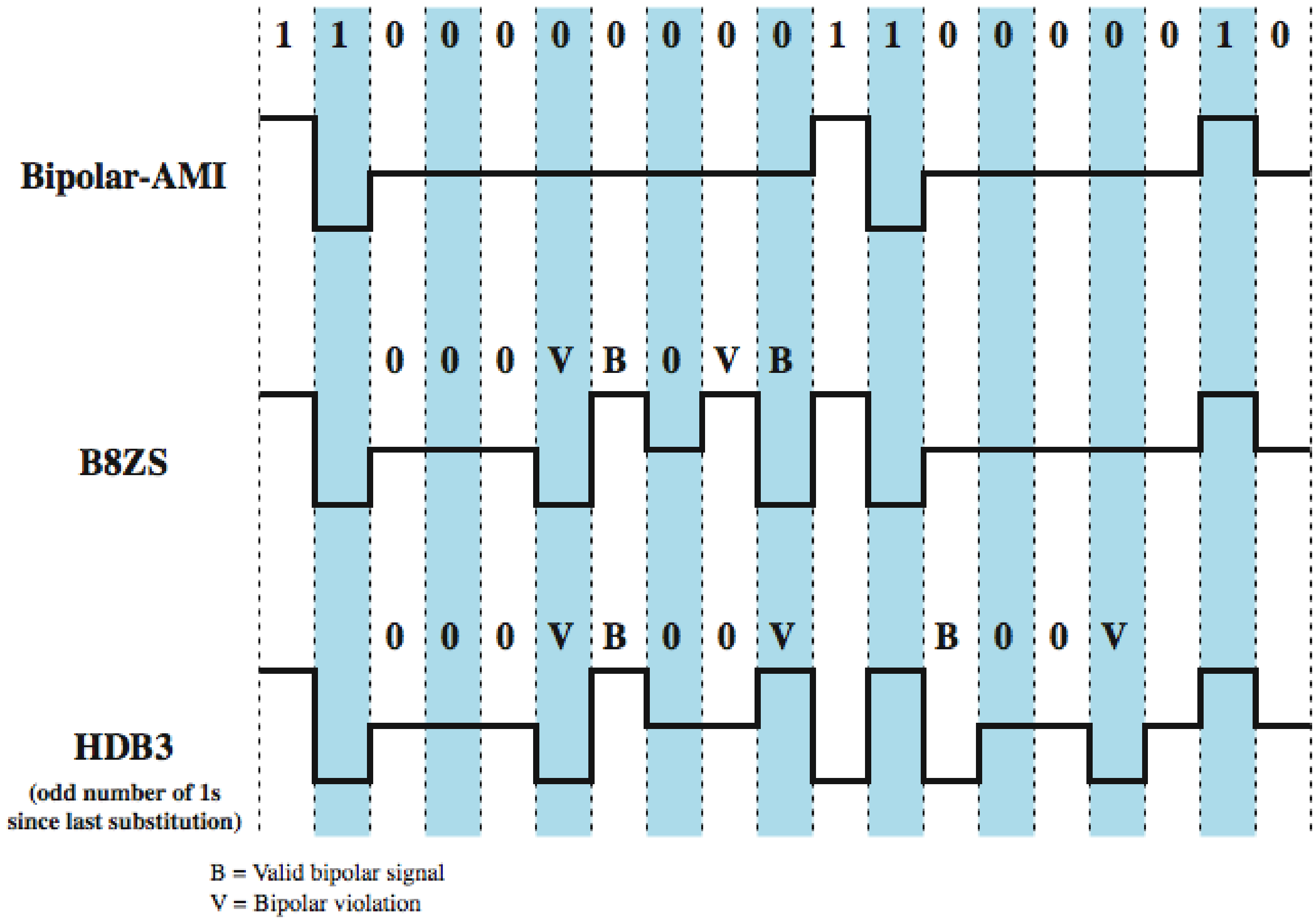
Rule:

- Encoding takes place as per Bipolar –AMI but every sequence of 4 zeros will be replaced by the following rules:

Polarity of the previous pulse	Number of bits since last substitution	
	Even	Odd
$-$	$000-$	$+00+$
$+$	$000+$	$-00-$

- Cause one code violations in Bipolar AMI code.
- Data stream: 0 0 0 0 1 0 1 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0

B8ZS and HDB3



Block Encoding

- 4B/5B similarly 8B/10B
- Rule
  - Every 4 bit data is encoded in 5 bit code.
  - 5 bit codes are selected such that it do not have no more than one leading 0 and no more then two trailing 0s.
  - Therefore the code will never have three consecutive 0s.
  - Resulted code is transmitted using NRZI.
  - Provide 80% of bandwidth utilization.
- 8B/10B is used over Fibre Channel and Gigabit Ethernet etc.

Signal Modulation Criteria

- The factor which determines how successful a receiver will be in interpreting an incoming signal depends on
  - Signal-to-noise ratio
  - Data rate
  - Bandwidth
- An increase in data rate increases bit error rate.
- An increase in SNR decreases bit error rate.
- An increase in bandwidth allows an increase in data rate.

Basic Modulation Techniques

- Digital data to analog signal
  - Amplitude-shift keying (ASK)
    - Amplitude difference of carrier frequency
  - Frequency-shift keying (FSK)
    - Frequency difference near carrier frequency
  - Phase-shift keying (PSK)
    - Phase of carrier signal shifted

Amplitude-Shift Keying

- One binary digit represented by presence of carrier, at constant amplitude
- Other binary digit represented by absence of carrier

$$s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{binary } 1 \\ 0 & \text{binary } 0 \end{cases}$$

- where the carrier signal is $A\cos(2\pi f_c t)$.

Amplitude-Shift Keying

- Inefficient modulation technique
- On voice-grade lines, used up to 1200 bps
- Used to transmit digital data over optical fiber

Frequency-Shift Keying

- Two binary digits represented by two different frequencies near the carrier frequency

$$s(t) = \begin{cases} A\cos(2\pi f_1 t) & \text{binary } 1 \\ A\cos(2\pi f_2 t) & \text{binary } 0 \end{cases}$$

- where f_1 and f_2 are offset from carrier frequency f_c by equal but opposite amounts

Frequency-Shift Keying

- Less susceptible to error than ASK.
- On voice-grade lines, used up to 1200 bps
- Used for high-frequency (3 to 30 MHz) radio transmission
- Can be used at higher frequencies on LANs that use coaxial cable
- Inefficient to utilize full channel capacity.

Multiple Frequency-Shift Keying

- More than two frequencies are used
- More bandwidth efficient but more susceptible to error

$$s_i(t) = A\cos 2\pi f_i t \quad 1 \le i \le M$$

$$f_i = f_c + (2i - 1 - M)f_d$$

$$f_c = \text{the carrier frequency}$$

$$f_d = \text{the difference frequency}$$

$$M = \text{number of different signal elements} = 2^L$$

$$L = \text{number of bits per signal element}$$

Phase-Shift Keying

- Two-level PSK (BPSK)
  - Uses two phases to represent binary digits

$$s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{binary } 1 \\ A\cos(2\pi f_c t + \pi) & \text{binary } 0 \end{cases}$$

$$= \begin{cases} A\cos(2\pi f_c t) & \text{binary } 1 \\ -A\cos(2\pi f_c t) & \text{binary } 0 \end{cases}$$

Differential PSK (DPSK)

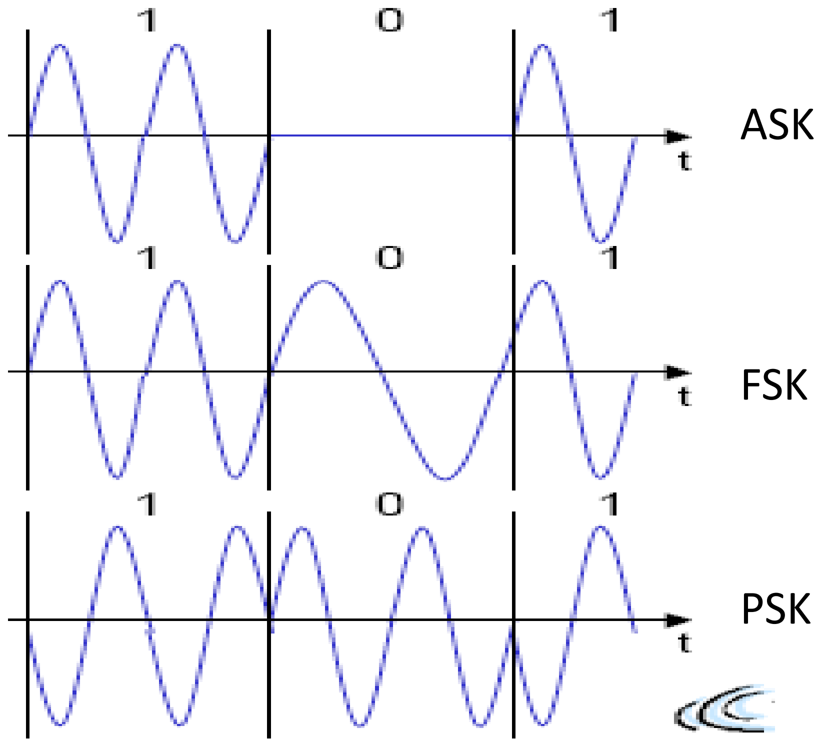
- Phase shift with reference to previous bit
  - Binary 0 – signal burst of same phase as previous signal burst
  - Binary 1 – signal burst of opposite phase to previous signal burst

Four-level PSK (QPSK)

- Each element represents more than one bit

$$s(t) = \begin{cases} A\cos\left(2\pi f_c t + \dfrac{\pi}{4}\right) & 11 \\ A\cos\left(2\pi f_c t + \dfrac{3\pi}{4}\right) & 01 \\ A\cos\left(2\pi f_c t - \dfrac{3\pi}{4}\right) & 00 \\ A\cos\left(2\pi f_c t - \dfrac{\pi}{4}\right) & 10 \end{cases}$$

Example of ASK, FSK and PSK



Quadrature Amplitude Modulation

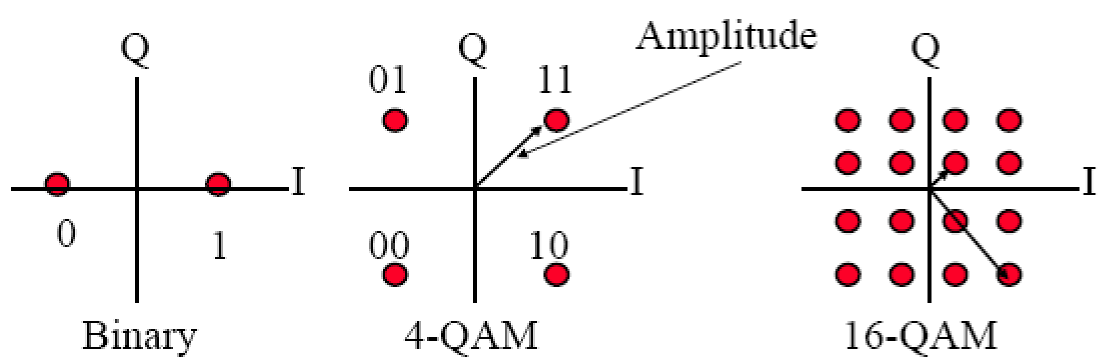
- QAM is a combination of ASK and PSK
  - Two different signals sent simultaneously on the same carrier frequency

$$s(t) = d_1(t)\cos 2\pi f_c t + d_2(t)\sin 2\pi f_c t$$

- Multiple amplitude and multiple phases are used in the signal to represent data.

Quadrature Amplitude Modulation

- It is possible to code n bits using one symbol
- For example with 2 amplitude and 4 phases the scheme will be 8-QAM and so on like 16-QAM, 32-QAM, 64-QAM, 256-QAM…



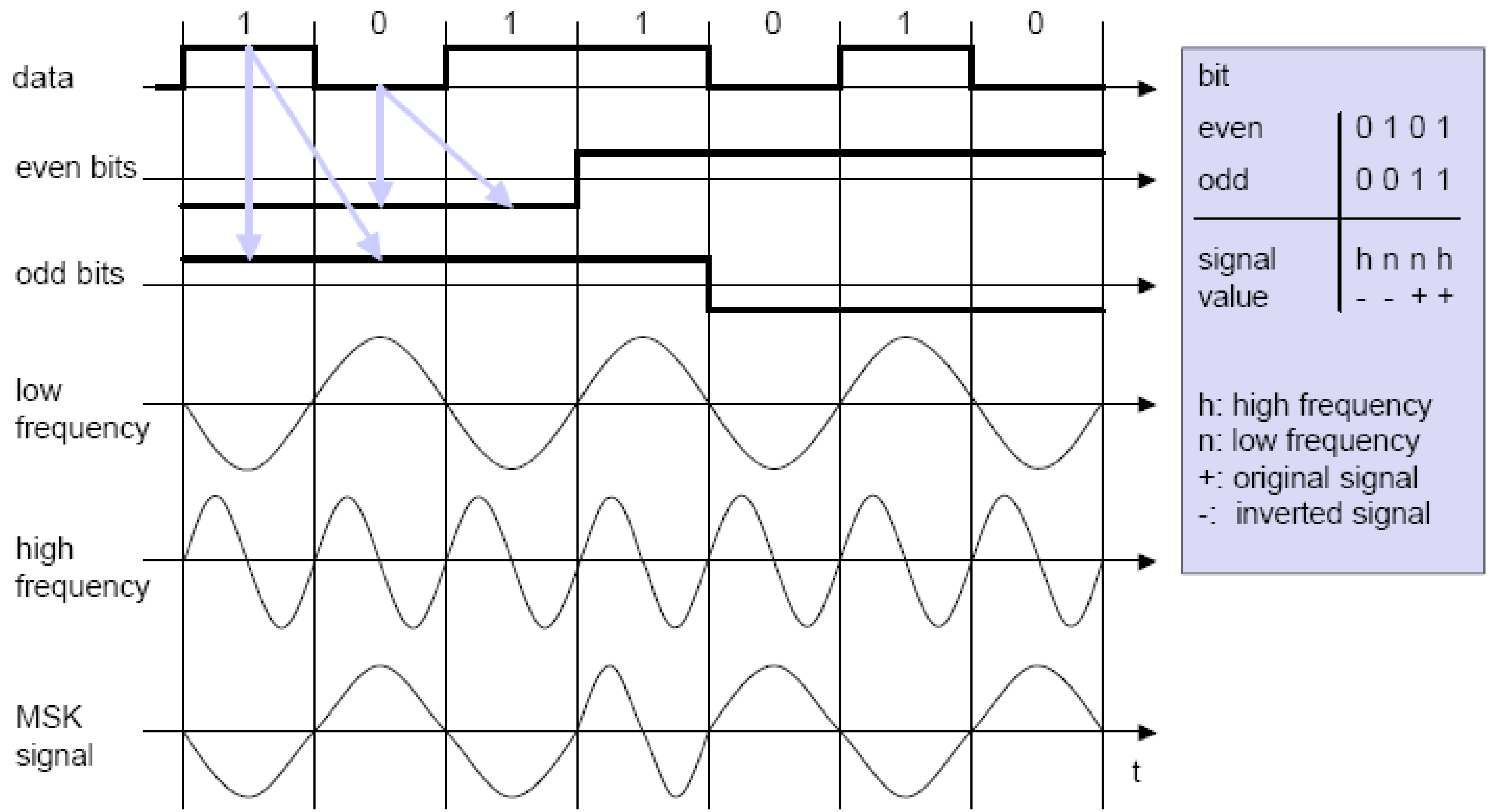
❑ 4-QAM⇒ 2 bits/symbol, 16-QAM ⇒4 bits/symbol, …

Constellations Diagram

Multiple Shift Keying (MSK)

- Bandwidth needed for FSK depends on the distance between the carrier frequencies.
- Special pre-computation avoids sudden phase shifts → MSK (Minimum Shift Keying)
- Bits are separated into even and odd bits, the duration of each bit is doubled.
- Depending on the bit values (even, odd) the higher or lower frequency, original or inverted is chosen.
- The frequency of one carrier is twice the frequency of the other. Equivalent to offset QPSK
- Even higher bandwidth efficiency can be achieved using a Gaussian low-pass filter → GMSK (Gaussian MSK), used in GSM.

Example of MSK



No phase shifts!

Signal propagation

- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$ in vacuum
- (d = distance between sender and receiver)
- Receiving power additionally influenced by
  - Path loss / fading: Depends upon distance and frequency
  - shadowing : Obstructions
  - Réflexion at large obstacles
  - Refraction depending on the density of a medium
  - Scattering at small obstacles
  - Diffraction at edges
  - Noise
  - Frequency Dispersion (Doppler Spread) due to motion
  - Interference
  - Multipath: Multiple reflected waves: Inter-symbol interference (ISI) due to dispersion

Quadrature Amplitude Modulation

- QAM used on asymmetric digital subscriber line (ADSL) and some wireless
- combination of ASK and PSK
- logical extension of QPSK
- send two different signals simultaneously on same carrier frequency
  - use two copies of carrier, one shifted 90°
  - each carrier is ASK modulated
  - two independent signals over same medium
  - demodulate and combine for original binary output