

Computer Networks and Communications

Lecture (03):

Data Transmission

Data transmission

- **Concepts & Terminology**
 - **Bandwidth**
 - **Data Rate**
 - **Channel Capacity**
- **Analog & Digital Data Transmission**
- **Transmission impairments**

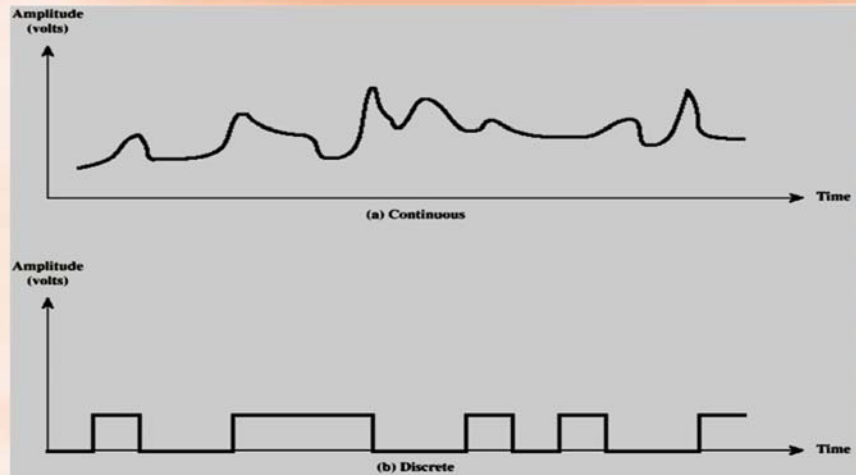
Terminology

- **Medium**
 - **Guided medium (e.g. twisted pair, optical fiber)**
 - **Unguided medium (e.g. air, water, vacuum)**
- **Direct link - No intermediate devices**
- **Point-to-point - Direct link (Only 2 devices share link)**
- **Multi-point - More than two devices share the link**

Terminology

- **Simplex - One direction (e.g. Television)**
- **Half duplex - Either direction, but only one way at a time (e.g. police radio)**
- **Full duplex - Both directions at the same time (e.g. telephone)**

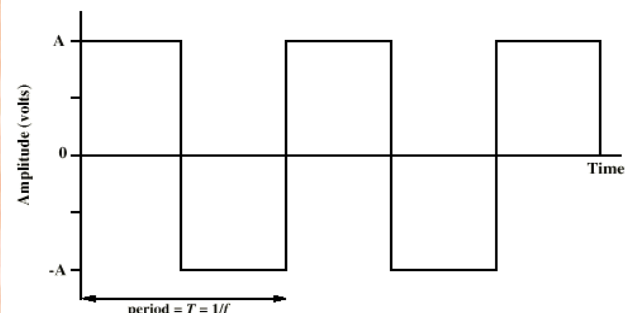
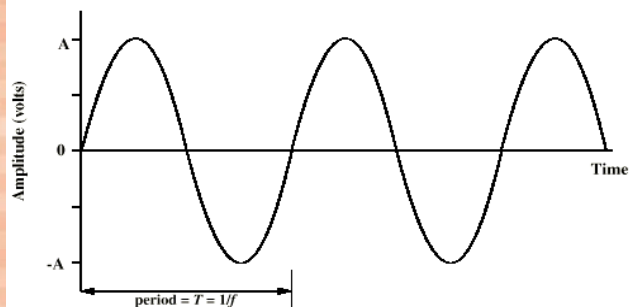
Continuous & Discrete Signals



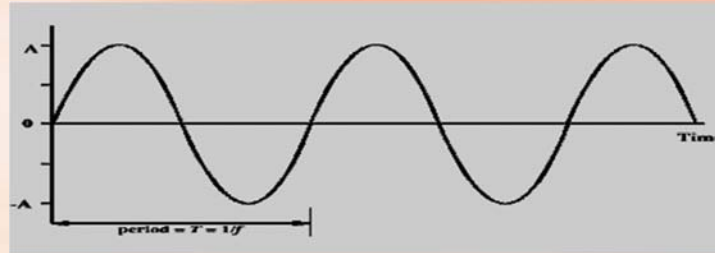
- **Continuous signal** - Varies in a smooth way over time
- **Discrete signal** - Maintains a constant level then changes to another constant level

Periodic Signals

- **Periodic signal:**
Pattern repeated over time
- **Aperiodic signal:**
Pattern not repeated over time

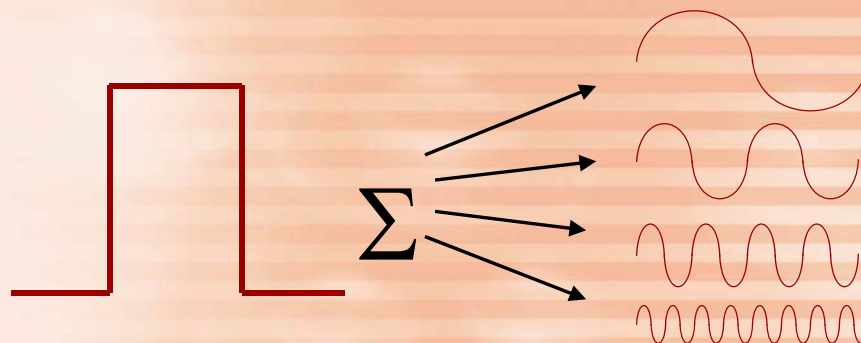


Sine Wave



- **General sine wave:** $s(t) = A \sin(2\pi ft + \phi)$.
- **Peak Amplitude (A)** - maximum strength of signal, generally in volts.
- **Frequency (f)** - rate of change of signal.
 - Hertz (Hz) or cycles per second.
 - Period = time for one repetition (T).
 - $T = 1/f$
- **Phase (ϕ)** - relative position in time.
- **Wavelength (λ)** - Distance occupied by one cycle.
 - $\lambda = vT$ where v is signal velocity.

Frequency Domain Concepts



- **Signal are usually made up of many frequencies.**
 - **Components are sine waves.**
 - **Fourier analysis:**
 - Any signal is made up of sine waves.
 - Can plot frequency domain functions.

Frequency Domain Concepts

Fourier Series:

$$g(t) = \frac{1}{2}A_0 + \sum_{n=1}^{\infty} A_n \sin(2\pi n f_0 t) + \sum_{n=1}^{\infty} B_n \cos(2\pi n f_0 t)$$

DC component

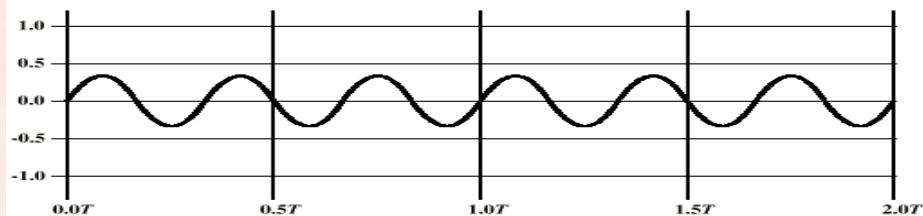
harmonics

Fundamental frequency

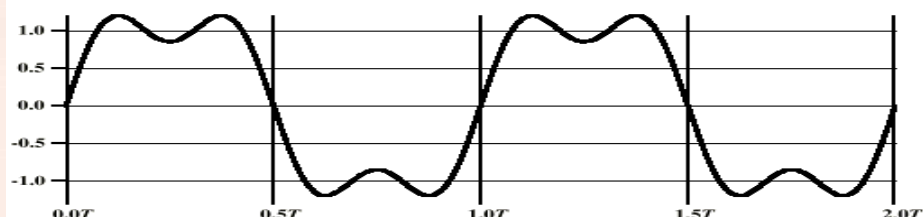
Frequency Domain Concepts



(a) $\sin(2\pi f t)$

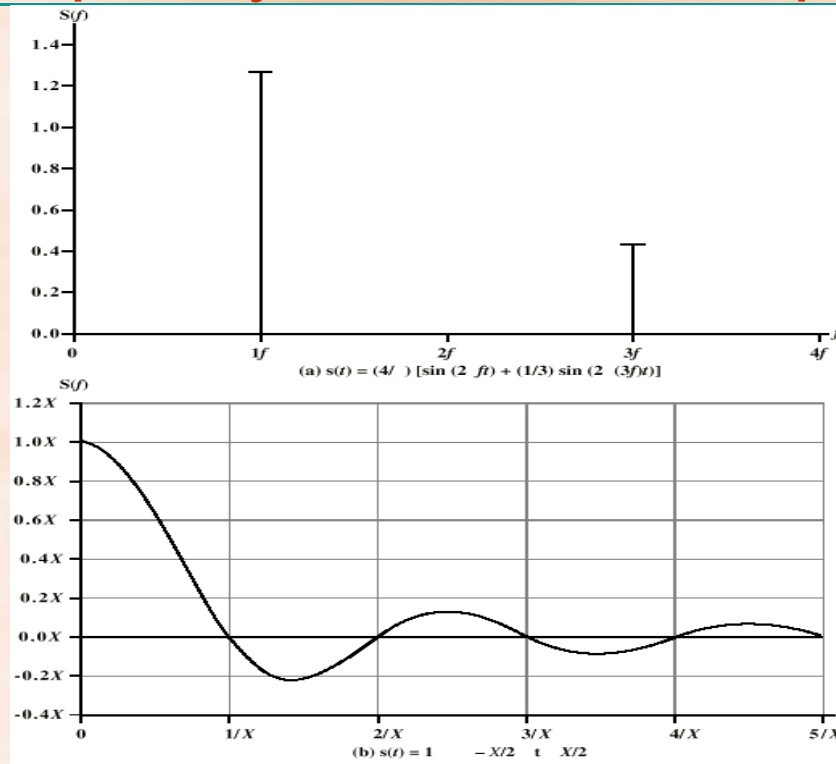


(b) $(1/3) \sin(2\pi (3f)t)$



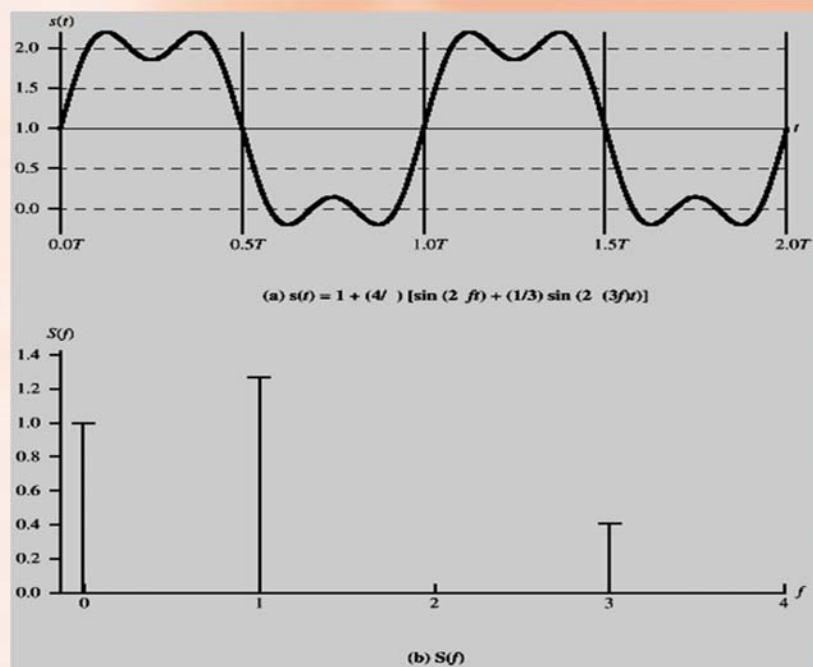
(c) $(4/3) [\sin(2\pi f t) + (1/3) \sin(2\pi (3f)t)]$

Frequency Domain Concepts

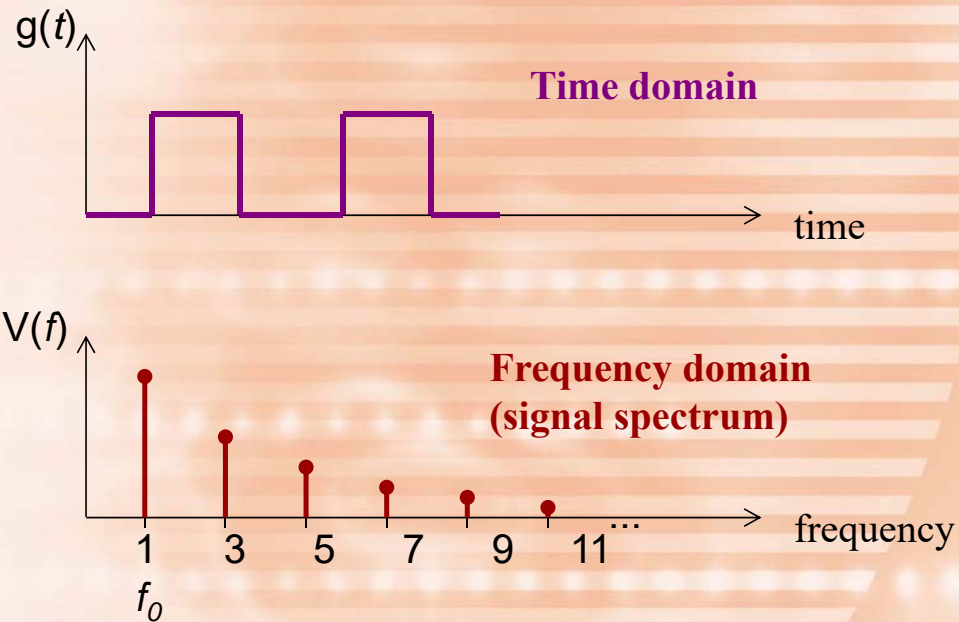


Signal with DC Component

- DC Component - Component of zero frequency.



Time & Frequency domains



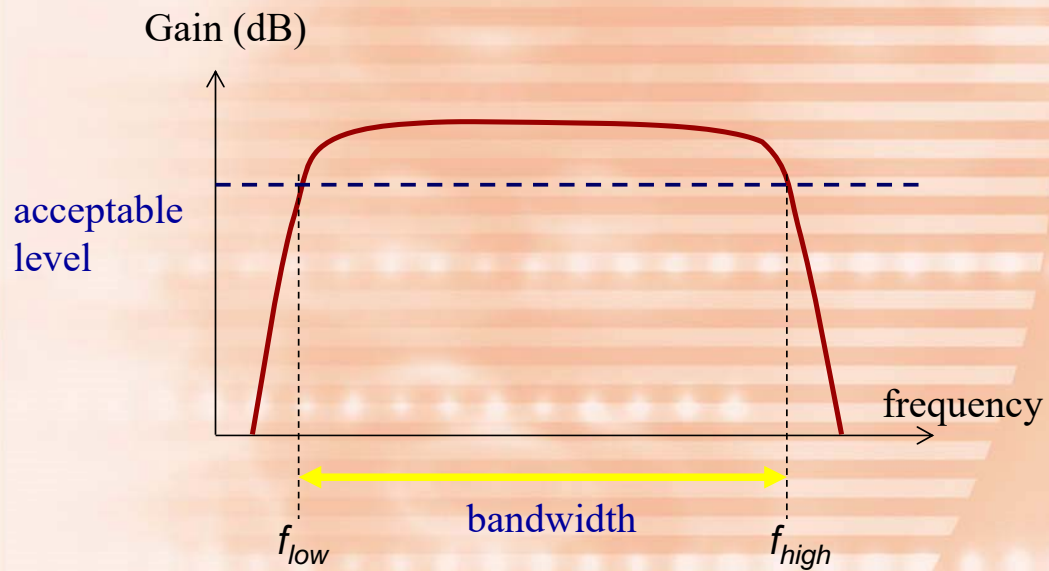
Spectrum & Bandwidth

- **Spectrum - range of frequencies contained in signal.**
 - **Absolute bandwidth - width of spectrum**
 - **Effective bandwidth - Often just *bandwidth***
 - Narrow band of frequencies containing most of the energy.

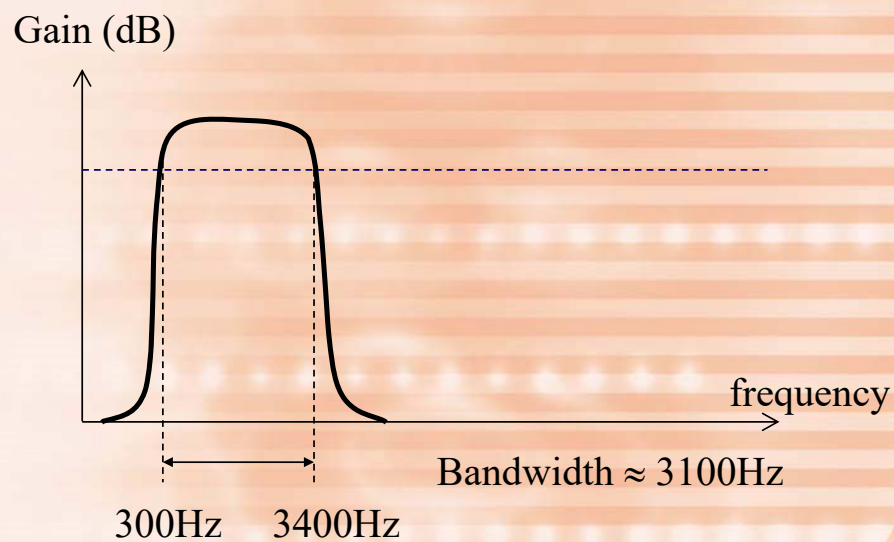
- **Examples**
 - **Speech signal 100 Hz to 7 kHz.**
 - **Normal telephone channel 300 Hz to 3400 Hz.**
 - **Voicegrade channel 0 to 4000 Hz.**

- **Signal bandwidth and Channel bandwidth.**

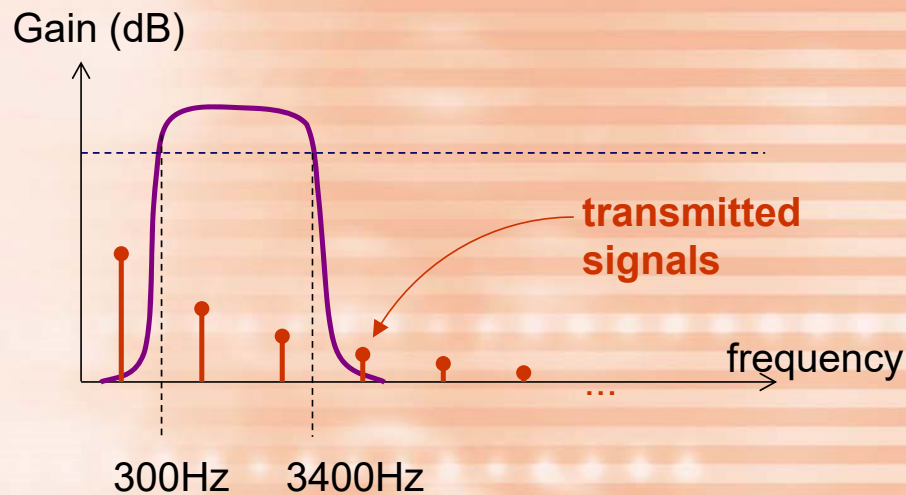
Channel Bandwidth



Bandwidth of a Telephone Line



Signals under Limited Channel Bandwidth



▪ Data Rate and Bandwidth:

- Any transmission system has a limited band of frequencies
- This limits the data rate that can be carried.

Data and Signals

▪ Data: Entities that convey meaning.

- Analog - Continuous values within some interval.
(e.g. sound, video)
- Digital - Discrete values (e.g. text, integers)

▪ Signals: Electric or electromagnetic representations of data.

- Analog
 - Continuously varying electric or optical wave.
 - Various media (wire, fiber optic, space).
 - freq range 20Hz-20kHz - Speech bandwidth 100Hz to 7kHz.
- Digital - Sequence of voltage pulses using two DC components.

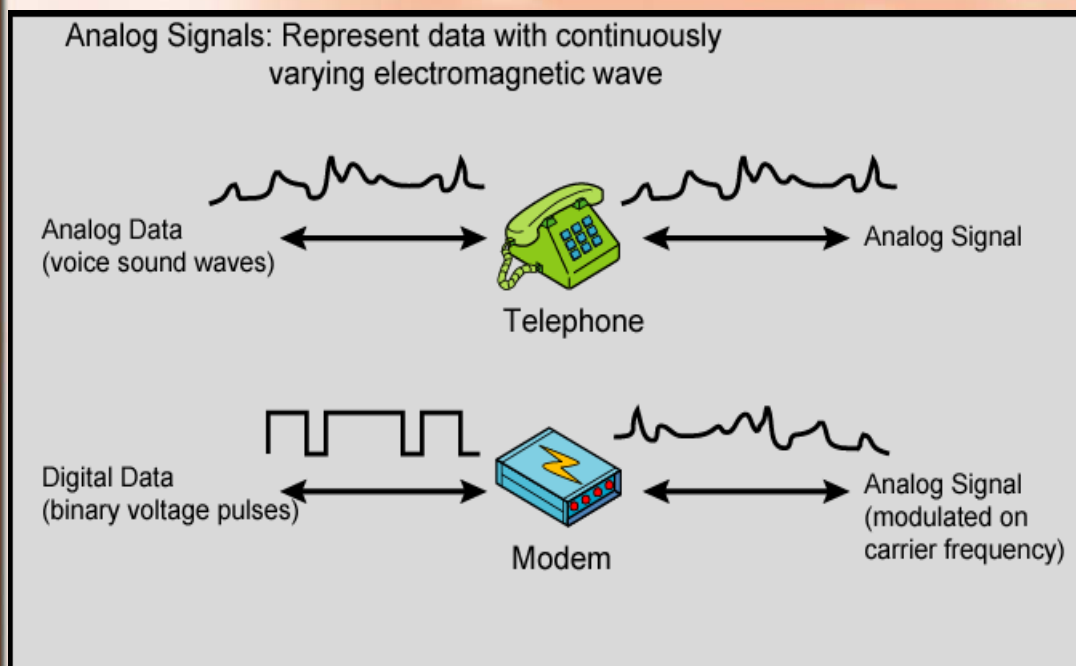
▪ Transmission: Communication of data by propagation and processing of signals

Transmission

- Usually use digital signals for digital data and analog signals for analog data.
- Can use analog signal to carry digital data.
 - Modem (Modulator/Demodulator)
 - Modulate digital data onto an analog carrier frequency.
 - PC modem over telephone lines.
- Can use digital signal to carry analog data.
 - Codec (Coder/Decoder)
 - Sample an analog signal to produce a stream of integers.
 - Compact Disc audio, DVD video

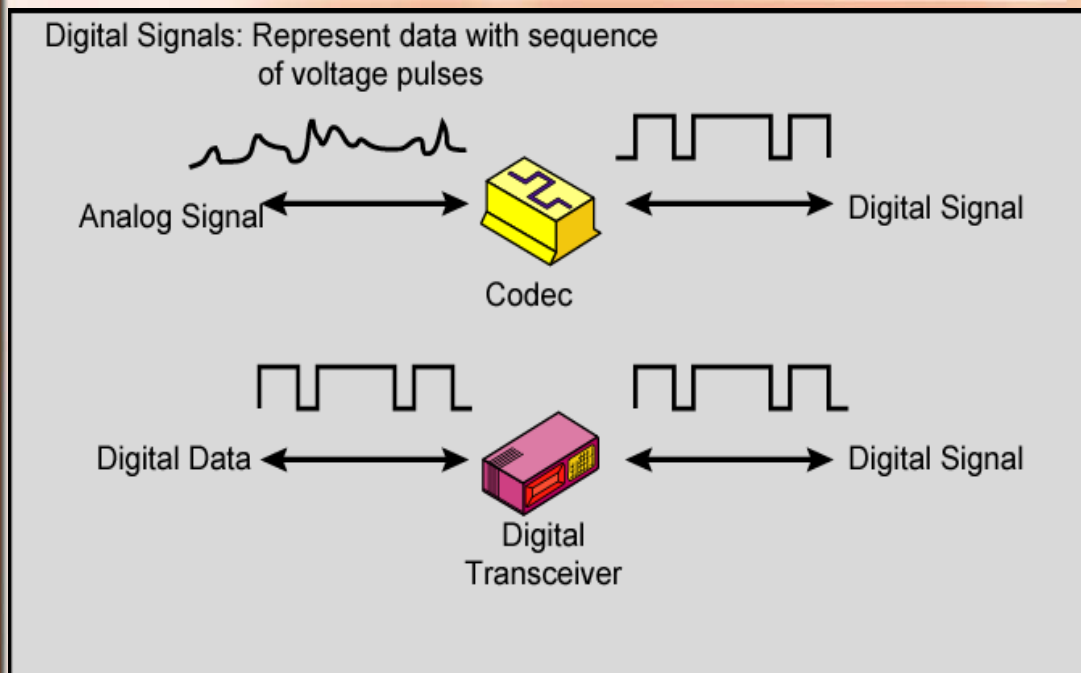
Transmission

- Analog signals carrying analog and digital data.



Transmission

• Digital signals carrying Analog and Digital Data.



Transmission

▪ Analog:

- Analog signal transmitted without regard to content.
- May be analog or digital data.
- Attenuated over distance.
- Use amplifiers to boost signal.
- Also amplifies noise.

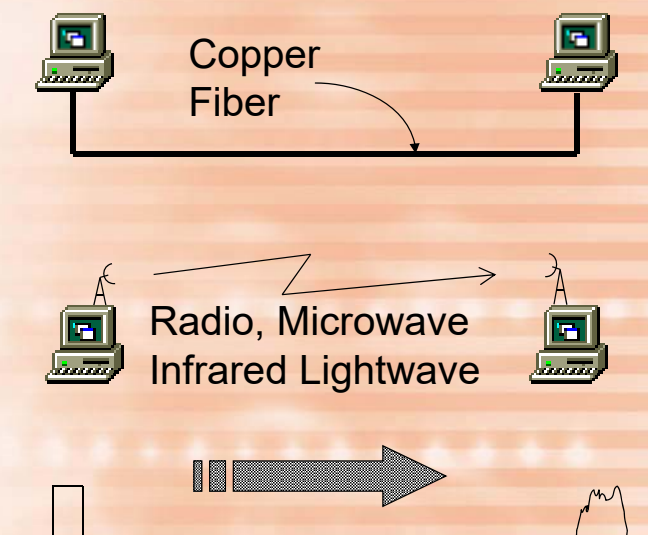
▪ Digital:

- Concerned with content.
- Integrity endangered by noise, attenuation etc.
- Repeater extracts bit pattern and retransmits. Attenuation is overcome.
- Noise is not amplified, signal is cleaned.

Advantages of Digital Transmission

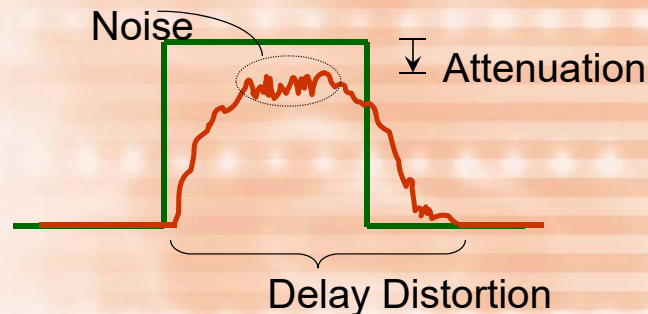
- **Digital technology** - Low cost due to LSI/VLSI technology.
- **Data integrity** - Longer distances over lower quality lines.
- **Capacity utilization**
 - High bandwidth links economical.
 - High degree of multiplexing easier with digital techniques.
- **Security & Privacy** - Encryption
- **Integration** - Can treat analog and digital data similarly

Transmission Impairments



Transmission Impairments

- **Signal received may differ from signal transmitted.**
- **Analog - degradation of signal quality.**
- **Digital - bit errors**
- **Impairments: Attenuation, Delay distortion & Noise**



Attenuation

- where signal strength falls off with distance
- depends on medium
- received signal strength must be:
 - strong enough to be detected
 - sufficiently higher than noise to receive without error
- so increase strength using amplifiers/repeaters
- is also an increasing function of frequency
- so equalize attenuation across band of frequencies used
 - eg. using loading coils or amplifiers

Delay Distortion

- **only occurs in guided media**
- **propagation velocity varies with frequency**
- **hence various frequency components arrive at different times**
- **particularly critical for digital data**
- **since parts of one bit spill over into others**
- **causing intersymbol interference**

Noise

- **additional signals inserted between transmitter and receiver**
- **thermal**
 - **due to thermal agitation of electrons**
 - **uniformly distributed**
 - **white noise**
- **intermodulation**
 - **signals that are the sum and difference of original frequencies sharing a medium**

Noise

- **crosstalk**
 - a signal from one line is picked up by another
- **impulse**
 - irregular pulses or spikes
 - eg. external electromagnetic interference
 - short duration
 - high amplitude
 - a minor annoyance for analog signals
 - but a major source of error in digital data
 - a noise spike could corrupt many bits

Signal to noise ratio (SNR)

- **Important parameter in determining the performance of a transmission system.**
 - Measured in decibel or dB to express ratio of two power, voltage or current levels.
 - A relative, not absolute measure.
 - A high SNR means high quality signal reception:

$$SNR_{dB} = 10 \log_{10} \left(\frac{\text{signal power } (S)}{\text{noise power } (N)} \right)$$

Signal to noise ratio (SNR)

$$SNR_{dB} = 10 \log_{10} \left(\frac{S}{N} \right)$$

$$\frac{S}{N} = 10^{0.1 * SNR_{dB}}$$

$\frac{S}{N}$	SNR_{dB}
0.5	-3.0103
1	0
2	3.0103
10	10
100	20
1000	30

Power loss:
(in Watts) $P_{loss} = P_{transmit} - P_{received}$

Power loss:
(in dB) $P_{loss} = 10 \log_{10} \left(\frac{P_{transmit}}{P_{received}} \right)$
 $= P_{transmit}^{dB} - P_{received}^{dB}$

Channel Capacity

- **Maximum rate at which data can be transmitted.**
 - **Data rate:** - in bits per second
- rate at which data can be communicated.
 - **Bandwidth:** - in cycles per second or Hertz.
constrained by transmitter and medium.
 - **Noise:** average level of noise over the communication path.
 - **Error Rate:** rate at which errors occurs.
- **Nyquist (1924):** Maximum bit rate on a noise-free channel.
- **Shannon (1948):** Maximum bit rate on a noisy channel.

Nyquist's Theorem

- Channel capacity (C) in noise free channel.
- Given a bandwidth of B (eg 4000Hz), the highest frequency signal that can be carried is 2B (eg 8000Hz).
- For two level signaling, $C = 2B$
- For multilevel signaling, $C = 2B \log_2 M$

M – number of discrete signal levels B – channel bandwidth

Nyquist's Theorem

$$C = 2 B \log_2 M \text{ bits/sec}$$

- For given bandwidth B in Hertz, the data rate can be increased by increasing M.
 - Increase receiver complexity.
 - Noise and other impairments will limit M.
- e.g. Telephone line:

Bandwidth = 3 kHz

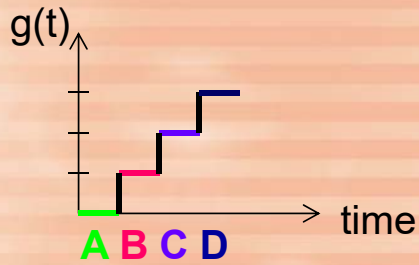
Signal level = 2 (i.e. Low/High)

$$\begin{aligned} \text{max. bit rate} &= 2 B \log_2 M \text{ bps} \\ &= 2 (3\text{k}) \log_2 2 \text{ bps} \\ &= 6000 \text{ bps} \end{aligned}$$

Baud rate

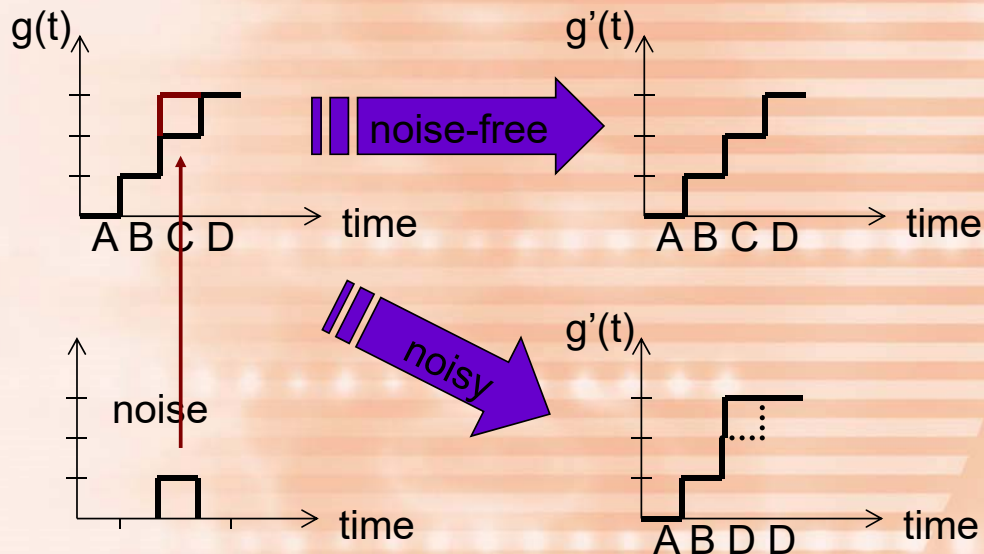
Signal Unit Bits

A	00
B	01
C	11
D	10



- Baud rate = maximum rate at which a signal can change its state, eg 4000 times/sec or 4000 signal units/sec
- Each signal unit carries $\log_2 M$ bits (Information Content), where M is number of signal levels, if M=4 then $\log_2 M=2$ bits of information
- Bit rate = $\log_2 M * \text{Baud Rate} = 2 * 4000 = 8000$ bps

Channel with Noise



Shannon's Law

- Theoretical maximum data rate (C).
- Takes into account bandwidth and SNR on a Noisy channel.
- The noise is white (thermal)

$$C = B \log_2 (1 + S/N) \text{ bits/sec}$$

channel bandwidth

signal-to-noise ratio

- For a given noise level, the data rate can be increased by increasing signal strength or bandwidth.
- However, noise increases with increased bandwidth or signal strength.

Shannon's Law: Example

e.g. Telephone line:

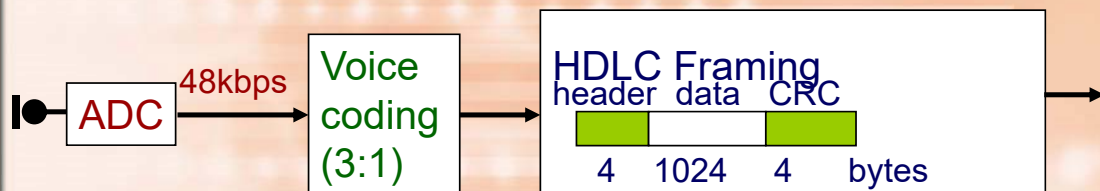
Bandwidth = 3k Hz

S/N = 1000/1 (or 30dB)

$$\begin{aligned} \text{max. bit rate} &= B \log_2 (1 + S/N) \text{ bps} \\ &= 3k \log_2 (1 + 1000) \text{ bps} \\ &\approx 30k \text{ bps} \end{aligned}$$

Problem

Voice signals are converted to digital signals at the ADC stage using a particular scheme. The scheme produces 48kbps. The output is then encoded by an advanced voice encoding scheme to reduce the data rate by 3 times. It is later fragmented and packed into frames. 1024 bytes are to be packed into an HDLC frame with 8 bytes of protocol overhead. If the channel bandwidth is 4kHz, what is the SNR required to support this transmission in a noisy channel.



ANSWER

$$C = B \log_2 (1 + S/N) \text{ bps}$$

Given:

> Bandwidth, $B = 4\text{kHz}$

> Channel $SNR =$ to be determined

Output data rate ADC = 48kbps

Output data rate after encoding = $48\text{kbps}/3 = 16\text{kbps}$

Output data rate including protocol overhead

$$= 16\text{kbps} * 1032/1024$$

$$= 16\text{kbps} * 1.009$$

$$16000 = 4000 * \log_2 (1 + S/N) \text{ bps}$$

$$4 = \log_2 (1 + S/N) \text{ bps}$$

$$2^4 = 16 = (1 + S/N) \Rightarrow S/N = 15 \text{ (15 to 1)}$$

Required Reading

**Data and Computer Communications,
10th Edition by William Stallings,
(c) Pearson Education - Prentice Hall, 2013**

>> Chapter 3