DATA AND COMPUTER COMMUNICATIONS

Lecture 2 Physical Layer - Data Transmission

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Based on Lecture slides by William Stallings

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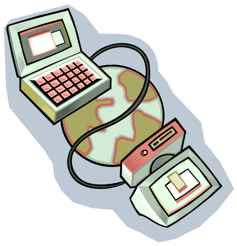
DATA TRANSMISSION

- The successful transmission of data depends on two factors:



- quality of the signal being transmitted
- characteristics of the transmission medium

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Transmission Terminology

Data transmission occurs between transmitter and receiver over some transmission medium.

Communication is in the form of electromagnetic waves.

Guided media
- twisted pair, coaxial cable, optical fiber

Unguided media (wireless)
- air, vacuum, seawater

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Transmission Terminology

Direct link
- no intermediate devices

Point-to-point
- direct link
- only 2 devices share link

Multi-point
- more than two devices share the link

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Transmission Terminology

- **Simplex**
  - signals transmitted in one direction
    - eg. Television

- **Half duplex**
  - both stations transmit, but only one at a time
    - eg. police radio

- **Full duplex**
  - simultaneous transmissions
    - eg. telephone

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Frequency, Spectrum and Bandwidth

- time domain concepts
  - analog signal
    - various in a smooth way over time
  - digital signal
    - maintains a constant level then changes to another constant level
  - periodic signal
    - pattern repeated over time
  - aperiodic signal
    - pattern not repeated over time

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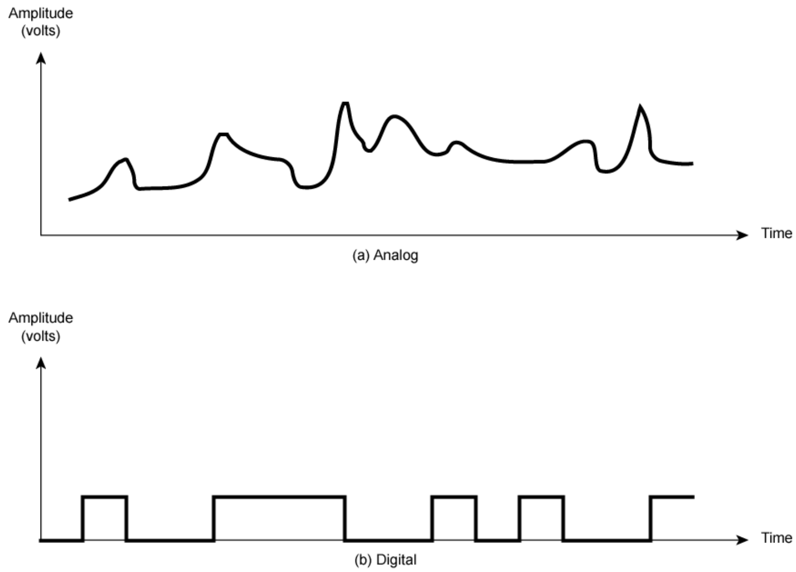
Analog & Digital Signals



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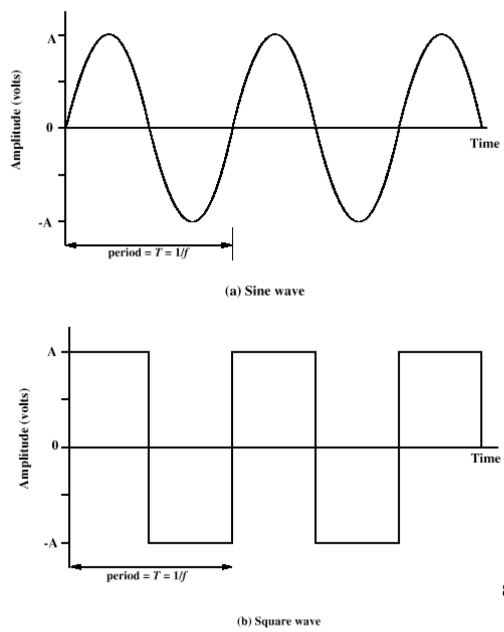
Periodic Signals



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SINE WAVE

- peak amplitude (A)
  - maximum strength of signal
  - 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

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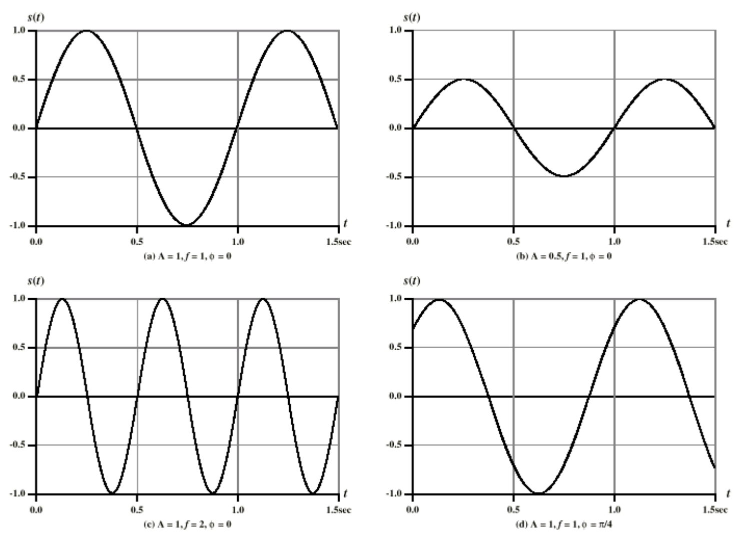
VARYING SINE WAVES
S(T) = A SIN(2πFT +Φ)



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WAVELENGTH (λ)

the wavelength of a signal is the distance occupied by a single cycle

can also be stated as the distance between two points of corresponding phase of two consecutive cycles

assuming signal velocity v, then the wavelength is related to the period as $\lambda = vT$

or equivalently $\lambda f = v$

especially when v=c

- $c = 3*10^8$ m/s (speed of light in

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FREQUENCY DOMAIN CONCEPTS

- signal are made up of many frequencies
- components are sine waves
- Fourier analysis can shown that any signal is made up of component sine waves, in which each component is a sinusoid
- can plot frequency domain functions

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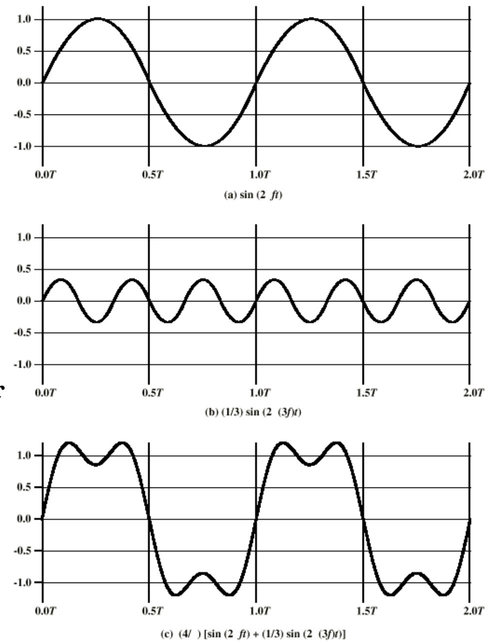
Addition of Frequency Components (T=1/f)

- c is sum of *f* & *3f*



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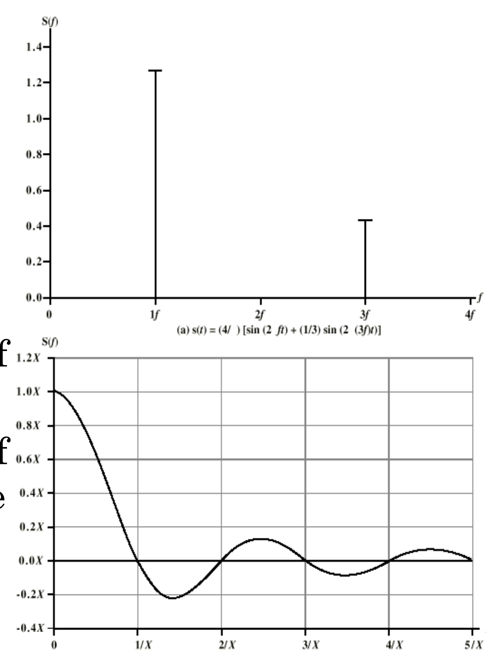
Frequency Domain Representations

- freq domain func of Fig 3.4c
- freq domain func of single square pulse



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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 energy
- DC Component
  - component of zero frequency

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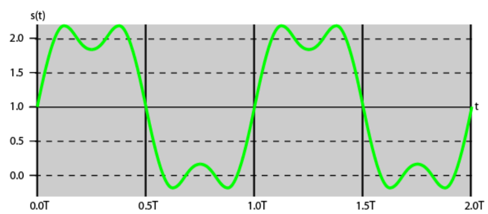
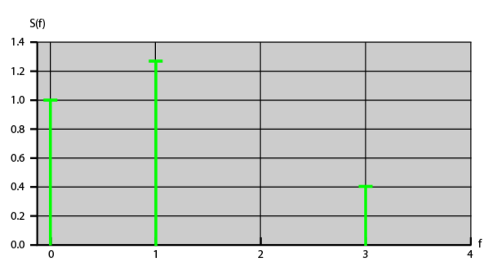
Signal with DC Component



(a) s(t) = 1 + (4/p) [sin (2pft) + (1/3) sin (2p(3f)t)]



(b) S(f)

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Data Rate and Bandwidth

- There is a direct relationship between data rate and bandwidth.

any transmission system has a limited band of frequencies → this limits the data rate that can be carried on the transmission medium → square waves have infinite components and hence an infinite bandwidth → most energy in first few components → limiting bandwidth creates distortions

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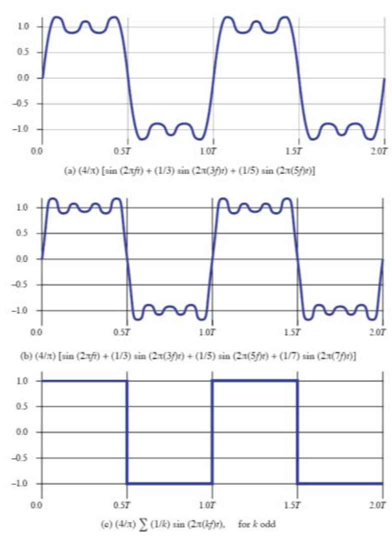
Data Rate and Bandwidth

- Consider

$$s(t) = A \times \frac{4}{\pi} \times \sum_{kodd, k=1}^{\infty} \frac{\sin(2\pi kft)}{k}$$



(a) (4/π) [sin (2πft) + (1/3) sin (2π(3f)t) + (1/5) sin (2π(5f)t)]

(b) (4/π) [sin (2πft) + (1/3) sin (2π(3f)t) + (1/5) sin (2π(5f)t) + (1/7) sin (2π(7f)t)]

(c) (4/π) ∑ (1/k) sin (2π(kf)t), for k odd

Analog and Digital Data Transmission

- data
  - entities that convey meaning
- signals
  - electric or electromagnetic representations of data
- signaling
  - physically propagates along medium
- transmission
  - communication of data by propagation and processing of signals

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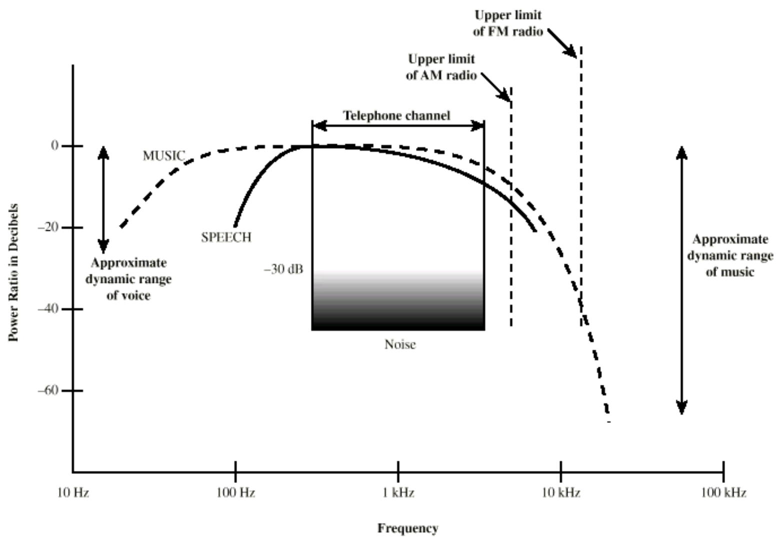
Acoustic Spectrum (Analog)



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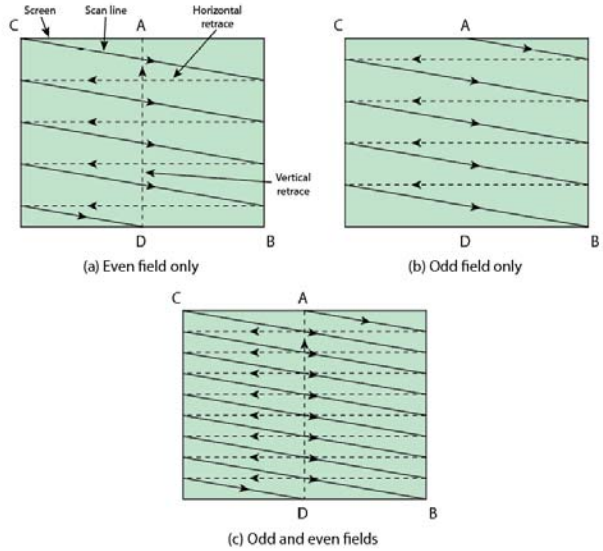
Analog and Digital Transmission



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Digital Data

- Examples:
- Text
- Character strings
- IRA

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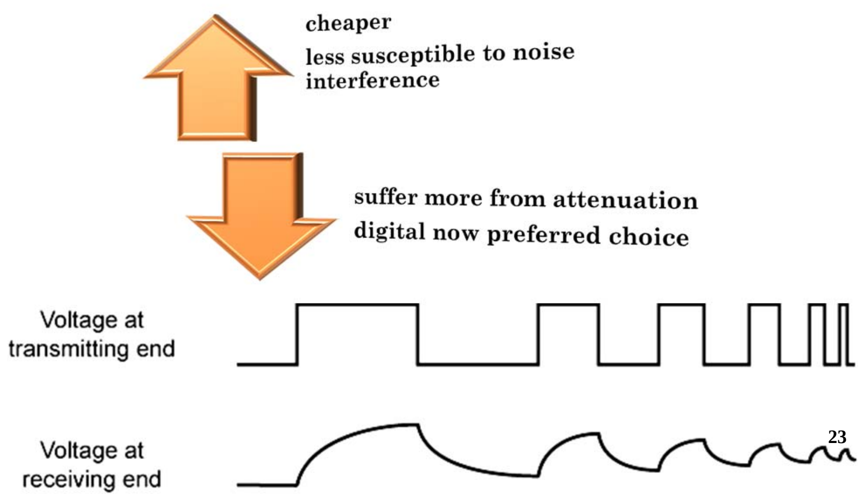
ADVANTAGES & DISADVANTAGES OF DIGITAL SIGNALS



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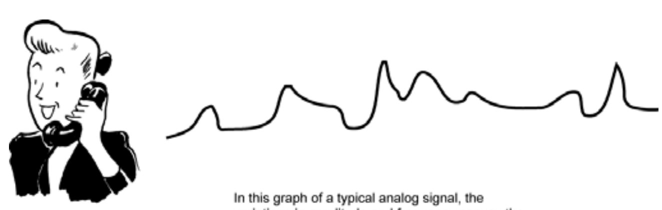
AUDIO SIGNALS

- freq range 20Hz-20kHz (speech 100Hz-7kHz)
- easily converted into electromagnetic signals
- varying volume converted to varying voltage
- can limit frequency range for voice channel to 300-3400Hz



In this graph of a typical analog signal, the variations in amplitude and frequency convey the gradations of loudness and pitch in speech or music. Similar signals are used to transmit television pictures, but at much higher frequencies.

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Video Signals

- USA - 483 lines per frame, at frames per sec
  - have 525 lines but 42 lost during vertical retrace
- 525 lines x 30 scans = 15750 lines per sec
  - 63.5μs per line
  - 11μs for retrace, so 52.5 μs per video line
- max frequency if line alternates black and white
- horizontal resolution is about 450 lines giving 225 cycles of wave in 52.5 μs
- max frequency of 4.2MHz

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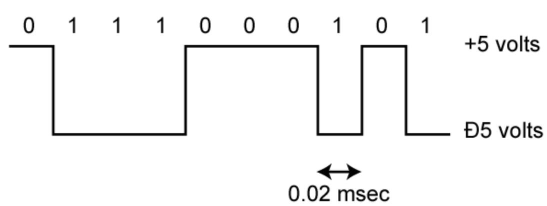
Digital Signals

- as generated by computers etc.
- has two dc components
- bandwidth depends on data rate



User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by Ð5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50 kbps).

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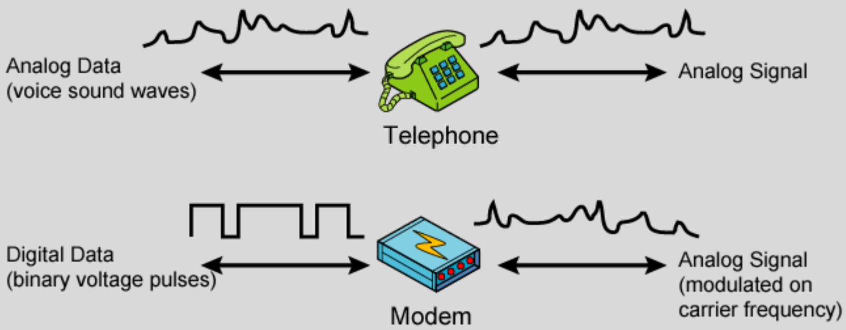
ANALOG SIGNALS

Analog Signals: Represent data with continuously varying electromagnetic wave



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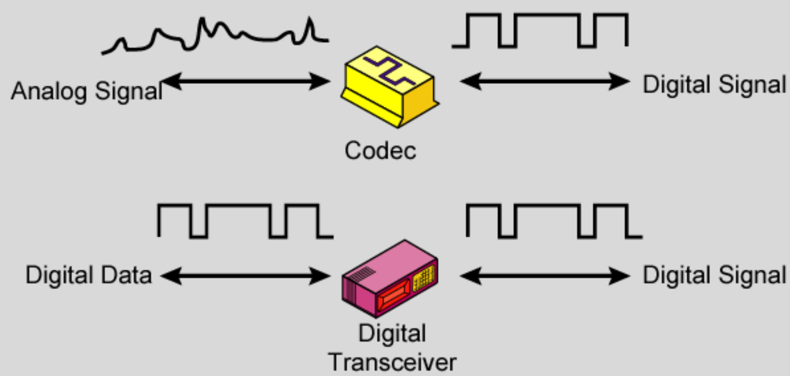
DIGITAL SIGNALS

Digital Signals: Represent data with sequence of voltage pulses



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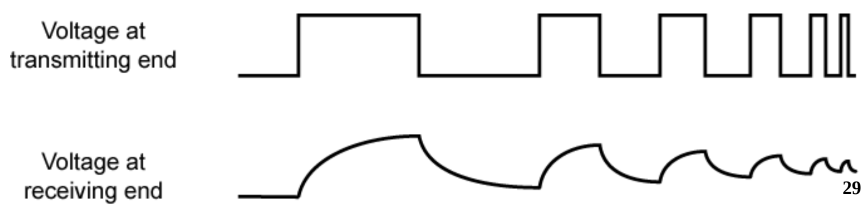
Advantages & Disadvantages of Digital Signals

- cheaper
- less susceptible to noise
- but greater attenuation
- digital now preferred choice



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Transmission Impairments

- signal received may differ from signal transmitted causing:
  - analog - degradation of signal quality
  - digital - bit errors
- most significant impairments are
  - attenuation and attenuation distortion
  - delay distortion
  - noise

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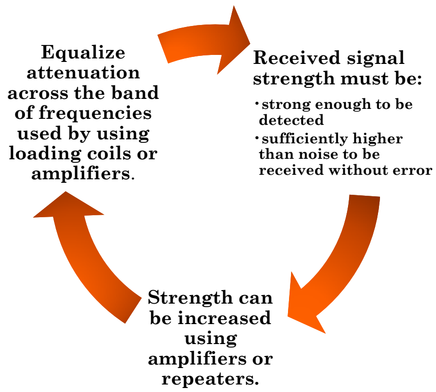
ATTENUATION

- signal strength falls off with distance over any transmission medium
- varies with frequency



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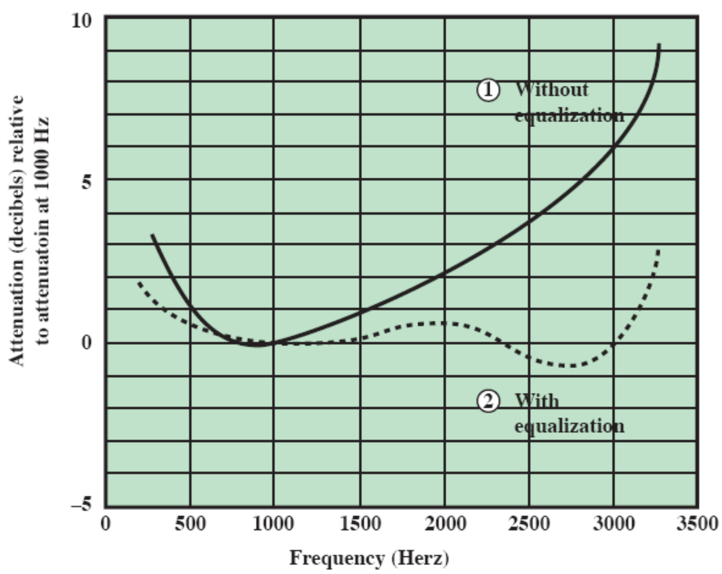

(a) Attenuation

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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

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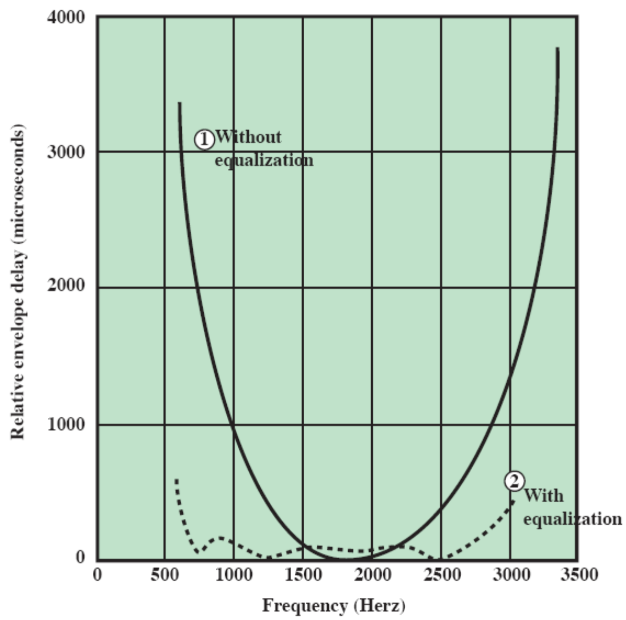

(b) Delay distortion

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NOISE

- unwanted signals inserted between transmitter and receiver

Thermal noise

- due to thermal agitation of electrons
- uniformly distributed across bandwidths
- referred to as white noise

Intermodulation noise

- produced by nonlinearities in the transmitter, receiver, and/or intervening transmission medium
- produce signals at a frequency that is the sum or difference of the two original frequencies

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NOISE

Crosstalk

- a signal from one line is picked up by another
- can occur by electrical coupling between nearby twisted pairs or when microwave antennas pick up unwanted signals

Impulsed Noise

- caused by external electromagnetic interferences
- noncontinuous, consisting of irregular pulses or spikes
- short duration and high amplitude
- minor annoyance for analog signals but a major source of error in digital data

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Channel Capacity

Maximum rate at which data can be transmitted over a given communications channel under given conditions

data rate	bandwidth	noise	error rate	limitations due to physical properties	main constraint on achieving efficiency is noise
in bits per second	in cycles per second or Hertz	average noise level over path	rate of corrupted bits		

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Nyquist Bandwidth

- consider noise free channels
- if rate of signal transmission is 2B then can carry signal with frequencies no greater than B
  - ie. given bandwidth B, highest signal rate is 2B
- for binary signals, 2B bps needs bandwidth B Hz
- can increase rate by using M signal levels
- Nyquist Formula is: $C = 2B \log_2 M$
- so increase rate by increasing signals
  - at cost of receiver complexity
  - limited by noise & other impairments

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SHANNON CAPACITY FORMULA

- consider relation of data rate, noise & error rate
  - faster data rate shortens each bit so bursts of noise affects more bits
  - given noise level, higher rates means higher errors
- Shannon developed formula relating these to signal to noise ratio (in decibels)
- SNR_{db}=10 $\log_{10}$ (signal/noise)
- Capacity C=B $\log_2$(1+SNR)
  - theoretical maximum capacity
  - get lower in practise

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SUMMARY

- looked at data transmission issues
- frequency, spectrum & bandwidth
- analog vs digital signals
- transmission impairments

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Decibels and Signal Strength

- Signal strength falls off exponentially, so loss is easily expressed in terms of decibel, with a logrithmic unit
- The net gain or loss in a cascaded transmission path can be calculated with simple addition and subtraction

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Decibel

- Decibel gain

$$G_{dB} = 10\log_{10}\frac{P_{out}}{P_{in}}$$

G_{dB} = gain, in decibel
P_{in} = input power level
P_{out} = output power level
$\log_{10}$ = logrithm to the base 10

- De

$$L_{dB} = -10\log_{10}\frac{P_{out}}{P_{in}} = 10\log_{10}\frac{P_{in}}{P_{out}}$$

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Decibel & dBW

- Can be used to measure the difference in voltage assuming $P=V^2/R$

$$L_{dB} = 10\log_{10}\frac{P_{in}}{P_{out}} = 10\log_{10}\frac{V_{in}^{2}/R}{V_{out}^{2}/R} = 20\log_{10}\frac{V_{in}}{V_{out}}$$

- Absolute decibel level of power in dBW (decibel-Watt) using 1Watt as reference

$$Power_{dBW} = 10\log_{10}\frac{Power_{W}}{1W}$$

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dBm & dBmV

- Absolute decibel level of power in dBW (decibel-milliWatt) using 1mW as reference

$$Power_{dBm} = 10\log_{10}\frac{Power_{mW}}{1mW}$$

- dBmV (decibel-millivolt) using 1mV as reference

$$Voltage_{dBmV} = 20\log_{10}\frac{Voltage_{mV}}{1mV}$$

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