EC 554
Data Communications

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Syllabus

- Tentatively

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Week 2	**Data Transmission**
Week 3	Signal encoding techniques
Week 4	Error Detection
Week 5	Error correction
Week 6	Flow Control
Week 7	Error control
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Week 9	Multiplexing
Week 10	Spread spectrum
Week 11	Wireless channel characteristics
Week 12	OFDM
Week 13	Packet switching
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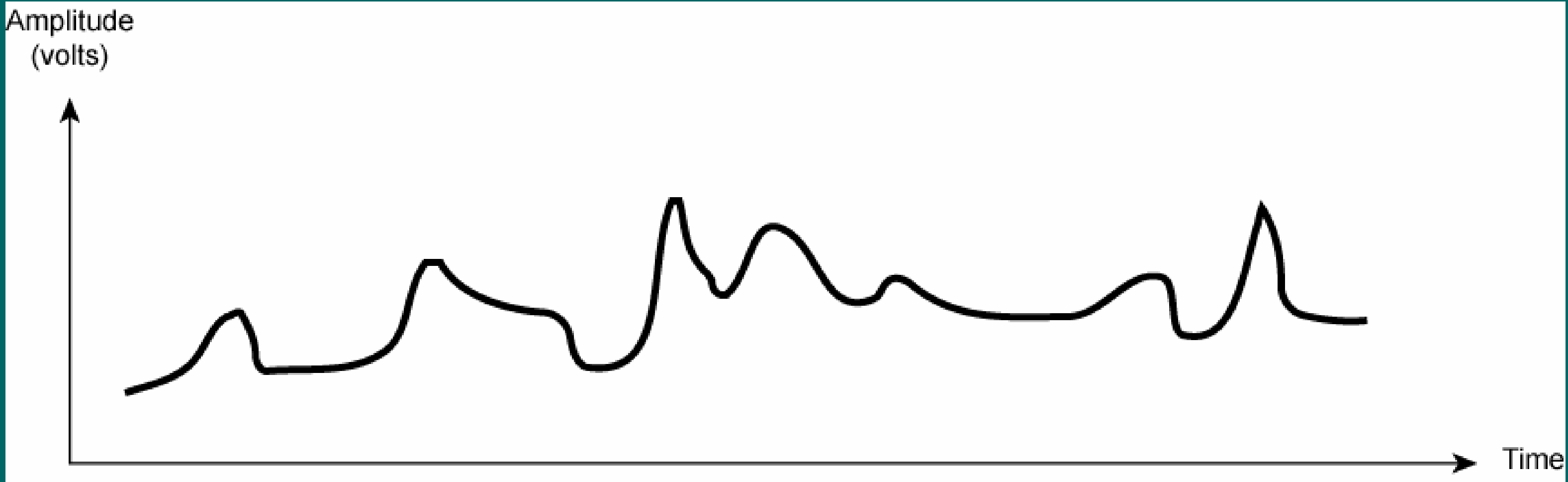
Transmission Terminology

- data transmission occurs between a transmitter & receiver via some medium
- guided medium
  - eg. twisted pair, coaxial cable, optical fiber
- unguided / wireless medium
  - eg. air, water, vacuum

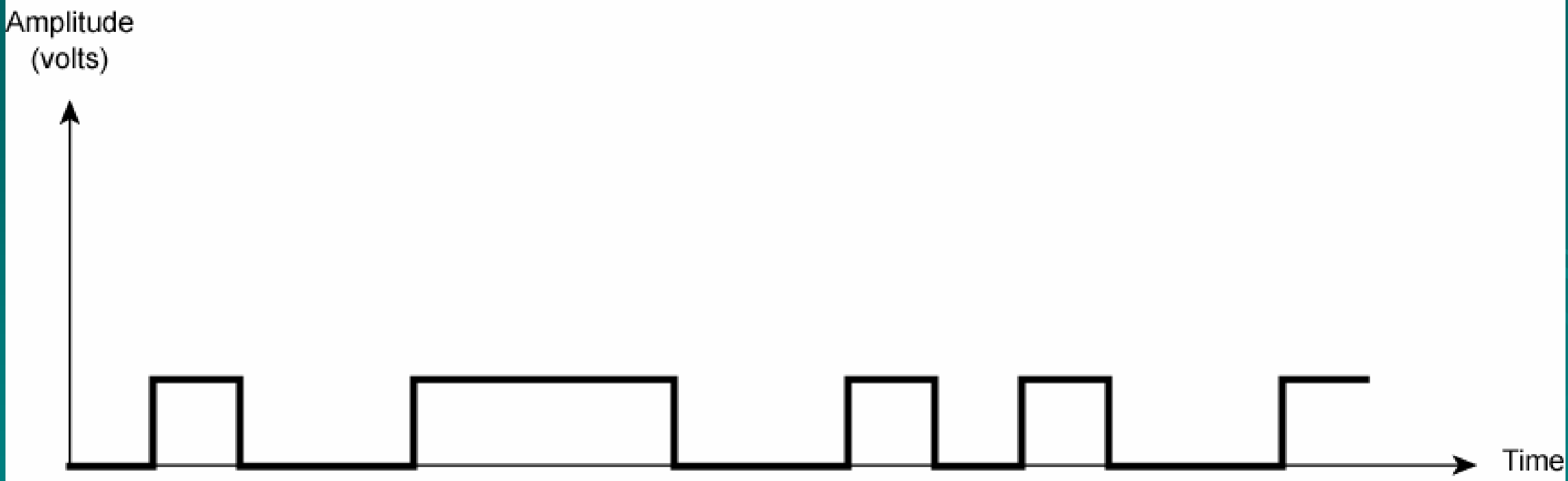
Frequency, Spectrum and Bandwidth

- 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

Analogue & Digital Signals

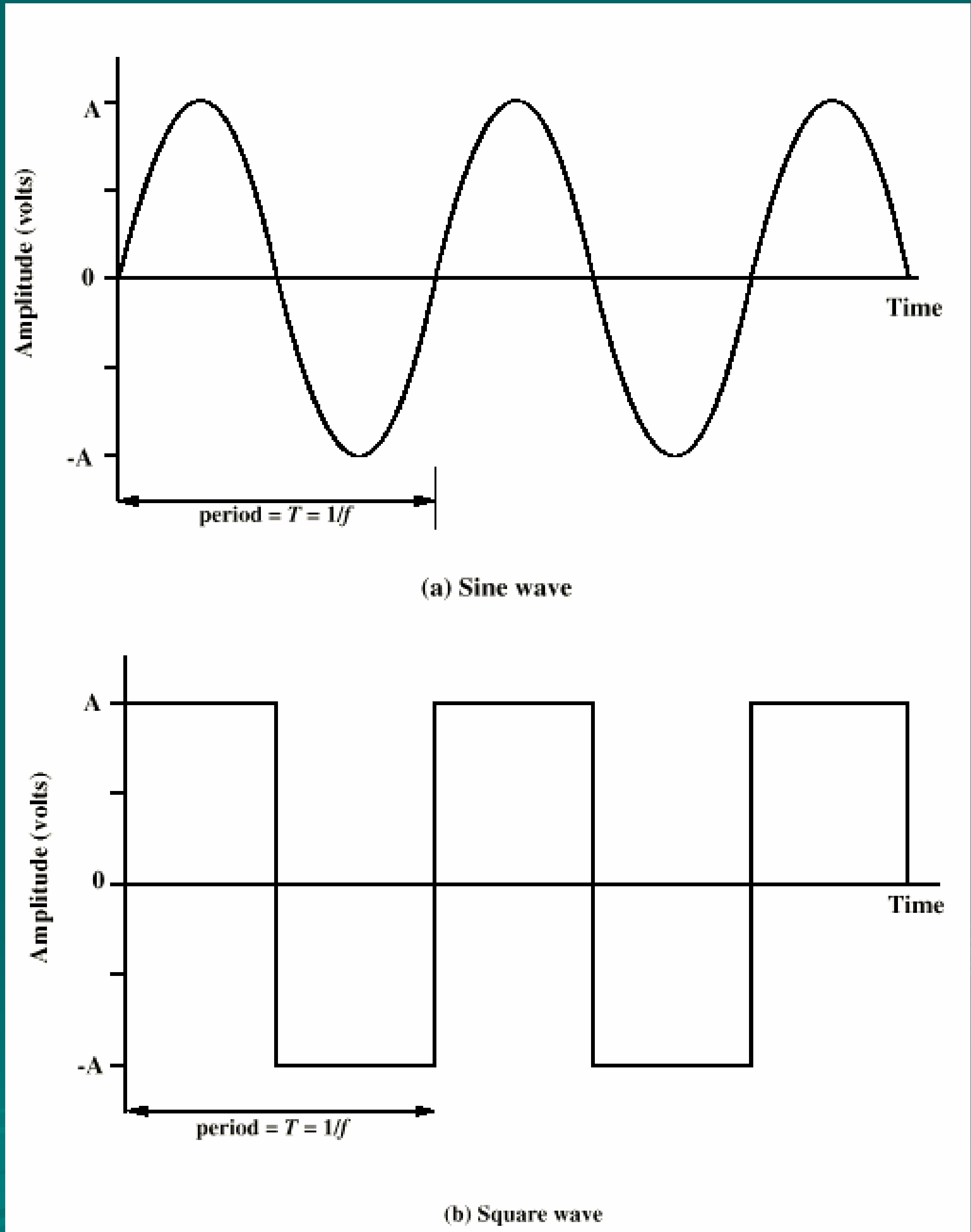


(a) Analog



(b) Digital

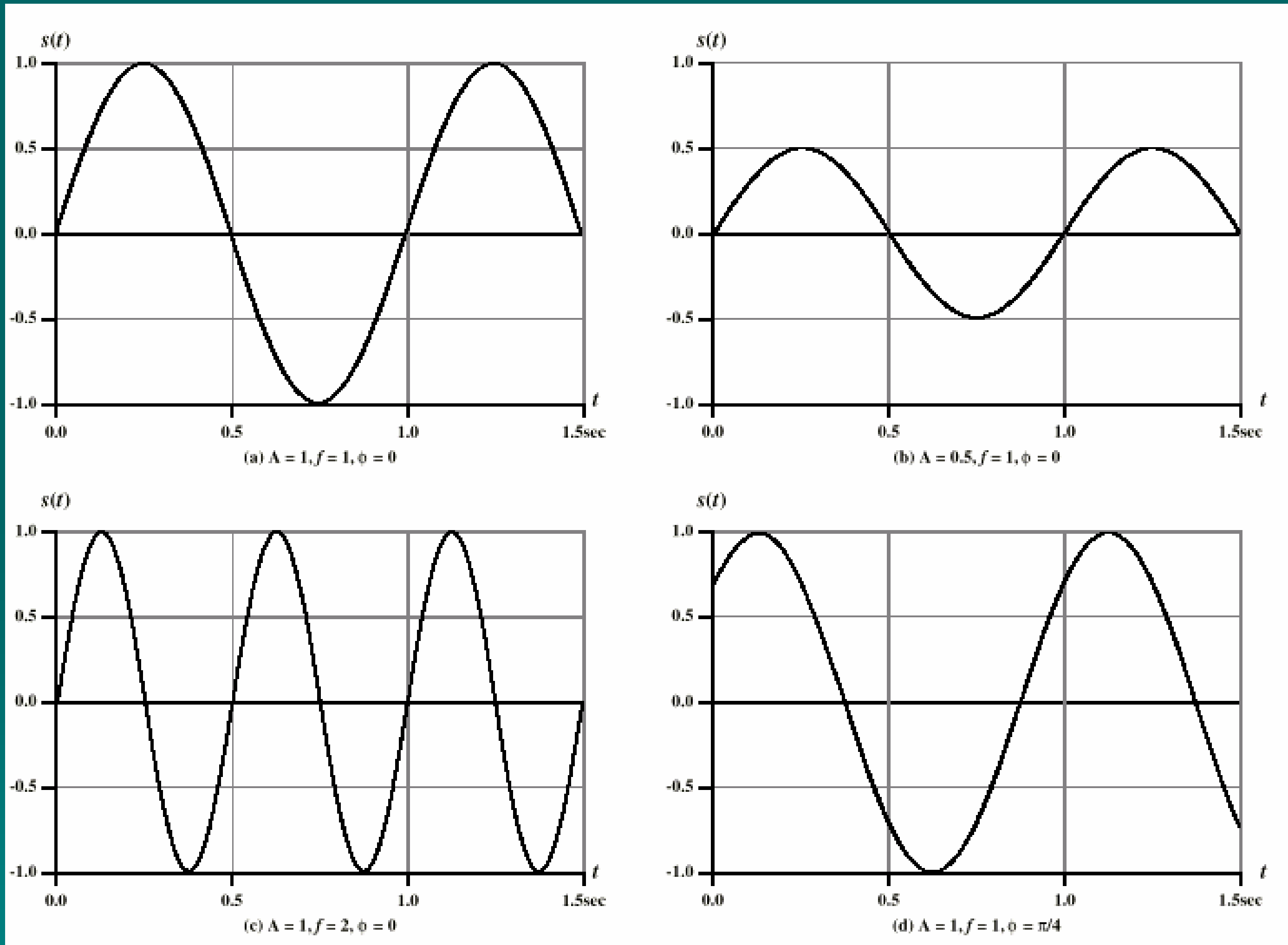
Periodic Signals



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

Varying Sine Waves
$s(t) = A \sin(2\pi ft + \Phi)$



Wavelength (λ)

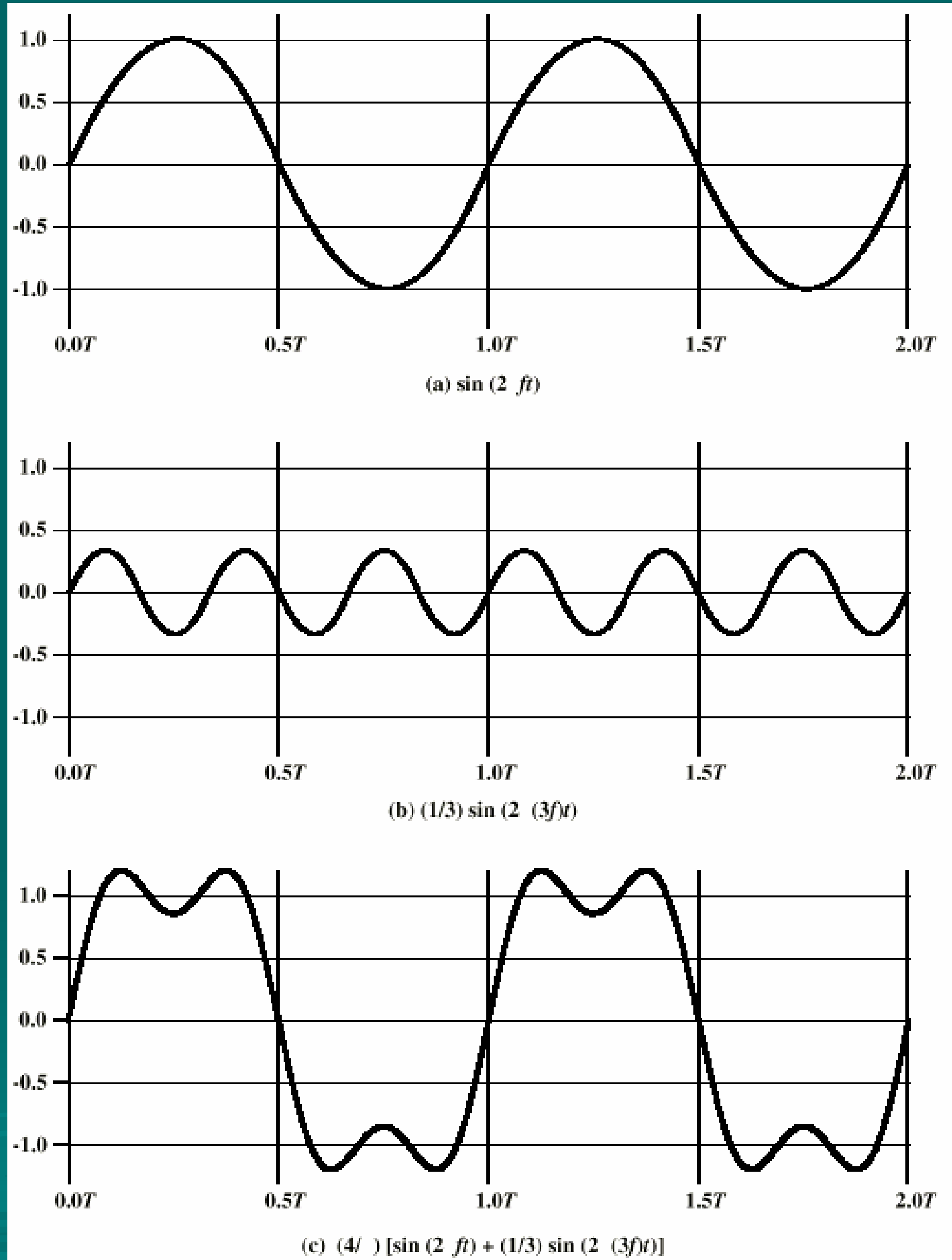
- is distance occupied by one cycle
- between two points of corresponding phase in two consecutive cycles
- assuming signal velocity v have $\lambda = vT$
- or equivalently $\lambda f = v$
- especially when $v=c$
  - $c = 3*10^8$ ms^{-1} (speed of light in free space)

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
- can plot frequency domain functions

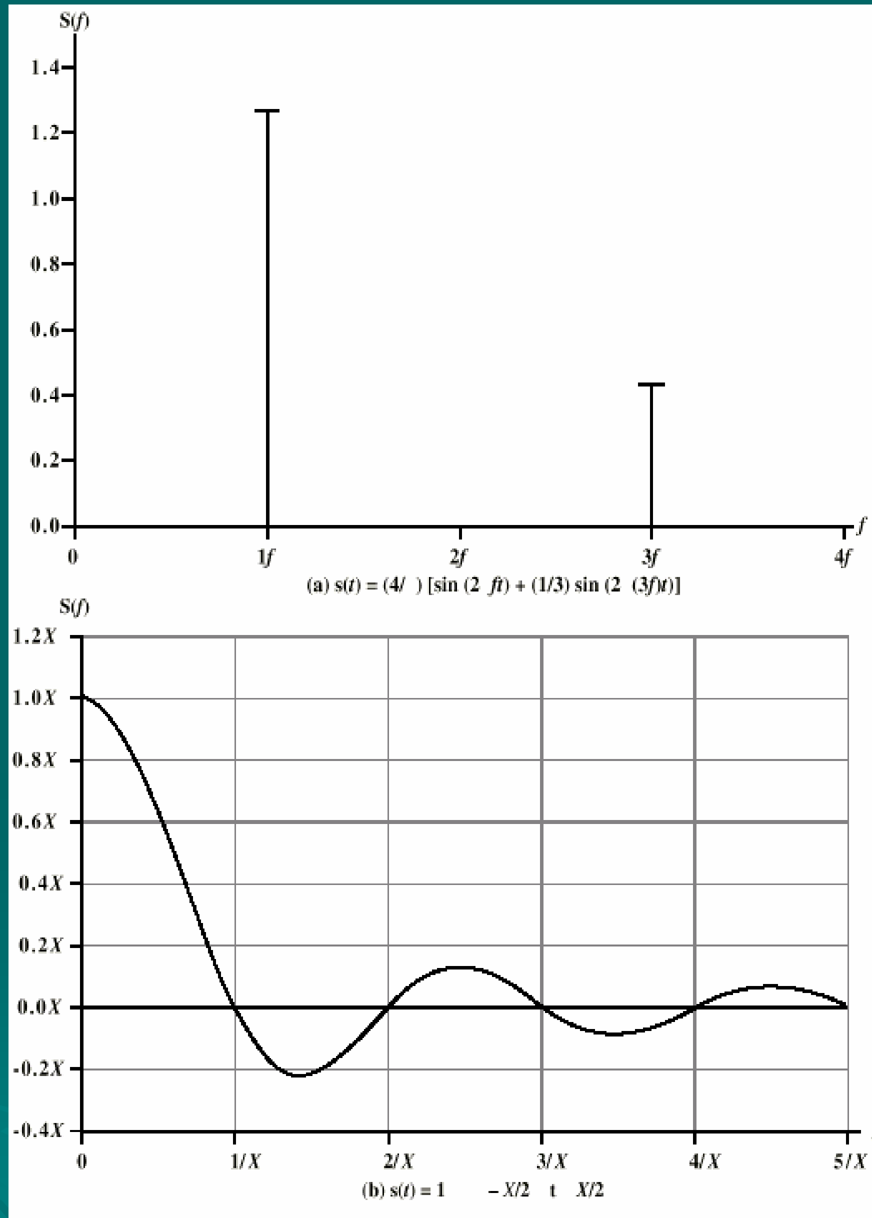
Addition of Frequency Components (T=1/f)

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



Frequency Domain Representations

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



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

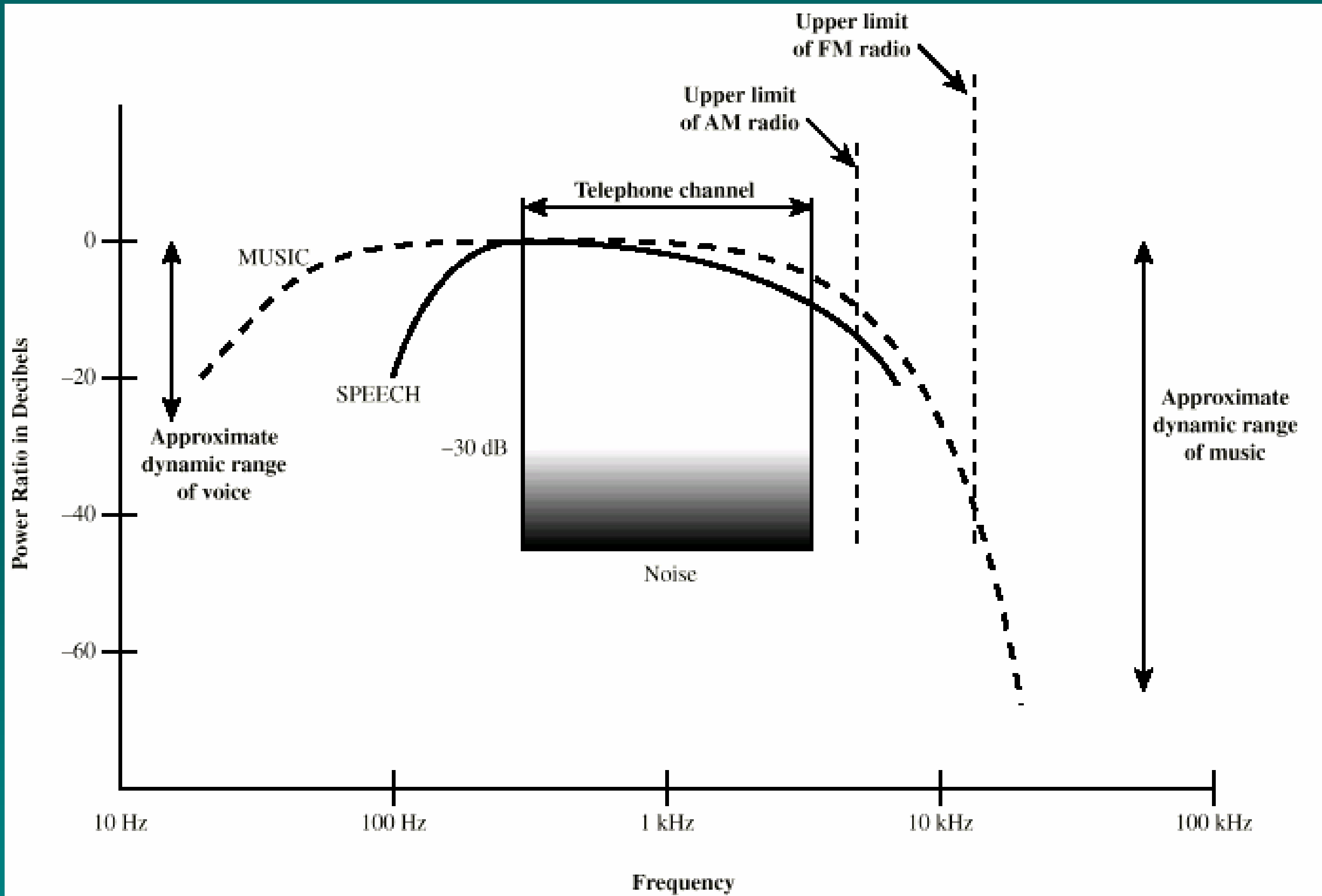
Data Rate and Bandwidth

- any transmission system has a limited band of frequencies
- this limits the data rate that can be carried
- square have infinite components and hence bandwidth
- but most energy in first few components
- limited bandwidth increases distortion
- have a direct relationship between data rate & bandwidth

Analog and Digital Data Transmission

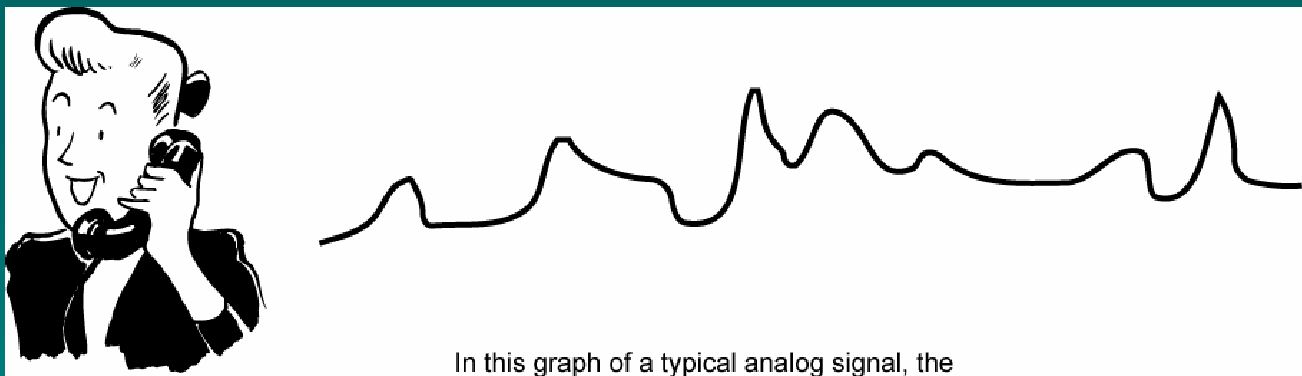
- data
  - entities that convey meaning
- signals & signalling
  - electric or electromagnetic representations of data, physically propagates along medium
- transmission
  - communication of data by propagation and processing of signals

Acoustic Spectrum (Analog)



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



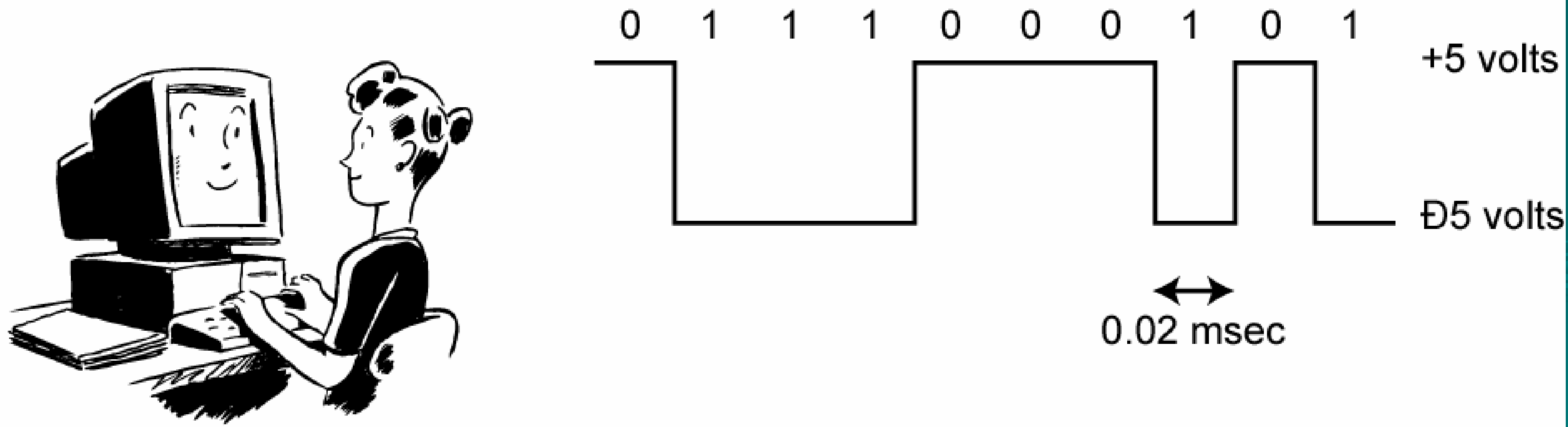
In this graph of a typical analog signal, the variations in amplitude and frequency convey the gradations of loudness and pitch in speech or music. Similar signals are used to transmit television pictures, but at much higher frequencies.

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

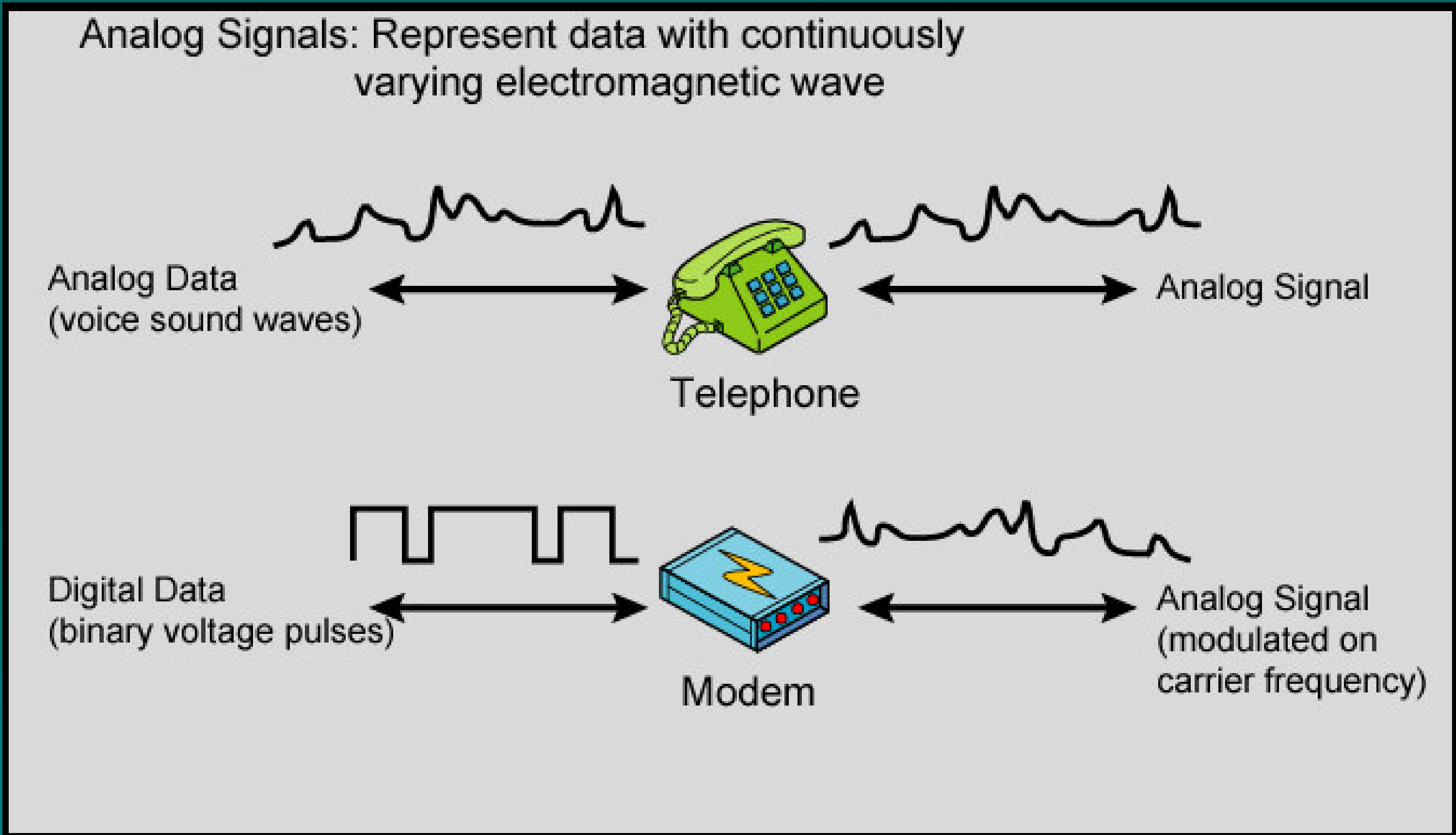
Digital Data

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

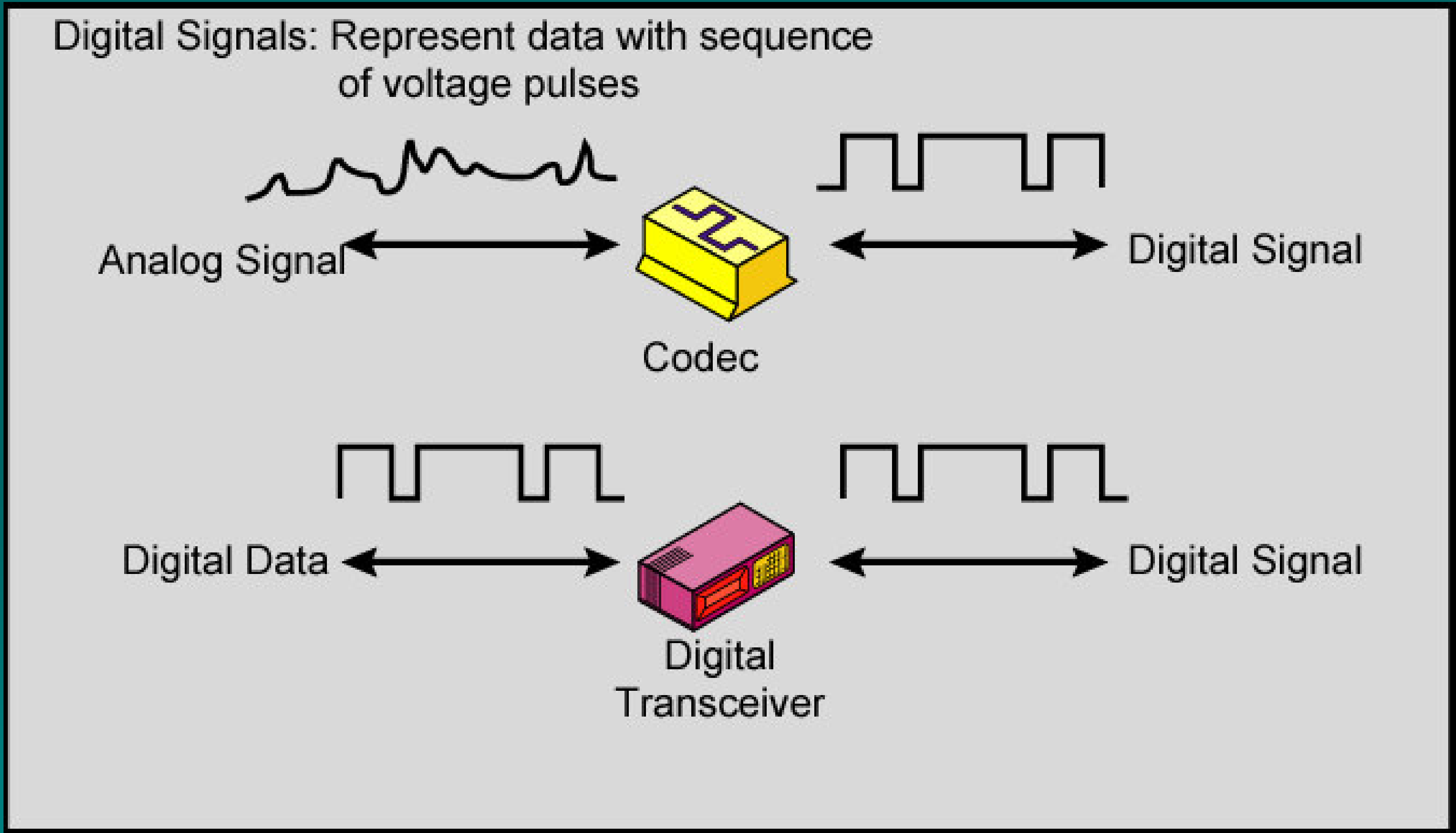


User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by Đ5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50 kbps).

Analog Signals

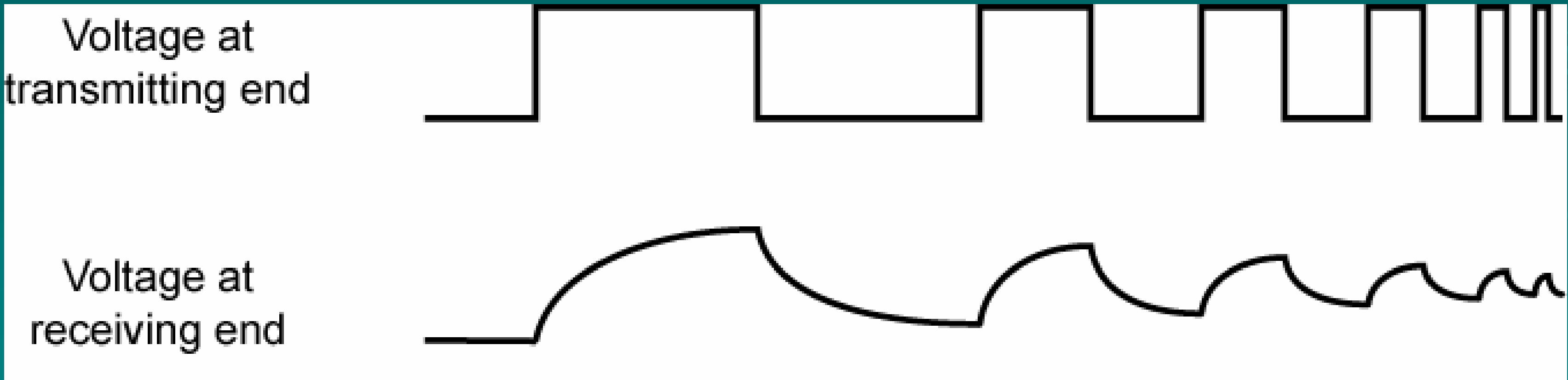


Digital Signals



Advantages & Disadvantages of Digital Signals

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



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

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

Channel Capacity

- max possible data rate on comms channel
- is a function of
  - data rate - in bits per second
  - bandwidth - in cycles per second or Hertz
  - noise - on comms link
  - error rate - of corrupted bits
- limitations due to physical properties
- want most efficient use of capacity

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

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

Summary

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