CSCI 465
Data Communications and Networks

Lecture 4

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Data Transmission

What we've got here is a failure to communicate.

Paul Newman
"Cool Hand"

Data Transmission (2)

- The successful transmission of data depends on two factors:
  - The quality of the signal being transmitted
  - The characteristics of the transmission medium

Data Transmission (3)

- Data transmission occurs between a transmitter and a receiver over some transmission medium.
  – Guided media – physical path
    - twisted pair, coaxial cable, optical fiber
  – Unguided (wireless) media
    - Air, water , vacuum

Transmission Terminology

- Direct link
  - Transmission path from transmitter to receiver with no intermediate devices (other than amplifiers)
- Point to point
  - Direct link between the only two devices sharing the medium (Note: can apply to unguided media)
- Multipoint
  - More than two devices share the same medium

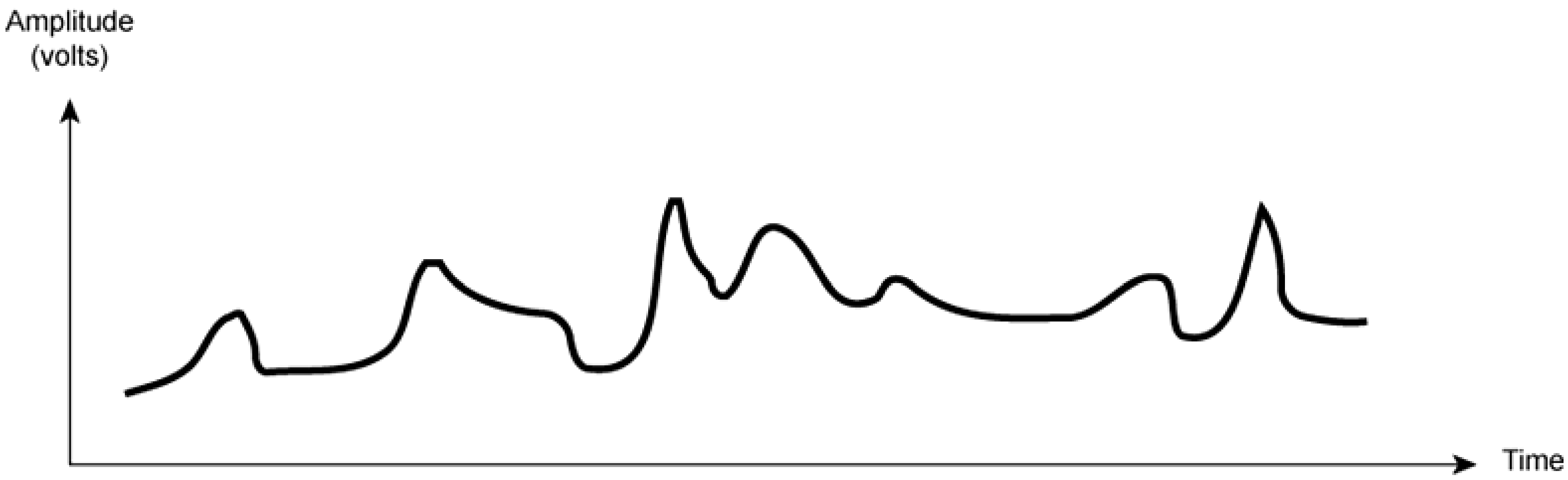
Transmission Terminology (2)

- Simplex
  - Signal transmitted in one direction
    - e.g. cable television
- Half-duplex
  - Both stations may transmit, but one at a time
    - e.g. police radio
- Full-duplex
  - Both stations may transmit simultaneously
    - e.g. telephone

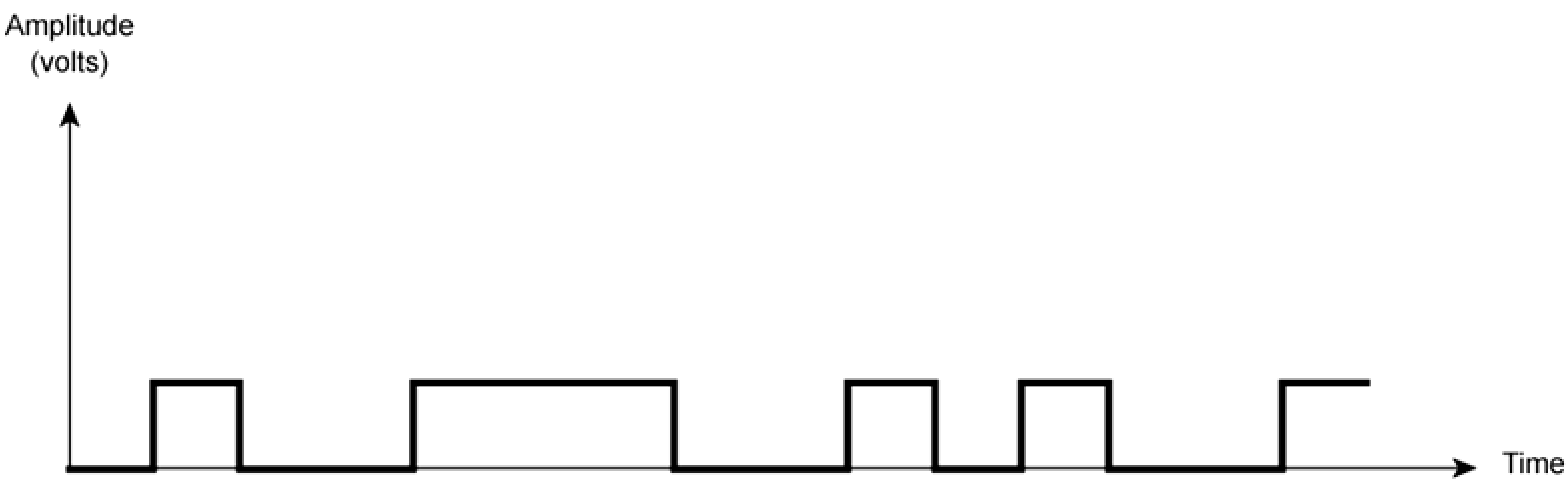
Analog vs Digital

- Analog signal
  – Signal intensity varies in a smooth, **continuous**, fashion over time – no breaks
- Digital signal
  – Signal intensity maintains constant level for some period of time and then abruptly changes to another constant level – discrete signals

Analog vs Digital (2)

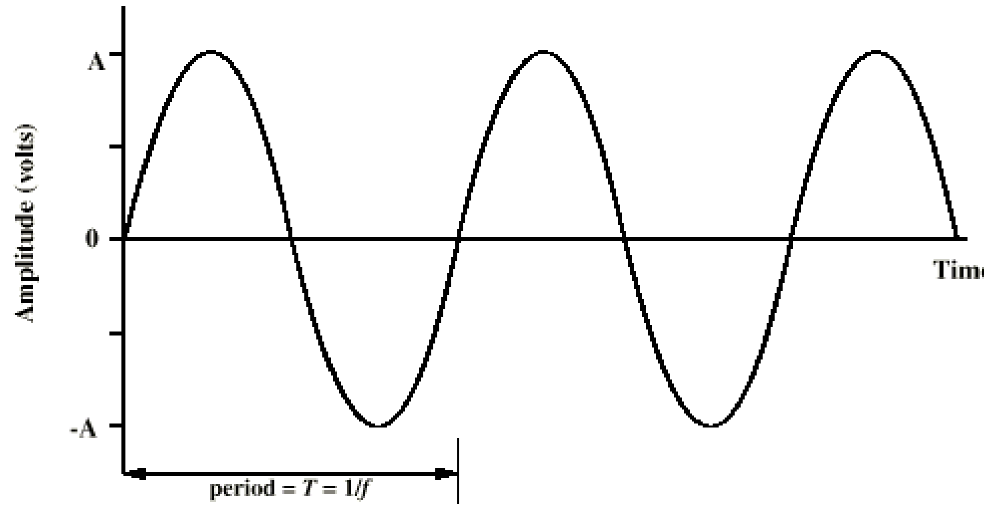


(a) Analog

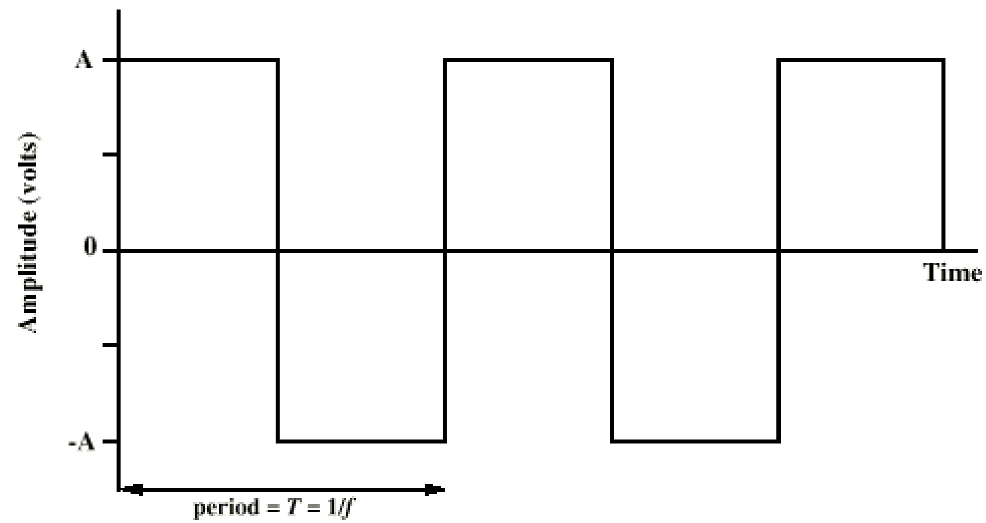


(b) Digital

Periodic Signals



(a) Sine wave



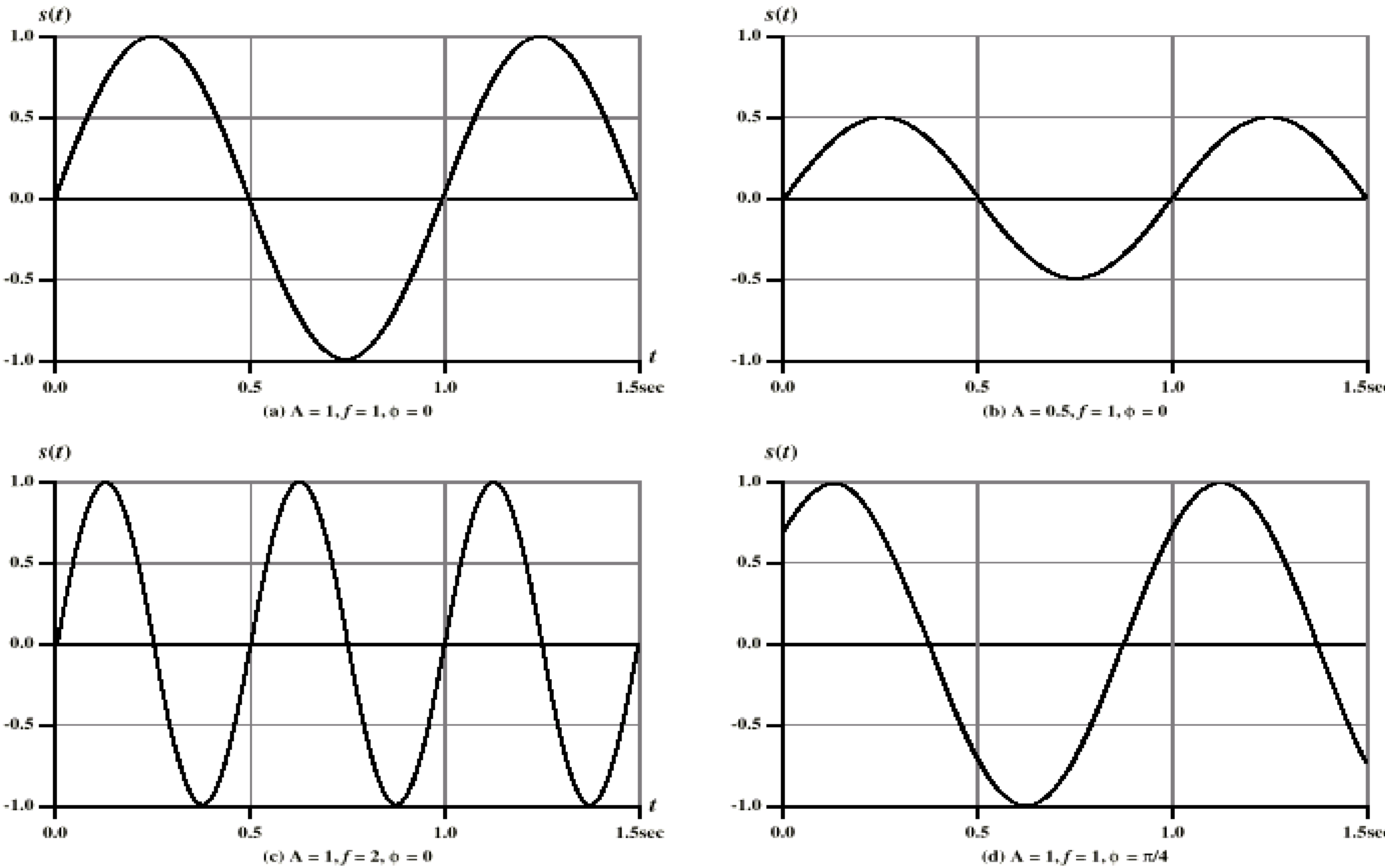
(b) Square wave

Sine Wave

(periodic continuous signal)

- Peak amplitude (A)
  - Maximum strength of signal
  - Typically measured in volts
- Frequency (f)
  - Rate at which signal repeats
  - Hertz (Hz) or cycles per second
  - Period (T) is time to repeat $T = 1 / f$
- Phase (ϕ)
  - **Relative position in time within a single period**

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



Wavelength (λ)

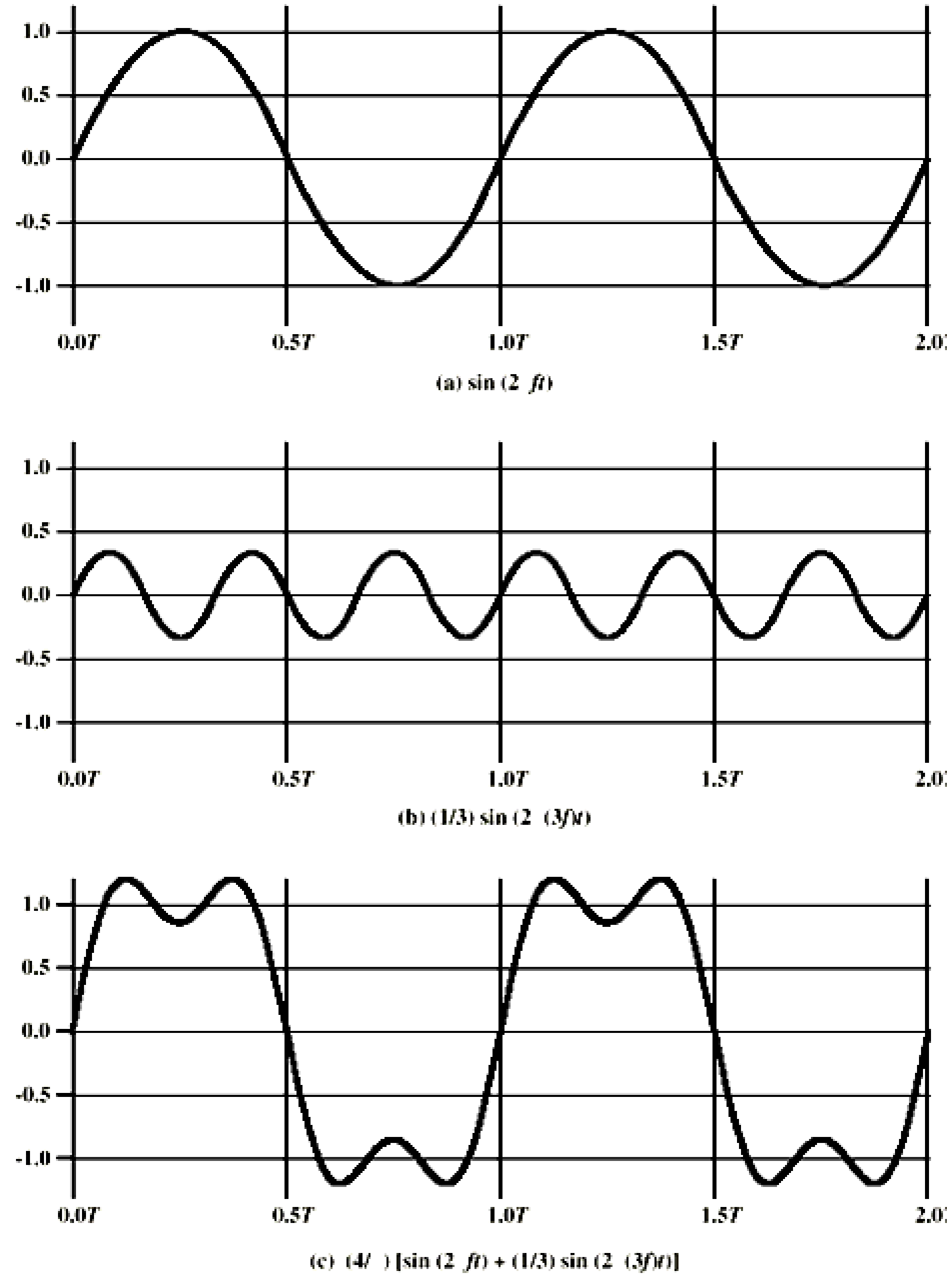
- Distance occupied by a single cycle
  or
  Distance between two points of corresponding phase of two consecutive cycles
- Signal with velocity v, then wavelength is
  $\lambda = vT$ or $\lambda f = v$
- Consider signal travelling at speed of light
  $v = c = 3 \times 10^8$ m/s

Frequency Domain Concepts

- Signals are made up of many frequencies
- Components are sine waves
- Fourier analysis can show any signal is made up of components at various frequencies
- Each component is a sinusoid
- Can plot frequency domain functions

Addition of Frequency Components (T = 1/f)

c is sum of f & 3f



(a) sin (2 ft)

(b) (1/3) sin (2 (3f)t)

(c) (4/) [sin (2 ft) + (1/3) sin (2 (3f)t)]

Spectrum & Bandwidth

- Spectrum
  - Range of frequencies contained in a signal
  - e.g. f and $3f$ on previous slide
- Absolute bandwidth
  - Width of the spectrum
  - e.g. $2f$
- Effective bandwidth (or just “bandwidth”)
  - Narrow band of frequencies containing most of the energy in the signal

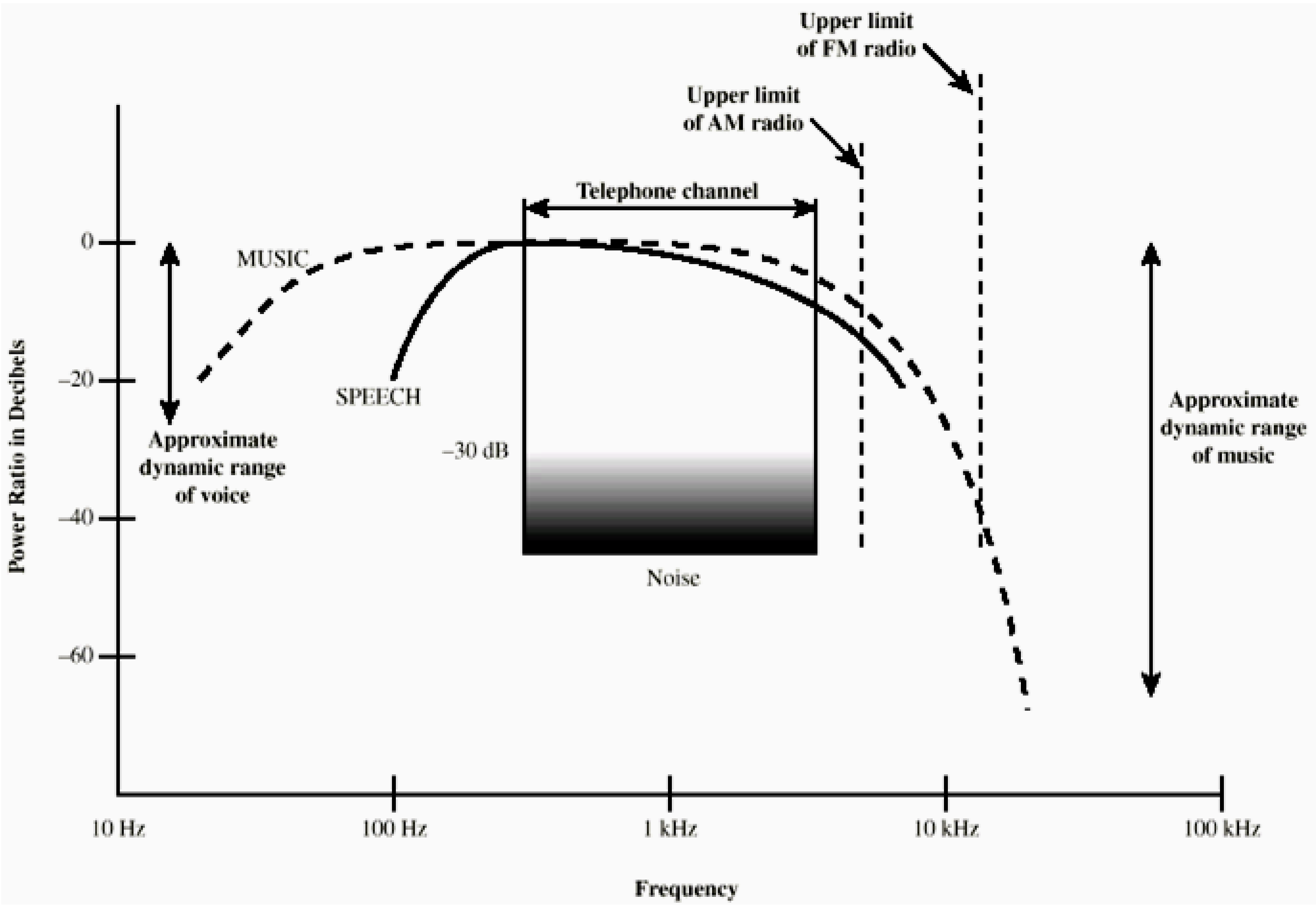
Data Rate and Bandwidth

- Any transmission system can carry only a limited band of frequencies
  - Limits the data rate that can be carried
- Square waves have infinite components
  - Infinite bandwidth
- Most energy in first few components
- Limiting bandwidth creates distortions

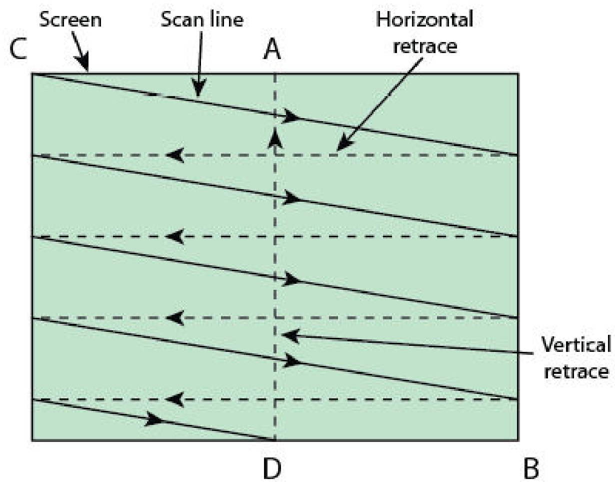
Data, Signals, and Transmission

- Data
  - Entities that convey information
- Signals
  - Electric or electromagnetic representations of data
- Signaling
  - Physical propagation of signal along medium
- Transmission
  - Communication of data by propagation and processing of signals

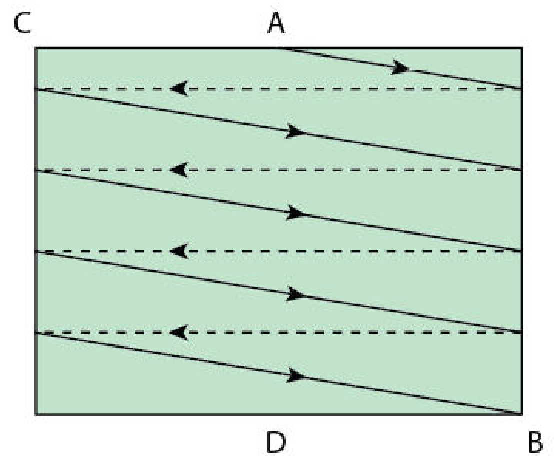
Acoustic Spectrum (Analog)



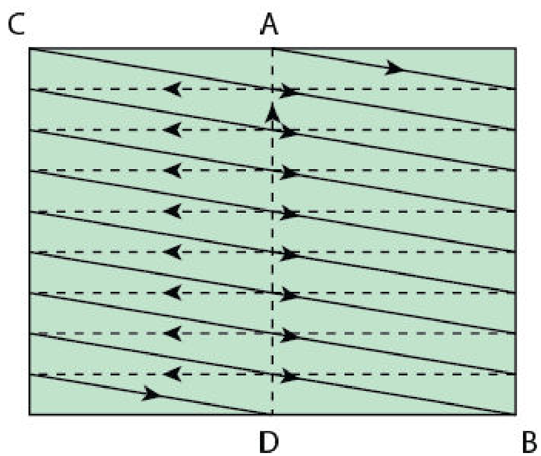
Video Interlaced Scanning



(a) Even field only



(b) Odd field only



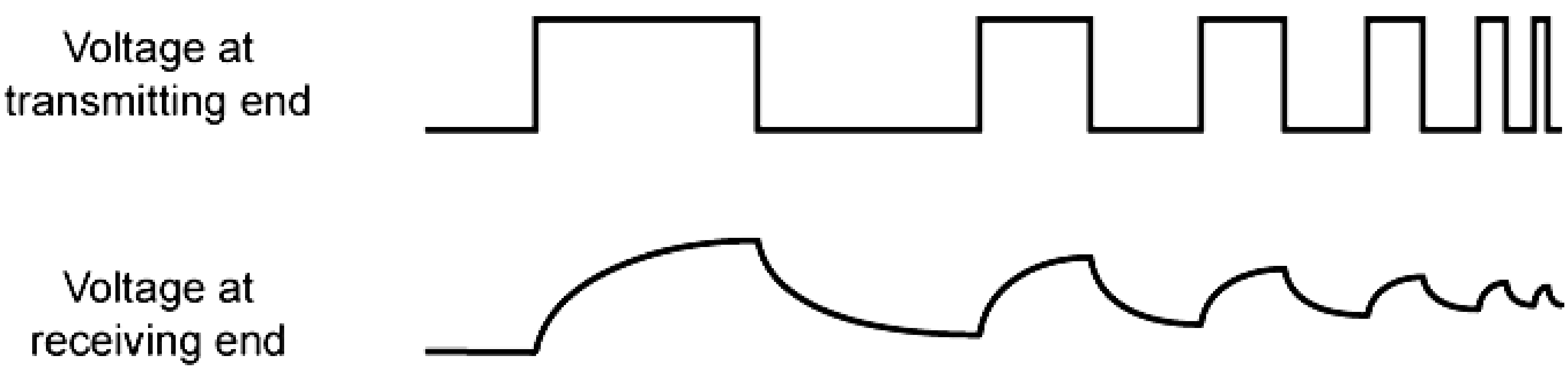
(c) Odd and even fields

Digital Data

- Text (character strings)
  - Coded into sequence of bits
    - IRA – International Reference Alphabet (ASCII)
  - 7-bit code with parity bit
- Image
  - Coded into pixels with number of bits per pixel
  - May then be compressed

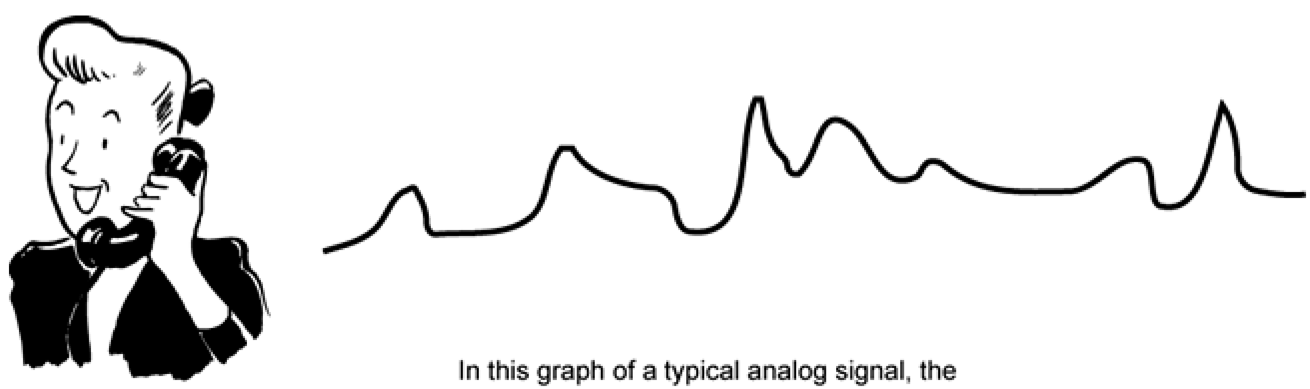
Digital Signals

- Advantages
  - Cheaper
  - Less susceptible to noise interference
- Disadvantages
  - Suffer more from attenuation (strength loss)



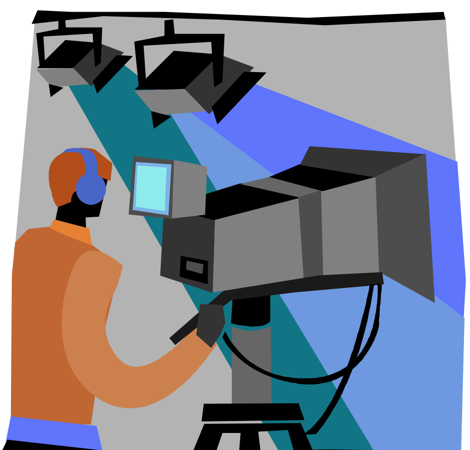
Audio Signals

- frequency range of typical speech is 100Hz-7kHz
- easily converted into electromagnetic signals
- varying volume converted to varying voltage
- can limit frequency range for voice channel to 300-3400Hz



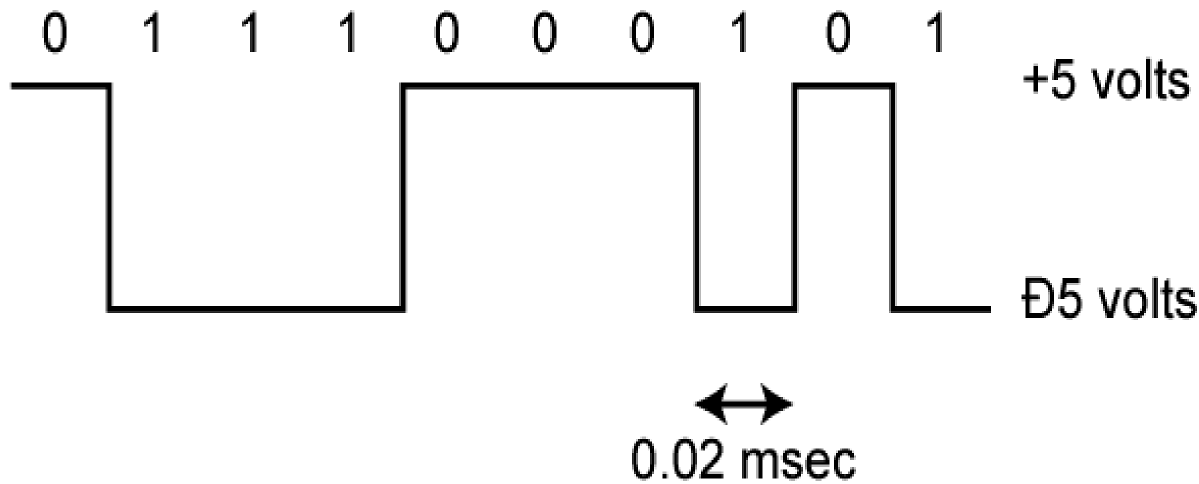
In this graph of a typical analog signal, the variations in amplitude and frequency convey the gradations of loudness and pitch in speech or music. Similar signals are used to transmit television pictures, but at much higher frequencies.

Video Signals



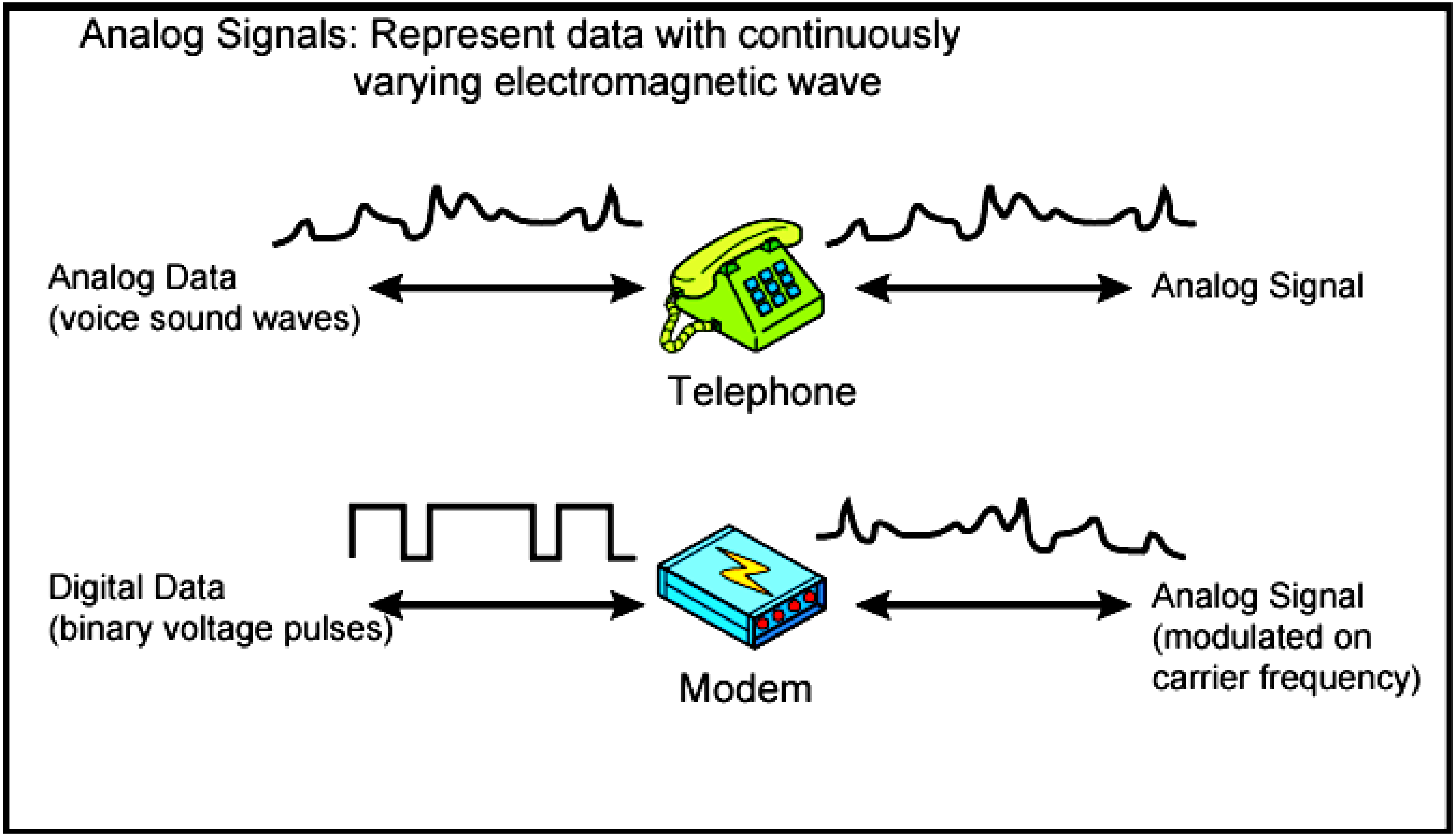
- to produce a video signal a TV camera is used
- USA standard is 483 lines per frame, at a rate of 30 complete frames per second
  - actual standard is 525 lines but 42 lost during vertical retrace
- horizontal scanning frequency is 525 lines x 30 scans = 15750 lines per second
- max frequency if line alternates black and white
- max frequency of 4.2MHz

Conversion of PC Input to Digital Signal

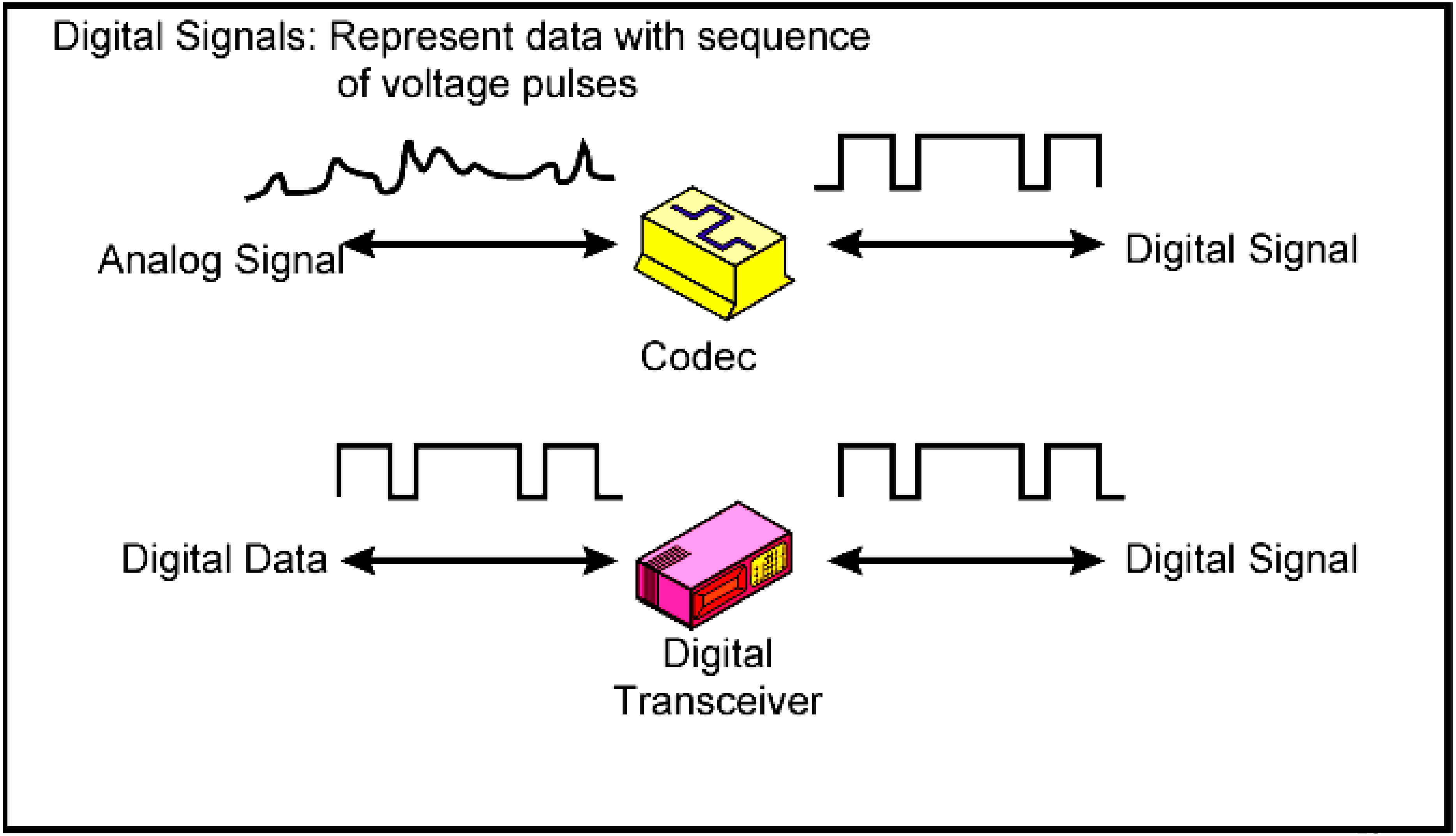


User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by Ð5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50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

Analog Signals



Digital Signals



Data and Signals

	Analog Signal	**Digital Signal**
Analog Data	Two alternatives: 1. Signal occupies the same spectrum as the analog data. 2. Analog data are encoded to occupy a different portion of the spectrum.	Analog data are encoded using a codec to produce a digital bit stream.
Digital Data	Digital data are encoded using a modem to produce analog signal.	Two alternatives: 1. Signal consists of two voltage levels to represent the two binary values 2. Digital data are encoded to produce a digital signal with desired properties.

Treatment of Signals

	Analog Transmission	Digital Transmission
Analog Signal	Is propagated through amplifiers; same treatment whether signal is used to represent analog or digital data.	Assumes analog signal represents digital data. Signal propagated through repeaters, where digital data are recovered and used to generate new outbound signal.
Digital Signal	Not used.	Digital signal represents a stream of 0s and 1s, which may represent digital data or may be an encoding of analog data. Signal is propagated through repeaters, where new outbound signal is generated from 0s and 1s.

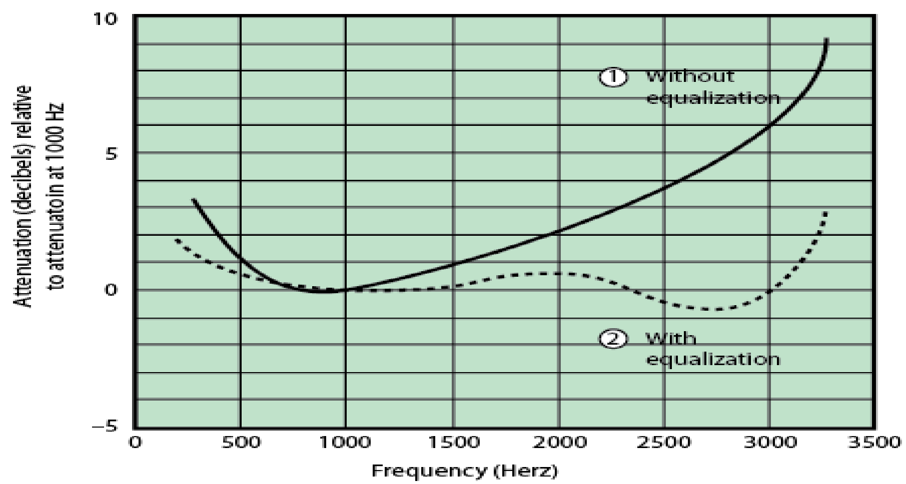
Transmission Impairments

- 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

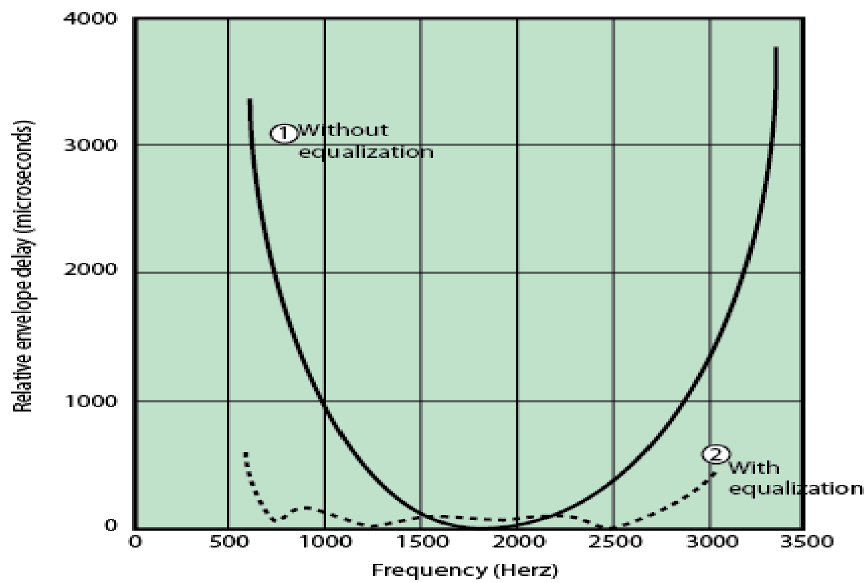
Attenuation

- Signal strength falls off with distance over any communications medium
- Varies with frequency – higher has more
- Received signal strength must be:
  - strong enough to be detected
  - sufficiently higher than noise to be received without error
- Strength increased with repeaters or amplifiers
- Adjust for attenuation by amplifying more at higher frequencies

Attenuation Distortion



(a) Attenuation



(b) Delay distortion

Delay Distortion

- occurs because propagation velocity of a signal through a guided medium varies with frequency
- various frequency components arrive at different times resulting in phase shifts between the frequencies
- particularly critical for digital data since parts of one bit spill over into others causing intersymbol interference

Noise

- Unwanted signals that are inserted somewhere between transmission and reception
- Major limiting factor in communications system performance

Categories of Noise

- Thermal Noise
  - Thermal agitation of electrons
  - Uniformly distributed across bandwidths
  - Referred to as “white noise”
- Intermodulation Noise
  - Produce unwanted signals at a frequency that is the sum or difference of two original frequencies
    - e.g. signals at 4 KHz and 8 KHz may add noise at 12 KHz and interfere with a 12 KHz signal

Categories of Noise (2)

- 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
- Impulse 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

Channel Capacity

- Maximum rate at which data can be transmitted over a given communications channel under given conditions
- Four concepts
  - Data rate - bits per second (bps))
  - Bandwidth - cycles per second – Hertz (Hz)
  - Noise – average noise level over path
  - Error rate – rate of corrupted bits
- Limitations are due to physical properties
- Main constraint on achieving efficiency is noise

Nyquist Bandwidth

In the case of a channel that is noise free:

- if rate of signal transmission is *2B* then can carry signal with frequencies no greater than *B*
  - 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: $C = 2B \log_2 M$
- data rate can be increased by increasing signals
  - however this increases burden on receiver
  - noise & other impairments limit the value of *M*

Shannon Capacity Formula

- considering the relation of data rate, noise and error rate:
  - faster data rate shortens each bit so bursts of noise corrupts more bits
  - given noise level, higher rates mean higher errors
- Shannon developed formula relating these to signal to noise ratio (in decibels)
- $SNR_{db} = 10 \log_{10}(\text{signal/noise})$
- capacity $C = B \log_2(1+SNR)$
  - theoretical maximum capacity
  - get much lower rates in practice