Data and Computer Communications

Data Transmission

Terminology (1)

- Transmitter
- Receiver
- Medium
  - Guided medium
    - E.G. Twisted pair, optical fiber
  - Unguided medium
    - E.G. Air, water, vacuum

Terminology (2)

- 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 (3)

- 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

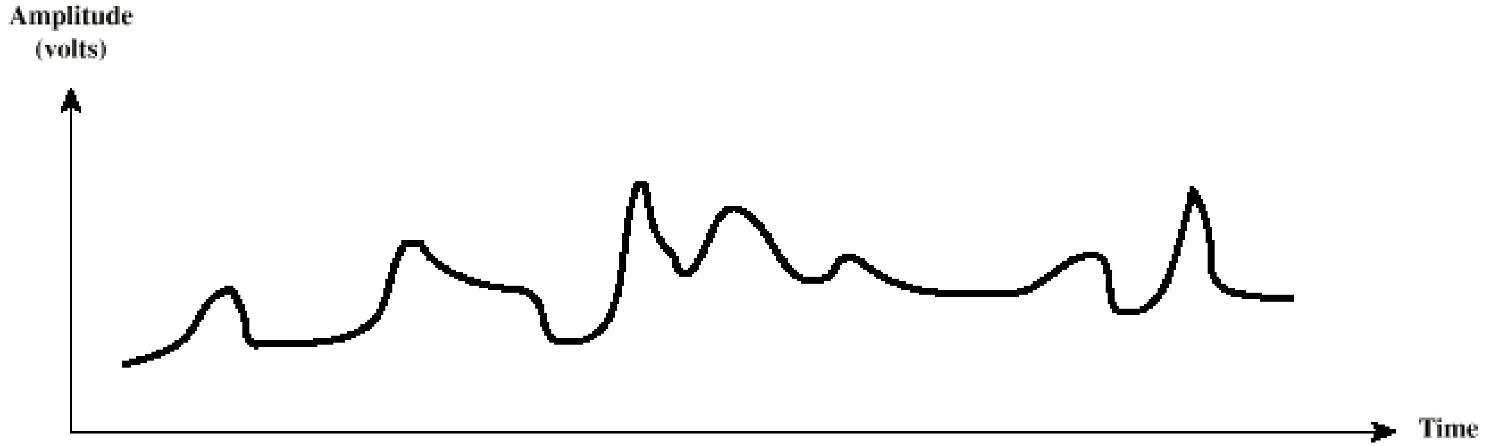
Frequency, Spectrum and Bandwidth

- Time domain concepts
- Frequency domain concepts

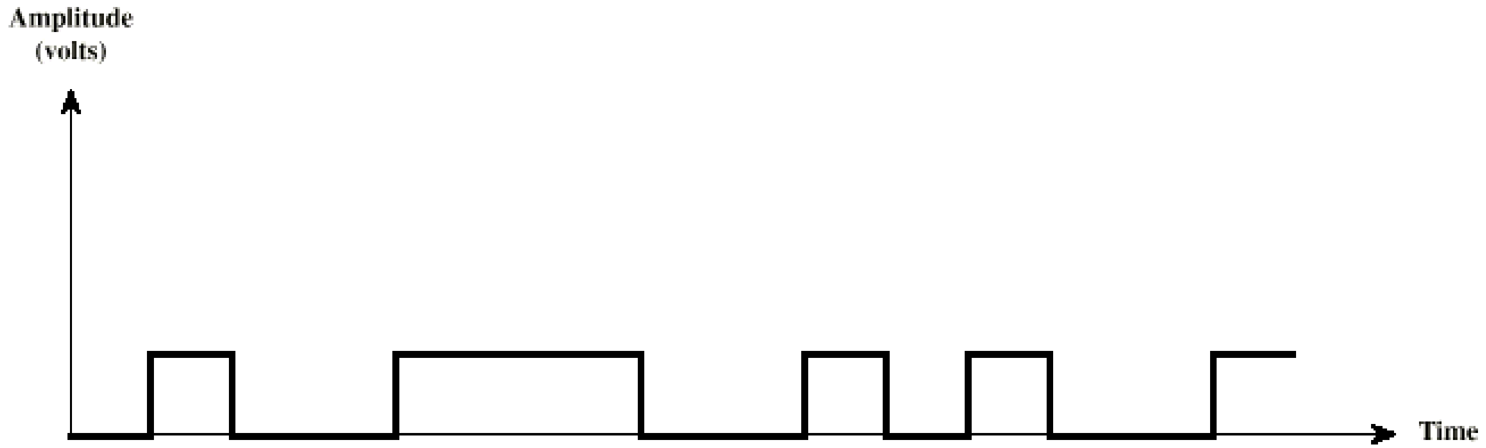
Time Domain Concepts

- Time domain concepts
  - Continuous signal
    - Various in a smooth way over time
  - Discrete signal
    - Maintains a constant level then changes to another constant level
  - Periodic signal
    - Pattern repeated over time
  - Aperiodic signal
    - Pattern not repeated over time

Continuous & Discrete Signals

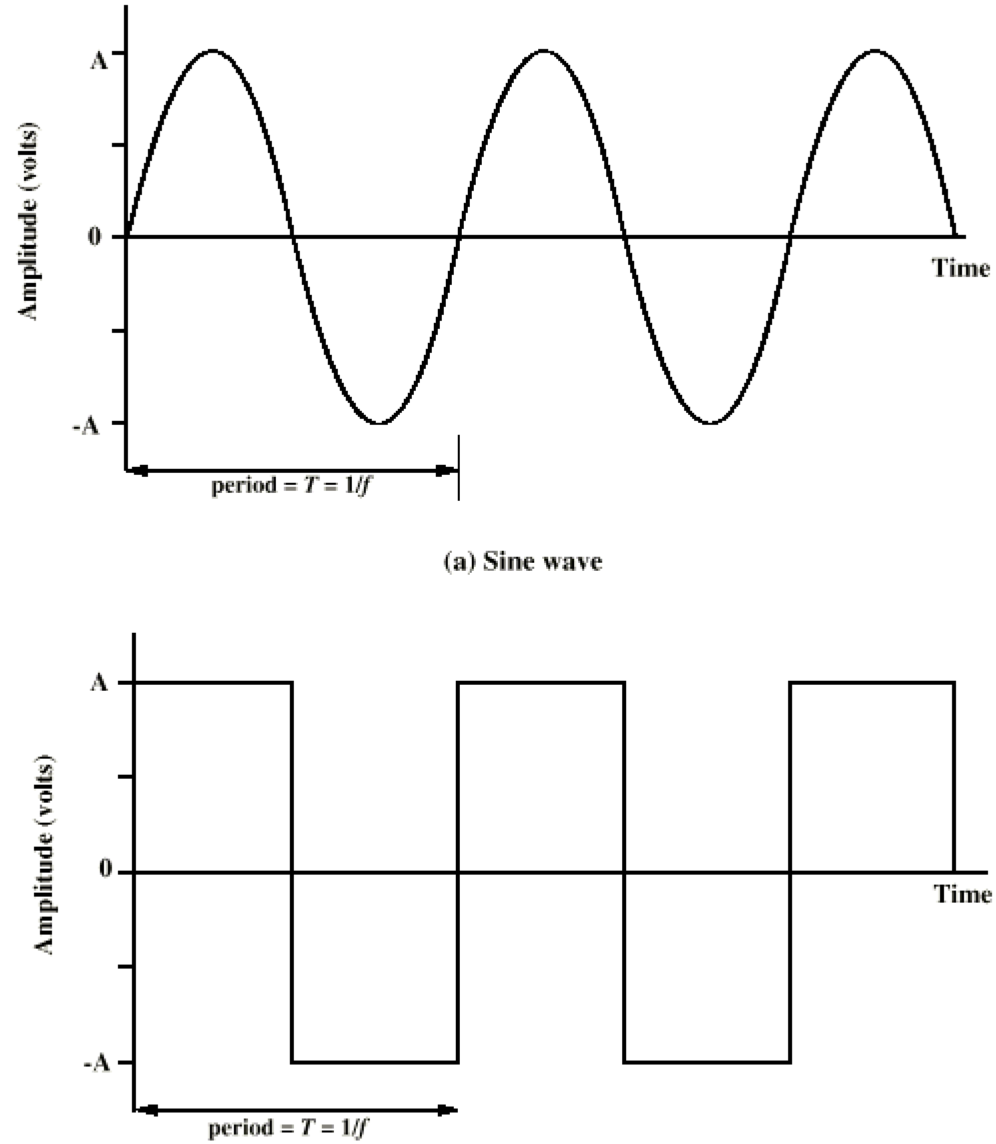


(a) Continuous



(b) Discrete

Periodic Signals



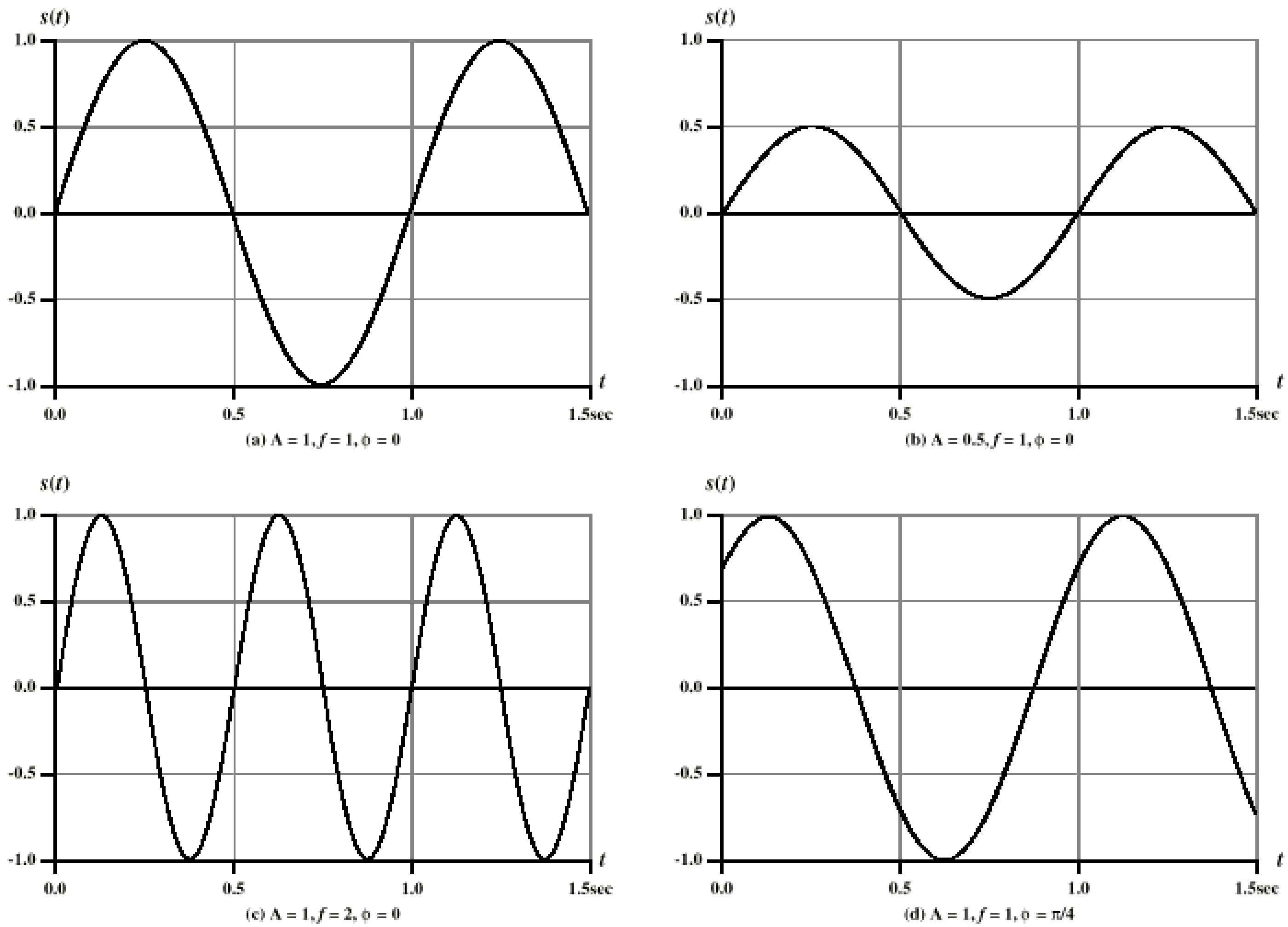
(a) Sine wave

(b) Square wave

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



Wavelength

- Distance occupied by one cycle
- Distance between two points of corresponding phase in two consecutive cycles
- λ
- Assuming signal velocity *v*
  - $\lambda = vT$
  - $\lambda F = v$
  - $C = 3*10^8\ ms^{-1}$ (speed of light in free space)

Frequency Domain Concepts

- Signal usually made up of many frequencies
- Components are sine waves
- Can be shown (Fourier analysis) that any signal is made up of component sine waves
- Can plot frequency domain functions

The Physical Layer

- The theoretical basis
  - Information can be transmitted on wires by varying voltage or current a function of time f(t).
- Fourier analysis
  - Periodic function g(t) with period T can be constructed by summing a number of sines and cosines.

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

f=1/T fundamental frequency

  - an, sine amplitude of the nth harmonics.
  - bn, cosine amplitude of the n^{th} harmonics.

Fourier Analysis (Cont.)

- A data signal that has a finite duration can be handled by just imagining that it repeats the entire pattern over and over forever.

$$a_n = (2/T)\int_0^T g(t)\sin(2\pi nft)\,dt$$

$$b_n = (2/T)\int_0^T g(t)\cos(2\pi nft)\,dt$$

$$c = (2/T)\int_0^T g(t)\,dt$$

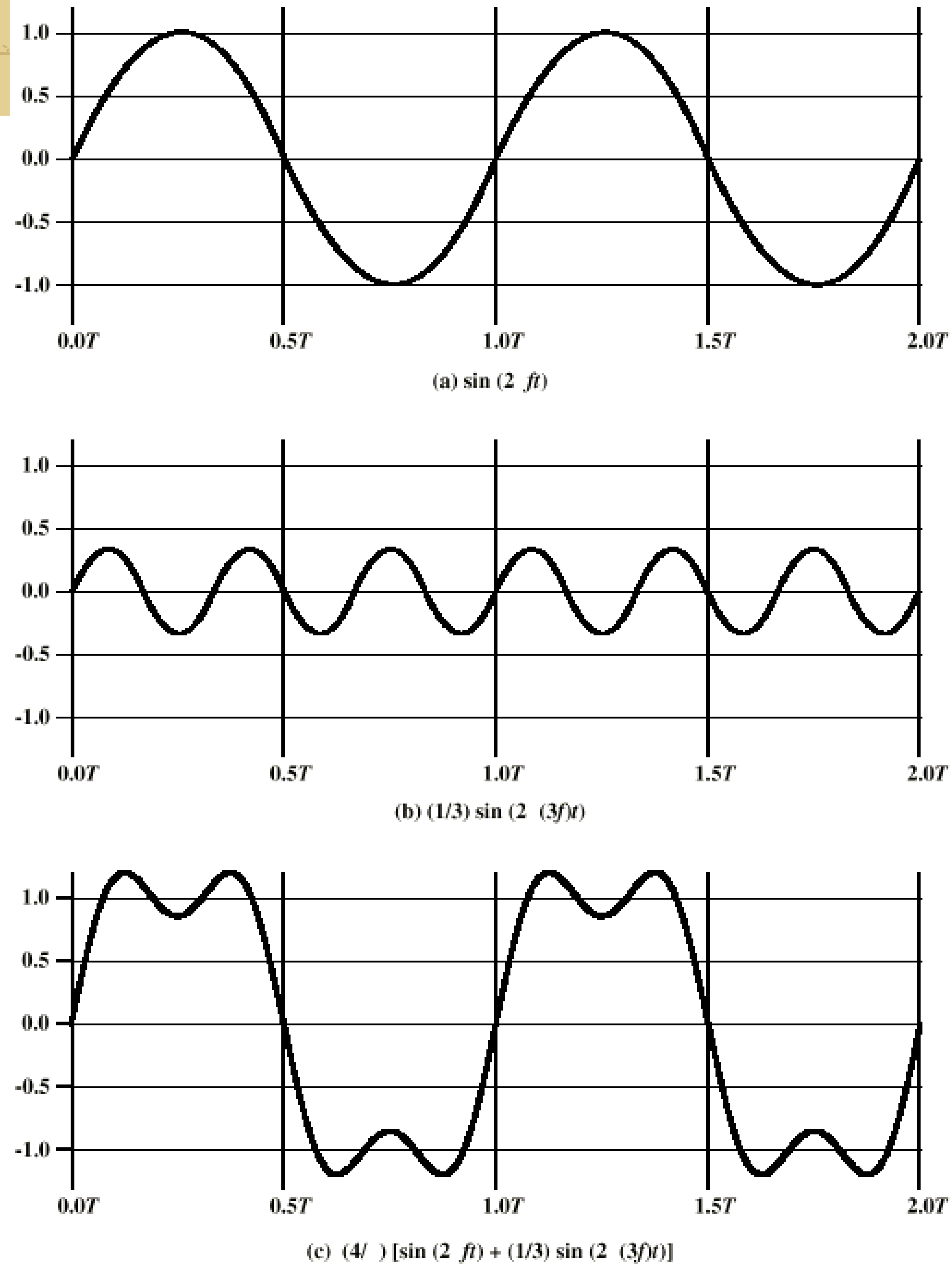
Bandwidth Limited Signals

- To send the letter "b":01100010.
- The root mean square amplitudes, $\sqrt{(a_n^2 + b_n^2)}$, for the first few terms are shown on the right hand side of fig 2.1(a).
- These values are of interest because their squares are proportional to the energy transmitted at the corresponding frequency.
- All signals loose some power when they are transmitted.
- The amplitudes are transmitted undiminished from 0 up to some frequency fc, where fc is the cut-off frequency.
- All frequencies above this cutoff frequency strongly attenuated.

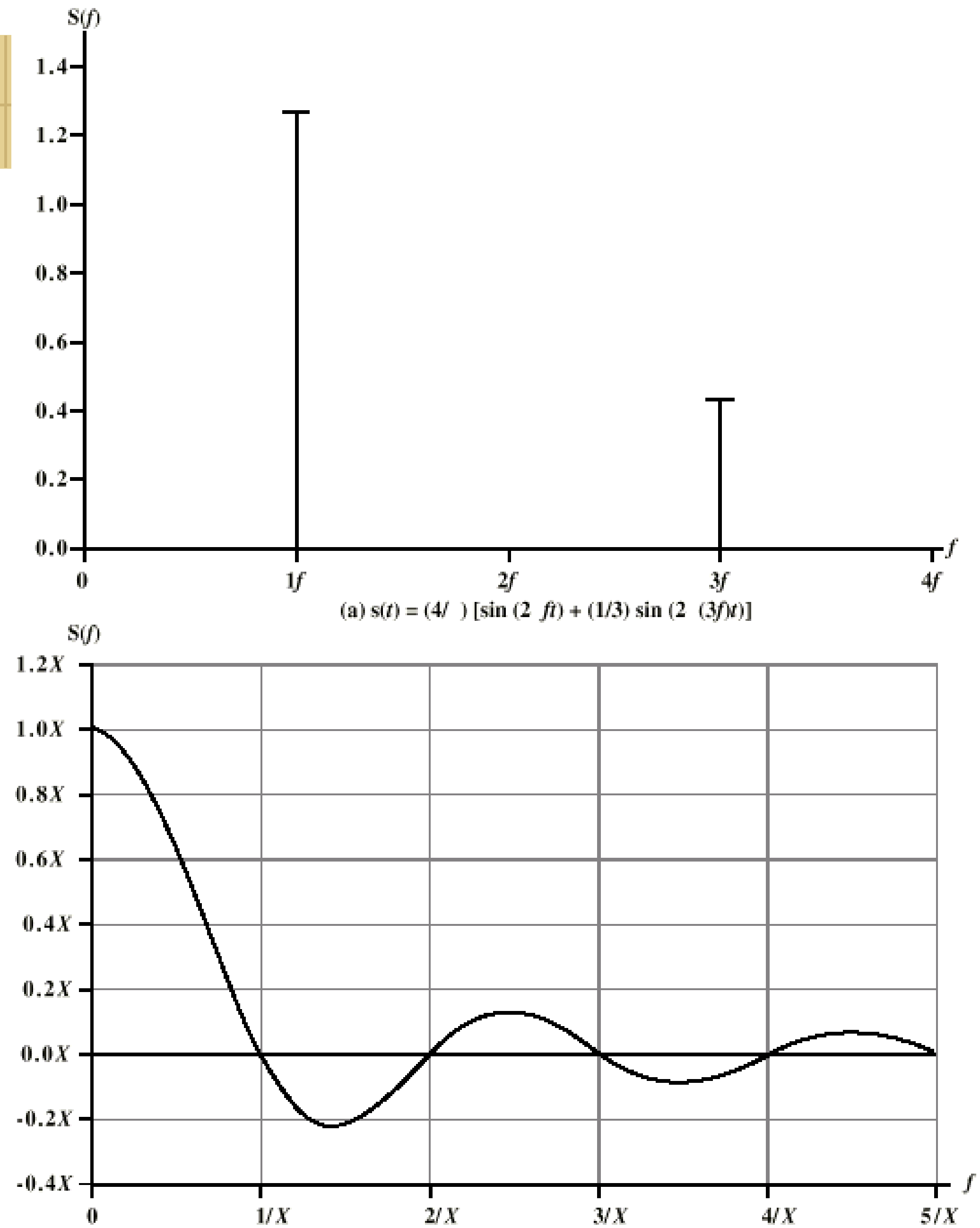
Bandwidth Limited Signals (Cont.)

- Time T required to transmit the character depends on both.
  - Encoding method.
  - Signaling speed.
- Number of changes per second is measured in **baud**.
- **Baud rate** does not equal **bit rate**.
- Example: if the transmission uses 0,1,2,3,4,5,6,7 voltages, then each signal value can be used to transmit 3-bites.
- Transmit rate =3* baud rate.
- Limiting the bandwidth limits the data rate, even for perfect channels.

Addition of Frequency Components



Frequency Domain Representations



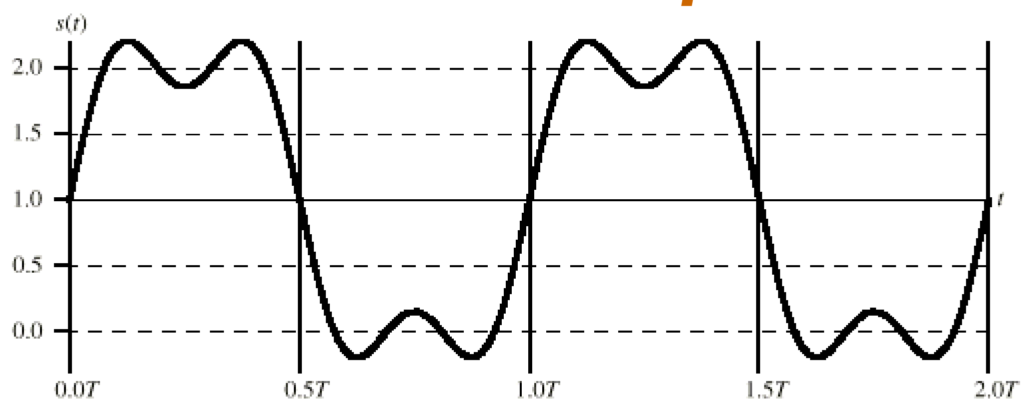
(a) s(t) = (4/) [sin (2 ft) + (1/3) sin (2 (3f)t)]

(b) s(t) = 1 – X/2 t X/2

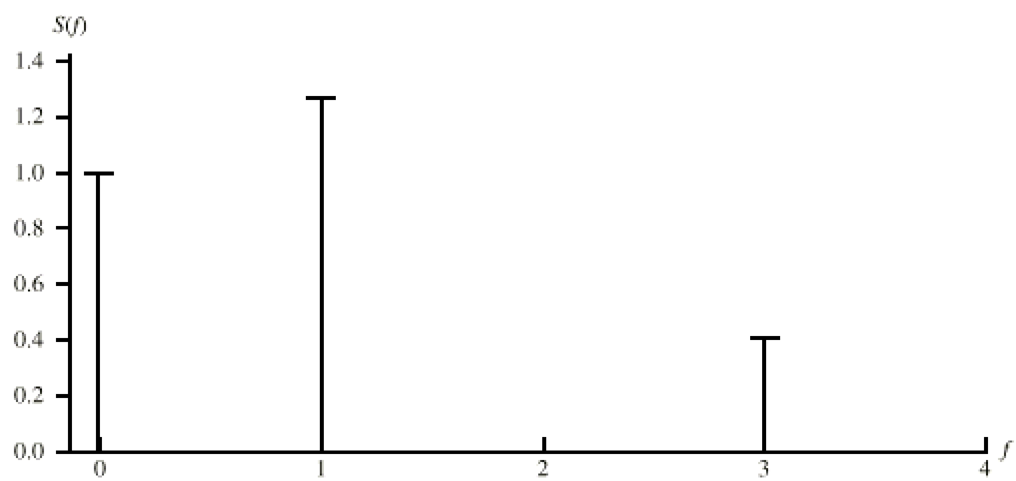
Spectrum & Bandwidth

- 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
- DC component
  - Component of zero frequency

Signal With DC Component



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

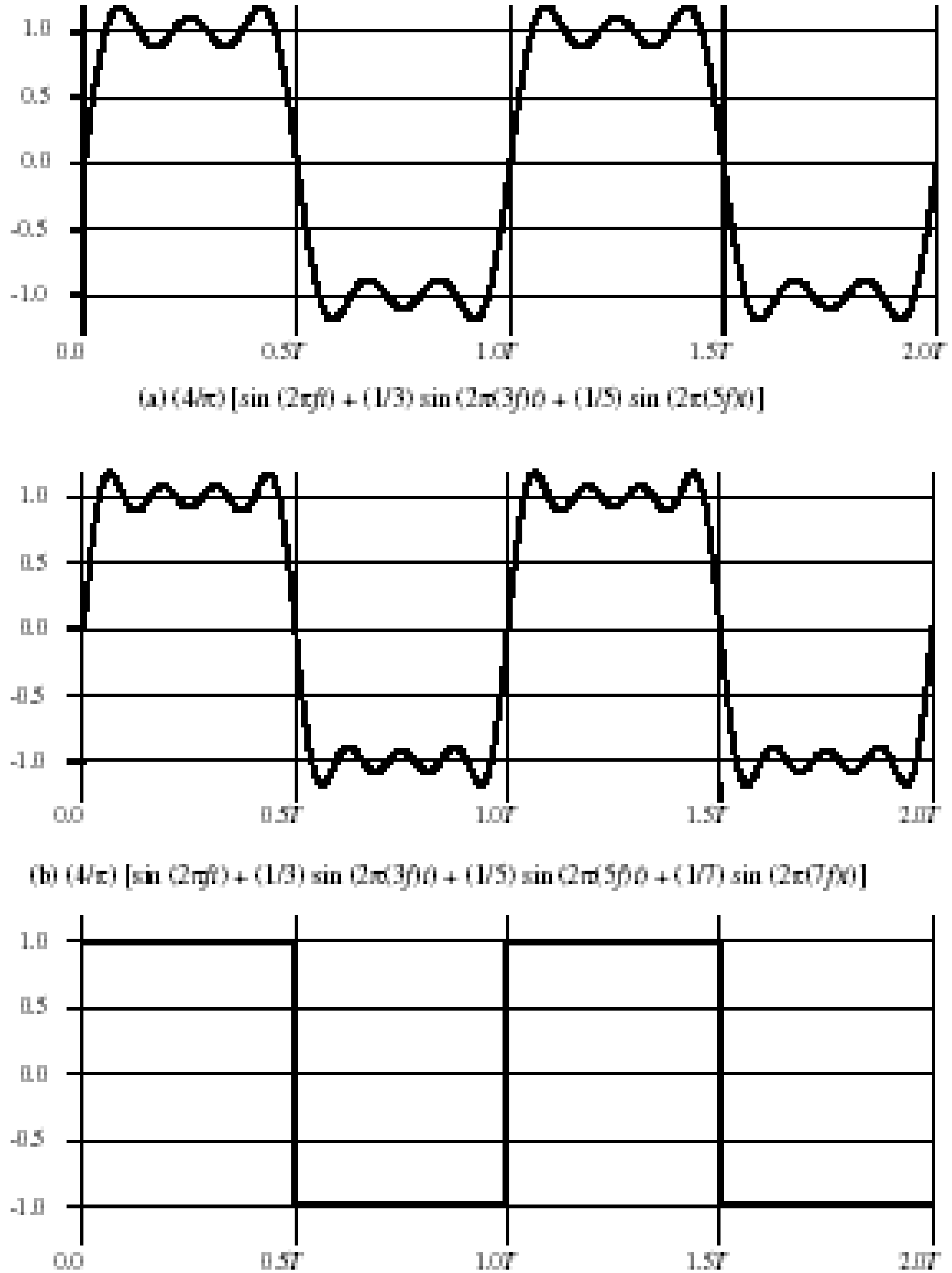


(b) S(f)

Data Rate and Bandwidth

- Any transmission system has a limited band of frequencies
- This limits the data rate that can be carried
- The higher the data rate of a signal, the greater is its effective bandwidth
- The higher the center frequency, the higher the potential bandwidth and therefore, higher the potential data rate.

Frequency Components of Square Wave ($T = 1/f$)



(a) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$

(b) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t) + (1/7)\sin(2\pi(7f)t)]$

(c) $(4/\pi)\sum(1/k)\sin(2\pi(kf)t)$,   for k odd

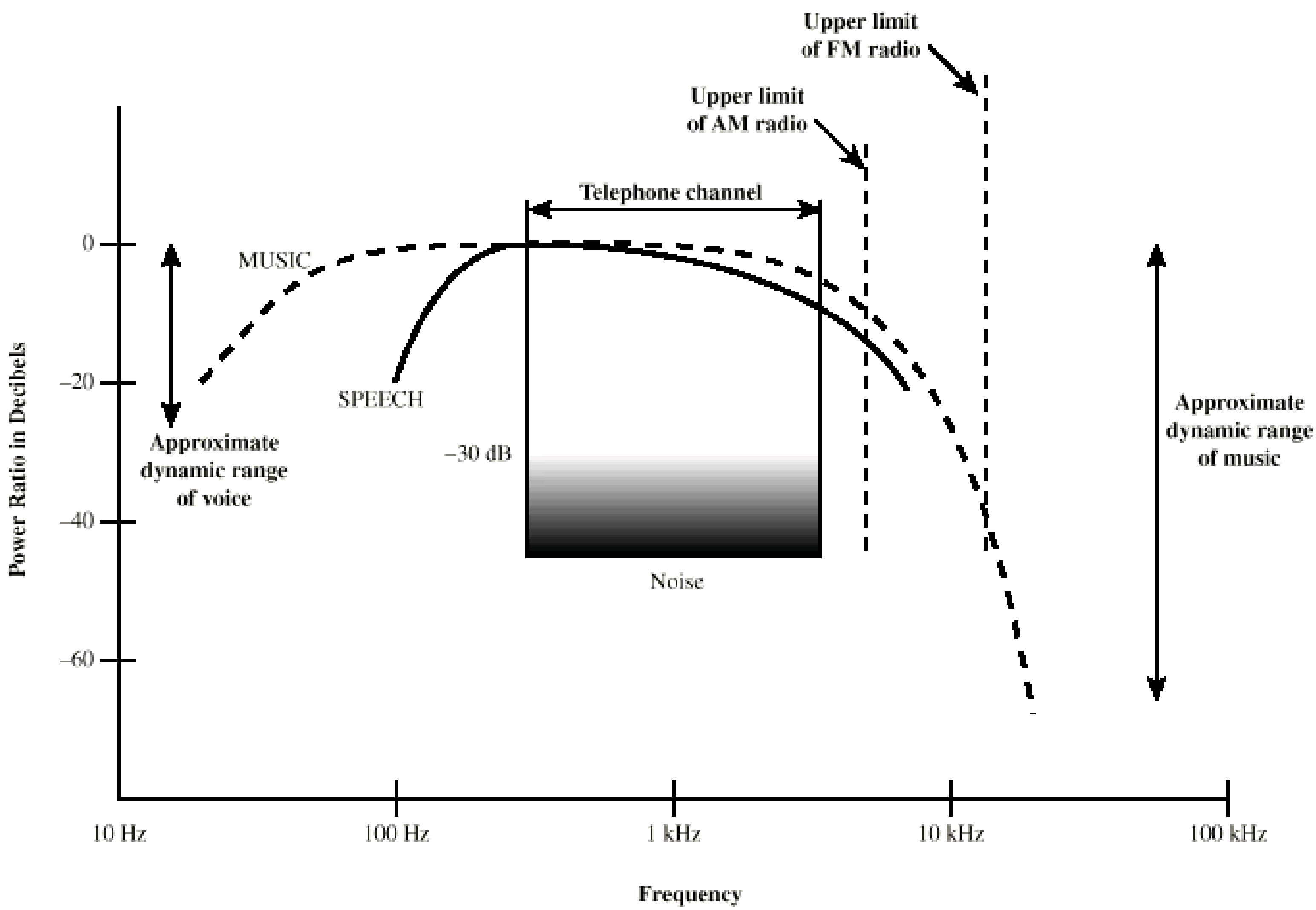
Analog and Digital Data Transmission

- Data
  - Entities that convey meaning
- Signals
  - Electric or electromagnetic representations of data
- Transmission
  - Communication of data by propagation and processing of signals

Data

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

Acoustic Spectrum (Analog)



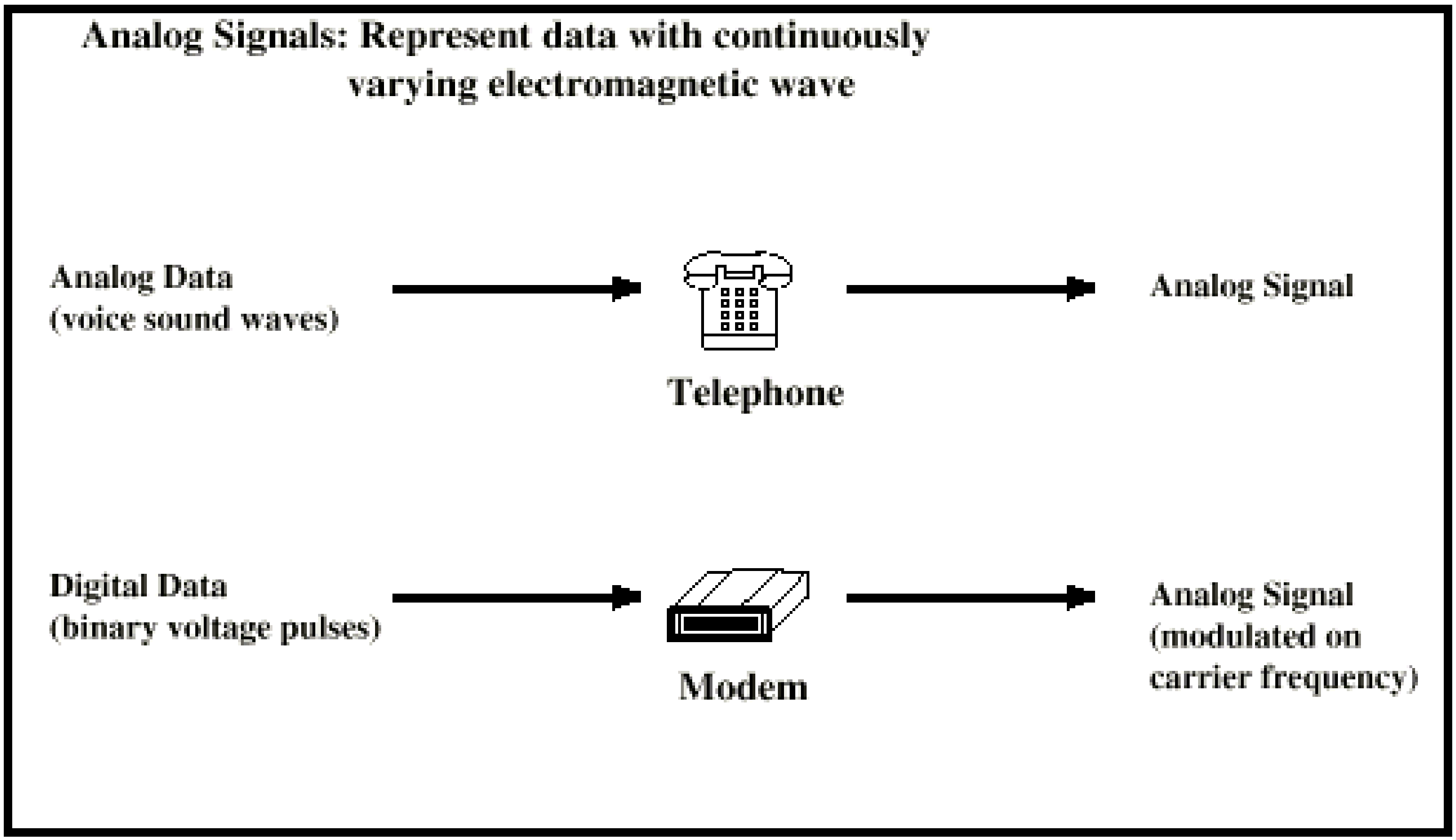
Signals

- Means by which data are propagated
- Analog
  - Continuously variable
  - Various media
    - Wire, fiber optic, space
  - Speech bandwidth 100hz to 7khz
  - Telephone bandwidth 300hz to 3400hz
  - Video bandwidth 4mhz
- Digital
  - Use two DC components

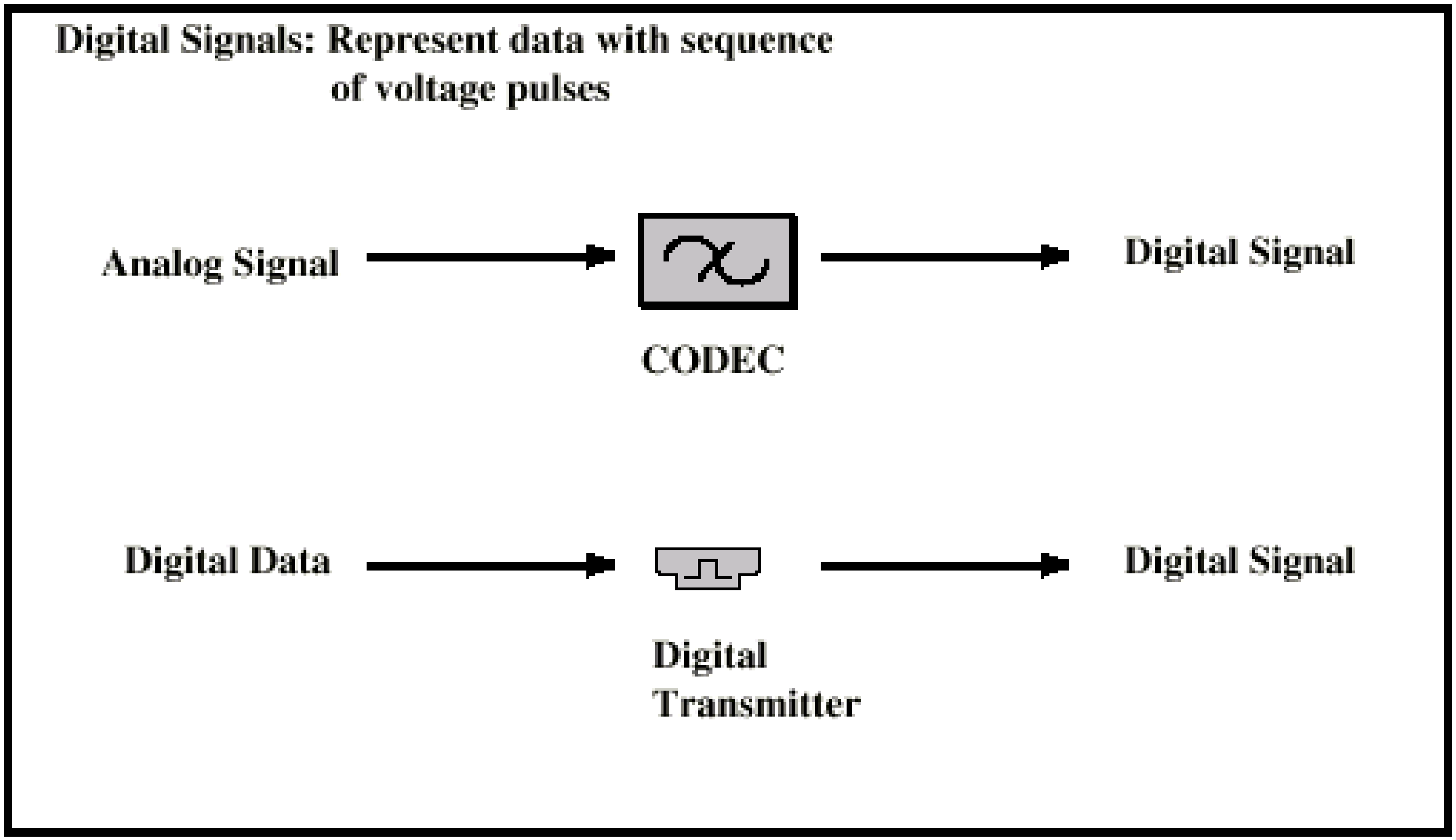
Data and Signals

- Usually use digital signals for digital data and analog signals for analog data
- Can use analog signal to carry digital data
  - Modem
- Can use digital signal to carry analog data
  - Compact Disc audio

Analog Signals Carrying Analog and Digital Data



Digital Signals Carrying Analog and Digital Data



Analog Transmission

- 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 Transmission

- Concerned with content.
- Integrity endangered by noise, attenuation etc.
- Repeaters used.
- Repeater receives signal.
- Extracts bit pattern.
- Retransmits.
- Attenuation is overcome.
- Noise is not amplified.

Advantages of Digital Transmission

- Digital technology
  - Low cost 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

- Signal received may differ from signal transmitted
- Analog - degradation of signal quality
- Digital - bit errors
- Caused by
  - Attenuation and attenuation distortion
  - Delay distortion
  - Noise

Attenuation

- Signal strength falls off with distance
- Depends on medium
- Received signal strength:
  - must be enough to be detected
  - must be sufficiently higher than noise to be received without error
- Attenuation is an increasing function of frequency

Delay Distortion

- Only in guided media
- Propagation velocity varies with frequency
- The velocity tends to be highest near the center frequency and fall off towards the two edges of the band
- Critical for Digital data

Noise

- Additional signals inserted between transmitter and receiver
- Thermal Noise (White Noise)
- Intermodulation Noise
- Crosstalk
- Impulse

Thermal Noise (White Noise)

- Due to thermal agitation of electrons
- Uniformly distributed across the frequency of spectrum

Intermodulation

- Signals that are the sum and difference of original frequencies sharing the medium
- Produced when there is some non-linearity in the transmitter, receiver or interacting transmission system

Crosstalk

- A signal from one line is picked up by another

Impulse

- Impulse
  - Irregular pulses or spikes
  - e.g. External electromagnetic interference
  - Short duration
  - High amplitude

Channel Capacity

- Data rate
  - In bits per second
  - Rate at which data can be communicated
- Bandwidth
  - In cycles per second of Hertz
  - Constrained by transmitter and medium
- Noise
  - This is the average level of noise over the communications path
- Error rate

Nyquist Bandwidth

- $C = 2B \log_2 M$

  Where

  - C = Capacity of the channel
  - B = Bandwidth
  - M = Number of discrete signal or voltage level

Shannon Capacity Formula

- $C = B \log_2 (1 + SNR)$.
  - Where.
  - C = Capacity of the channel in bits per sec.
  - B = Bandwidth in Hertz.
  - SNR = Signal-to-Noise ratio in dB.
  - $(SNR)dB = 10 \log_{10}$ (signal power/noise power).
  - The formula assumes White noise (thermal noise).
  - Impulse noise, attenuation distortion or delay distortion is not accounted for.
  - The wider the bandwidth, the more noise, thus as B increases, SNR decreases.

Example

- Spectrum of the channel = 3 to 4 MHz
- SNR = 24dB
- Then B = 4MHz – 3MHz = 1MHz

  SNR_{dB} = 24dB = 10 $\log_{10}$ (SNR)

  SNR = 251
- Using Shannon's formula,

  $C = 10^6 * \log_2(1+251) \sim 10^6 * 8 = 8$ Mbps
- Based on Nyquist's formula

  $C = 2B \log_2 M$

  $8 * 10^6 = 2 * (10^6) * \log_2 M$

  $4 = \log_2 M$

  $M = 16$

The Expression E_b/N_o

- The ratio of signal energy per bit to noise power density per hertz
- 1 watt = 1 J/s
- $E_b = ST_b$
  - E_b = energy per bit in a signal
  - S = signal power
  - T_b = time required to send one bit
  - R = data rate = $1 / T_b$
  - $E_b / N_o = (S/R) / N_o = S / kTR$, or in decibel notation
  - $(E_b/N_o)_{dB} = S_{dBW} – 10\log R – 10\log k – 10\log T$
  - $(E_b/N_o)_{dB} = S_{dBW} – 10\log R + 228.6\ dBW – 10\log T$

The Expression E_b/N_o (Cont.)

- As R increases, the transmitted signal power must increase to maintain the required E_b/N_o
- Example
  - E_b/N_o = 8.4 dB is required for a bit error rate of 10^{-4}. If the effective noise temperature is 290^oK(room temp.), data rate is 2400 bps, what received signal level is required ?
  - 8.4 = S(dBW) – 10 log2400 + 228.6 dBW – 10 log290

    = S(dBW) – (10)(3.38) + 228.6 – (10)(2.46)

    S = -161.8 dBW