Previously

- OSI – Open Systems Interconnection – Refence Model Specification
- TCP/IP – Protocol Specification
- Critique – OSI vs. TCP/IP

Theoretical Basis

Fourier
Bandwidth
Data Rate

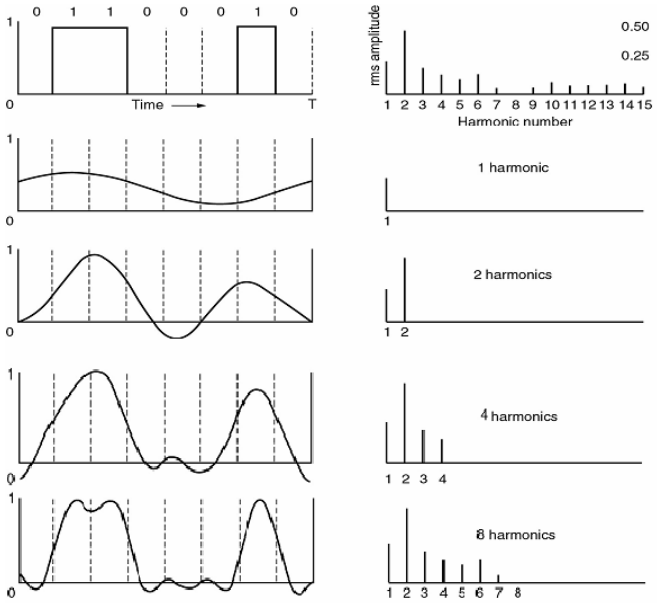
- Fourier Analysis
- Bandwidth-limited signals
- Maximum Data Rate

Fourier Analysis

- Sinusoids
  - Electromagnetic signals are made up of many frequencies (in practice),
  - Any (Data) signal can therefore be represented as a weighted sum of (possible infinite) number of sines and cosines (sinusoids)

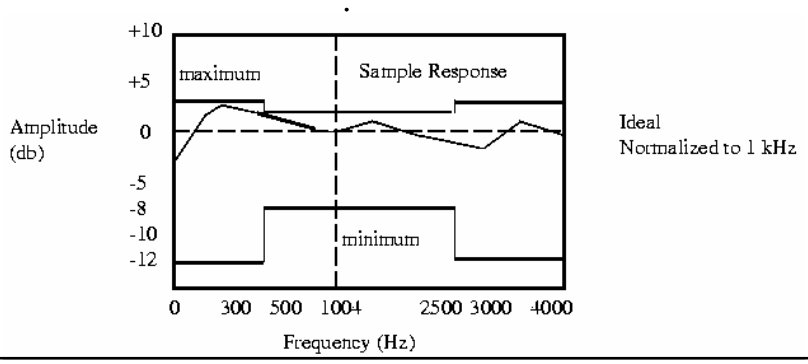
$$g(t) = 1/2c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

Successive Approximation



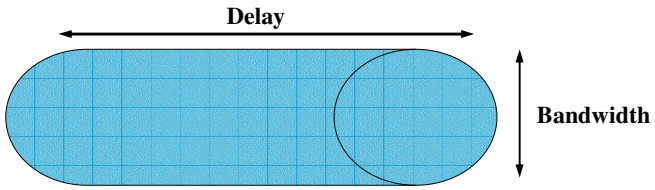
Bandwidth limitations

- Power
  - Attenuation: is the loss of energy as signals propagate outwards. It is frequency dependant.
  - Distortion: Different Fourier components (different frequencies) propagate at different speeds in the wire.



Bandwidth Limitations - 2

- Bandwidth
  - Quoted as the range of frequencies for which at least half the power is received (physics). In networks, usually Bits per second (bps) that can be transmitted on the link.
  - Further restrictions imposed by the specific telecommunication system used by signals, (e.g. telephone system limits bandwidth to 3.1KHz)



Bandwidth Limitations - 3

- Telephone lines
  - Voice signal band-limited to 20Hz – 20 KHz,
  - What's being lost?

    Telephone can transmit signals between approximately 300Hz and 3400Hz. Effective bandwidth of 3.1KHz.

    Original signal loses it's very low and high frequency components.

Max Data Rate

- Nyquist's Formula: $C=2H\log_2 V$
- Complete Reconstruction
  - If a signal is band-limited (by a low-pass filter),
  - Then it can be exactly reconstructed from 2*H exact samples per second,
  - Only applies to a noiseless channel,
  - Example: Telephone limited to 6200bps (2*3.1KHz)
- $C = 2\ H\ \log_2\ V$
  - C is the capacity (the max data rate) in bits/sec
  - H is the bandwidth
  - V number of discrete signal levels

Shannon-Hartley's Law

- How many signal levels?
  - The more signal levels the less the separation between them and the greater the susceptibility to noise,
- $C = H \log_2 (1 + S/N)$
  - C: is the capacity,
  - H: is the bandwidth,
  - S/N: is the ratio of signal power (S) to random noise (N) on the channel
    - Generally expressed in dB
    - $dB = 10 \text{ Log}_{10} (S/N)$

Question

- Given a voice-grade telephone line with a 20dB signal to noise ratio. What is max theoretical data rate and how many signal levels would be required to achieve this ?