Information theory and coding

This lecture:

Capacity of a transmission medium.

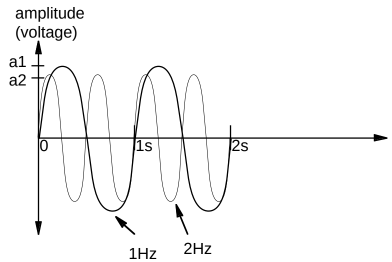
- Physical limitations.
- Real world transmission media (revision)

Representing data as electrical signals.

- Signal characteristics.

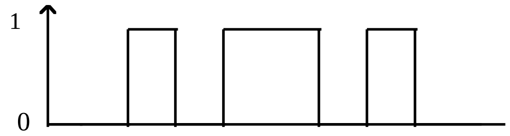
Bandwidth

- “How big is the pipe ?”
- Expressed in Hz
- Depends on the type of medium:
  - twisted pair Khz (Mhz for short distances)
  - coaxial cable 100Mhz+
  - fibre Gbit/s
  - etc
- *n*Hz = *n* complete oscillations per second
- Higher frequency (bandwidth) allows more rapidly changing signal.



Digital signals

- A perfect digital signal has instantaneous transitions between signal levels.



- This gives rise to very high frequency components.
- Therefore given a limited bandwidth a digital signal is distorted.
  - Increasing bandwidth reduces distortion
  - increasing transition speed increases distortion.
- For a given bandwidth there is a maximum signalling rate beyond which a signal is unrecoverable

Maximum data rates

Nyquist showed that if

C = maximum data rate

B = Bandwidth

M = number of levels per signal element

Then theoretically,

$$C = 2 * B * \log_2 M$$

defines the maximum channel capacity.

Assuming:

no noise

no attenuation

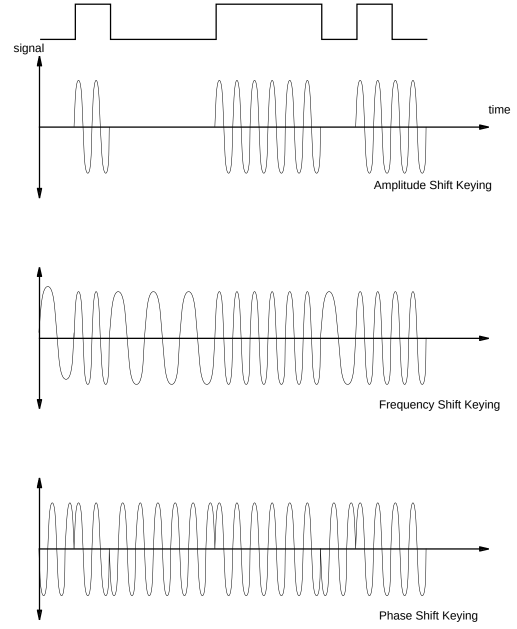
Signals, data and encoding

We can have:

- Digital data and digital signals
- Digital data and analogue signals
  modems
- Analogue data and digital signals
  codec's
- Analogue data and analogue signals
  multiplexing

Digital data, analogue signal

3 possibilities:

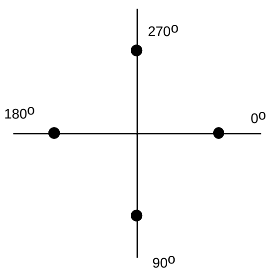


Modems

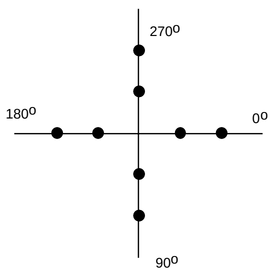
- More than 2 levels are possible per signal element.
  - eg. Bell 201C modem uses:

    00 = 45^{o}, 01=135^{o}, 10=225^{o}, 11=315^{o}
- Can combine more than one method.
- Baud rate $\neq$ data rate

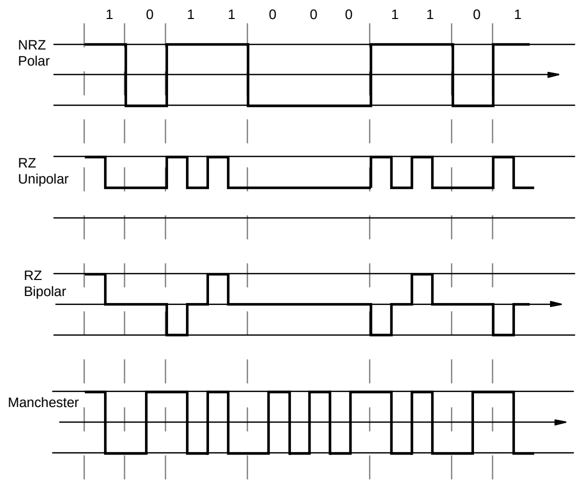
PSK - 4 levels per signal element



PSK and ASK- 8 levels per signal element



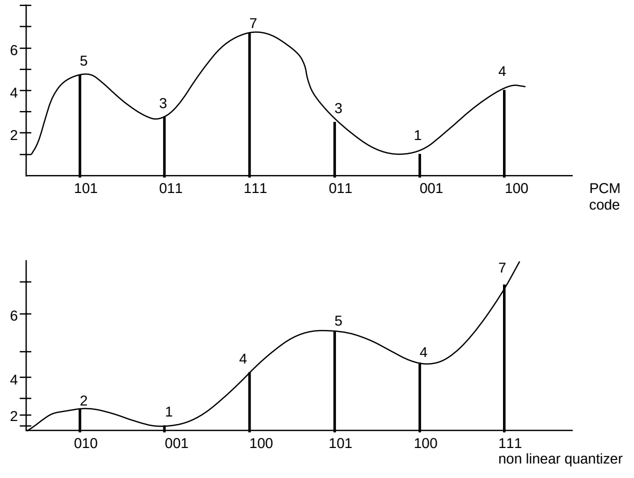
Digital data, digital signal



- Polar NRZ common inside computers
- Bipolar RZ, common on T1-carrier
- Manchester common on LANs
- considerations:

  -DC component, synchronisation

Analogue data, digital signal



- Sampling theorem (Nyquist) states that:

  sampling rate =>2*frequency
- Non linear quantization improves average error.

Pulse Code Modulation

Example:

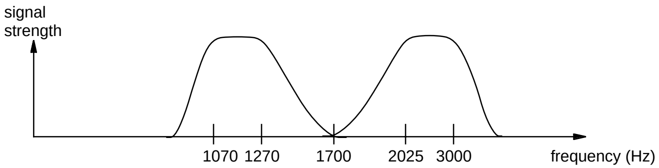
Telephone grade voice = 128 levels (7bits).

Bandwidth 4kHz = 8000 samples / sec.

Therefore 56kbps data rate which needs 28 Khz bandwidth !

Analogue data, Analogue signal

- Used to shift signal frequency into the frequency range of the carrier.
- Allows several low bandwidth signals to be placed on a high bandwidth carrier.



Bell 108 series modem

Example:

What data rate (in bits per second) can we achieve with a modem using a 4 phase modulated signal (0, 90, 180, 270) over a 3Khz analog telephone line ?

Bandwidth = 3000Hz

levels per signalling element = 4

$$C = 2.3000.\log_2(4)$$
$$= 6000.2$$
$$= 12000 \text{ bit/s}$$

Allowing for noise

- Transmission capacity of a medium with noise.
- Real transmission media introduce a level of continuous ‘random’ variation to the transmitted signals.
- Error correction coding when spurious noise outside the expected noise level exists.
- Shannon-Hartley theorem gives the maximum theoretical throughput possible in the presence of a given level of noise.

Shannon - Hartley

if

- B = Bandwidth
- S = signal power (watts)
- N = noise power (watts)

then Signal-Noise-Ratio in decibels (dB):

$$SNR = 10\log_{10}\left(\frac{S}{N}\right)$$

Shannon Hartley states:

$$C = B\log_2\left(1+\frac{S}{N}\right) \quad \text{bits per second}$$

example: B=3Khz, SNR=20dB (typical PSTN)

$$20 = 10\log_{10}\left(\tfrac{S}{N}\right) \;\therefore \tfrac{S}{N} = 10^{\left(\frac{20}{10}\right)} = 10^2 = 100$$

$$\therefore C = 3000.\log_2(1+100) = 19963\text{bit/s}$$

Summary

- Different bandwidth characteristics of analogue and digital signals.
- Data may be converted from one form to another for transmission.
- We have an overview of what signalling techniques can be used.
- Digital data and signalling technologies are becoming widespread...