Networks

Prof. Dr. Harry Wijshoff
harryw@liacs.nl

Universiteit Leiden

Data Transmission

Via Medium:

Guided	Unguided
Twisted pair	ether
coax	water
fiber	

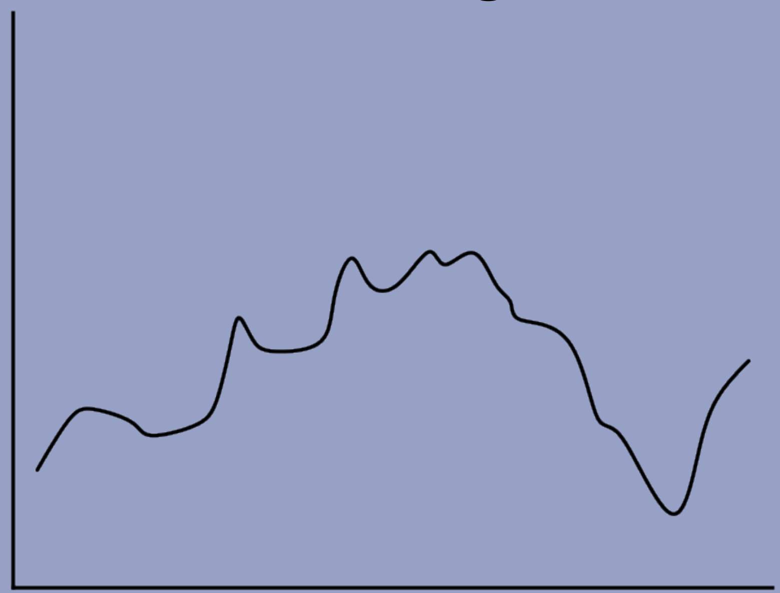
Information:

Analog	Digital
audio	bits
video	numbers
	letters

Data Transmission

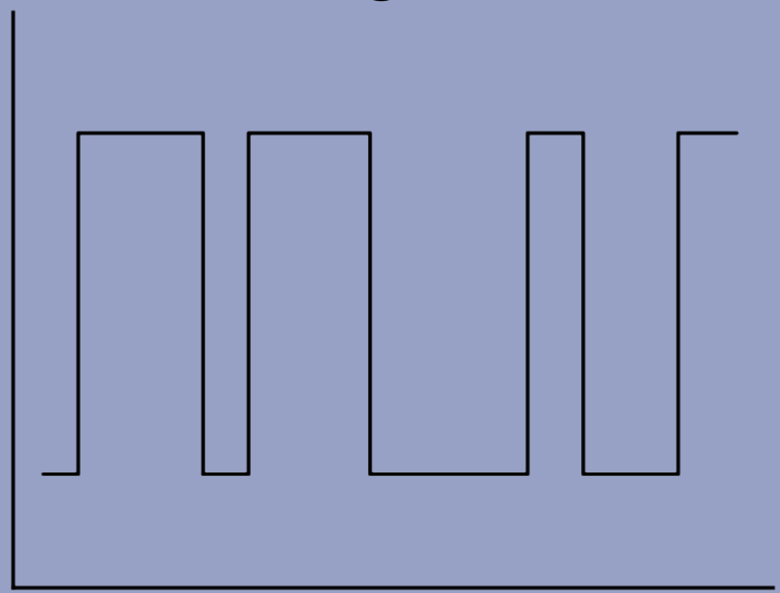
In principle two ways

Analog



"Unlimited levels"

Digital



2 (or more) discrete levels

Data Transmission

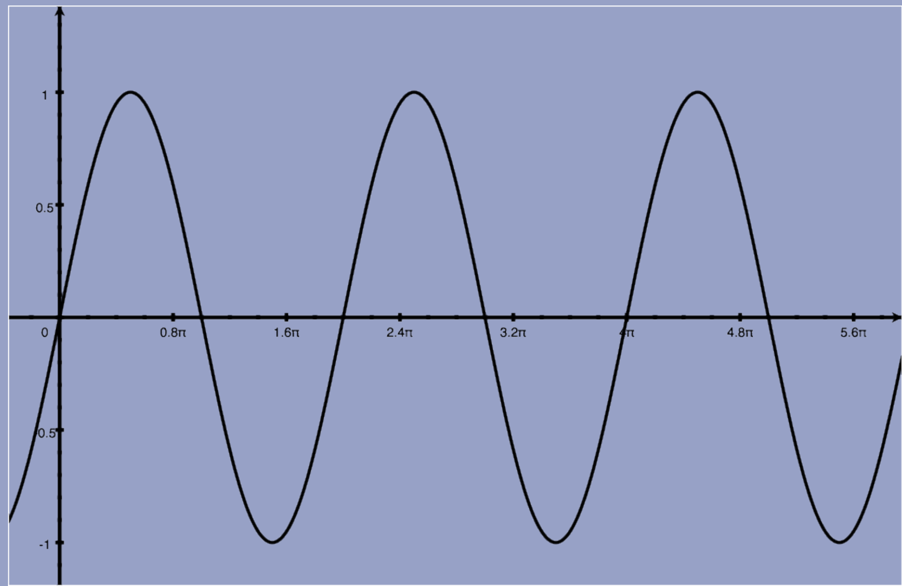
Actually EVERY SIGNAL will in the end arrive as a sequence of sine waves. So in the end they will become analog.

Fast Fourier Transforms

Basic signal: sine

$$s(t) = A\sin(2\pi f t + \psi)$$

A = amplitude
f = frequency
ψ = phase



Fast Fourier Transforms

If the sine wave moves, the following holds:

$$\lambda = vT \qquad \text{where: } T = \frac{1}{f}$$

or: $\lambda f = v$

λ is the wave length

v is the speed

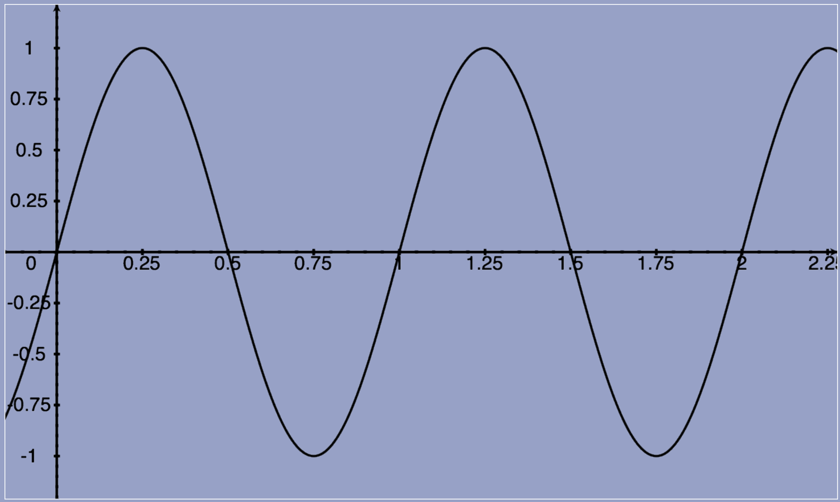
light: $v = c = 299792458 \approx 3 \times 10^8 \text{ m/s} \quad (\text{in 1 ns: } \approx 30 \text{ cm})$

coax: $v = (0.65 \sim 0.8)c$ depending on the quality of the coax cable and *f*

Larger *f*: higher speed

Fast Fourier Transforms

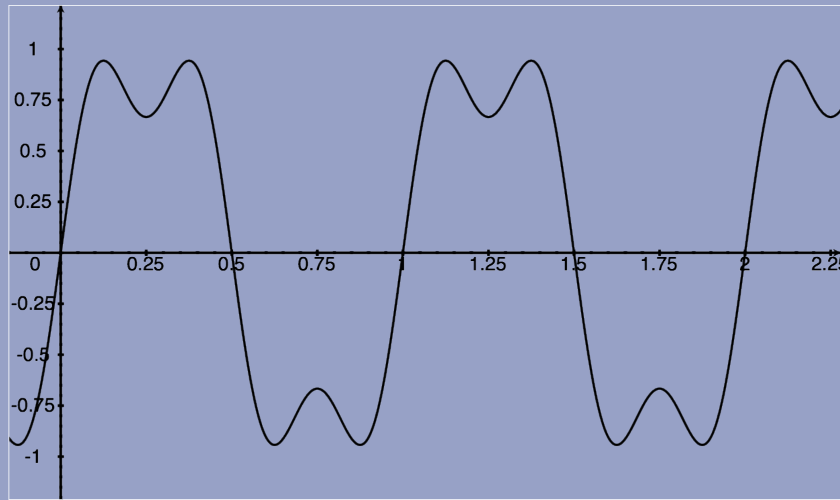
Every signal that is transmitted is a sum of different sine waves.

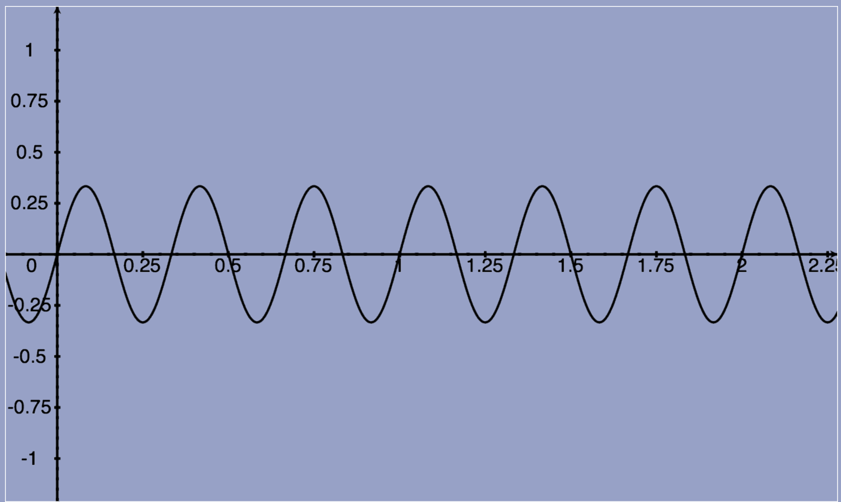


$$\sin(2\pi f_1 t)$$

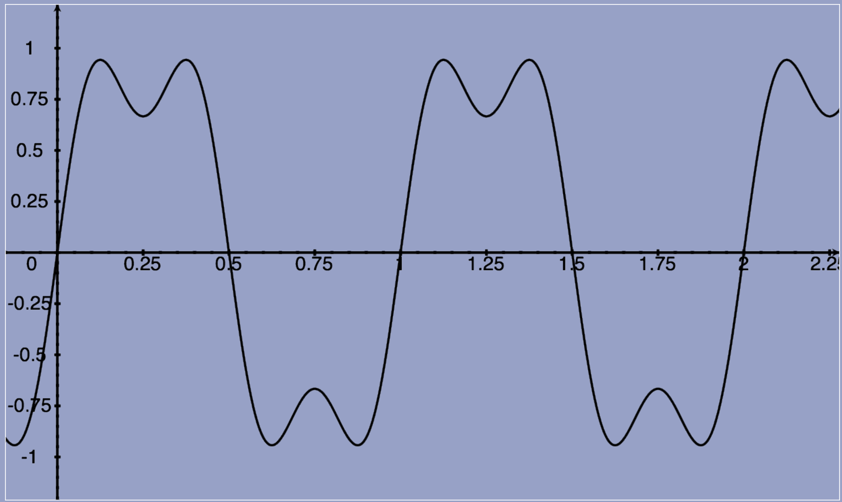
+

=





$$\frac{1}{3}\sin(2\pi(3f_1)t)$$



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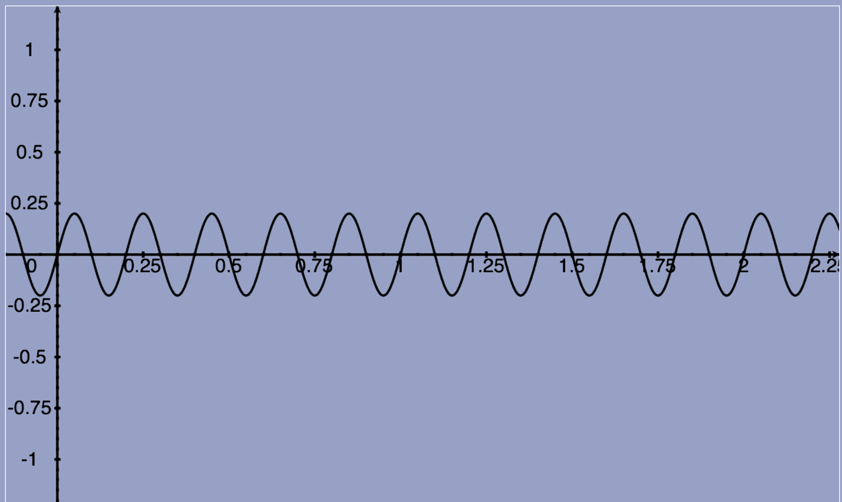
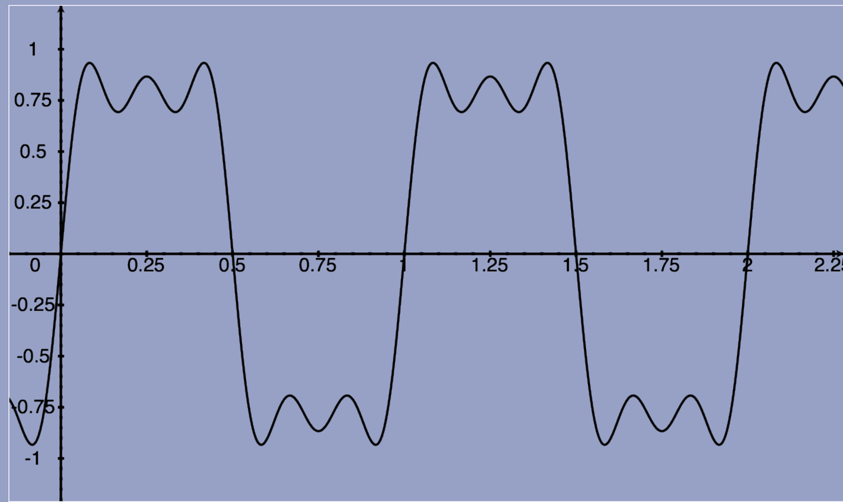
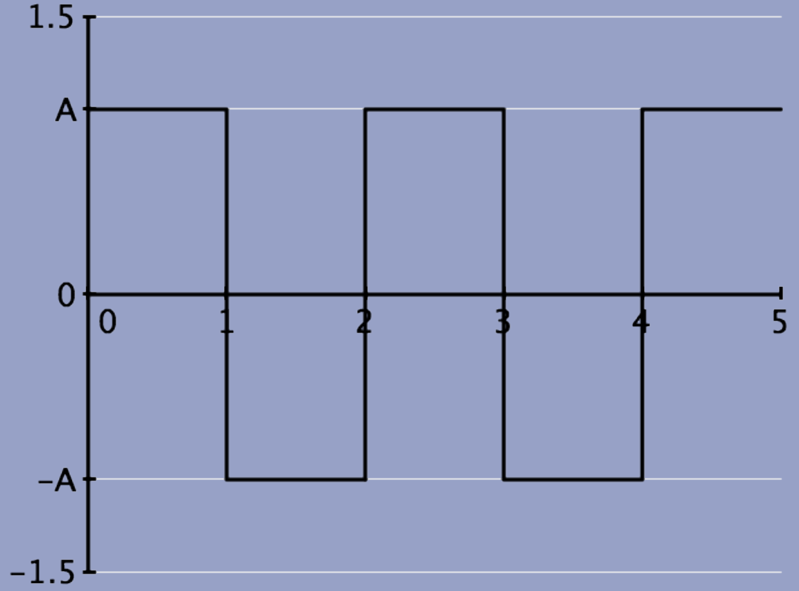


$$\frac{1}{5}\sin(2\pi(5f_1)t)$$

=

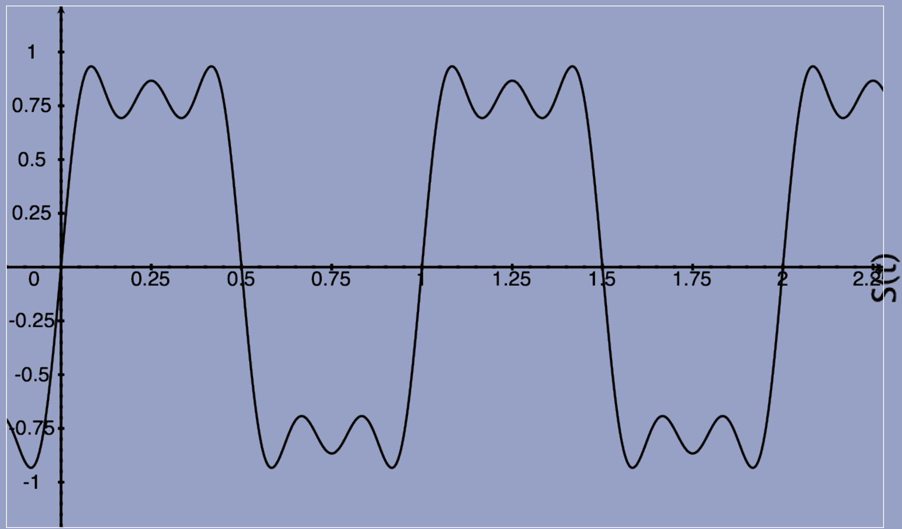


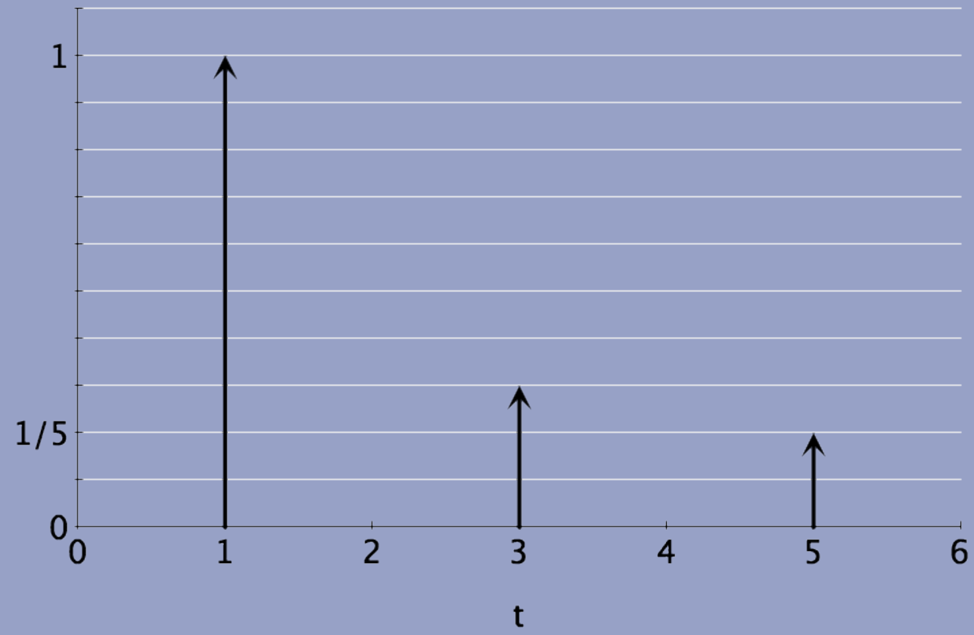
In fact, the square wave:



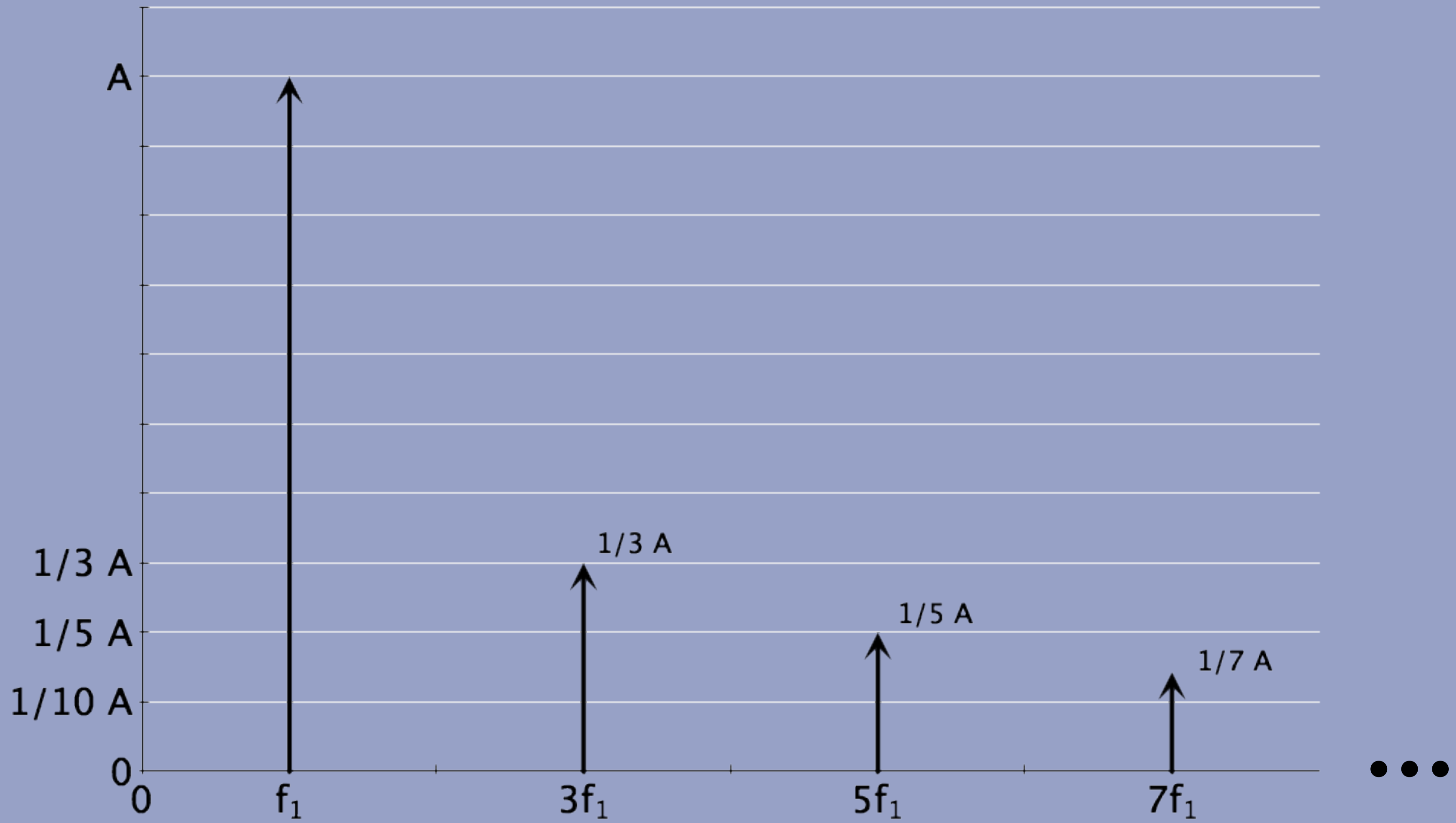
$$\equiv s(t) = A \sum_{k=1,3,5...}^{\infty} \frac{1}{k} \sin(2\pi k f_1 t)$$

In addition to the time domain function s(t) there is also a frequency domain function: S(t), that gives the max amplitude per frequency. For the sum of the first three sines we have:

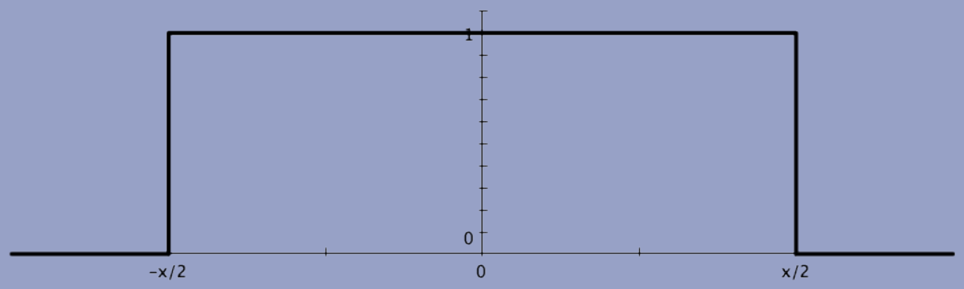


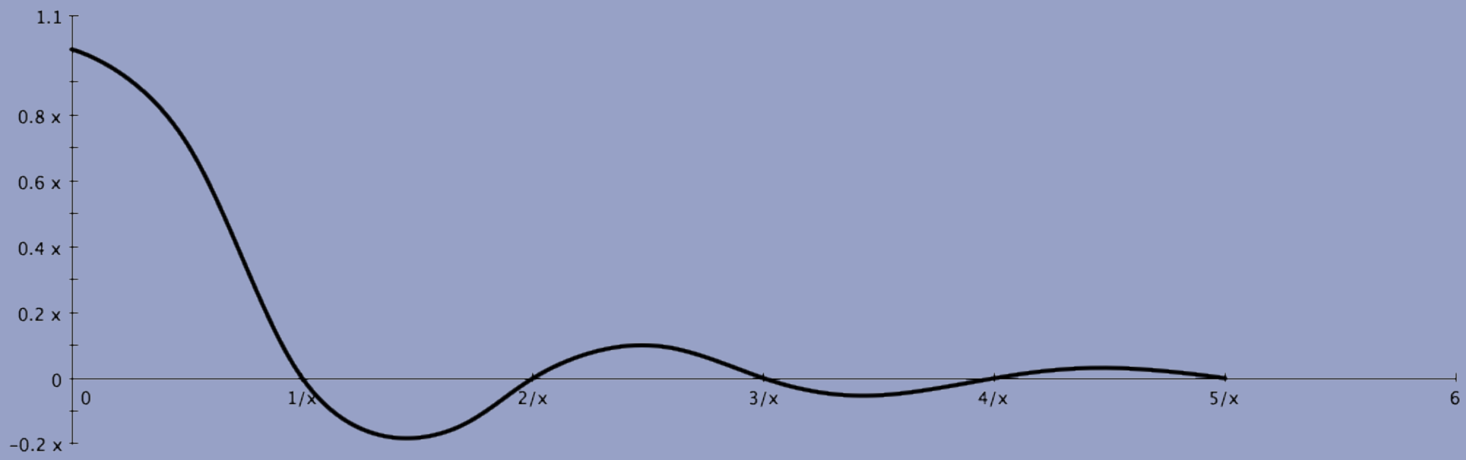


For the square wave:



For a pulse:





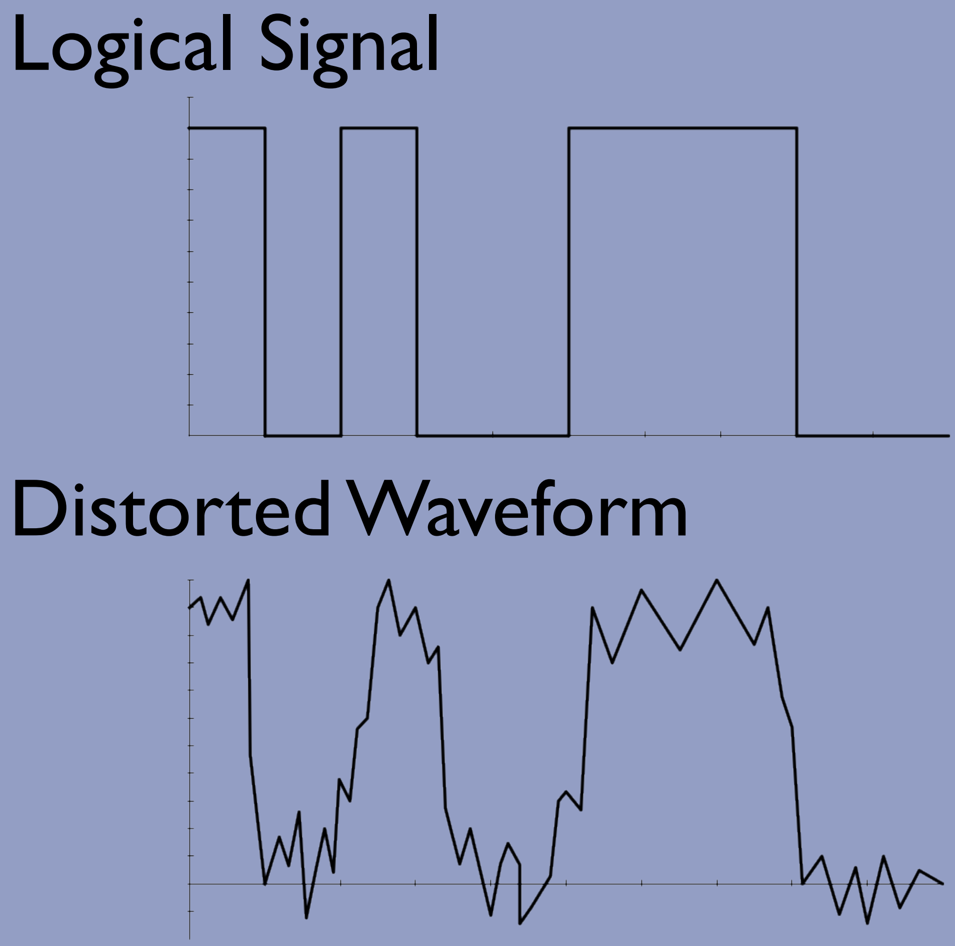
- The *spectrum* of a signal: the frequencies that the signal is composed of

- The absolute bandwidth: the max frequency - min frequency

- Effective bandwidth: bandwidth where the most energy (amplitude) is in.

Distortions

- In practice, signals sent over some medium will be distorted.



Distortions

- Caused by:
  - Attenuation and attenuation distortion
  - Delay distortion
  - Noise

Distortions

- Attenuation
  - Signal strength diminishes over the distance of the transmission.
  - Guided transmission: exponential
  - Unguided transmission: more complicated and heavily dependent on the medium.

- The reduction in signal strength is for most part formalised by Graham Bell
- From there we have: deciBell (1/10 Bell)
- The difference in signal strength between I_1 and I_0 is:

$$10 \times {}^{10}\log\left(\frac{I_1}{I_0}\right) \text{ dB}$$

- or:

$$\frac{I_1}{I_0} = 10^{\frac{L}{10}}$$

- At 3dB loss, the signal will be $10^{1/3} \approx 2$ times as weak.
- At 20dB loss: 100 times as weak.
- In terms of amplitude (A), the difference in signal strength is:

$$10 \times {}^{10}\log \frac{A_1^2}{A_0^2}\ \mathrm{dB} = 20 \times {}^{10}\log \frac{A_1}{A_0}\ \mathrm{dB}$$

The advantage of this exponential scale is that level losses in different parts of a cable can simply be added together.

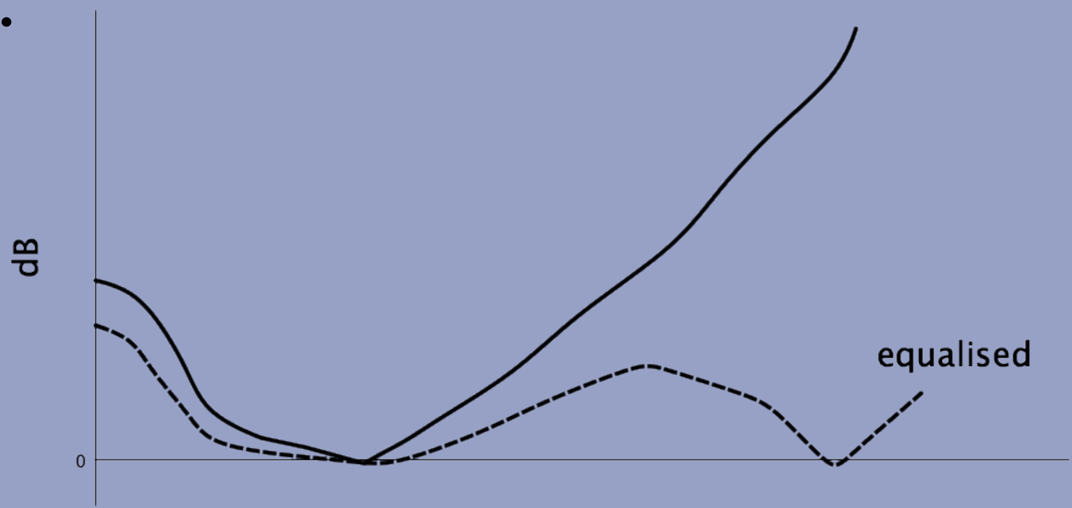
Problems:

- Signal must be strong enough so it can be detected
- Signal must be stronger enough than noise
- Attenuation is depending on frequency

The lower the frequency the more power (think of water waves).

Thus, the higher the frequency, the faster the wave is extinguished.

Generally no problem with digital transmission, but is problematic with analog transmission. Can be equalised.

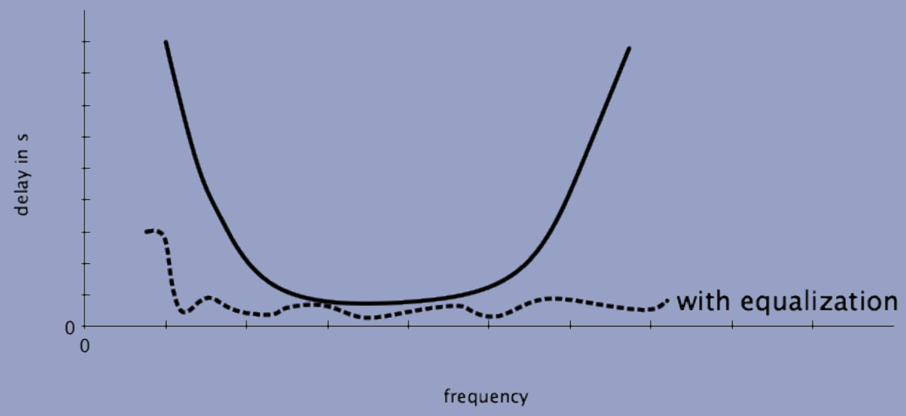


Delay Distortion

- The speed of transmission is frequency dependent.
- Generally, the middle of the bandwidth is the fastest, and the two ends are the slowest.

Delay Distortion

- Due to the relative large effect in the lower frequencies, this is a problem in digital transmission.
- One bit can flow over in to another bit.
- **Inter symbol interference**.
  - Limiting factor in digital transmission.



Noise

- Thermal noise
- Impulse/burst noise

Thermal Noise

- “White noise”
- Caused by thermal agitation of electrons.
- Always there.
- Depending on temperature.
- Relatively constant amplitude, can be compensated.

Impulse/Burst Noise

- Caused by for example:
  - Lightning
  - Wiring errors
- In principle, no problem for analog transmissions (transient crackling)
- Problem for digital transmission where bits can be lost.

Channel Capacity

- Nyquist (based on delay distortion)
  - At bandwidth B (medium dependent), a data rate of 2B is possible.
  - Thus at B Hz → 2B bps (bits per second).
  - In case of more than 2 levels are used:
    - B Hz → 2B ^{2}log M bps

Nyquist Example

- Modem (tel): 3100 Hz
- At 2 levels: 6200 bps
- At 8 levels: 18600 bps

Shannon

- Signal to Noise Ratio
- $\mathrm{SNR_{dB}} = 10^{10}\log(\frac{\text{signal power}}{\text{noise power}})$
- Theoretical maximum:
  B Hz $\rightarrow$ B ^{2}log (1 + SNR) bit rate

Shannon Example (1/2)

- Assume medium: 3 MHz - 4 MHz and SNR_{db} = 24 dB.
- Then:
  - B = 4 - 3 MHz = 1 MHz
  - SNR = signal power / noise power = 251
    ($24 = 10\ {}^2\log SNR \Rightarrow SNR = 10^{2.4}$)
  - Bandwidth = $10^6\ {}^2\log(1+251) \approx 10^6 \times 8$ = 8 Mbps

Shannon Example (2/2)

- With Nyquist:
  - $8 \times 10^6 = 2\ B\ {}^2\log M$
  - thus: $8 = 2\ {}^2\log M$
  - thus: M = 16 (needed levels)

Medium and Characteristic Bandwidth

In addition to the bandwidth of the signal, the bandwidth of the transmission medium and the device will be important.

Medium	Range	Bandwidth
Electricity & telephone (voice/ music)	10Hz-10kHz	≈10 kHz
Twisted Pair (UTP/STP)	$10\text{-}10^8$ Hz	≈100 MHz
Coax	$1000 - 10^9$ Hz	≈1 GHz
Radar	$10^9\text{-}10^{11}$ Hz	≈100 GHz
Infrared	$10^{11}\text{-}10^{14}$ Hz	≈100 THz
Optical fiber	$10^{14}\text{-}10^{15}$ Hz	≈1 PHz

Optical Fiber

For optical fiber:

$$\lambda = \frac{v}{f} = \frac{3 \times 10^8}{5 \times 10^{14}} \approx 10^{-6} \text{ m}$$

Thus, the length of an optical wave = 10^{-6} m = 1 μm

1 μm	With of a pit in a CD
100 μm	With of a newspaper sheet
6 μm	Aluminium foil

Coax

Assuming v = c:

$$\lambda = \frac{3 \times 10^8}{10^9} = 0.3 \text{ m} = 30 \text{ cm}$$

More exact:

$$\frac{0.65 \times 3 \times 10^8}{10^9} \leq \lambda \leq \frac{0.8 \times 3 \times 10^8}{10^9}$$

$$19.5 \text{ cm} \leq \lambda \leq 24 \text{ cm}$$