

# Networks

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# Data Transmission

Via Medium:

Guided	Unguided
Twisted pair	ether
coax	water
fiber	

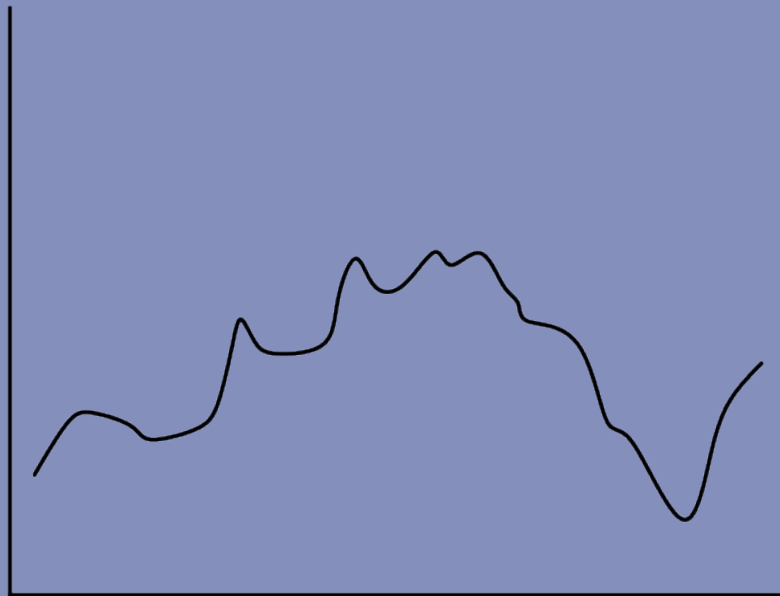
Information:

Analog	Digital
audio	bits
video	numbers
	letters

# Signal Transmission

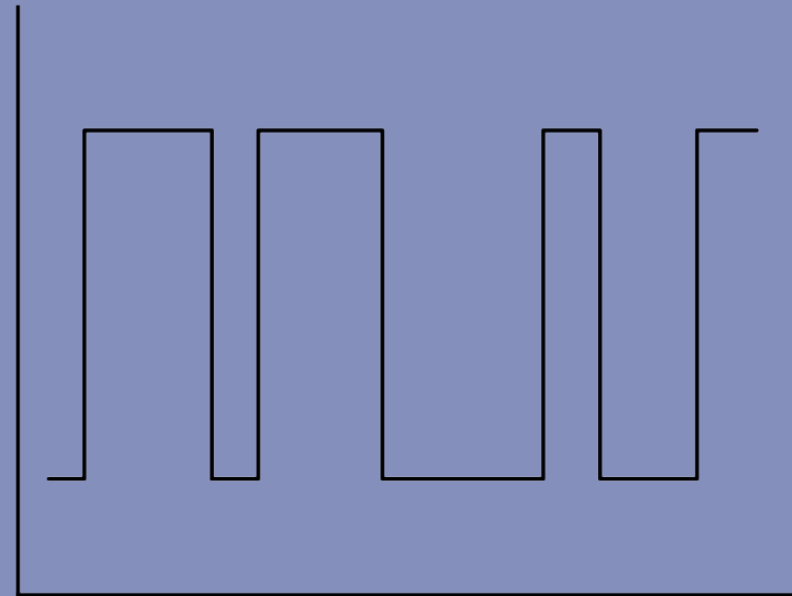
In principle two ways

Analog



“Unlimited levels”

Digital



2 (or more) discrete levels

# Signal 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

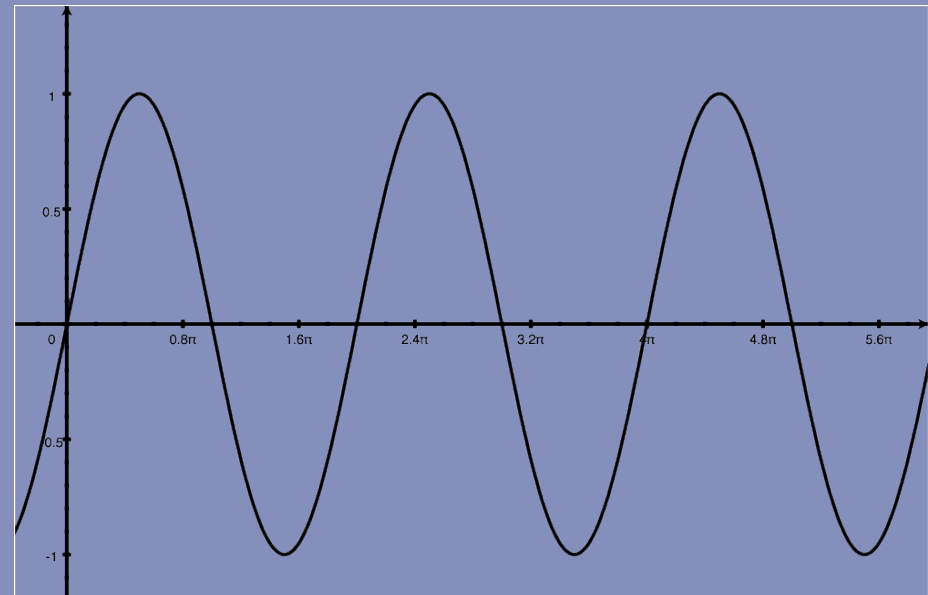
Basic signal: sine

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

$A$  = amplitude

$f$  = frequency

$\psi$  = phase



# Fast Fourier Transforms

If the sine wave moves, the following holds:

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

or:  $\lambda f = v$

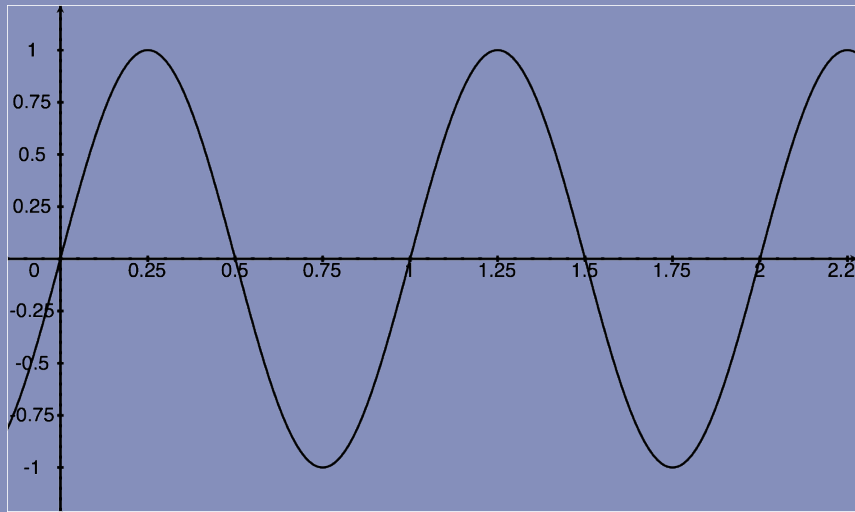
$\lambda$  is the wave length  
 $v$  is the speed

light:  $v = c = 299792458 \approx 3 \times 10^8$  m/s (in 1 ns:  $\approx 30$  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

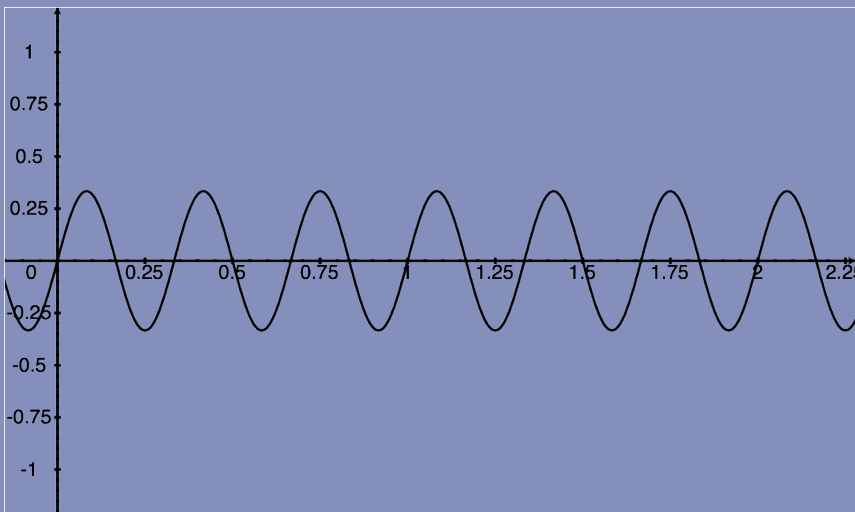
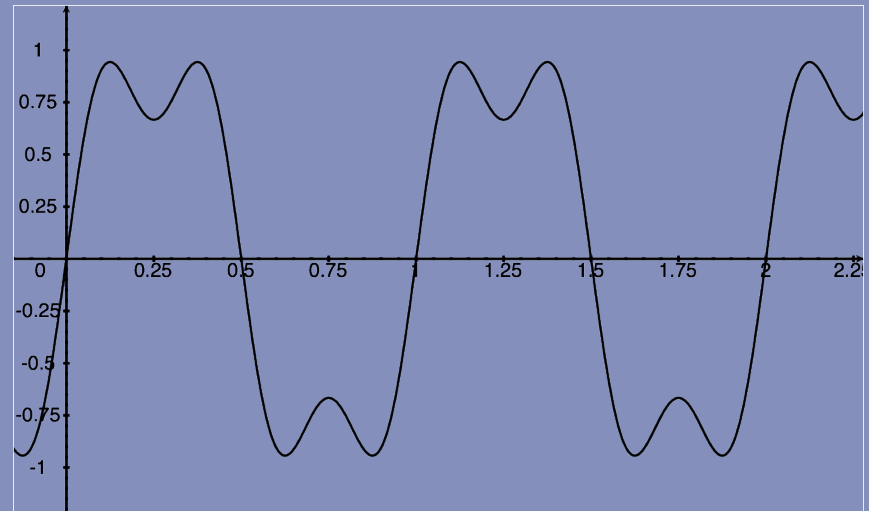
Every signal that is transmitted is  
a sum of different sine waves.



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

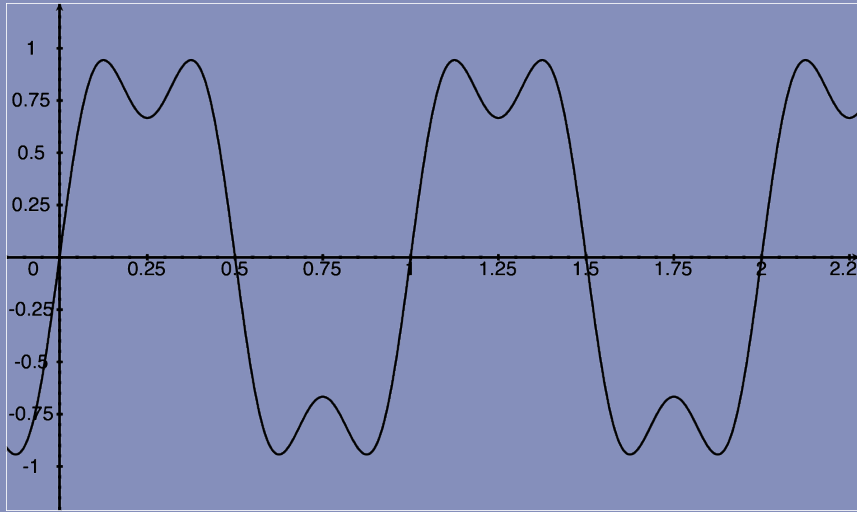
+

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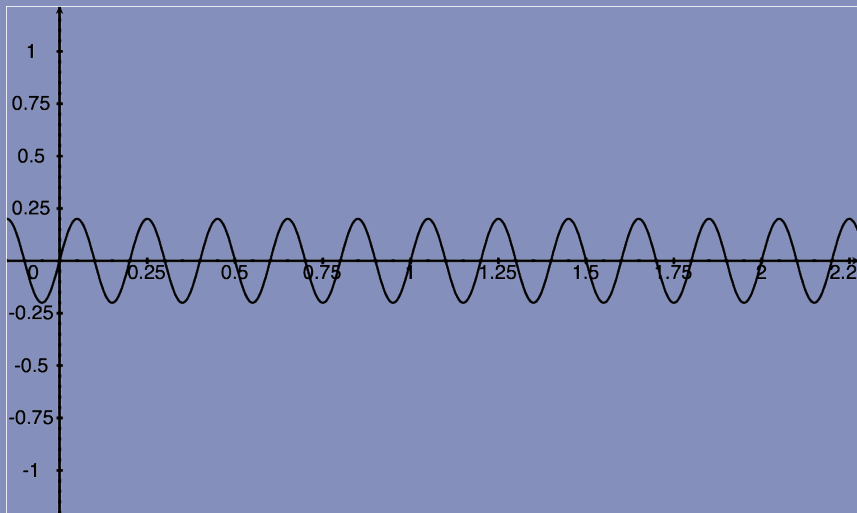
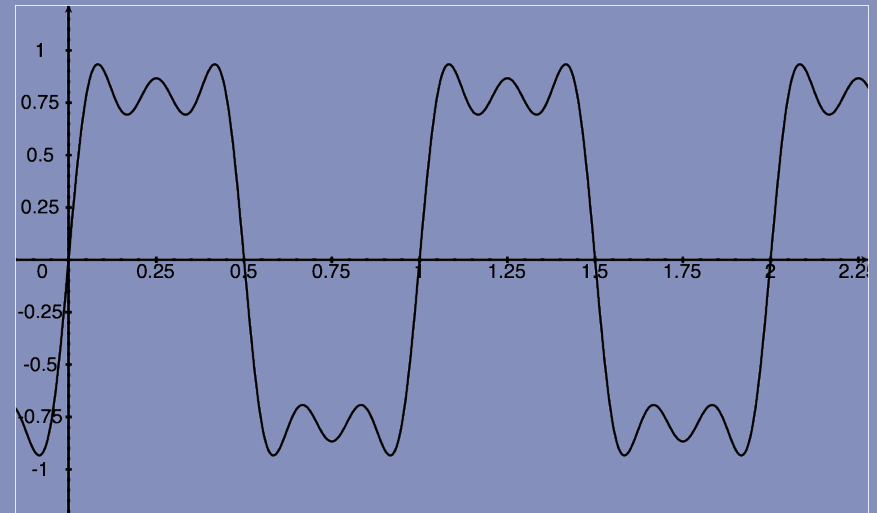
$$\frac{1}{3} \sin(2\pi(3f_1)t)$$





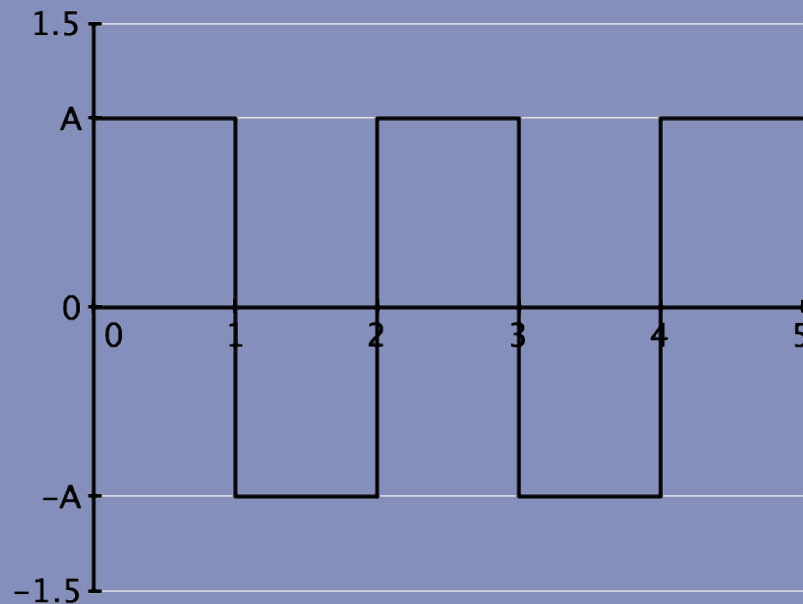
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$$\frac{1}{5} \sin(2\pi(5f_1)t)$$

In fact, the square wave:



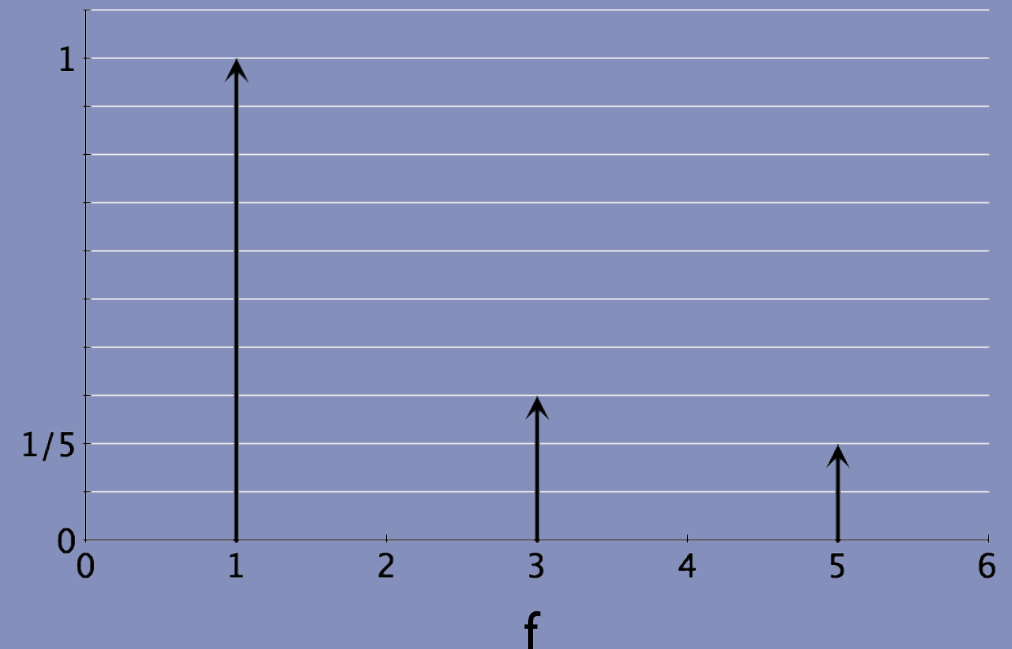
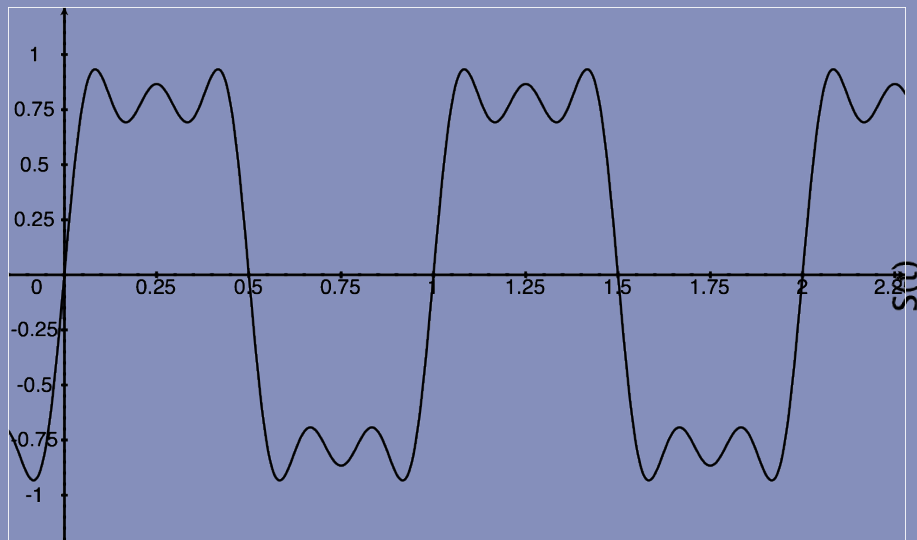
$$\equiv s(t) = A \sum_{k=1,3,5,\dots}^{\infty} \frac{1}{k} \sin(2\pi k f_1 t)$$

# The sound of Sine wave versus a Square wave at 440 Hz

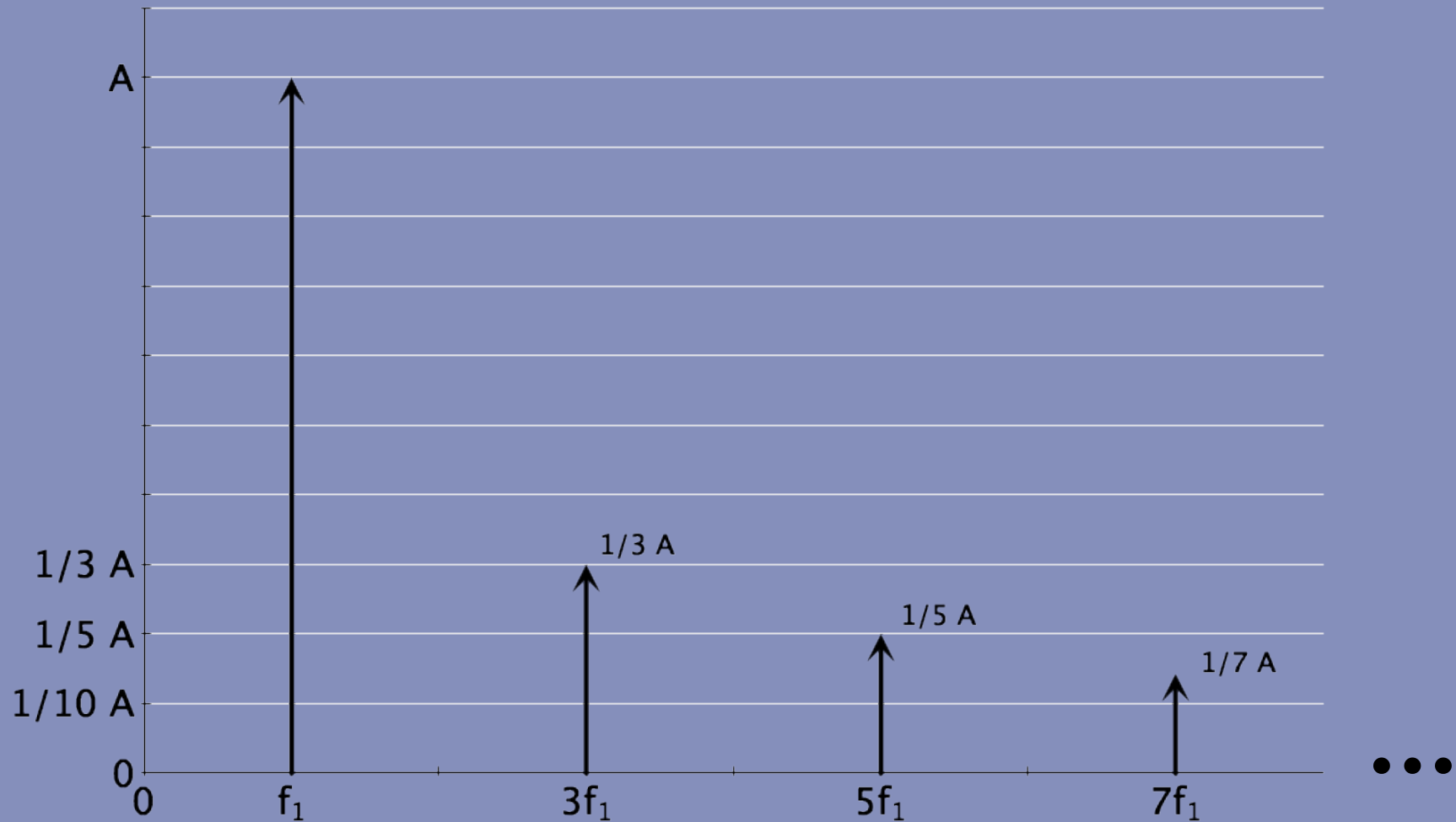
<https://www.youtube.com/watch?v=teb64y-D2sA>

<https://www.youtube.com/watch?v=GI0qLid60xw>

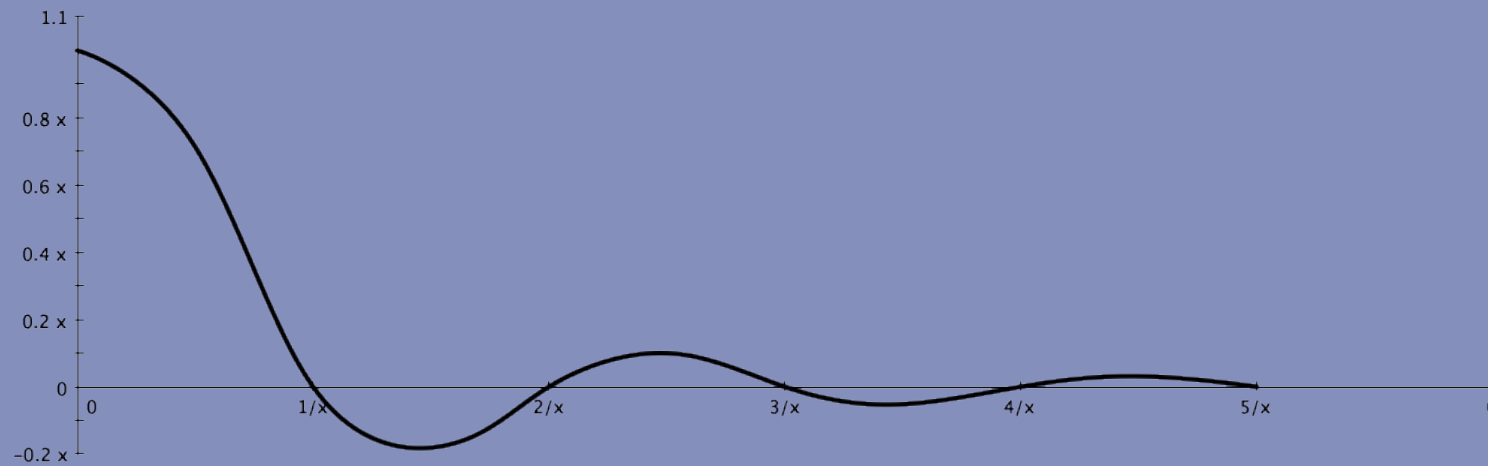
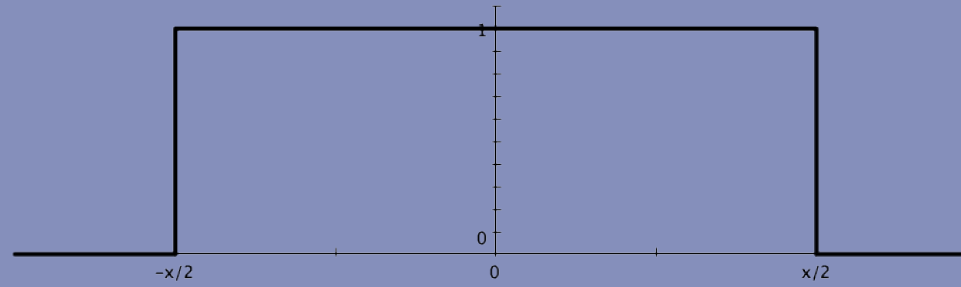
In addition to the time domain function  $s(t)$  there is also a frequency domain function:  $S(f)$ , that gives the max amplitude per frequency. For the sum of the first three sines we have:



For the square wave:



For a pulse:

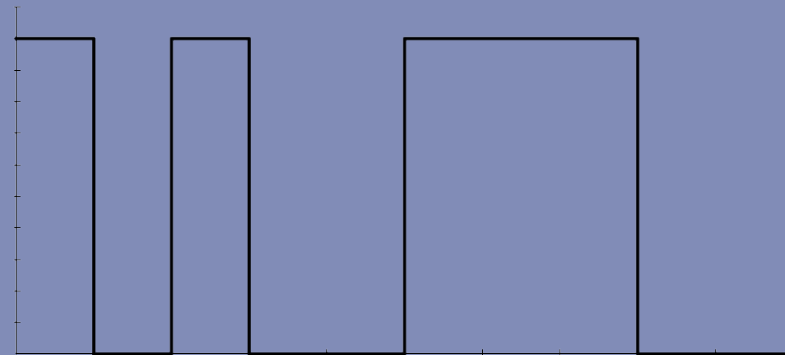


- The **Spectrum** of a signal: the frequencies that the signal is composed of
- The **Absolute bandwidth**:  
the max frequency - min frequency
- **Effective bandwidth**: bandwidth where the most energy (amplitude) is in.

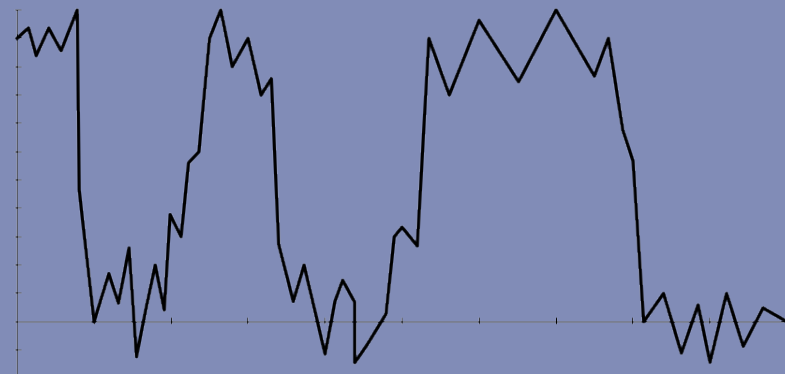
# Distortions

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

Logical Signal



Distorted Waveform





# Causes of Distortions

- **Attenuation** (also called attenuation distortion)
- **Delay** distortion
- **Noise**

# 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 the most part formalized by Graham Bell to measure the quality of telephone cables
- From there we have: deciBell (1/10 Bell)
- The difference in signal strength between  $I_1$  and  $I_0$  is:

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

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:

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

# The use of dB in acoustics

- The “absolute” dB level indicating sound pressure is defined relative to a reference sound pressure level
- The reference sound pressure level is set to be the level of sound which is the typical threshold of detecting the sound by an average human (20 micropascals in air)
- dB is then computed as

$$20 \times \log_{10} \left( p_{\text{measured}} / p_{\text{ref}} \right)$$

with  $p_{\text{ref}} = 20$  micropascals in air

So dB = 100 means:  $p_{\text{measured}} = 20 \times (10^{(100/20)}) =$

2000000 micropascals = 2 pascals air pressure

Ear drums rupture at 160 dB =  $20 \times (10^{(160/20)}) = 2000000000$   
micropascals = 2000 pascals (a range of  $10^8$ )

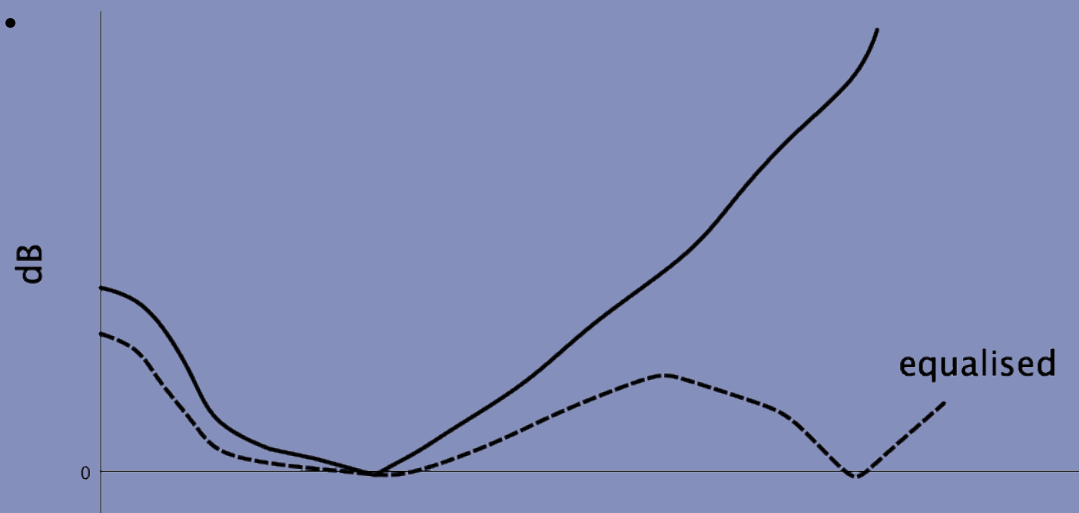
# **Problems associated with attenuation**

- Signal must be sufficiently strong so it can be detected
- Signal must be stronger 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.



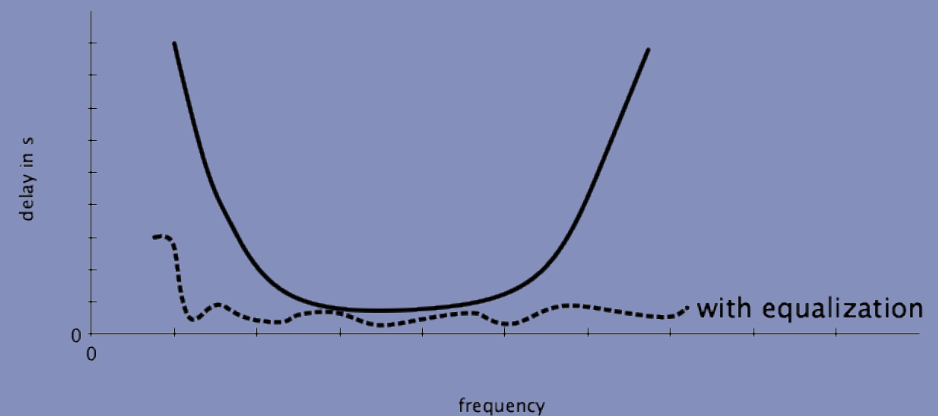
# Delay Distortion

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



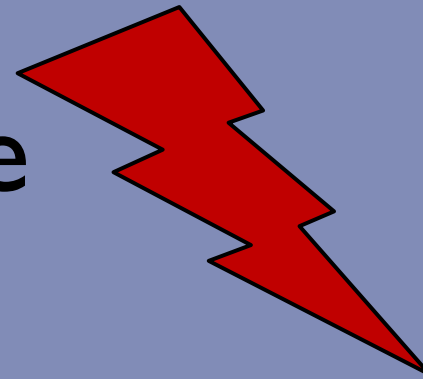
# Delay Distortion

- ❑ 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  $\rightarrow 2B$  bps (bits per second).
- ❑ In case of more than 2 levels are used:

$$B \text{ Hz} \rightarrow 2B \log_2 M \text{ bps}$$

# Nyquist Example

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

# Shannon

- Signal to Noise Ratio

- $$\text{SNR}_{\text{dB}} = 10 \log\left(\frac{\text{signal power}}{\text{noise power}}\right)$$

- Theoretical maximum:

B Hz  $\rightarrow$   $B \log_2(1 + \text{SNR})$  bit rate

# Shannon Example (1/2)

Assume medium: 3 MHz - 4 MHz and  $\text{SNR}_{\text{db}} = 24$  dB.

Then:

$$B = 4 - 3 \text{ MHz} = 1 \text{ MHz}$$

$$\text{SNR} = \text{signal power} / \text{noise power} = 251$$

$$(24 = 10 \log \text{SNR} \Rightarrow \text{SNR} = 10^{2.4})$$

$$\text{Bit rate} = 10^6 \log_2 (1+251) \approx 10^6 \times 8 = 8 \text{ Mbps}$$



# Shannon Example (2/2)

With Nyquist:

$$8 \times 10^6 = 2 B^2 \log M$$

$$\text{So, } 8 = 2^2 \log M \text{ (} B = 1 \text{)}$$

therefore  $M = 16$  (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)	10-10 <sup>8</sup> Hz	≈ 100 MHz
Coax	1000 - 10 <sup>9</sup> Hz	≈ 1 GHz
Radar	10 <sup>9</sup> -10 <sup>11</sup> Hz	≈ 100 GHz
Infrared	10 <sup>11</sup> -10 <sup>14</sup> Hz	≈ 100 THz
Optical fiber	10 <sup>14</sup> -10 <sup>15</sup> 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 =  $10^{-6} \text{ m} = 1 \mu\text{m}$

1 $\mu\text{m}$	Width of a pit in a CD
100 $\mu\text{m}$	Width of a newspaper sheet
6 $\mu\text{m}$	Aluminium foil

# Coax

Assuming  $v = c$ :

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

More exact:

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

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