Human Body as a signal source

Signal processing

G.Schay, Biostatistics and informatics, 1. Dec. 2011.

Human Body as signal source

Signals in medicine

Information content of signals

Signal detection - transducers

Explained through examples
there are endless possibilities

Signals in medicine

$$H = p \cdot \log_2\left(\frac{1}{p}\right)$$

Information content in Bits

Signal is something which carries **Information**

Human body as signal source: everything which is a signal,and comes from the body

Here in the cartoon:

Information : Head or Tail?

Signal:
- Optical: we simply look at the coin,and see the image
- Digital: after encoding: 1/0

“I wish I could be as calm as JB when it comes to making decisions.”

Transmitting information – information **coding**

in general

Information **source**

encoding

Transmission **channel**

decoding

Information reciever
destination

an example

Which side is up?

1  0

encoding Sides : Head or Tail
into Numbers: 1,0

Speech, waves in the air, sms

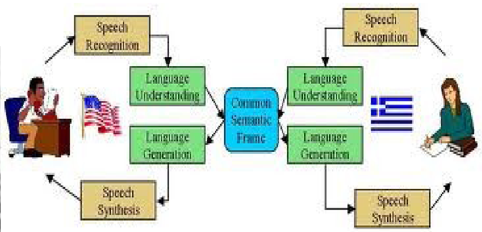
decoding 1,0 ⟶ head, tail

1  0

Decide who wins

Signals in medicine

Signal is something which carries **Information**



Here in speech:

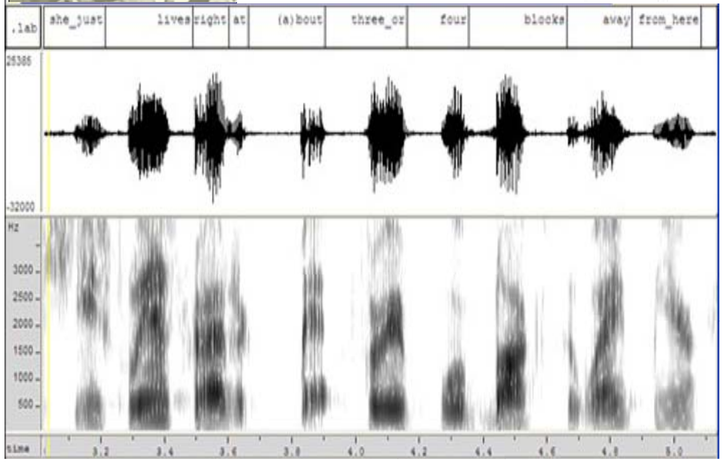
Information : „what we say"

Signal:
- Audio: pressure waves in the air
- encoding: electrical signal from Microphone

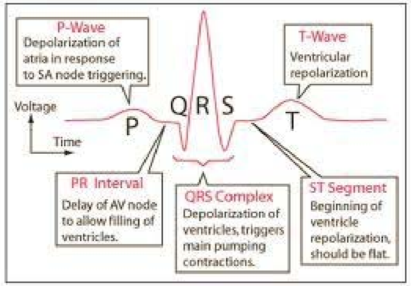
- encoding: formal grammar

- decoding: electrical to Mechanical (loudspeaker)

- decoding: natural language understanding



Signals in medicine



Information: Heart cycle

ECG: Electro CardioGraphy

Signal:

Original: voltage across points (eg. two arms)

Encoding: None,
But Filtering required

Removal of unwanted portion of the signal

Signals in medicine

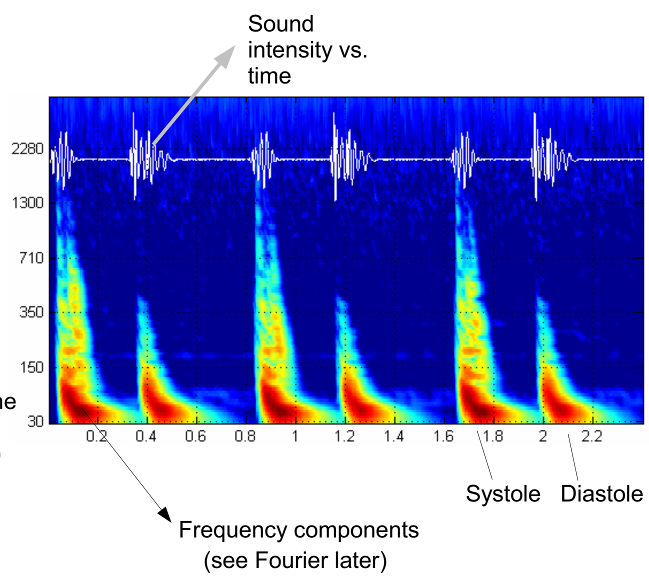
Heart beat

Signal:

Original: Acoustic waves (sound)

Encoded: electrical signal from the microphone.

Encoded: Coloured image on the computer screen (frequency spectrum)



Information: Heart cycle parameters, anatomical and flow problems.

Signals in medicine

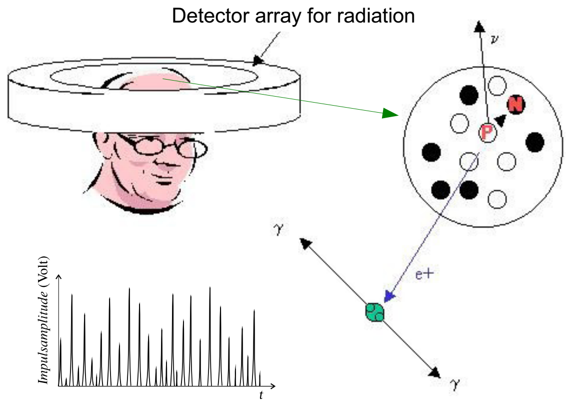
PET: Positron Emission Tomography

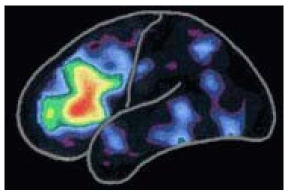
Signal:

Original: γ-photons

Encoded: electrical pulses from the detector.

Encoded: Coloured image on the computer screen

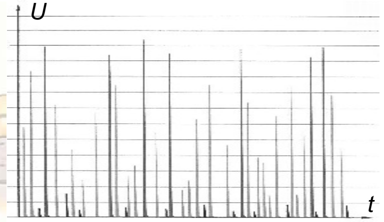


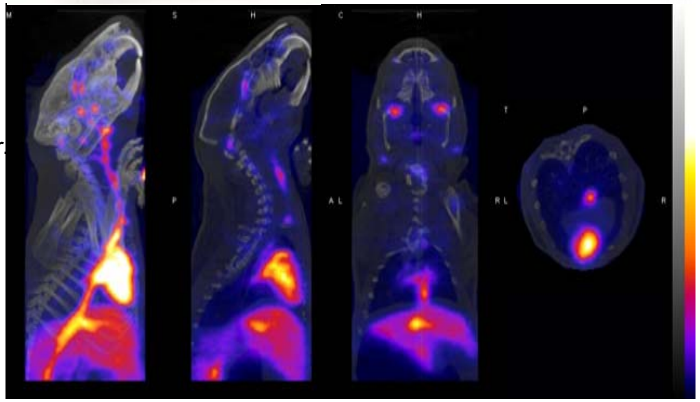


Information: Location of drug, labeling molecule, etc.

Signals in medicine

SPET-CT: Scanning Positron Emission Tomography Computer Tomography





Signal:
Original: γ-photons
X-ray photons

Encoded: electrical pulses
From the detector

Encoded: Coloured image

Information:
Anatomy (X-ray)
Label (desease,etc)

Signals in medicine

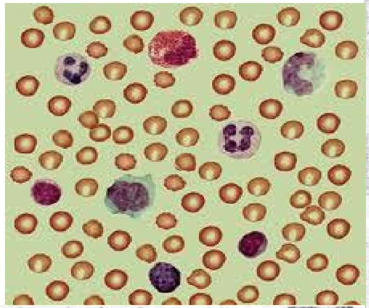
Heart beat

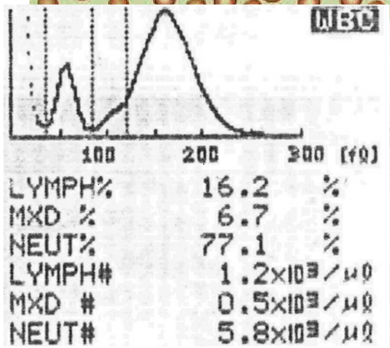
Signal:
Original: Cell types and count in unit volume

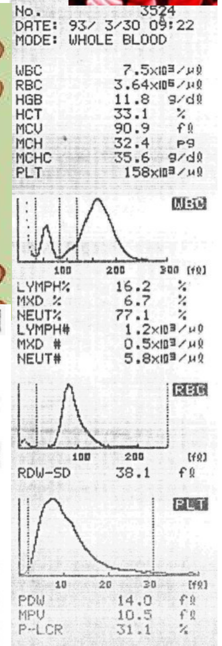
Encoded: electrical signal from the cell sorter.

Encoded: Areas under the histogram

Information: Blood composition







Signal processing

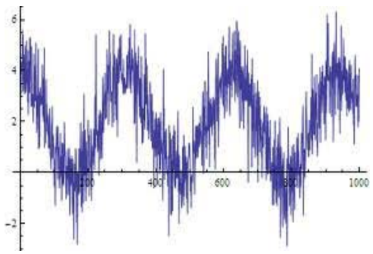
Types of signals

Electric signals – analog signal chain
(amplifier, frequency response,Fourier theorem)

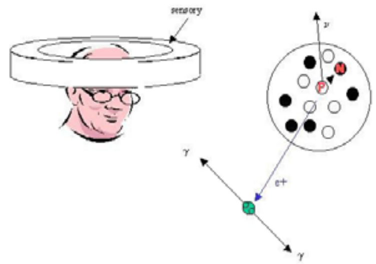
Digital signal processing (DSP)

Types of signals

Electric



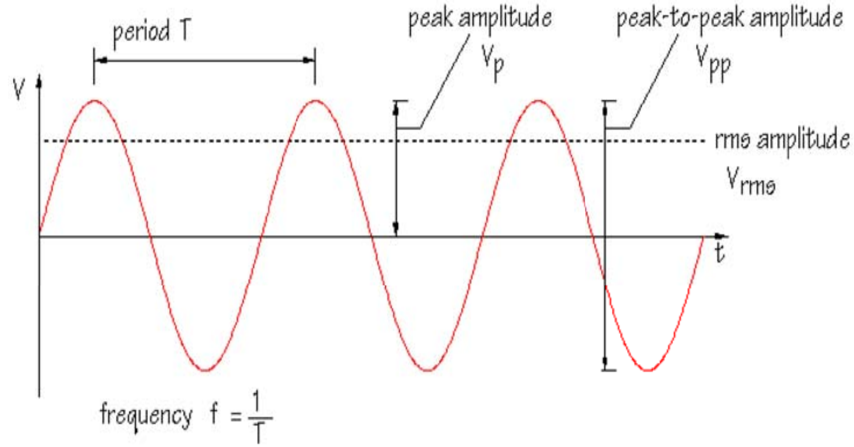
Not electric



Types of signals

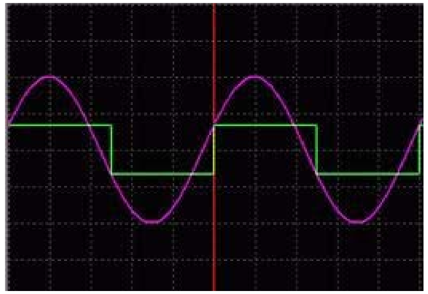
constant

variable in time

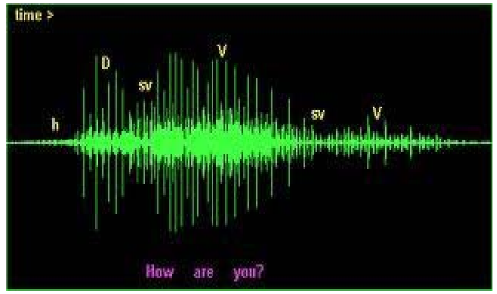


Types of signals

Periodic

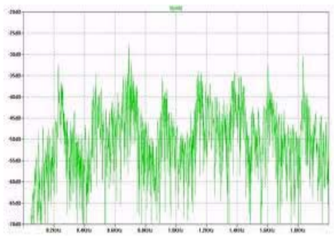


Not periodic

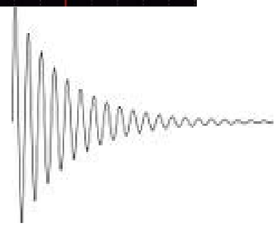


Types of signals

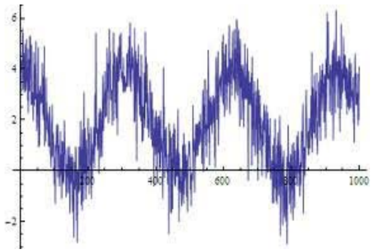
Random



Deterministic

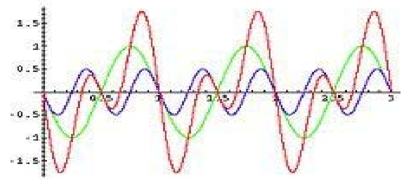


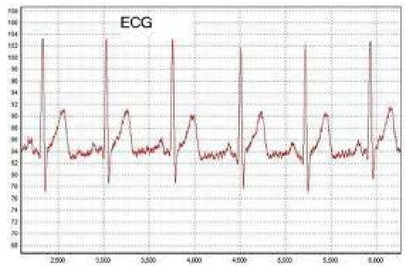
Mixed : most often!



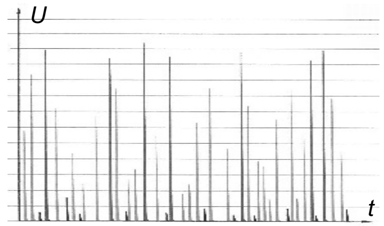
Types of signals

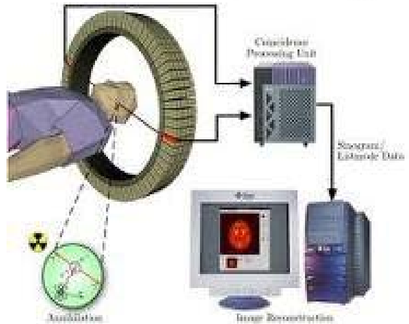
Continuous





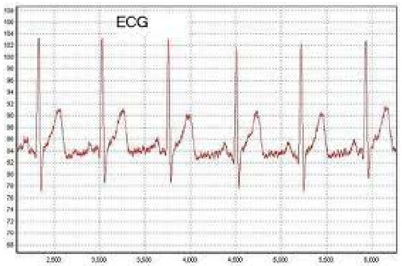
Pulses





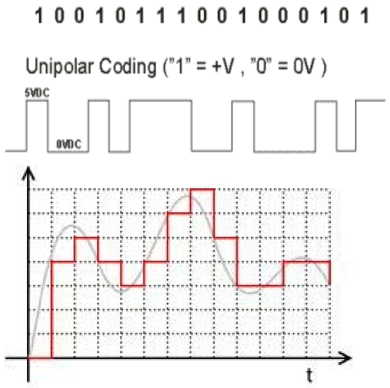
Types of signals

Analog



Theoretically unlimited resolution
in time and magnitude
(measurement system limit only)

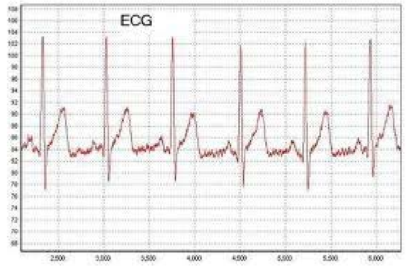
Digital



Digital: represented with numbers
Finite resolution

Digital signals are a form of **encoding** : digital to electrical
electrical to digital

Information content of signals

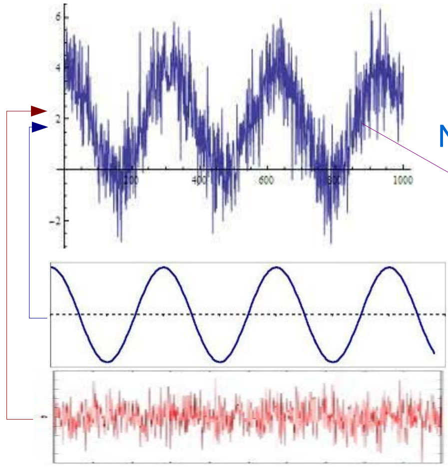


Analog signals – infinite information content?

Do we really need ***unlimited*** resolution?

Do we even **have** ulimited resolution in real-life analog singals?

Theoretically unlimited resolution
in time and magnitude
(measurement system limit only)



No!

We always have a real signal as:

S = Information + Noise

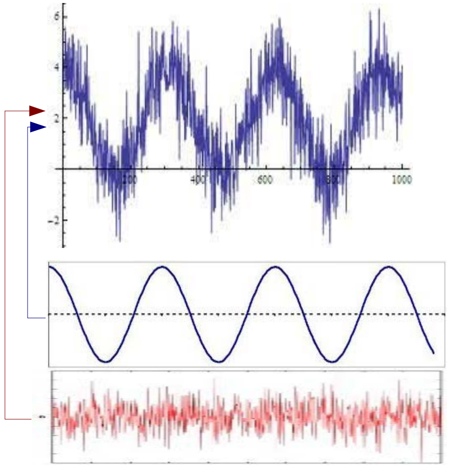
Information

+

Noise

Information content of signals

Analog signals – infinite information content?



We have Information + Noise

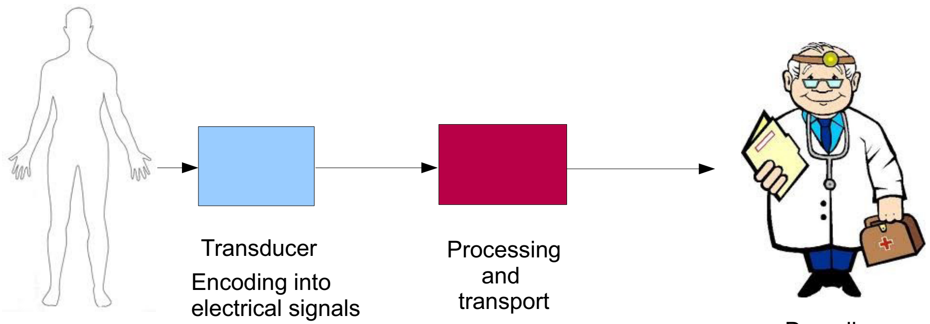
Goal: **Preserve and transport information** without increasing the noise content.

Information $U = A_{inf} \cdot \cos(\omega t + \phi)$

+

Noise $Noise(t) = A_{noise} \cdot Random(t)$

Transporting and processing signals



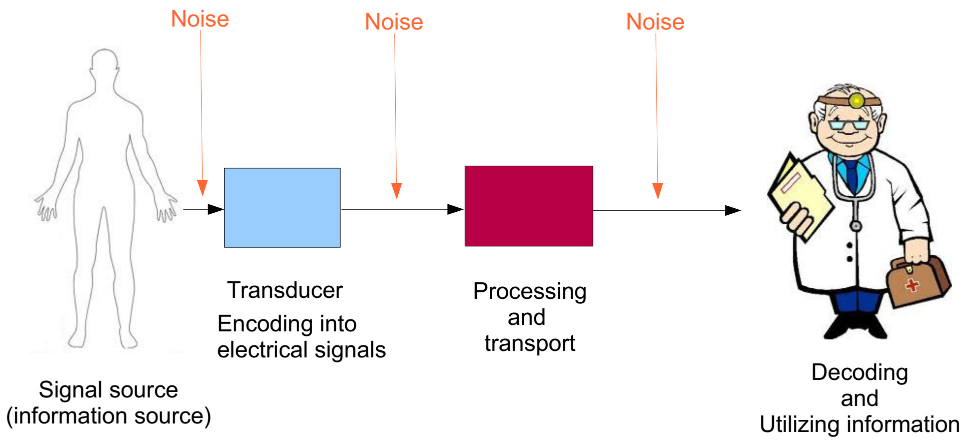
Signal source
(information source)

Transducer
Encoding into
electrical signals

Processing
and
transport

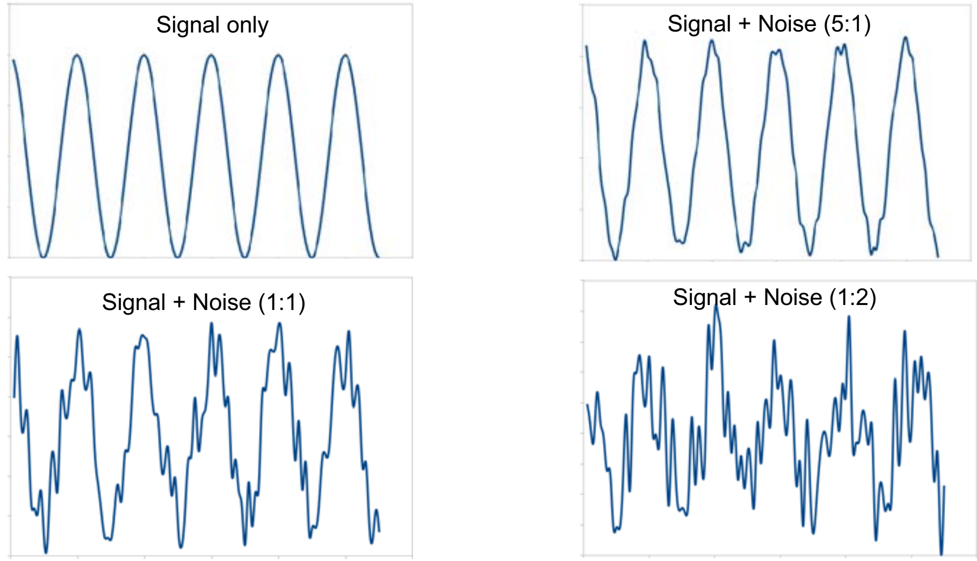
Decoding
and
Utilizing information

Transporting and processing signals



We need to separate information from noise!

Transporting and processing signals



Transporting and processing signals

Amplifiers

Task: amplify signal, without addition of noise
(only transport information)
Combat noise in the chain: Amplifiy the signal at the beginning!

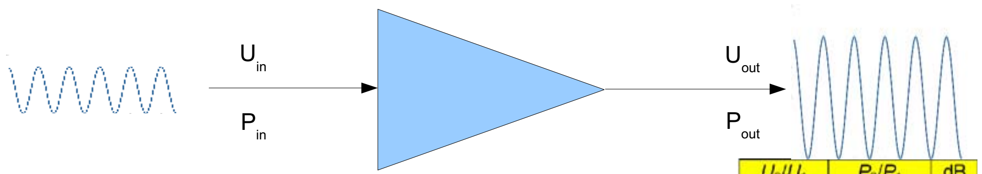
In real-life no amplifier is ideal, they always distort the signal

We need to characterize amplifiers, and other signal-transporting / processing elements of the signal chain.

Analysis of amplifiers

The technique is applicable to *any* transport/coding!

Basic analysis: amplifier gain



U_2/U_1	P_2/P_1	dB
1,414	2	3
2	4	6
	8	9
3,16	10	10
	20	13
10	100	20
	$1000=10^3$	30
$100=10^2$	$10000=10^4$	40
$1000=10^3$	10^6	60

$$P = U \cdot I = U^2 / R$$

$$n = 10 \cdot \log\left(\frac{P_{output}}{P_{input}}\right) \quad [dB]$$

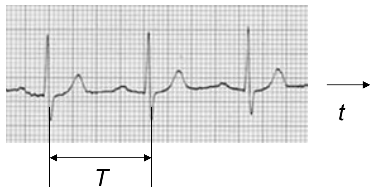
$$\frac{P_2}{P_1} = 10 \Leftrightarrow 10 \cdot \lg 10\,\text{dB} = = 10 \cdot 1\text{dB} = 10\text{dB}$$

$$\frac{P_2}{P_1} = 2 \Leftrightarrow 10 \lg 2\,\text{dB} = = 10 \cdot 0{,}3\,\text{dB} = 3\text{dB}$$

Analysis of amplifiers - complex signals

Fourier theorem: Any arbitrary (periodic) signal
can be split into sine/cosine functions with varying frequency and amplitude
OR from a set of such functions it can be recovered

$$Signal(t) \longleftrightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$



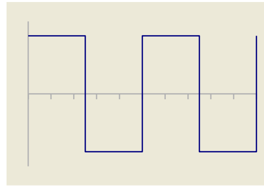
Where in the case of periodic signals ω_i = k·f , f = 1/T and k = 1,2,3,4,5.....

Base frequency

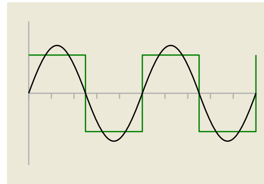
overtones

Analysis of amplifiers - Fourier theorem

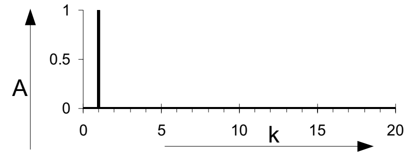
$$Signal(t) \longleftrightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$



Original signal



k=1



Spectrum

Amplitudes vs k (or frequency)

Analysis of amplifiers - Fourier theorem

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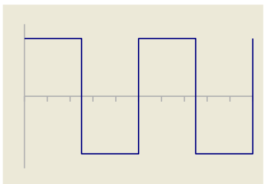
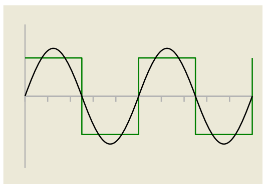
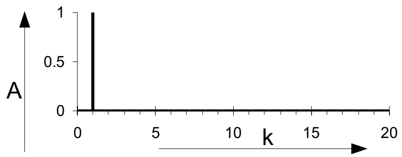
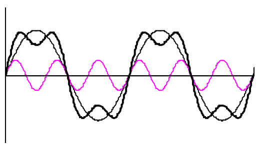


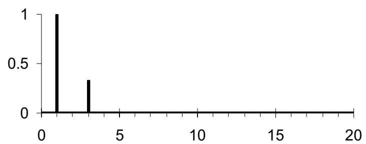
Original signal







k=1,2,3



Analysis of amplifiers - Fourier theorem

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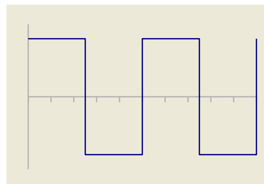
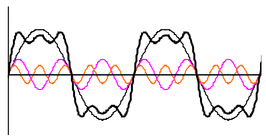
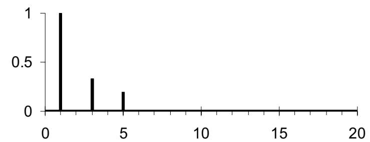
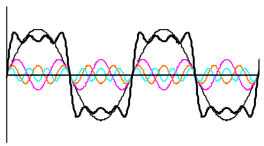
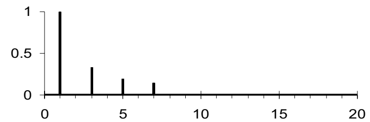


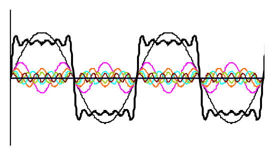
Original signal

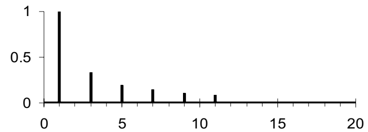






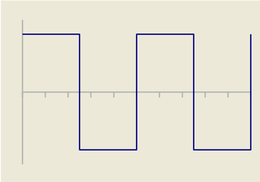




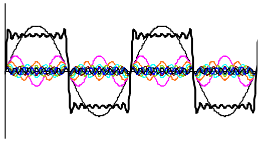


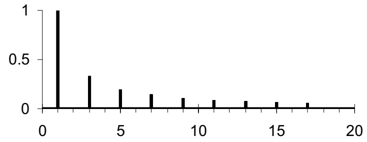
Analysis of amplifiers - Fourier theorem

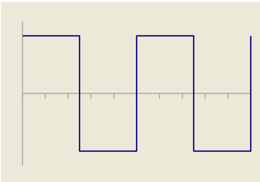
$$Signal(t) \longleftrightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$



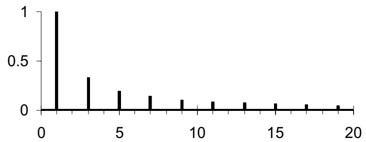
Original signal







Infinite number of components



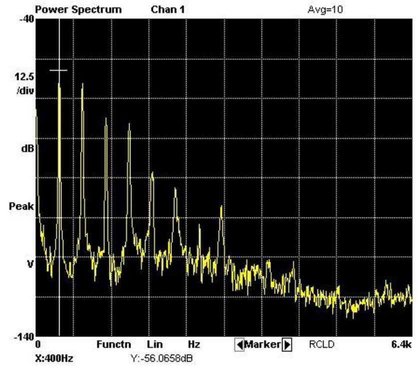
But: they are all related, so information is the same!

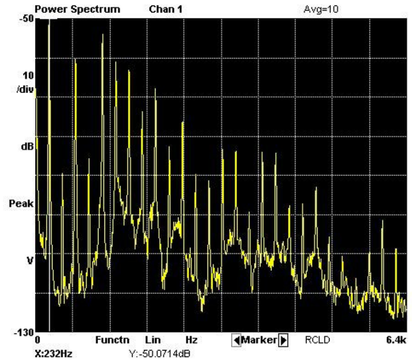
Analysis of amplifiers - Fourier theorem

$$Signal(t) \longleftrightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$

Non-periodic signals: Fourier transform

$$F(\omega) = \frac{1}{\sqrt{(2\pi)}} \cdot \int_{-\infty}^{+\infty} f(t) e^{i\omega t} dt$$





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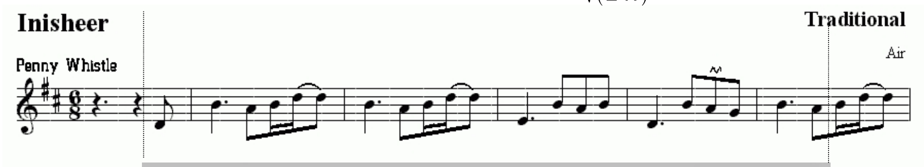
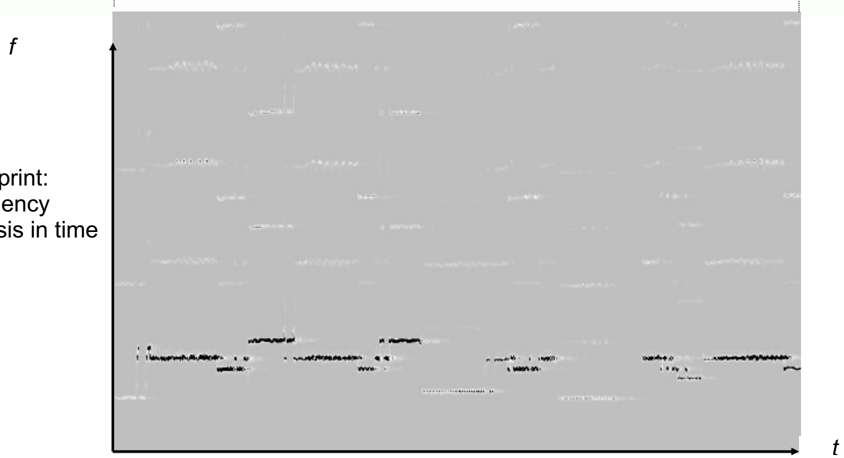


Voiceprint: Frequency analysis in time



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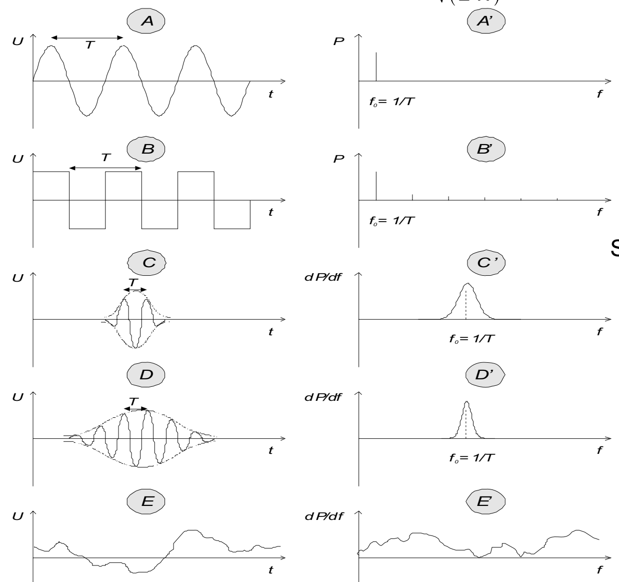
Non-periodic signals: Fourier transform

$$F(\omega) = \frac{1}{\sqrt{(2\pi)}} \cdot \int_{-\infty}^{+\infty} f(t) e^{i\omega t} dt$$

Signal in time



Infinite sine wave has a single line as spectrum

Signal in frequency

Longer sine-signal has narrower spectrum

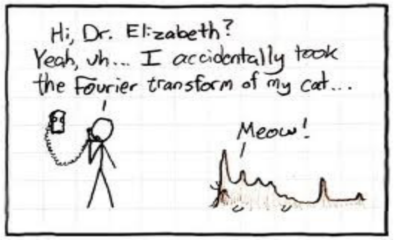
Analysis of amplifiers - Fourier theorem

$$Signal(t) \longleftrightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$

Non-periodic signals: Fourier transform

$$F(\omega) = \frac{1}{\sqrt{(2\pi)}} \cdot \int_{-\infty}^{+\infty} f(t) e^{i\omega t} dt$$

Any signal is just a representation of information



We can have many pictures of the same

Time-based (more convetional)

or

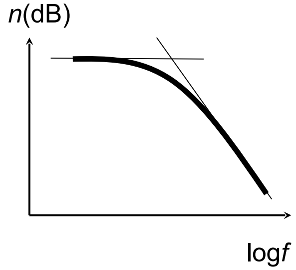
Frequency-based
(useful,but a bit abstract)

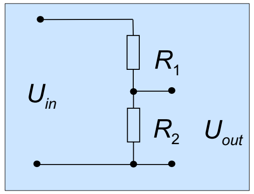
Fourier-transform is the „art of engineering"

(Picasso: La Crucifixion)

Analysis of amplifiers - Transfer function of filters

Low-pass filter

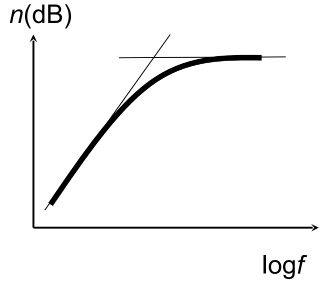


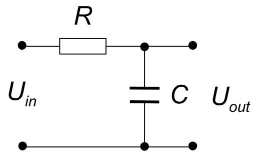


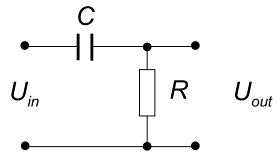
$$U_{output} = U_{input} \cdot \frac{R_2}{R_1 + R_2}$$

Substitute one R with C

High-pass filter

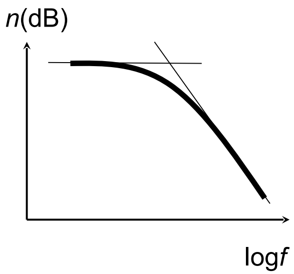


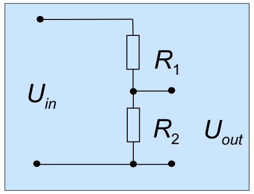




Analysis of amplifiers - Transfer function of filters

Low-pass filter



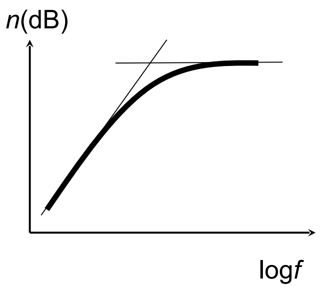


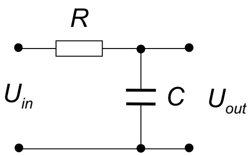
$$U_{output} = U_{input} \cdot \frac{R_2}{R_1 + R_2}$$

Substitute one R with C

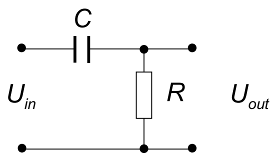
$$R_C = \frac{1}{C\omega}$$

High-pass filter



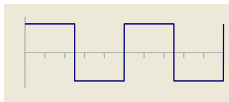


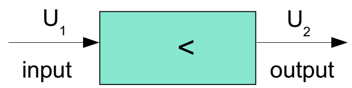
$$U_{out} = \frac{1}{\sqrt{1 + R^2 C^2 \omega^2}} \cdot U_{input}$$

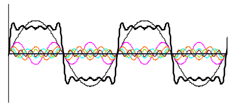


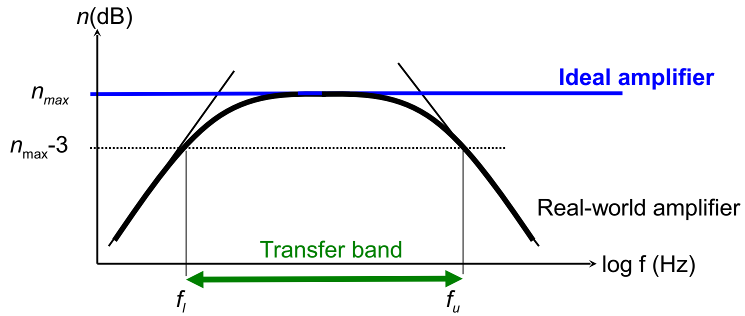
$$U_{out} = \frac{R C \omega}{\sqrt{1 + R^2 C^2 \omega^2}} \cdot U_{input}$$

Analysis of amplifiers - Transfer function of amplifiers







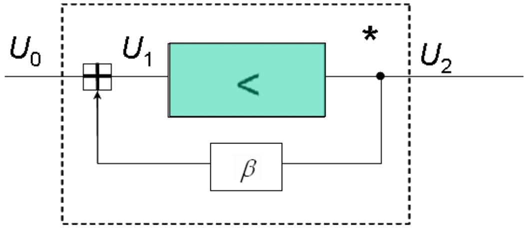


Amplifiers are not ideal, they have input and output capacitance,etc.

The output signal may *not* contain all frequency components!

Distortion, information loss / alteration

Analysis of amplifiers - Transfer function of amplifiers



Summation point

Feedback in amplifiers

Modification of **gain** and ***Transfer function***

$(a) \quad U_1 = U_0 + \beta U_2 \qquad (b) \quad A_U = \frac{U_2}{U_1}$ Amplifier gain

$$(c) \quad A_U^* = \frac{U_2}{U_0} = \frac{U_1 A_U}{U_0} = \frac{(U_0 + \beta U_2) A_U}{U_0} = A_U + \beta \frac{U_2}{U_0} A_U = A_U + \beta A_U^* A_U$$

$$A_U^* - \beta A_U^* A_U = A_U \qquad \boxed{A_U^* = \frac{A_U}{1 - \beta A_U}}$$ Gain with feedback circuit

β > 0 : positive feedback
β < 0 : negative feedback
$A_u\beta = 1$: oscillator (output without input signal: signal generator)

Analysis of amplifiers - Transfer function of amplifiers

Gain Bandwidth Product

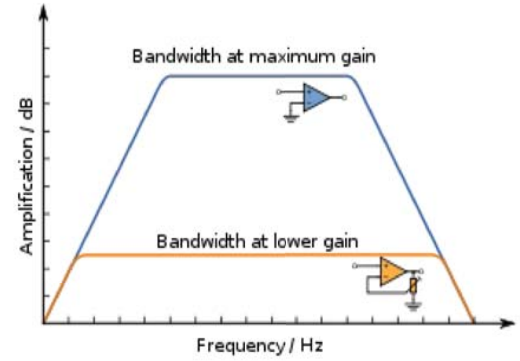
Gain · Bandwidth = constant

The available power to the amplifier can either be put to use as:

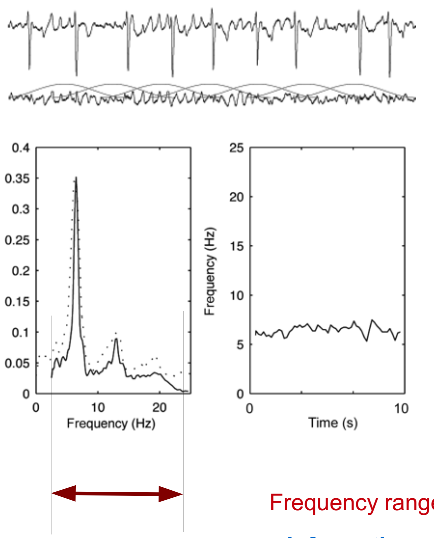
high signal gain over a limited bandwidth

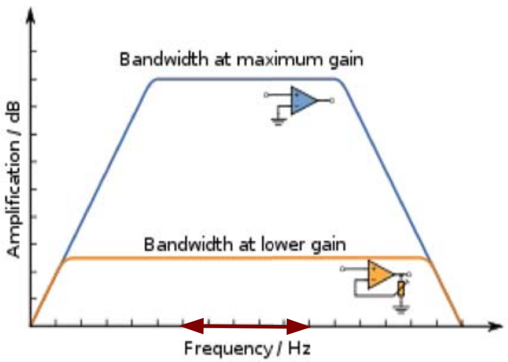
or

limited gain over a wide bandwidth.



Analysis of amplifiers - Transfer function of amplifiers





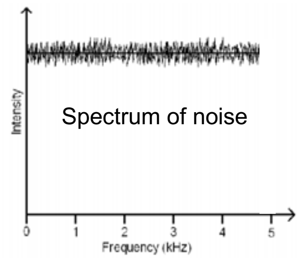
Frequency range of the signal must match the bandwidth!

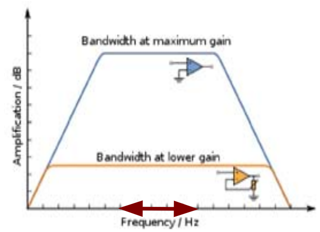
Information preservation = spectrum preservation

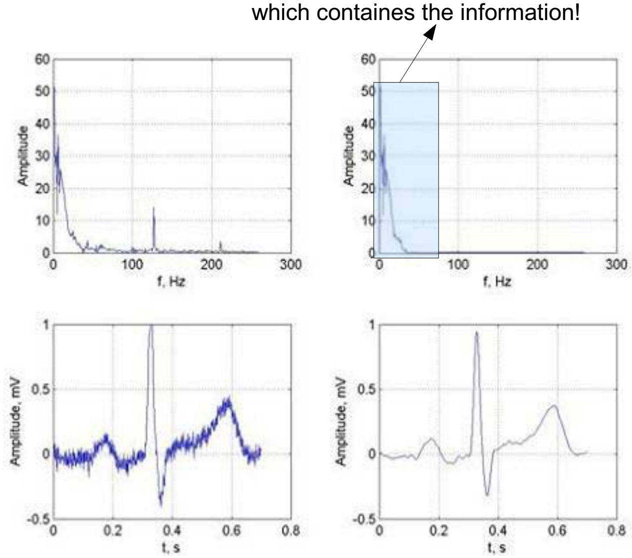
Analysis of amplifiers - Transfer function of amplifiers

During analog signal transport at every stage noise will be added! → degradation

Just transport that part of the spectrum which containes the information!







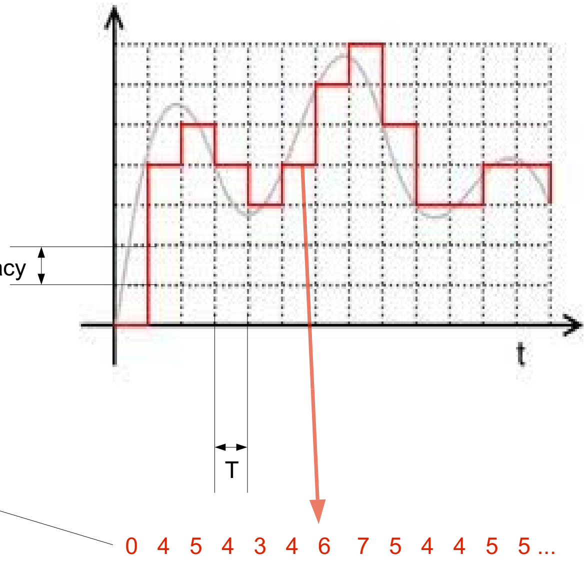
Digital signals – A/D conversion (ADC)

The analog signal can be represented by numbers:

We measure the signal every T seconds, and transmit the result only.

Measurement accuracy

(how many bits)



Digital signals are discrete in time and in value

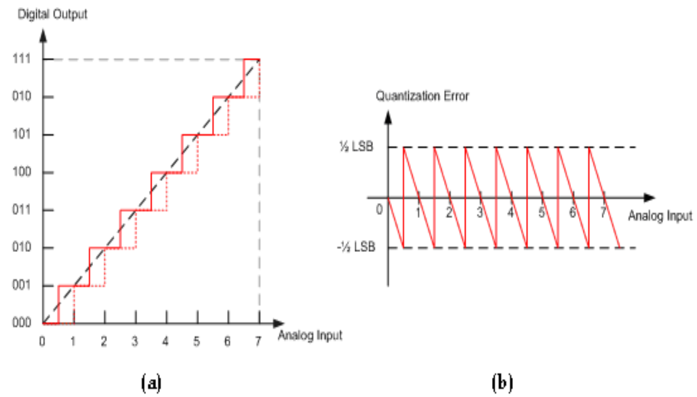
Numbers can be transported / stored or processed losslessly!

Digital signals - Quantization

Digital signals are discrete in time and in value

What happens to the original parts between?

They get lost!



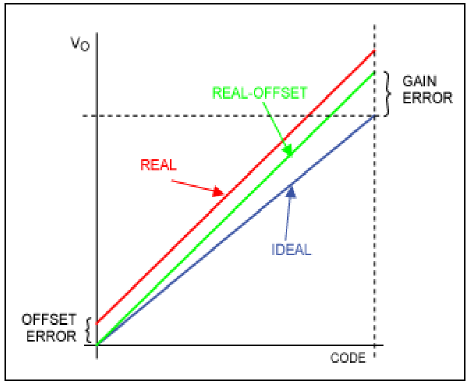
Digital signals – Restoration (DAC)

Recovery of analog signals:

Digital to analog converter

This is easily realized to be near-ideal

Many-bits, fast DAC-s are cheap



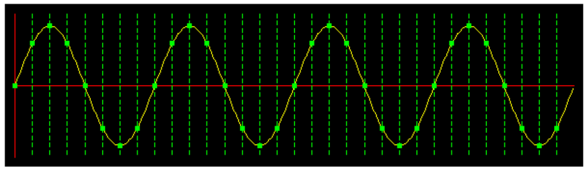
Pitfalls to avoid

Digital signals – Sampling of sine waves

For non-sine signals: „first apply Fourier, then sample each sine"

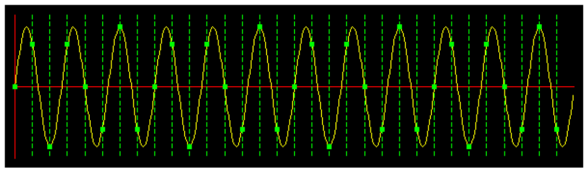
f = 1000 Hz
fs = 8000 Hz

No problem



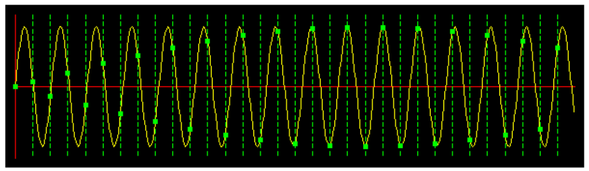
f = 3000 Hz
fs = 8000 Hz

Still no problem



f = 3900 Hz
fs = 8000 Hz

Still no problem



Digital signals – Sampling of sine waves

For non-sine signals: „first apply Fourier, then sample each sine”

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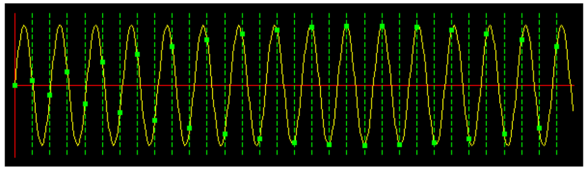
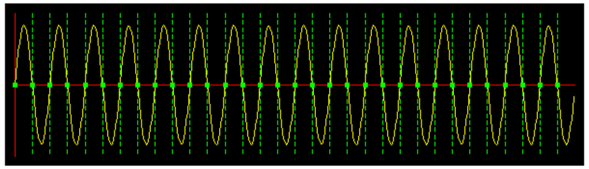


f = 4000 Hz
fs = 8000 Hz

Signal lost!



Nyquist theorem: sampling frequency must be at least 2x the frequency of the sine

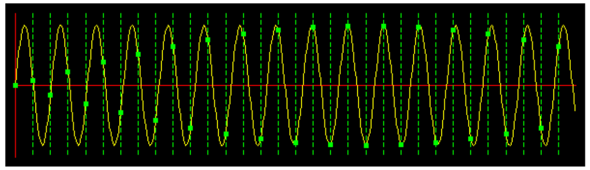
Digital signals – Nyquist

Nyquist theorem: sampling frequency must be at least 2x the frequency of the sine

good

f = 3900 Hz
fs = 8000 Hz

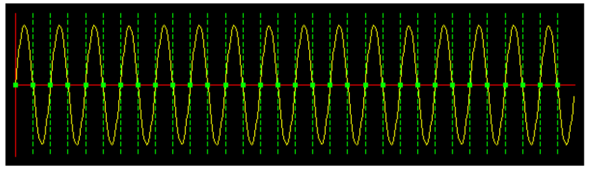
Still no problem



bad

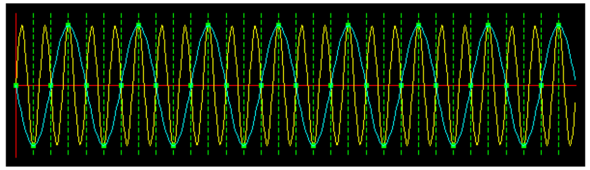
f = 4000 Hz
fs = 8000 Hz

Signal lost!



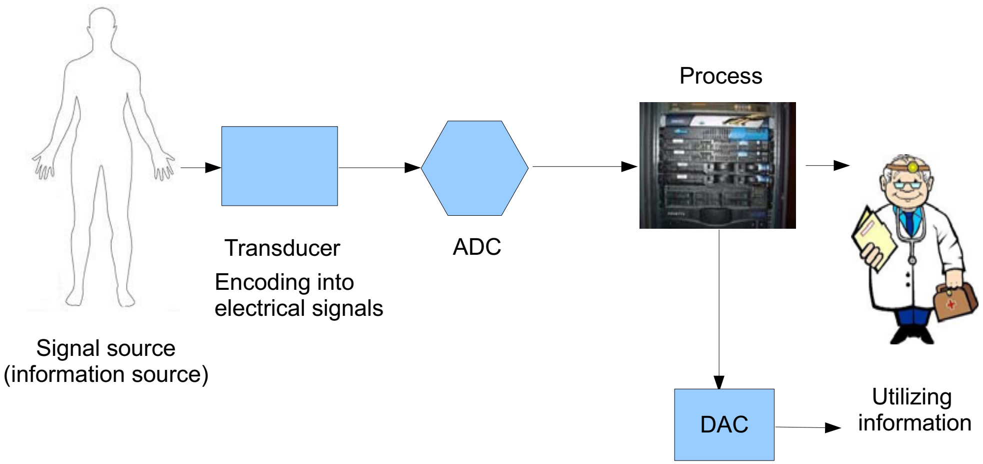
f = 6000 Hz
fs = 8000 Hz

Signal lost!
Aliasing



Artefact sine appears instead of the real input

Digital signals – Digital Signal Processing

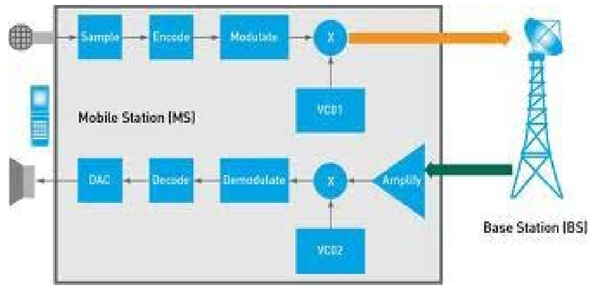


DSP in everyday life

Digital data can be further manipulated : encoded/decoded/compressed,etc.

Cell phone

Sample, encode,transmit,decode,DAC



CD/DVD player
Light:digital 1010110...
DAC: from stream of numbers
Analog music / video