

Human Body as a signal source

Signal processing

G.Schay

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

$$H = \sum p * \log_2 \frac{1}{p}$$

Signal is something which carries **Information**

Information content in Bits

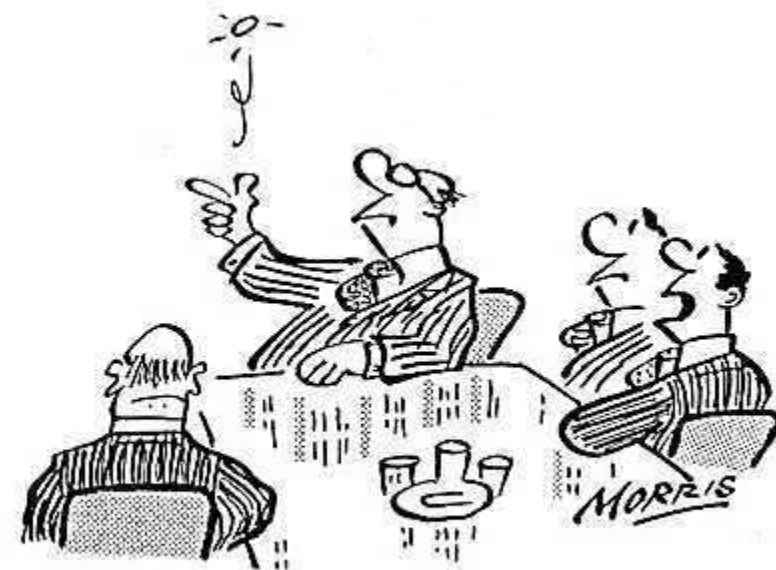
Human body as signal source: everything which is a signal, and comes from the body

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 **receiver**
destination



an example

Which side is up?

encoding



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

Speech, waves in the air, sms

decoding

1,0 → head, tail



Decide who wins

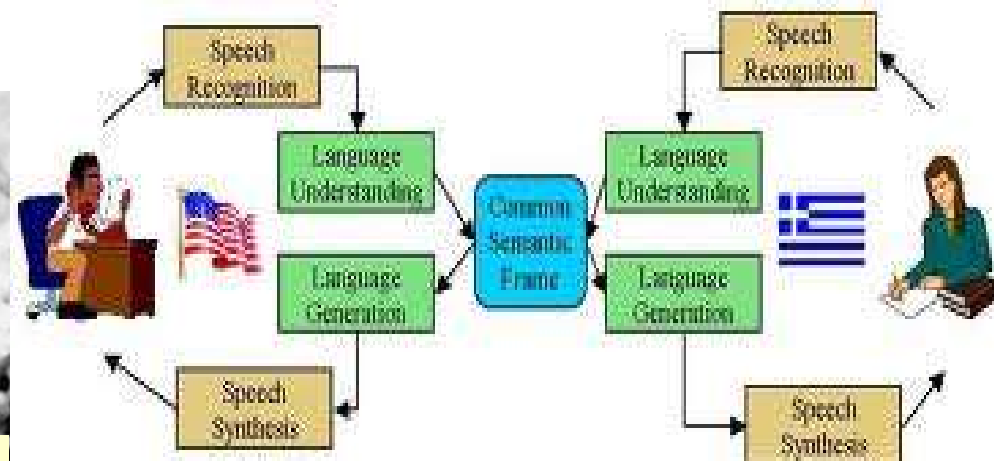
$$H = P_{tail} * \log_2 \frac{1}{P_{tail}} + P_{head} * \log_2 \frac{1}{P_{head}} = \frac{1}{2} * \log_2 \frac{1}{2} + \frac{1}{2} * \log_2 \frac{1}{2} = 1 \text{ [Bit]}$$

Signals in medicine

Signal is something which carries Information



Eugene Debs 1918 Ohio



Here in speech:

Information : „what we say”

Signal:

- Audio: pressure wave in the air

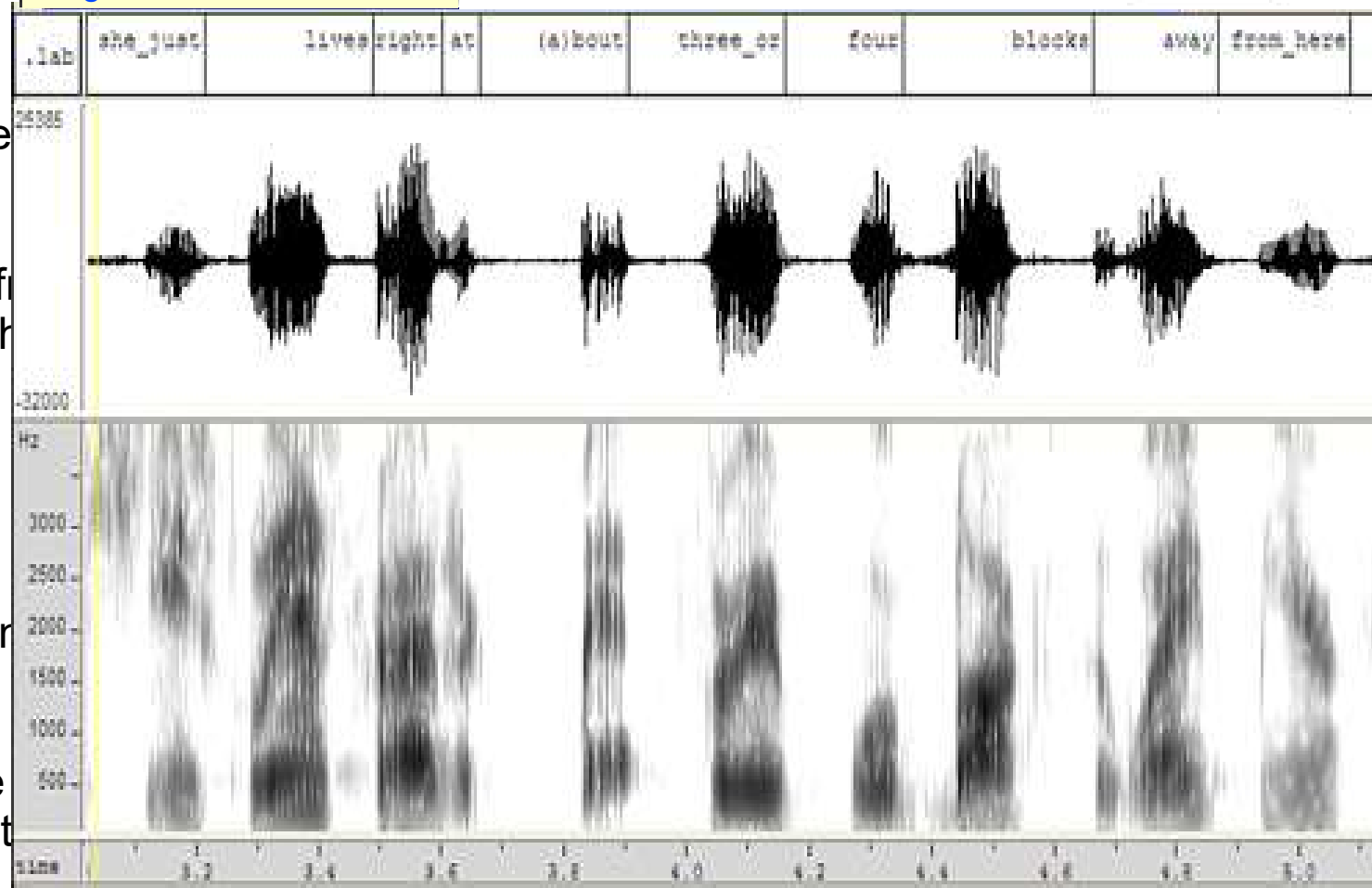
- encoding: electrical

signal from Microphone

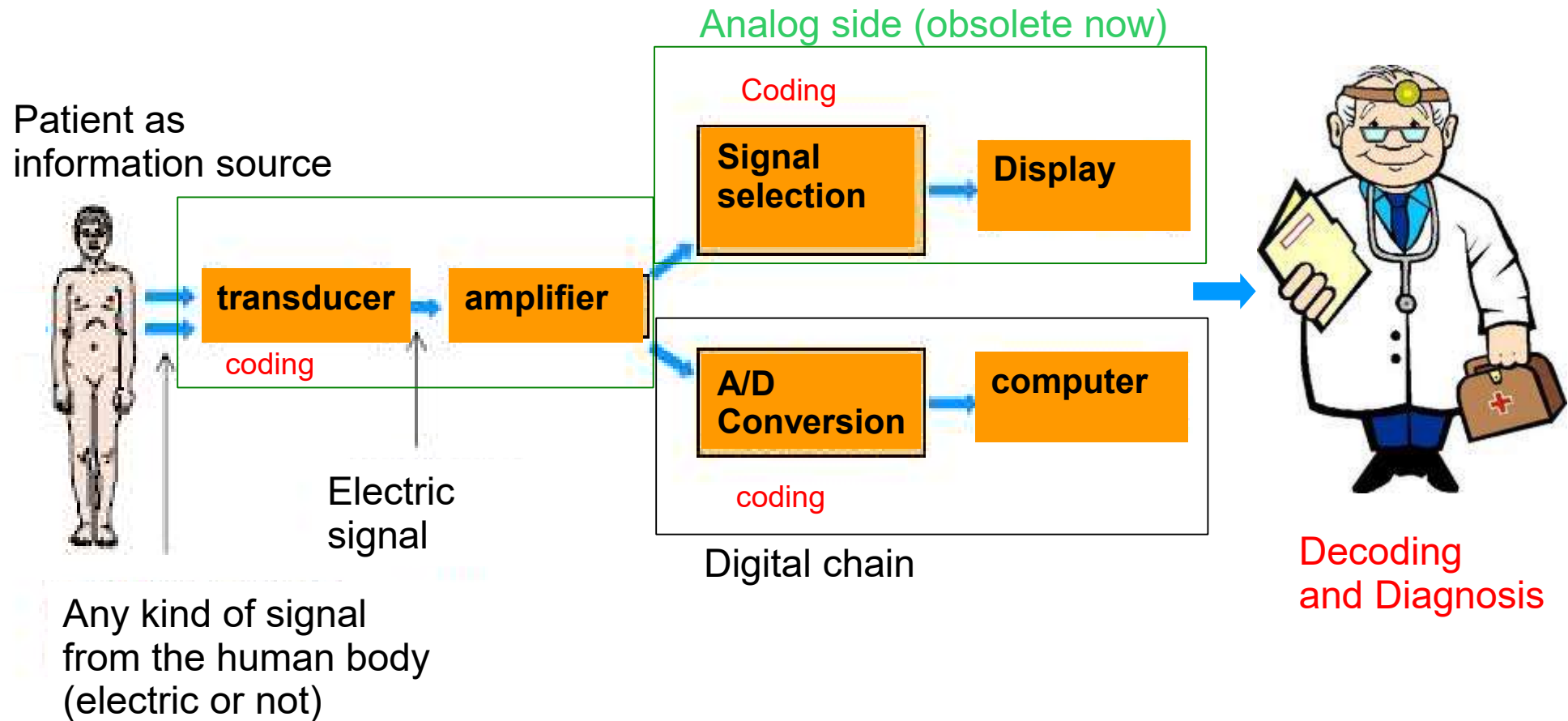
- encoding: formal grammar

- decoding: electrical to Mechanical (loudspeaker)

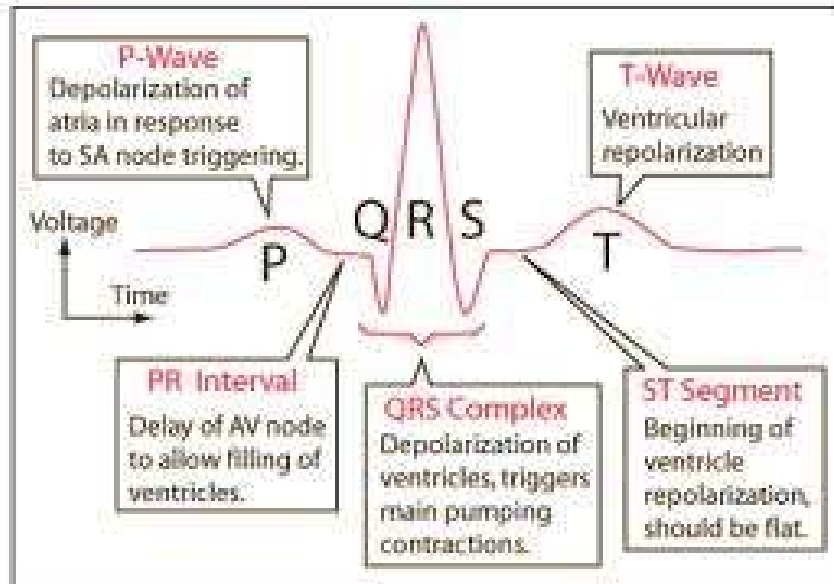
- decoding: natural language understanding



Medical signal processing chain



Signals in medicine



Information: Heart cycle

ECG: Electro CardioGraphy

Signal:

Original:

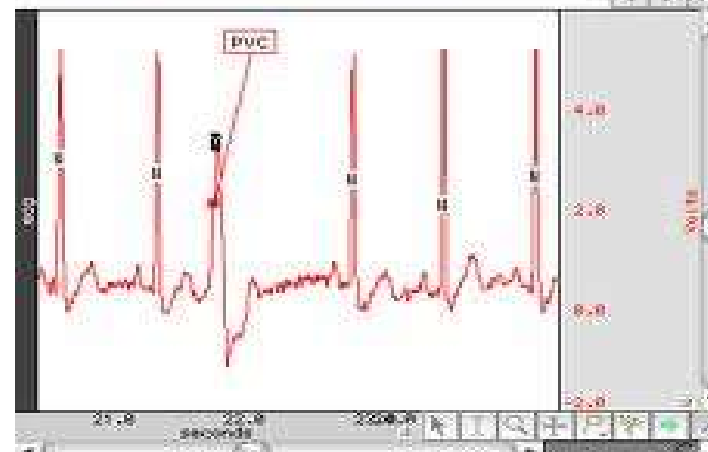
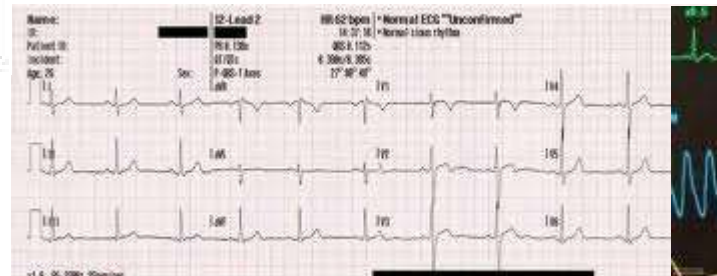
voltage across points
(eg. two arms)

Encoding:

None,

But **Filtering** required

Removal of unwanted portion of the signal



Signals in medicine

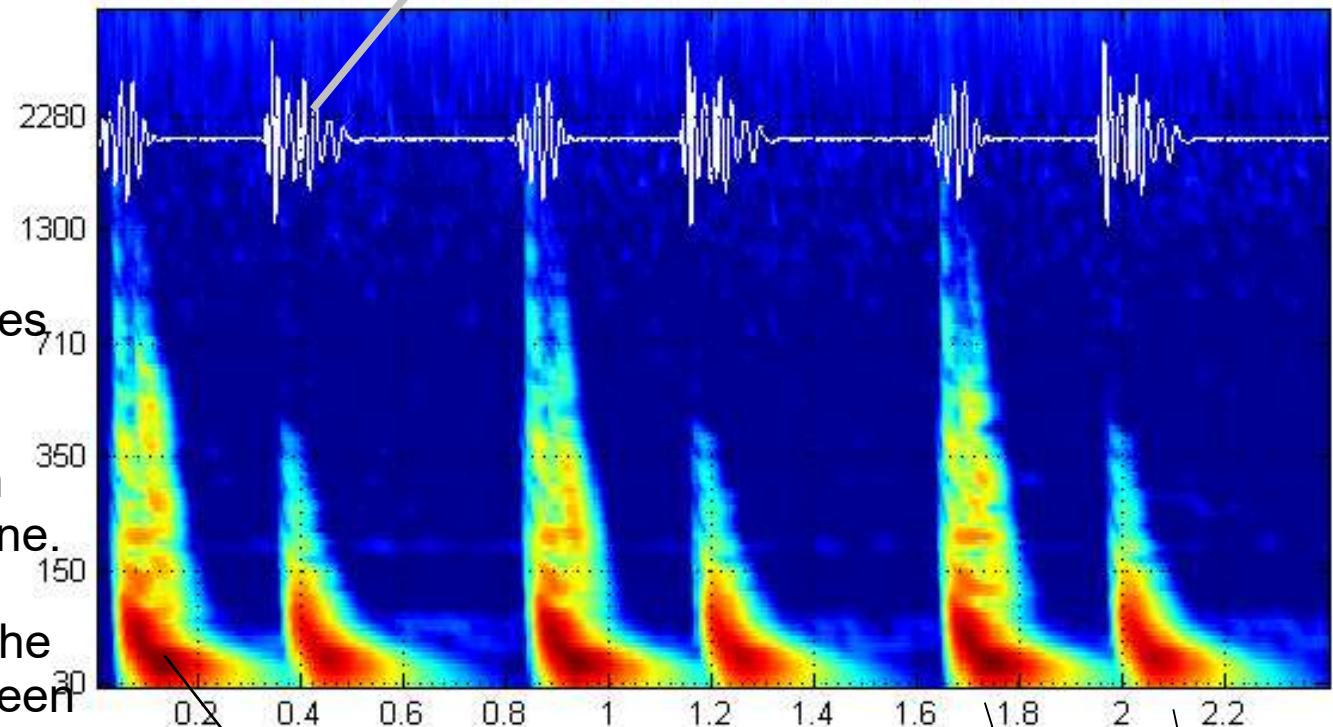
Heart beat

Signal:
Original:

Encoded: electrical signal from
the microphone.

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

Sound
intensity vs.
time



Frequency components
(see Fourier later)

Systole Diastole

Information: Heart cycle parameters, anatomical and flow problems.

Signals in medicine

PET: Positron Emission Tomography

Signal:

Original:

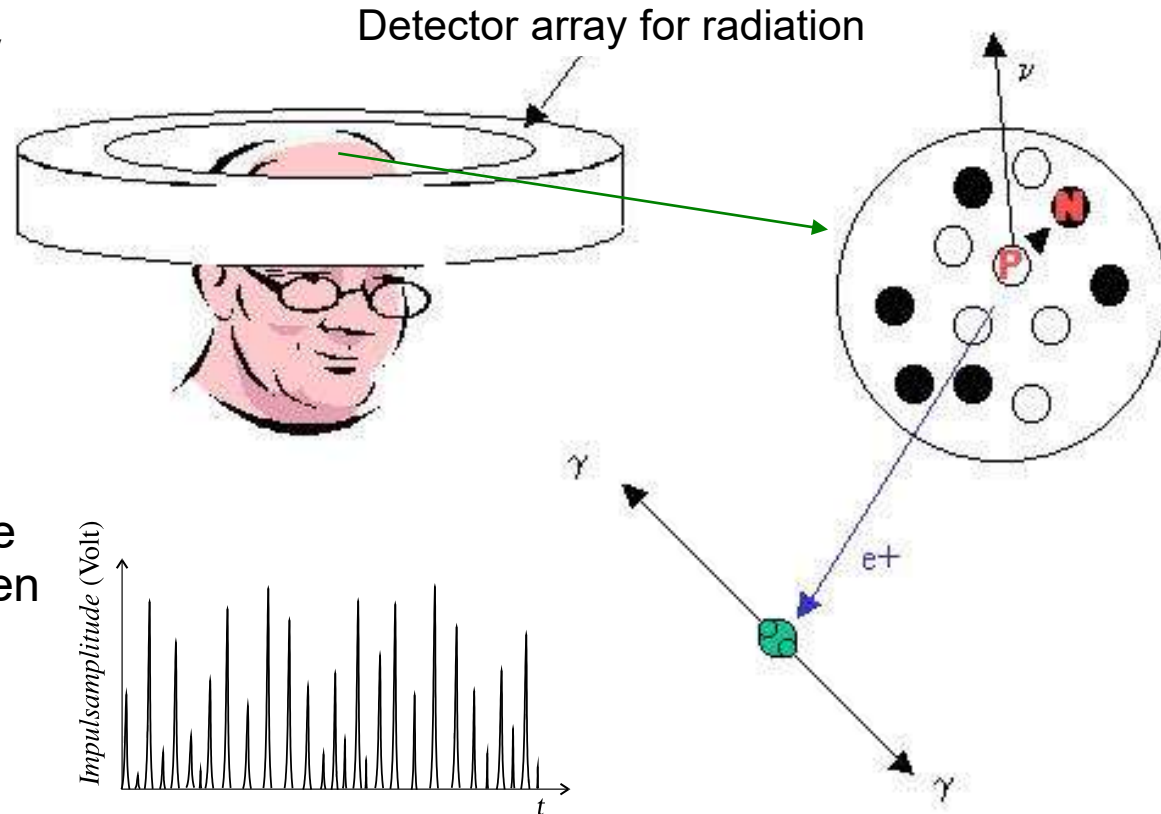
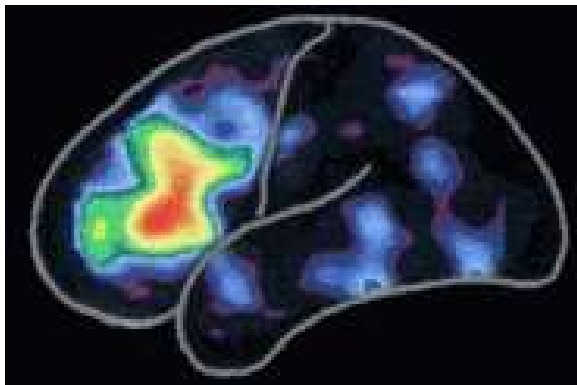
γ -photons

Encoded:

electrical pulses from the detector.

Encoded:

Coloured image on the computer screen

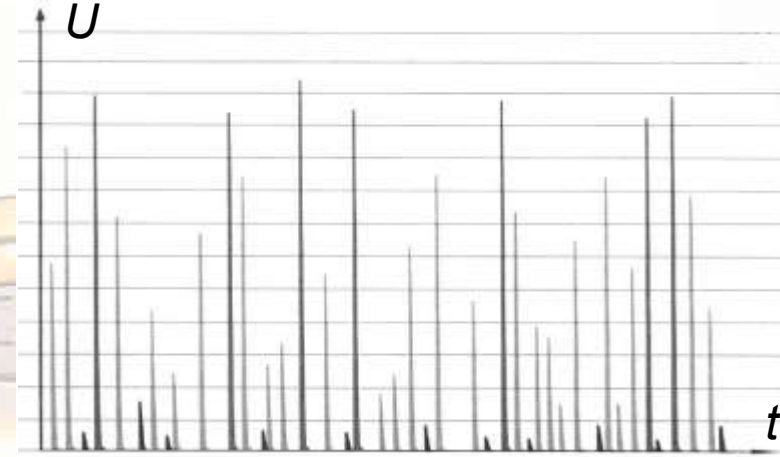


Information: Location of drug, labeling molecule, etc.

Signals in medicine

SPET-CT:
Single Photon Emission
Computed Tomography

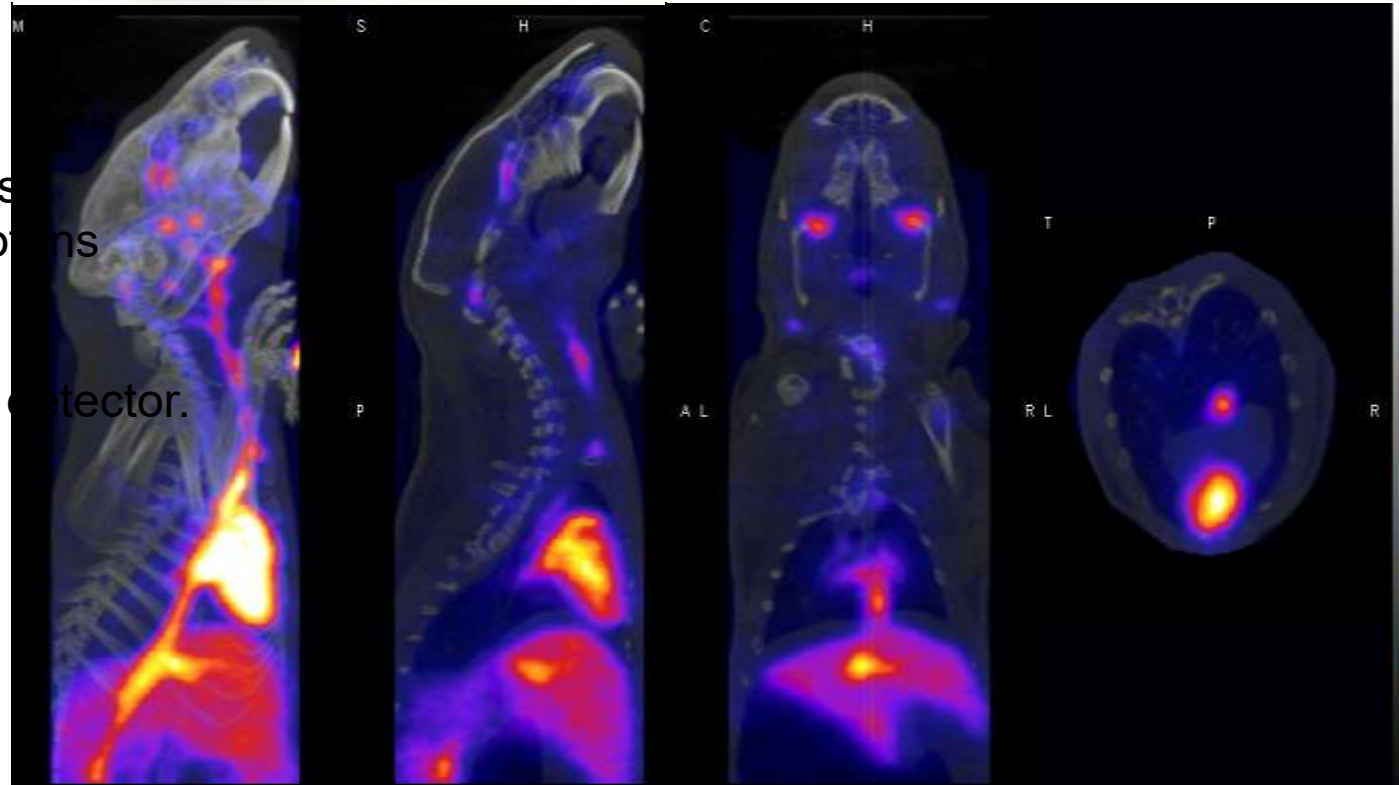
Computer Tomography



Signal:
Original: γ -photons
X-ray photons

Encoded: electrical pulses
From the detector.

Encoded: Coloured image
Information:
Anatomy (X-ray)
Label (disease, etc)



Signals in medicine



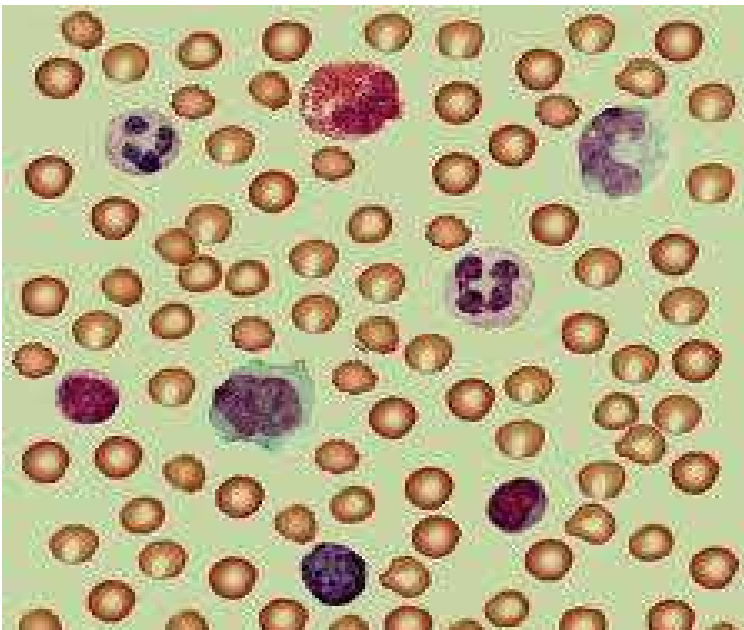
Heart beat

Signal:
Original: Cell types and count
in unit volume

Encoded: electrical signal from
the cell sorter.

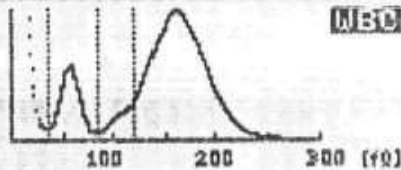
Encoded: Areas under the histogram

Information: Blood composition

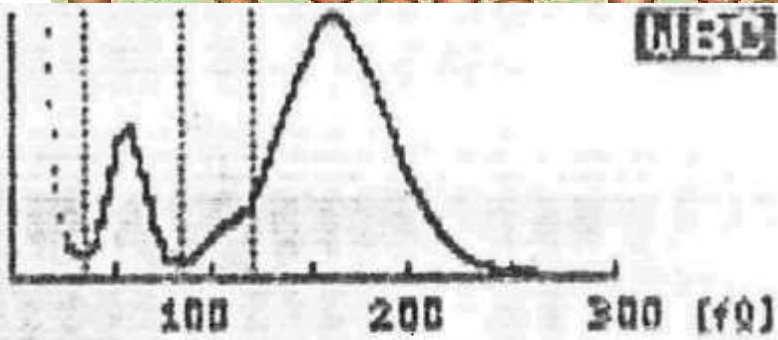


No. 3524
DATE: 93/ 3/30 09:22
MODE: WHOLE BLOOD

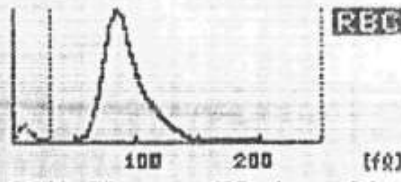
WBC	7.5x10 ³ /μl
RBC	3.64x10 ⁶ /μl
HGB	11.8 g/dl
HCT	33.1 %
MCV	90.9 fl
MCH	32.4 pg
MCHC	35.6 g/dl
PLT	158x10 ³ /μl



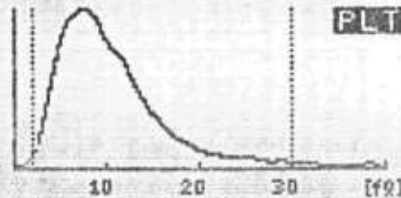
LYMPH%	16.2	%
MXD %	6.7	%
NEUT%	77.1	%
LYMPH#	1.2x10 ³ /μl	
MXD #	0.5x10 ³ /μl	
NEUT#	5.8x10 ³ /μl	



LYMPH%	16.2	%
MXD %	6.7	%
NEUT%	77.1	%
LYMPH#	1.2x10 ³ /μl	
MXD #	0.5x10 ³ /μl	
NEUT#	5.8x10 ³ /μl	



RDW-SD	38.1	fl
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PDW	14.0	fl
MPV	10.5	fl
P-LCR	31.1	%

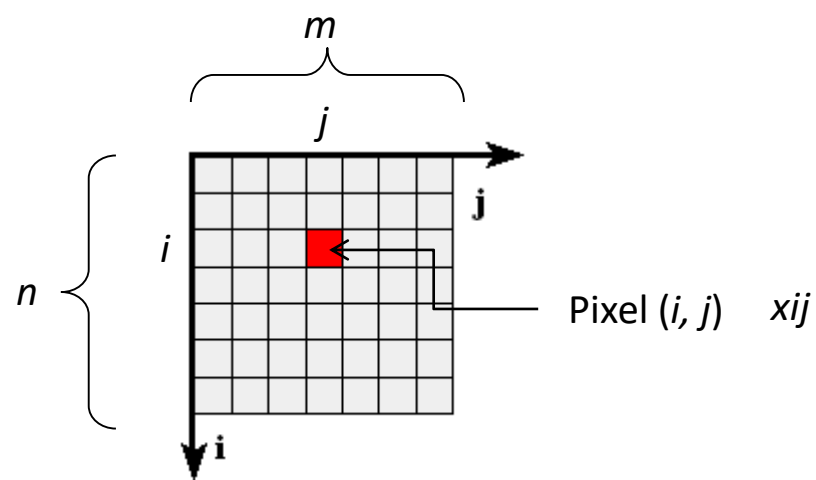
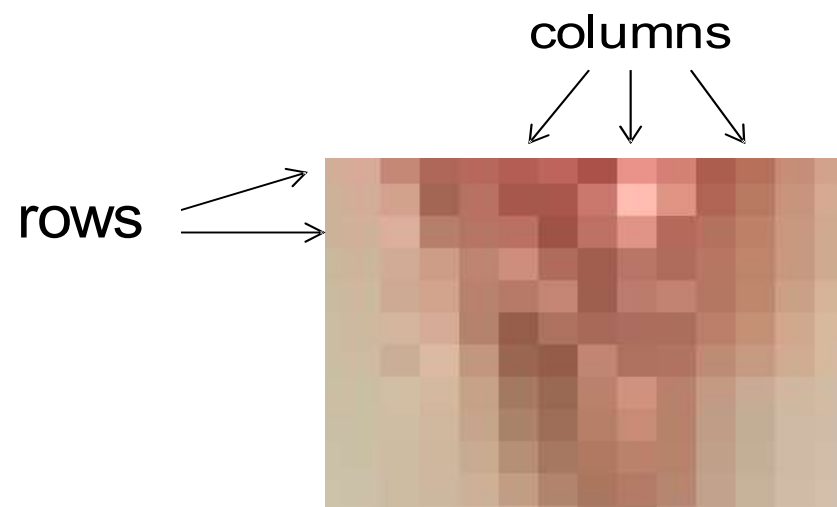
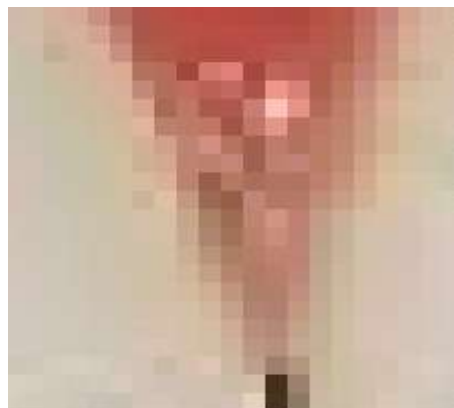
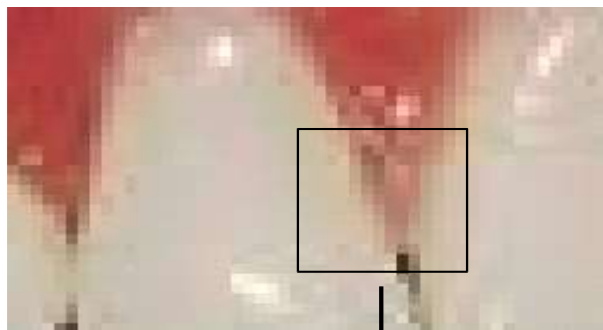
Basics of medical imaging:

Pixel

Voxel

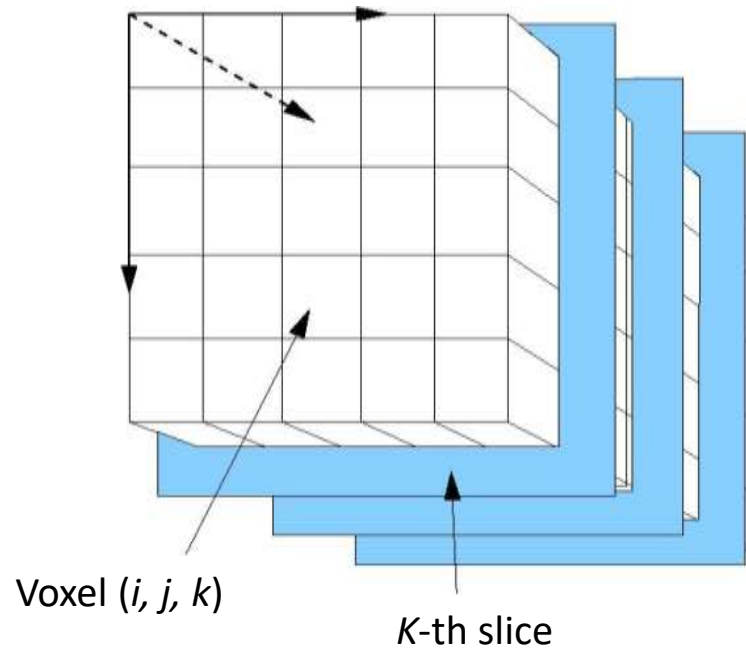
Image

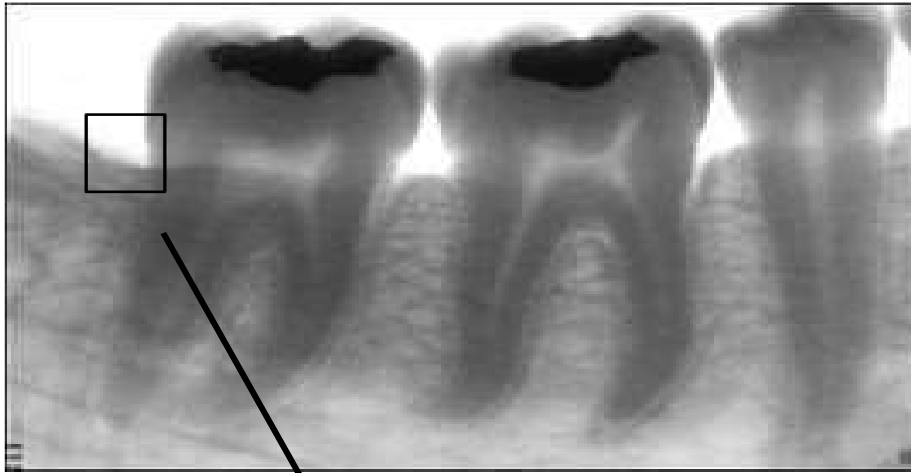
Tomogram



A 3D model can be made from
Joining many 2D slices together.

The reconstruction volume is thus
a box



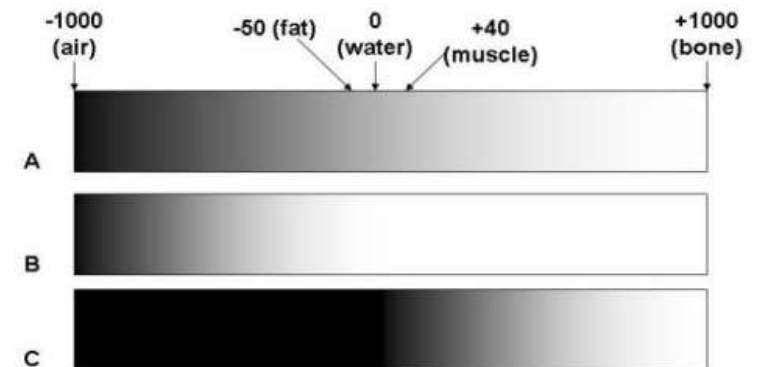


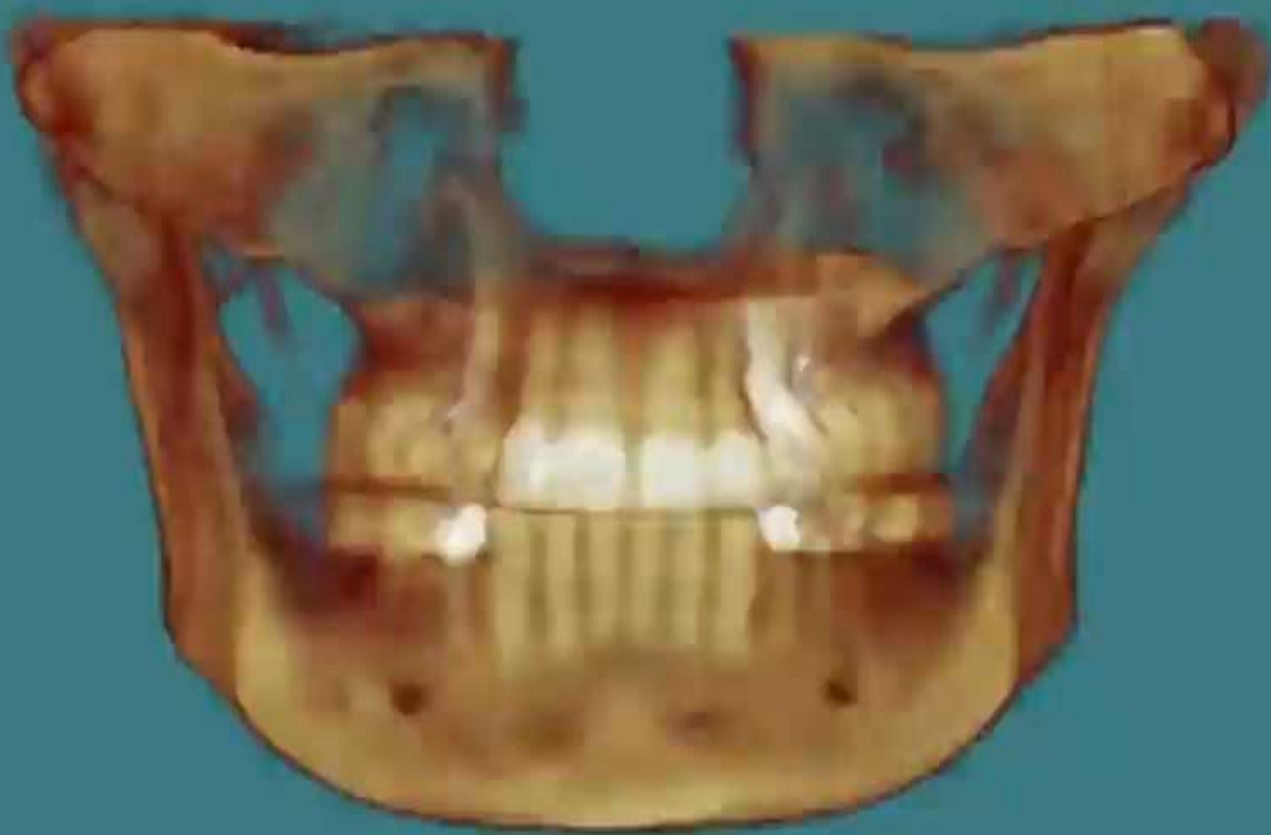
Windowing:

Only show a specific part of the full scale.

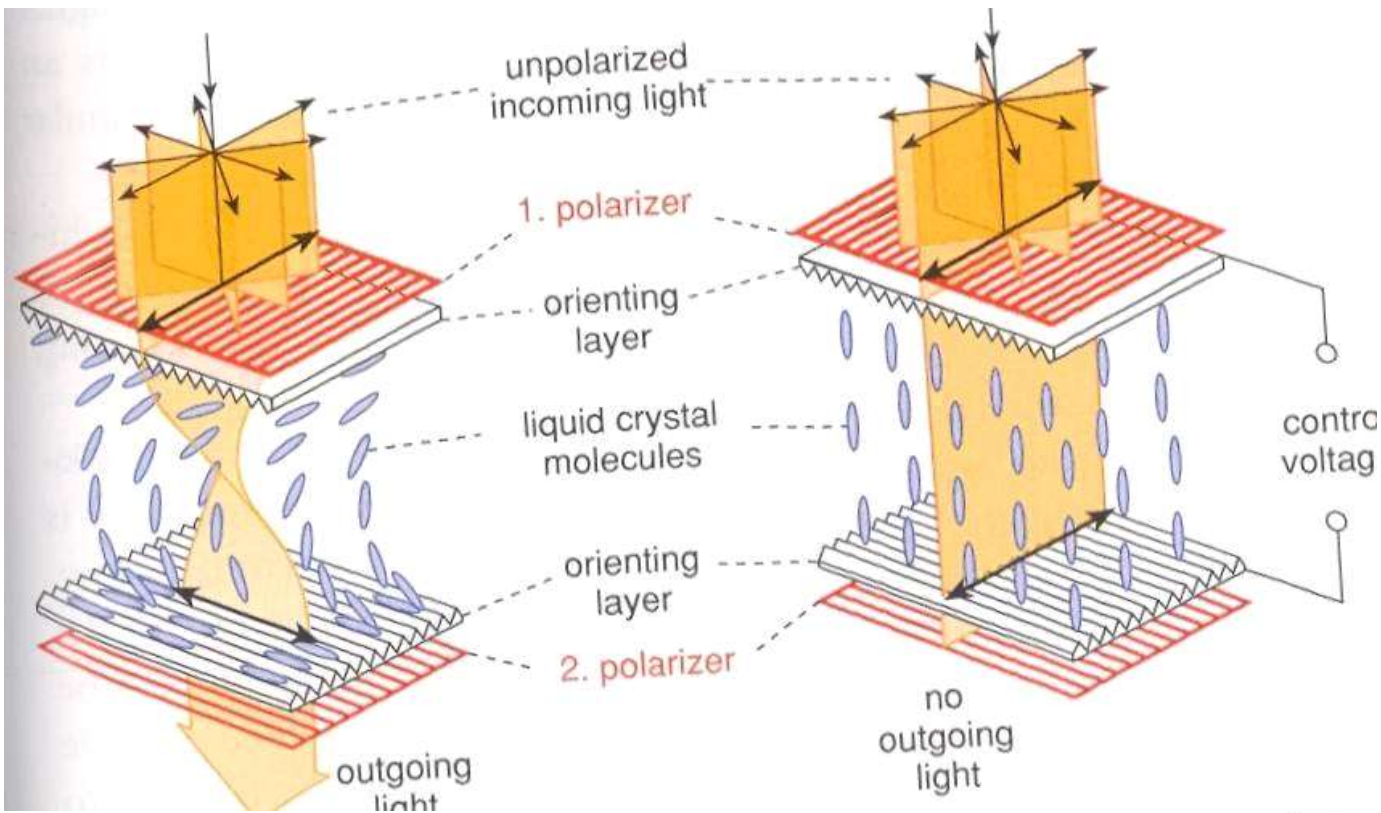
Reason: the human eye can not differentiate too many colors/brightness values

Gray scales of a CT image at different „windows”.



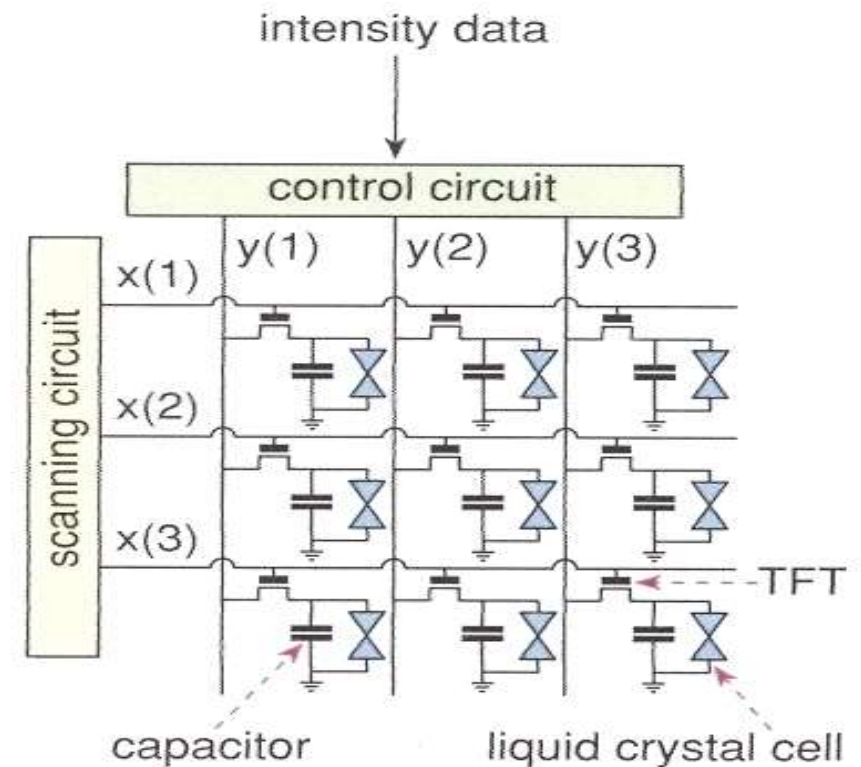


Liquid Crystal Display

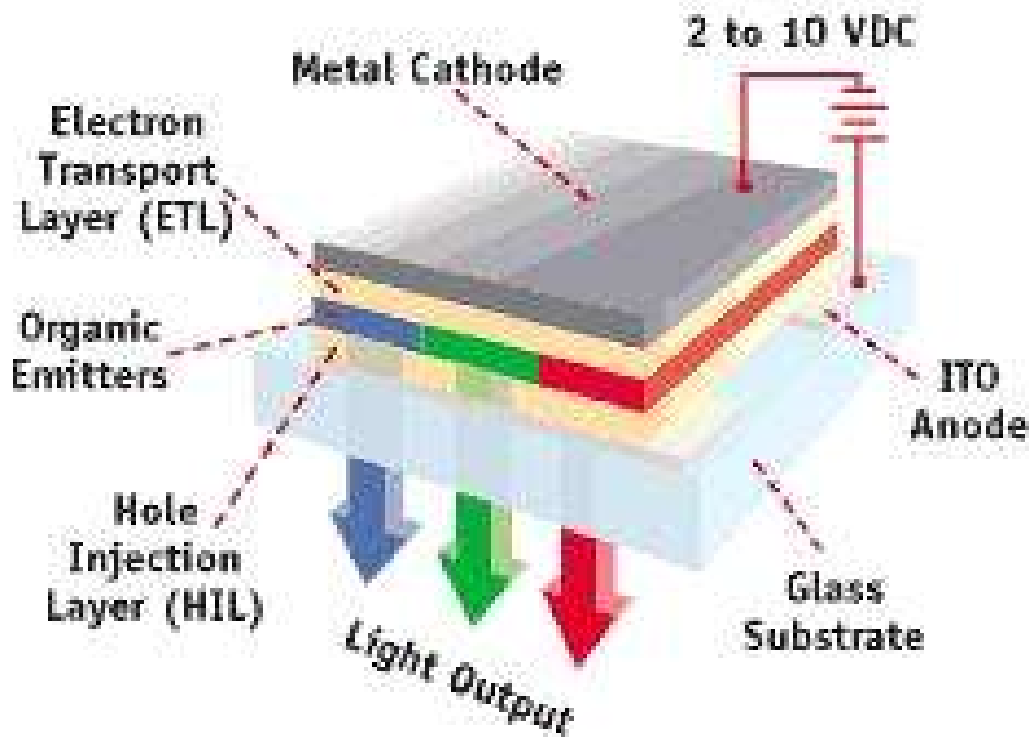


Thin Film Transistor display

A very thin (transparent) transistor layer switches each pixel. This improves the speed.

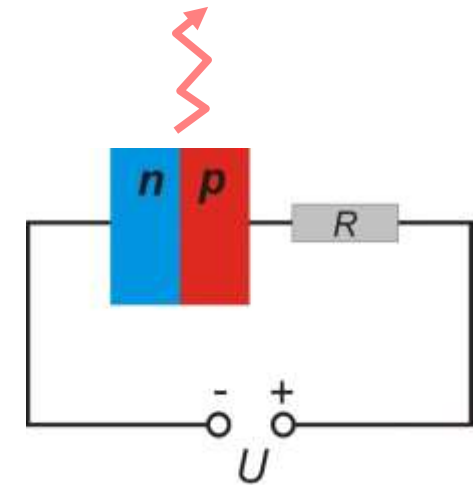


OLED Structure

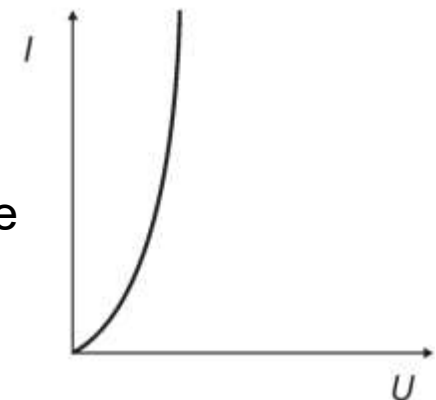


Structure of 1 pixel

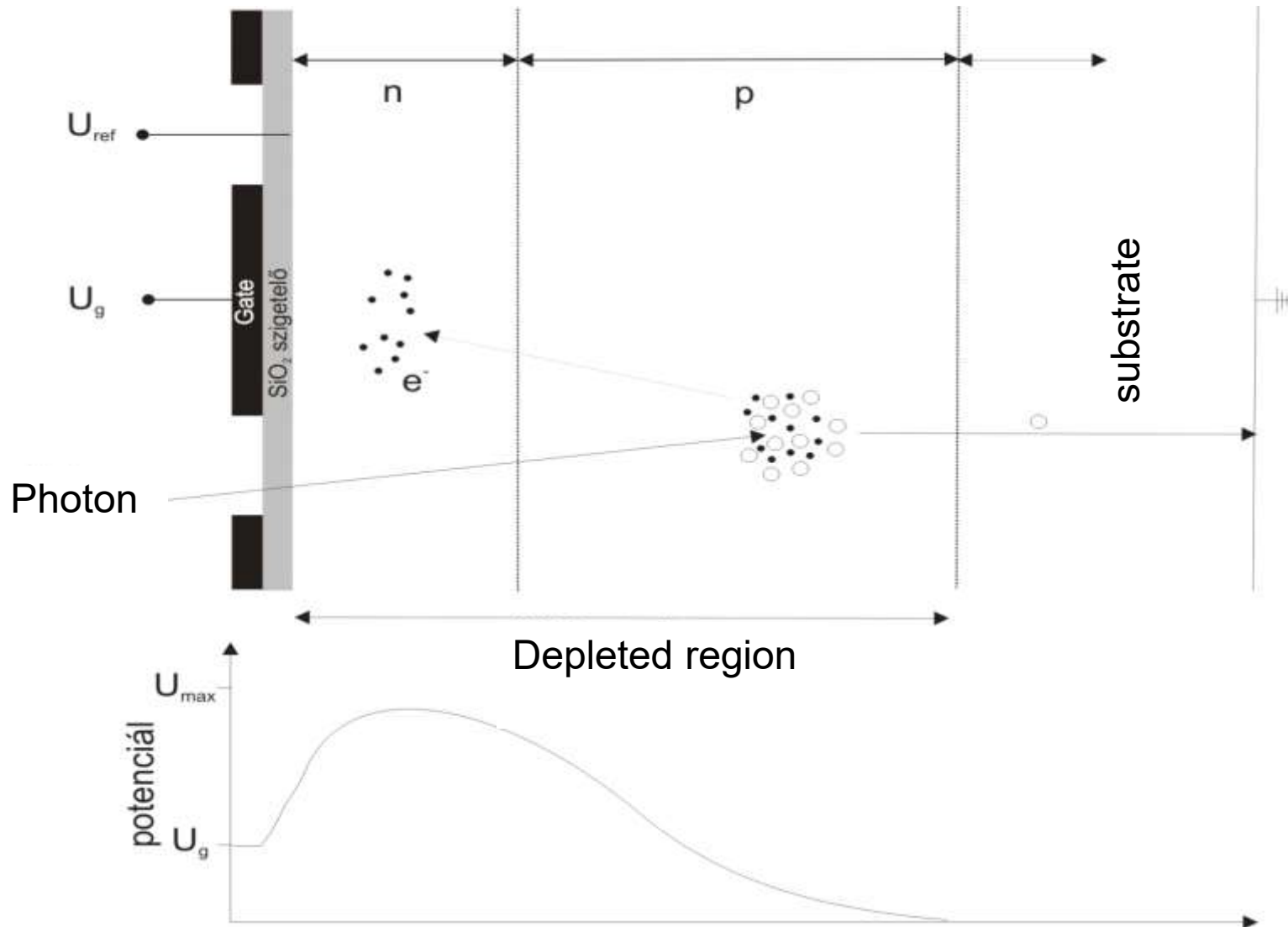
O(rganic)*LED displays*



Light Emitting Diode



Charge Coupled Device (CCD)



CCD-s are also used for X-ray imaging

Signal processing

Types of signals

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

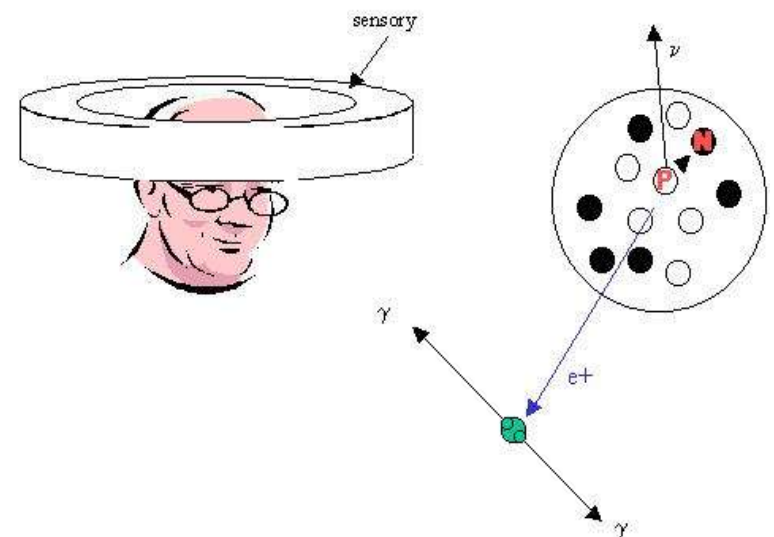
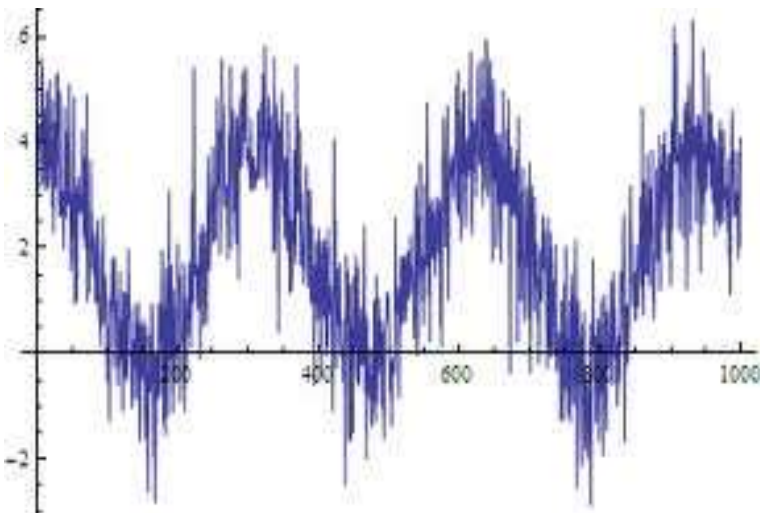
Digital signal processing (DSP)

Types of signals

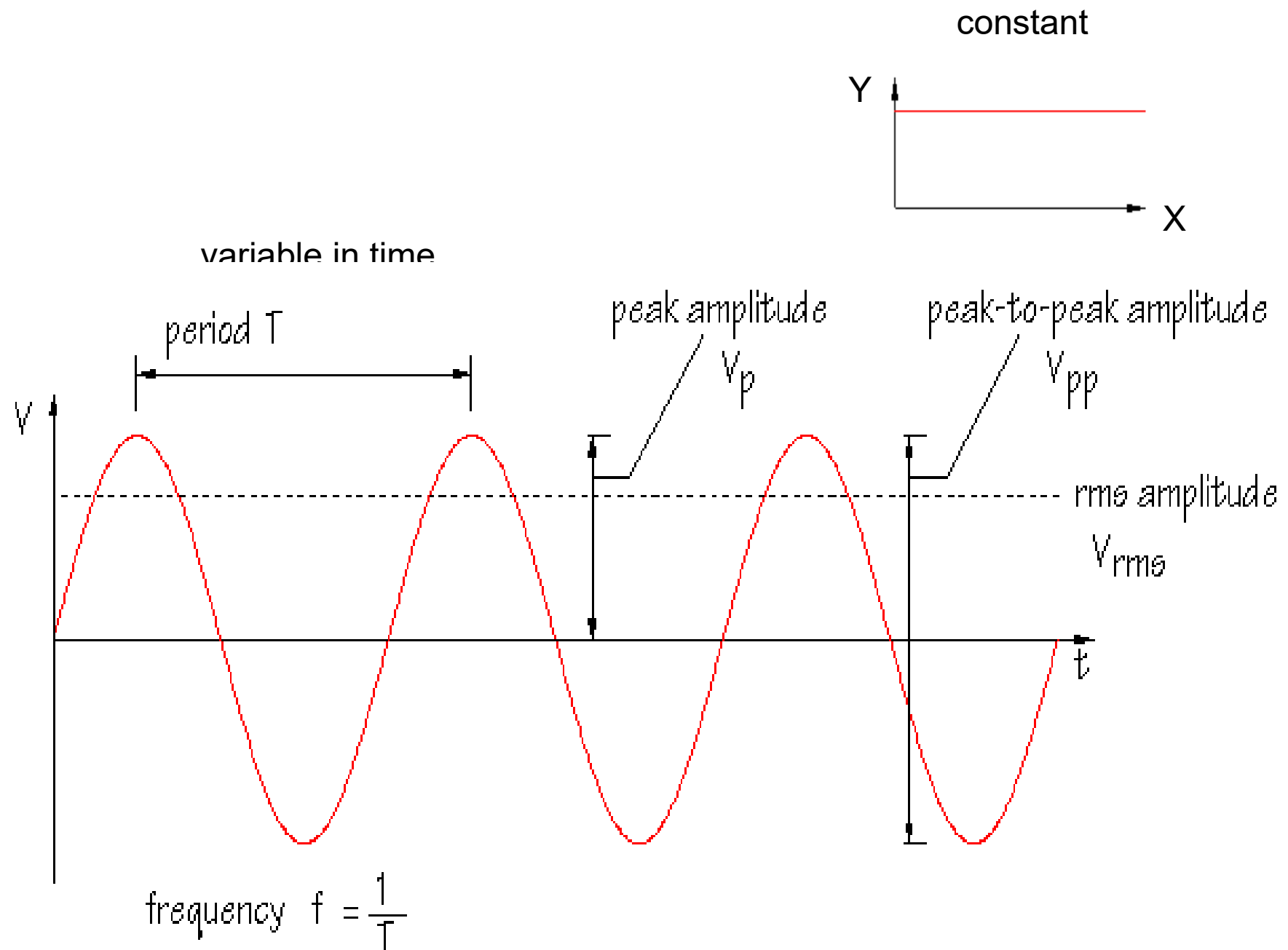
Electric



Not electric

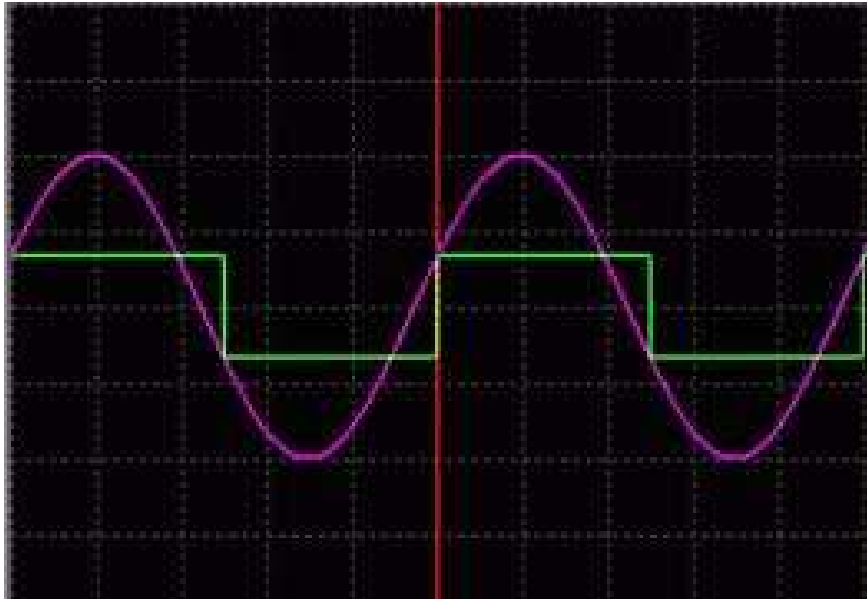


Types of signals

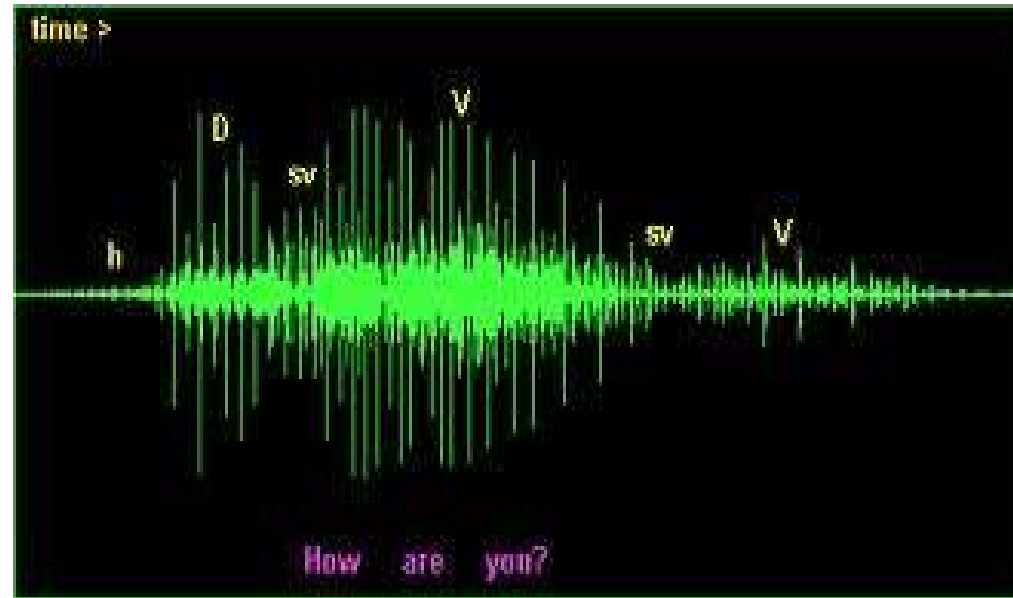


Types of signals

Periodic

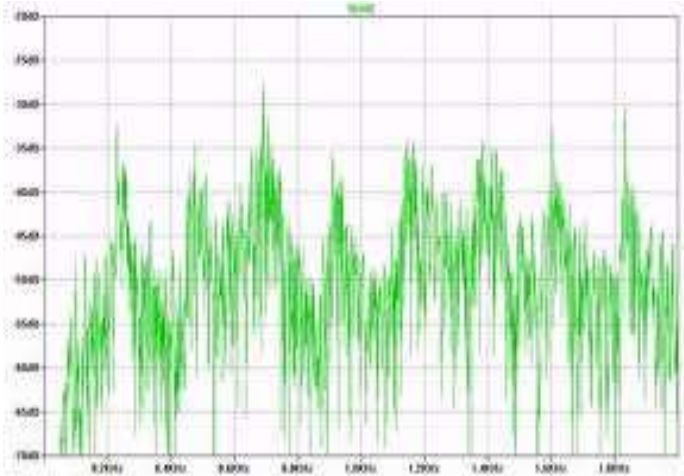


Not periodic

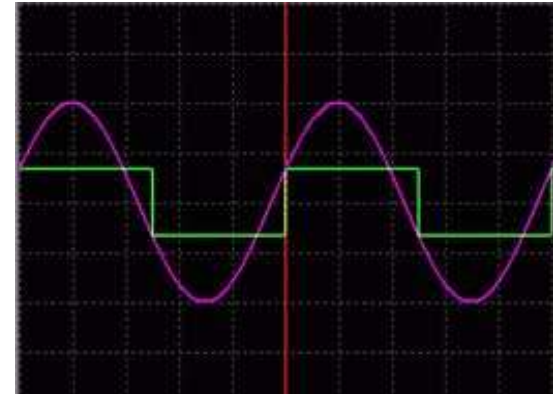


Types of signals

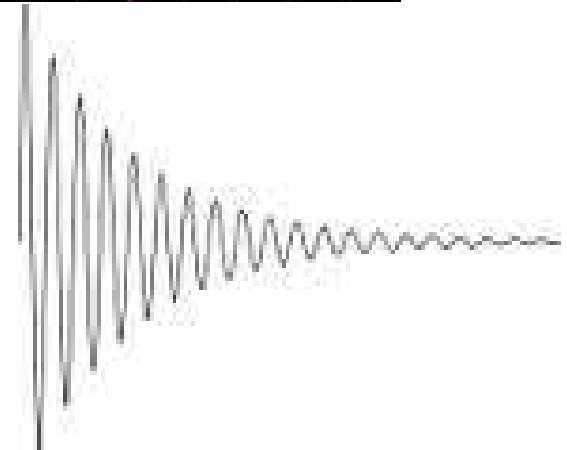
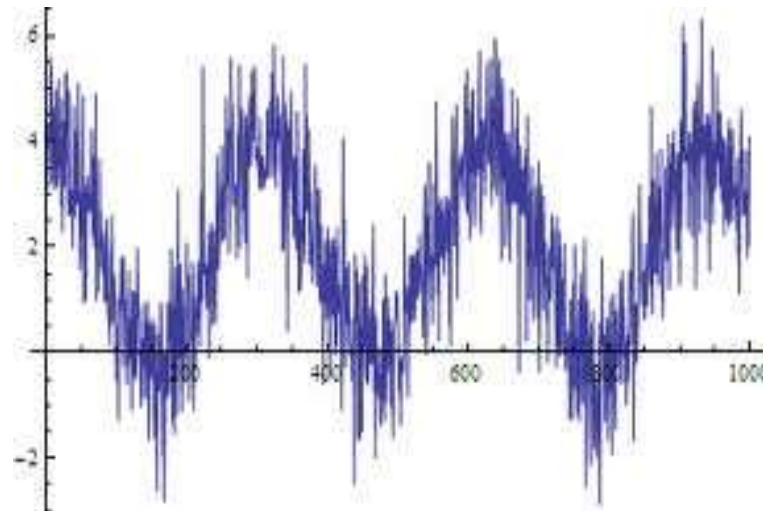
Random



Deterministic

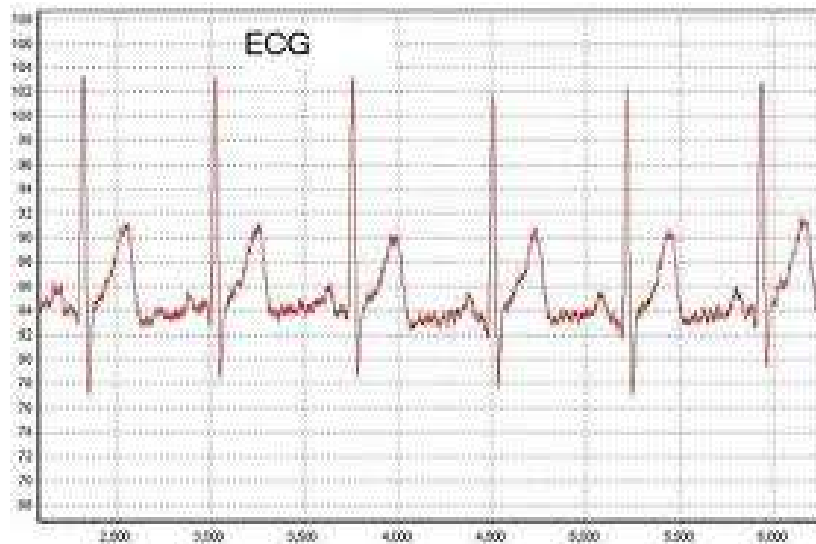
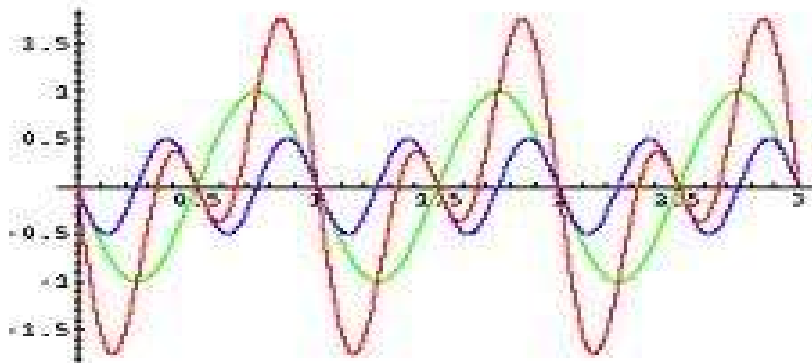


Mixed : most often!

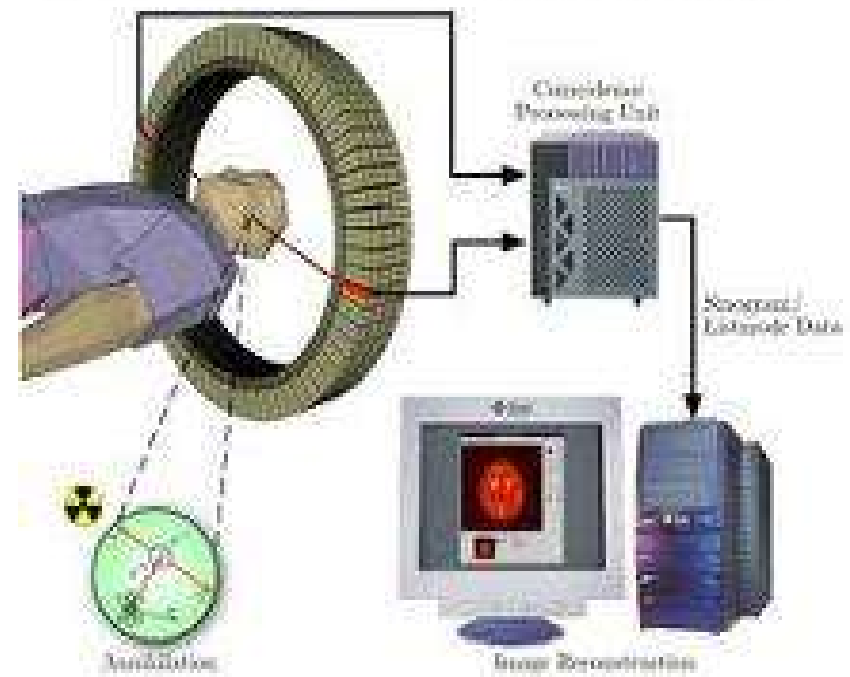
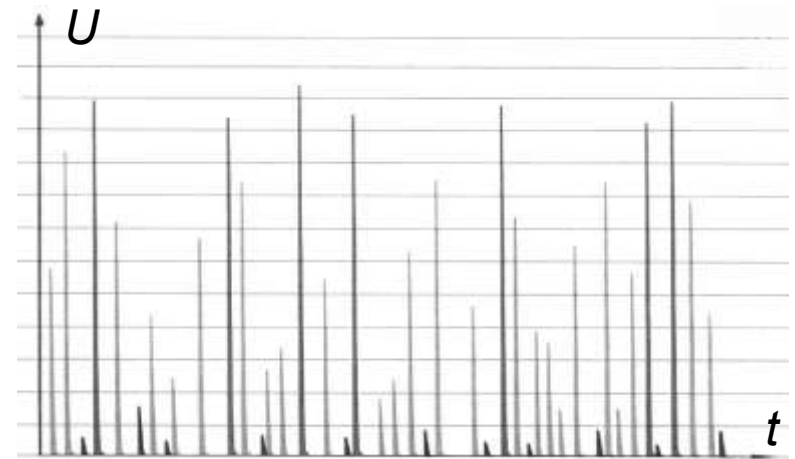


Types of signals

Continuous

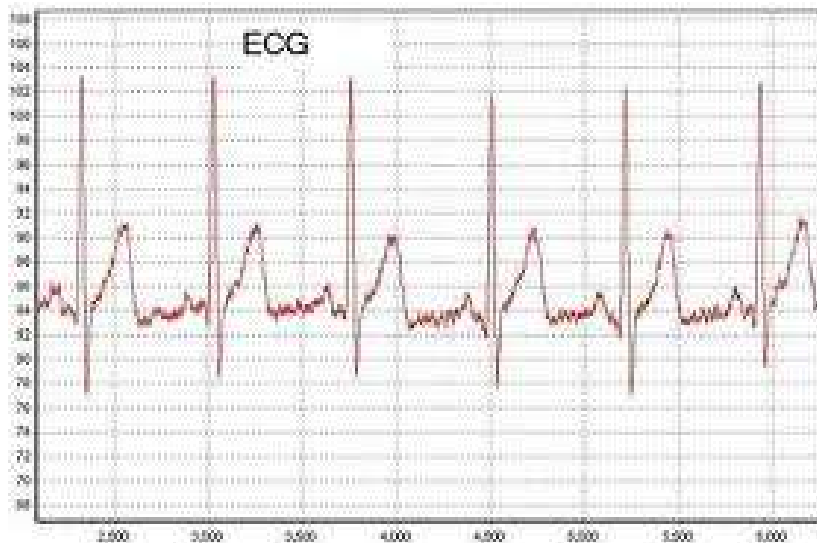


Pulses



Types of signals

Analog

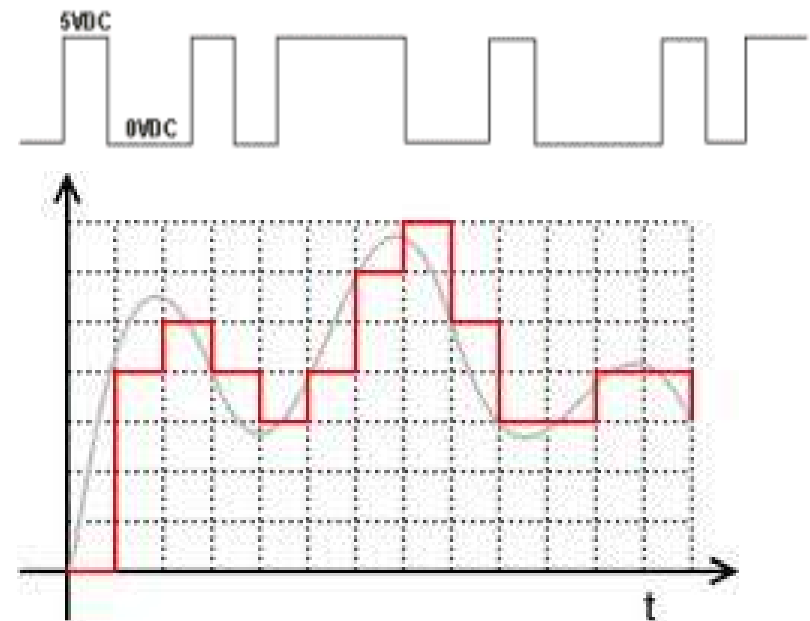


Theoretically unlimited resolution
in time and magnitude
(measurement system limit only)

Digital

1 0 0 1 0 1 1 1 0 0 1 0 0 0 1 0 1

Unipolar Coding ("1" = +V , "0" = 0V)



Digital: represented with numbers

Finite resolution

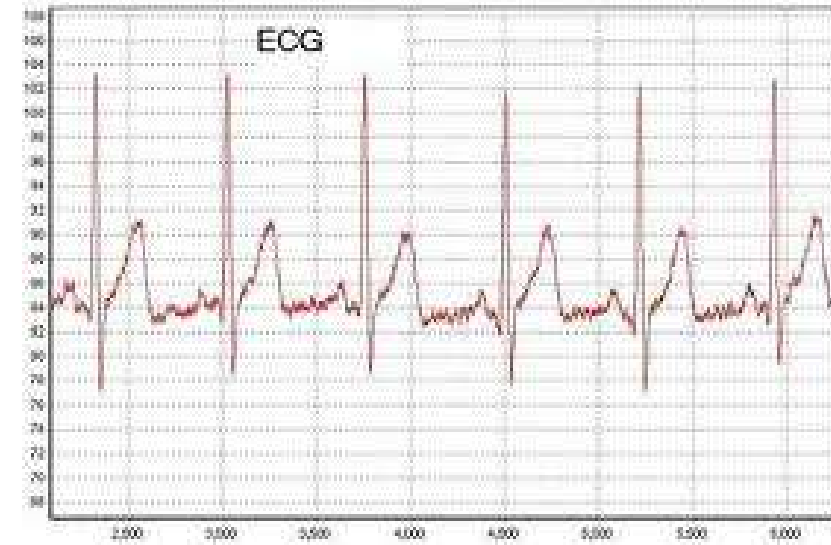
Digital signals are a form of
encoding : digital to electrical
electrical to d

Information content of signals

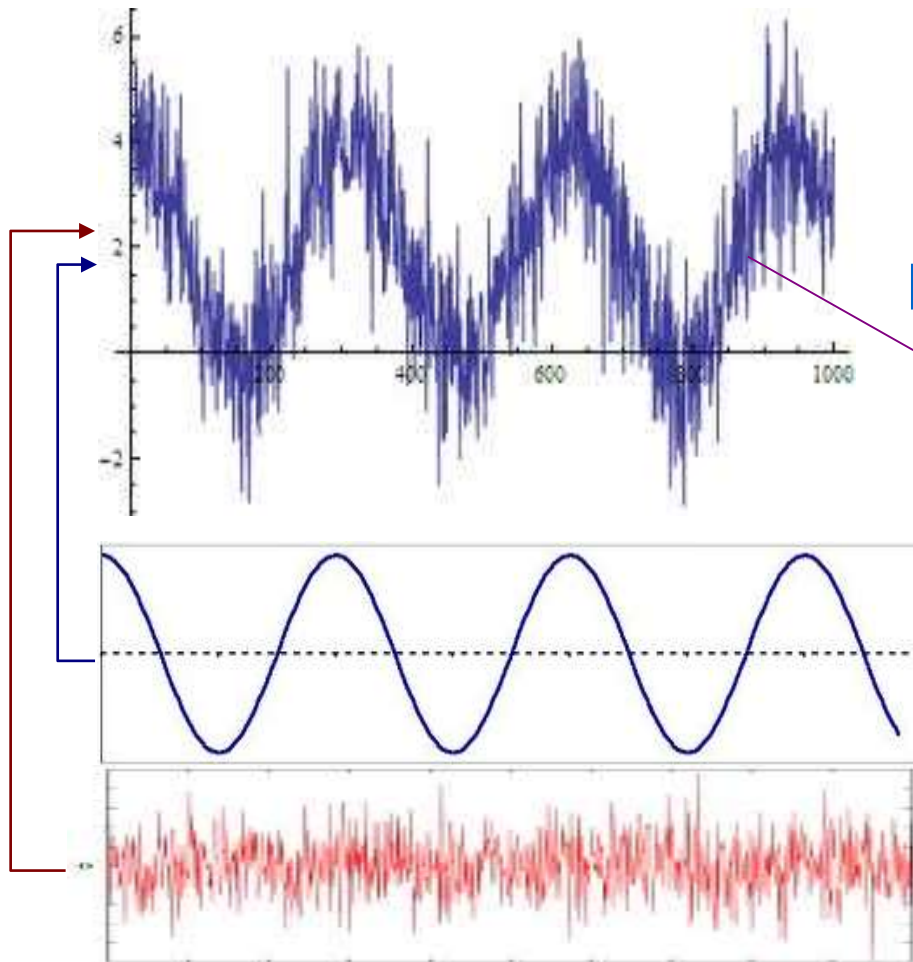
Analog signals – infinite information content?

Do we really need **unlimited** resolution?

Do we even **have** unlimited resolution in real-life analog signals?



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



No!

We always have a real signal as:

$$S = \text{Information} + \text{Noise}$$

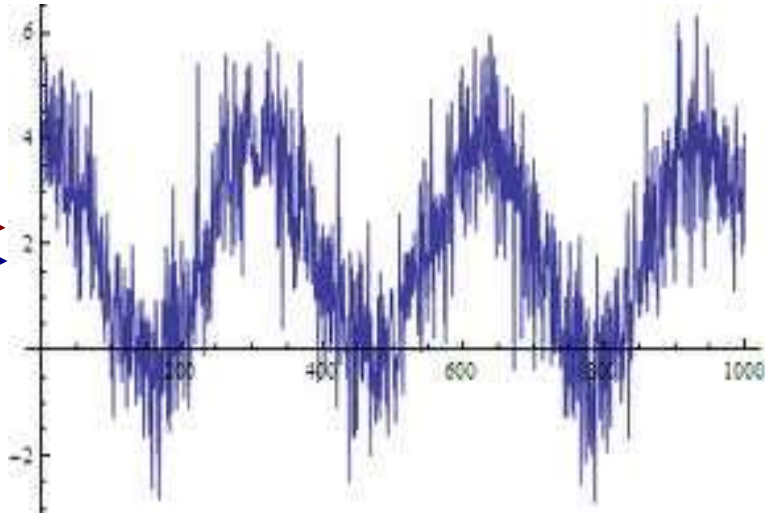
Information

+

Noise

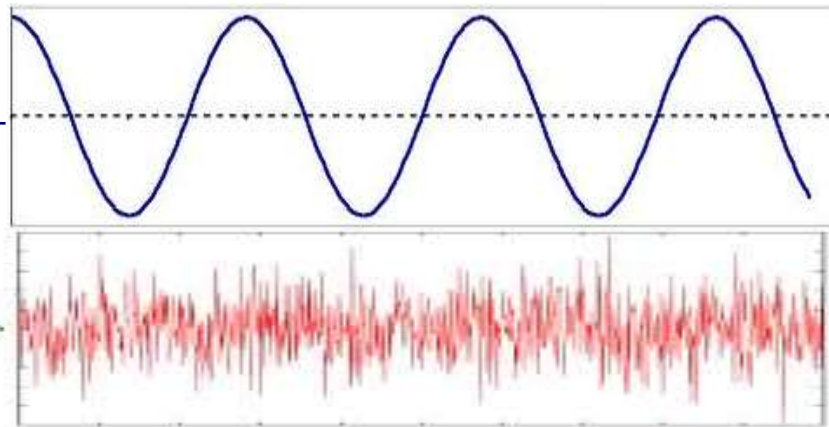
Information content of signals

Analog signals – infinite information content?



We have Information + Noise

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

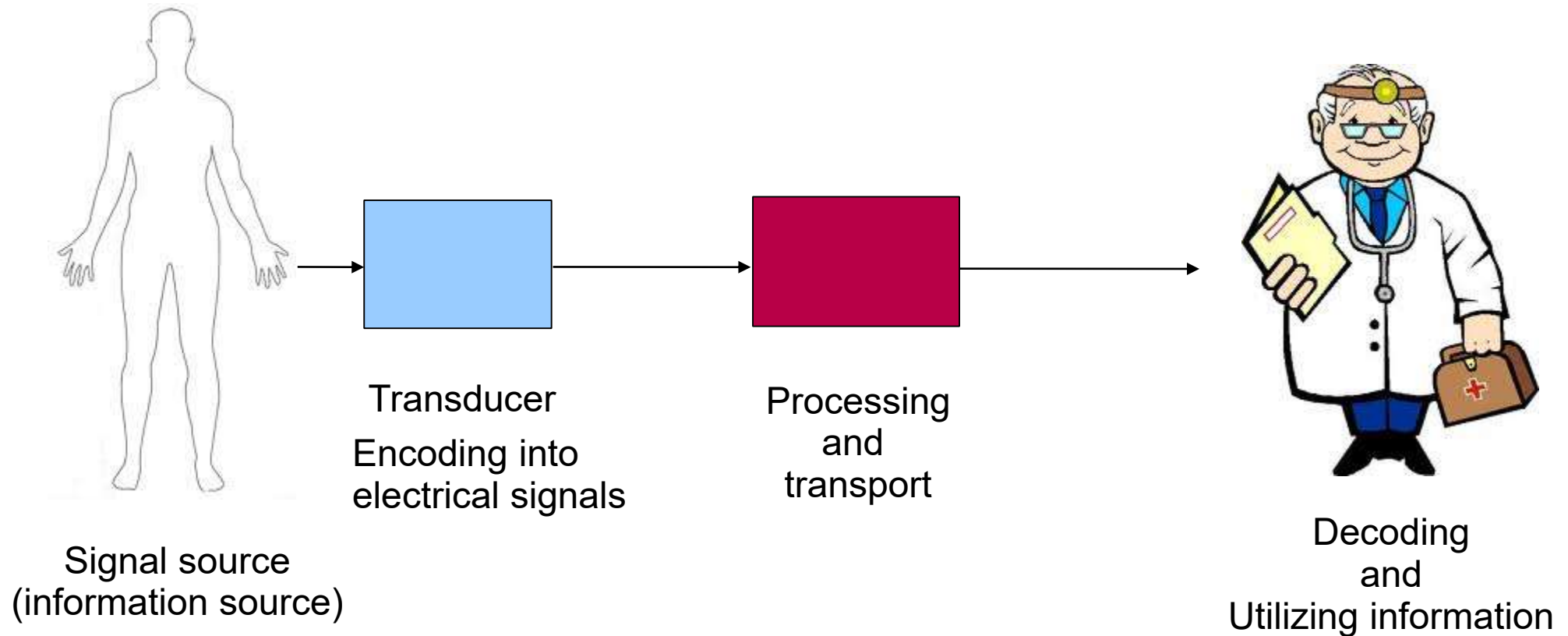


Information $U = A_{\text{inf}} \cdot \cos(\omega t + \phi)$

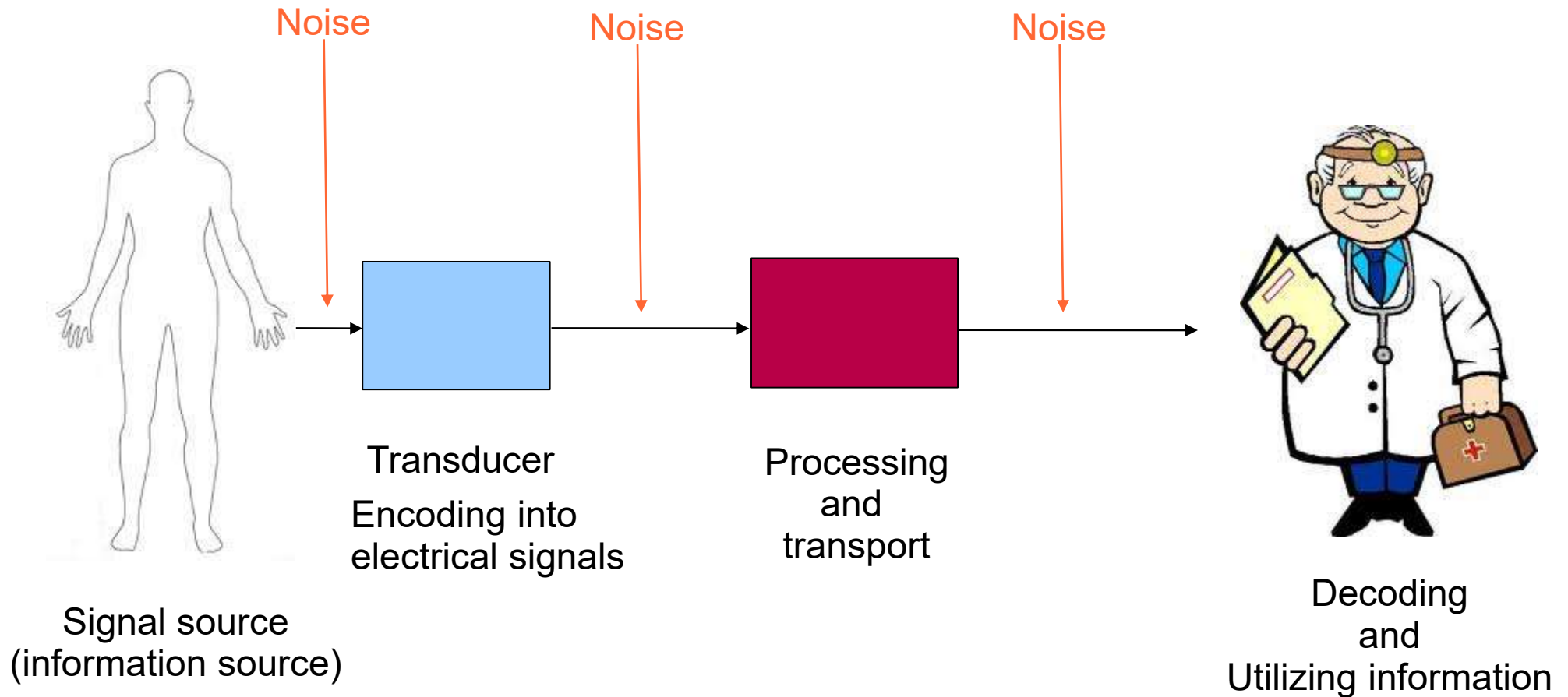
+

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

Transporting and processing signals

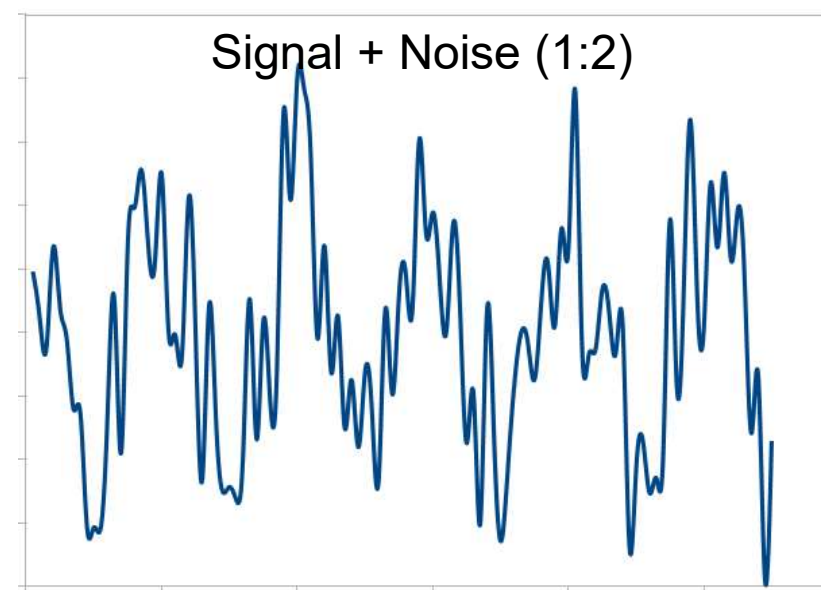
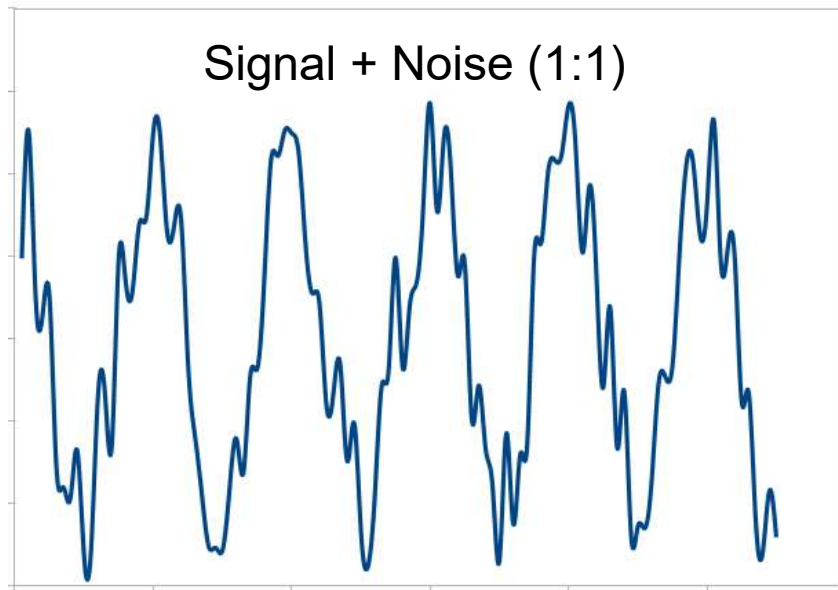
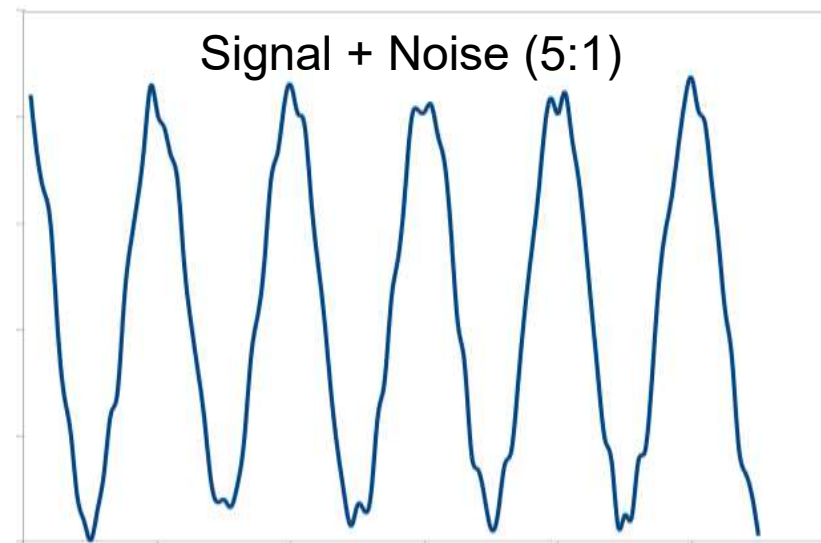
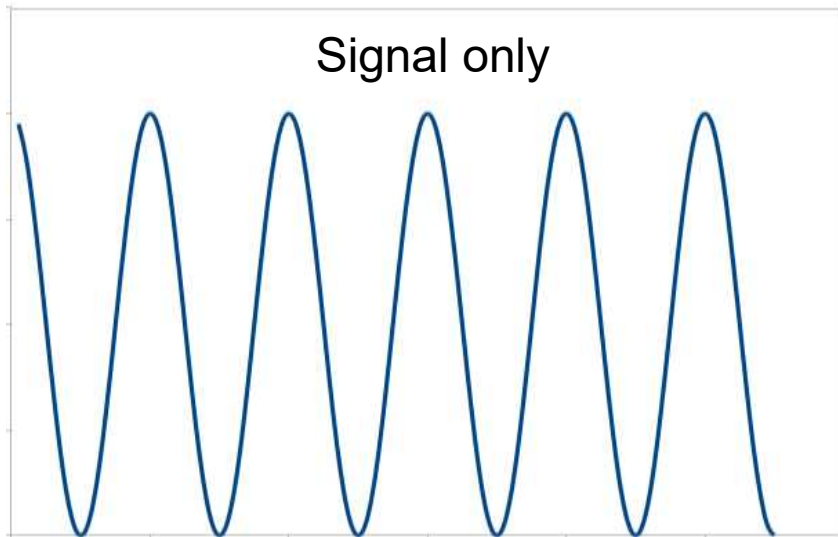


Transporting and processing signals



**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: Amplify the signal at the beginning!

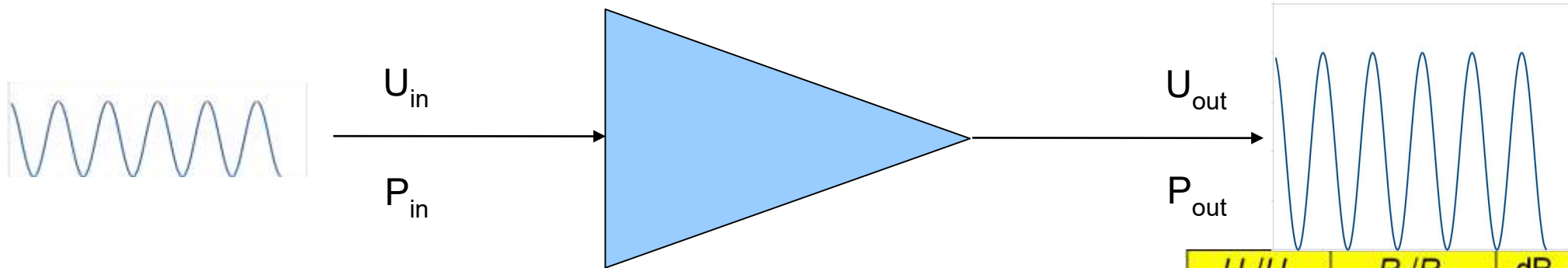
In real-life no amplifier is ideal, they always distort the signal

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



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

$$n = 10 \log \frac{P_{output}}{P_{input}} \quad [dB]$$

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

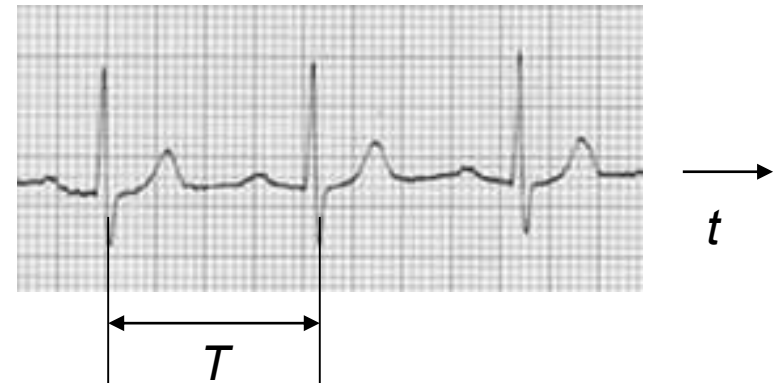
$$\frac{P_2}{P_1} = 10 \Rightarrow 10 \log 10 = 10 \text{ dB}$$

$$\frac{P_2}{P_1} = 100 \Rightarrow 10 \log 100 = 20 \text{ dB}$$

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

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



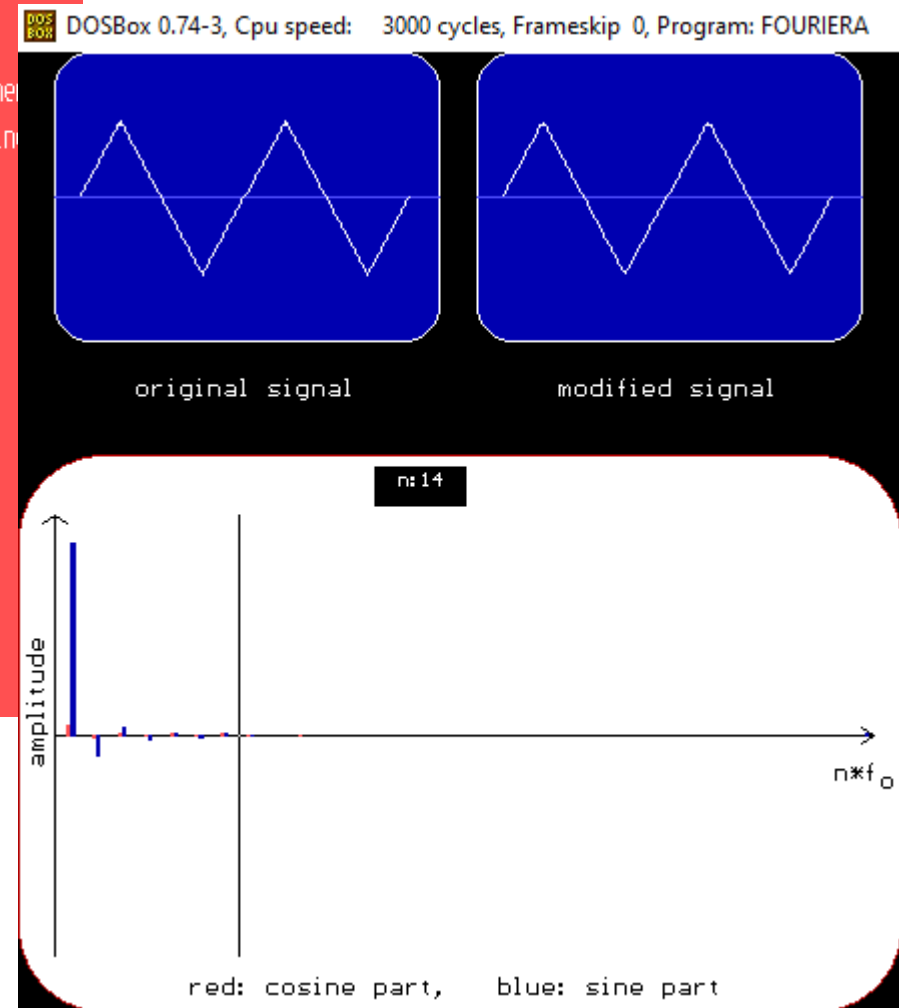
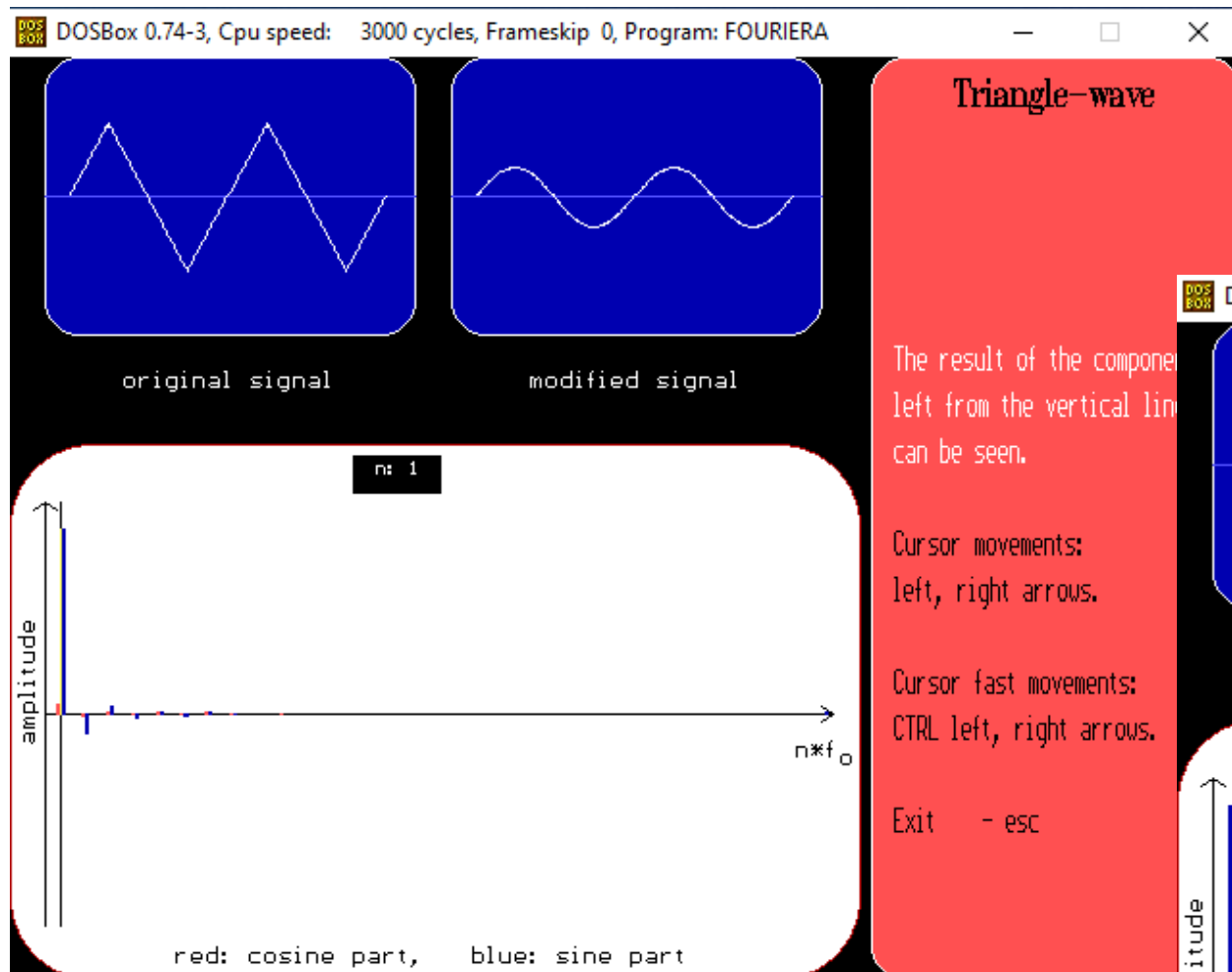
Where in the case of periodic signals $\omega_i = k \cdot f$, $f = 1/T$ and $k = 1, 2, 3, 4, 5, \dots$

Base frequency

overtones

Analysis of amplifiers - Fourier theorem

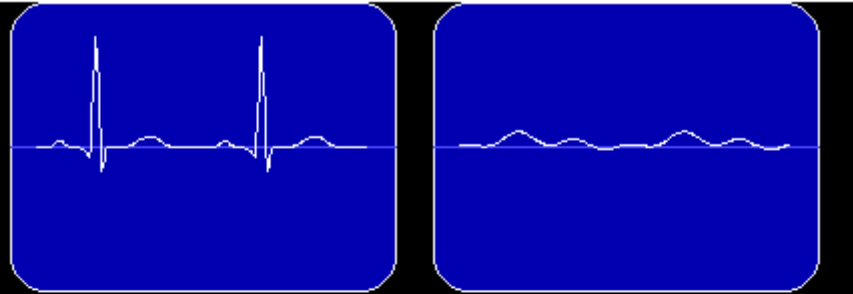
$$\text{Signal}(t) \leftrightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$



Analysis of amplifiers - Fourier theorem

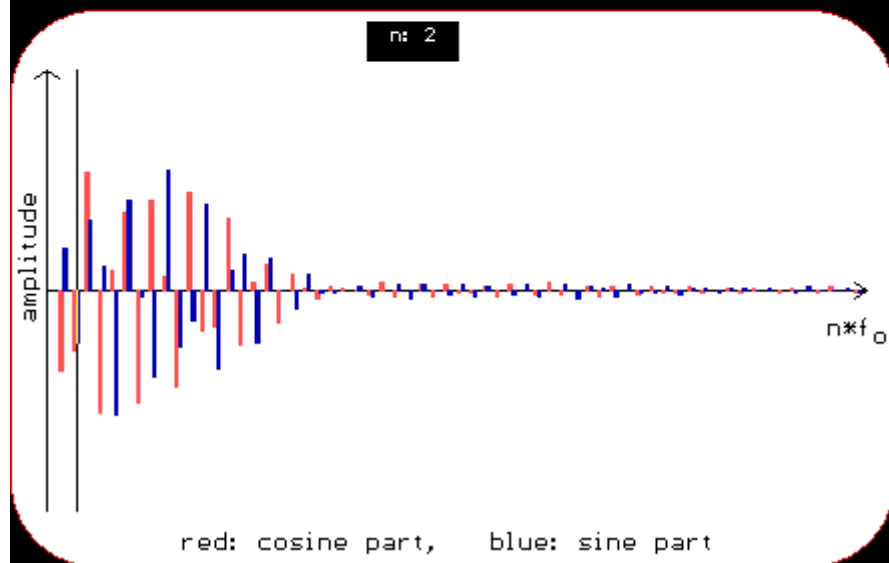
$$\text{Signal}(t) \leftrightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$

DOSBox 0.74-3, Cpu speed: 3000 cycles, Frameskip 0, Program: FOURIERA

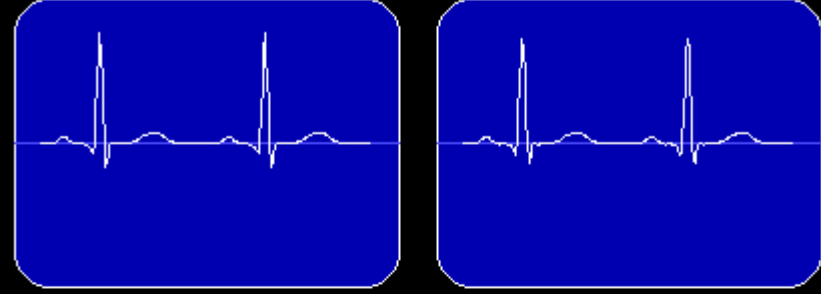


original signal

modified signal

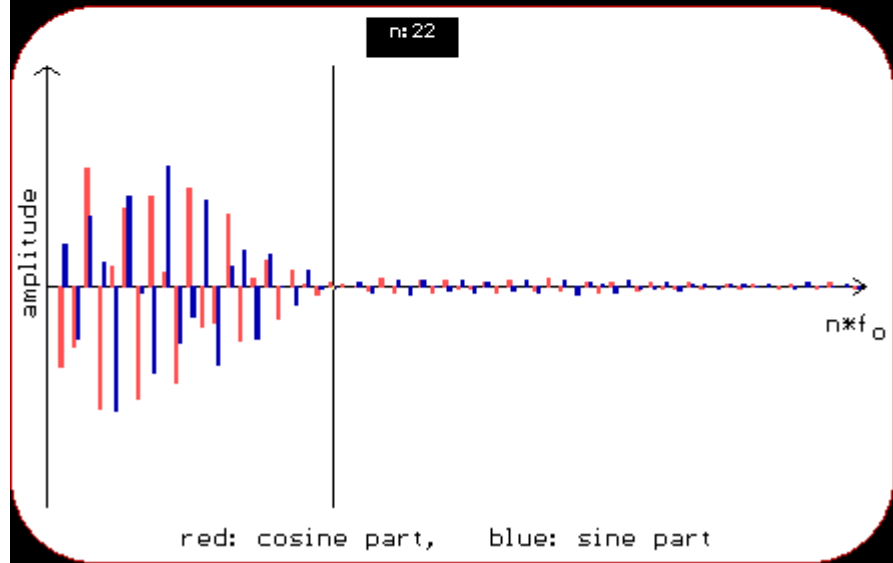


DOSBox 0.74-3, Cpu speed: 3000 cycles, Frameskip 0, Program: FOURIERA



original signal

modified signal

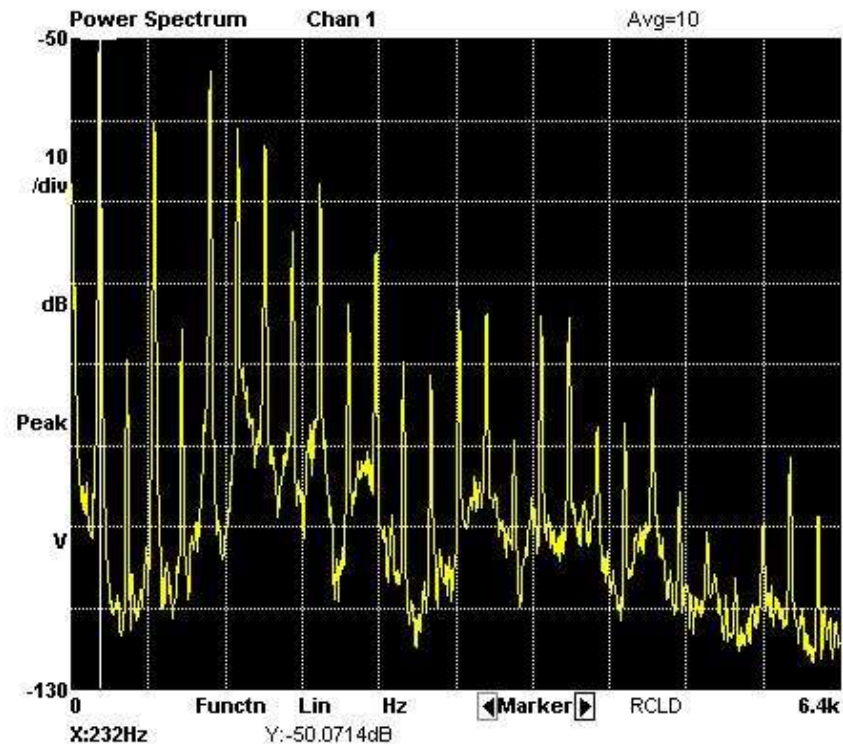
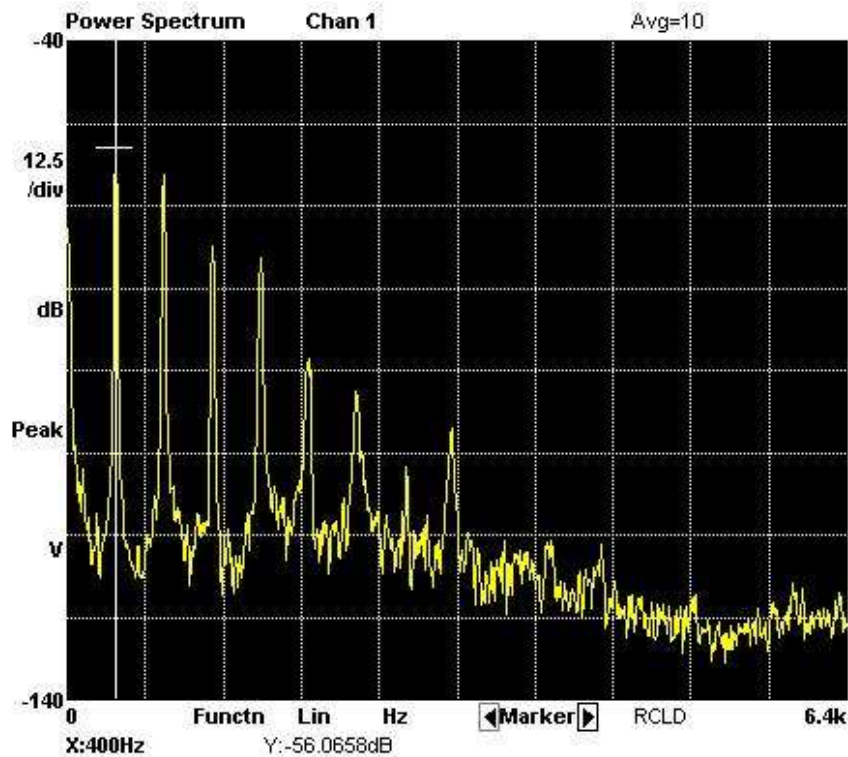


Analysis of amplifiers - Fourier theorem

$$\text{Signal}(t) \leftrightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$

Non-periodic signals: Fourier transform

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



Spectrum analysis

6kHz

5kHz

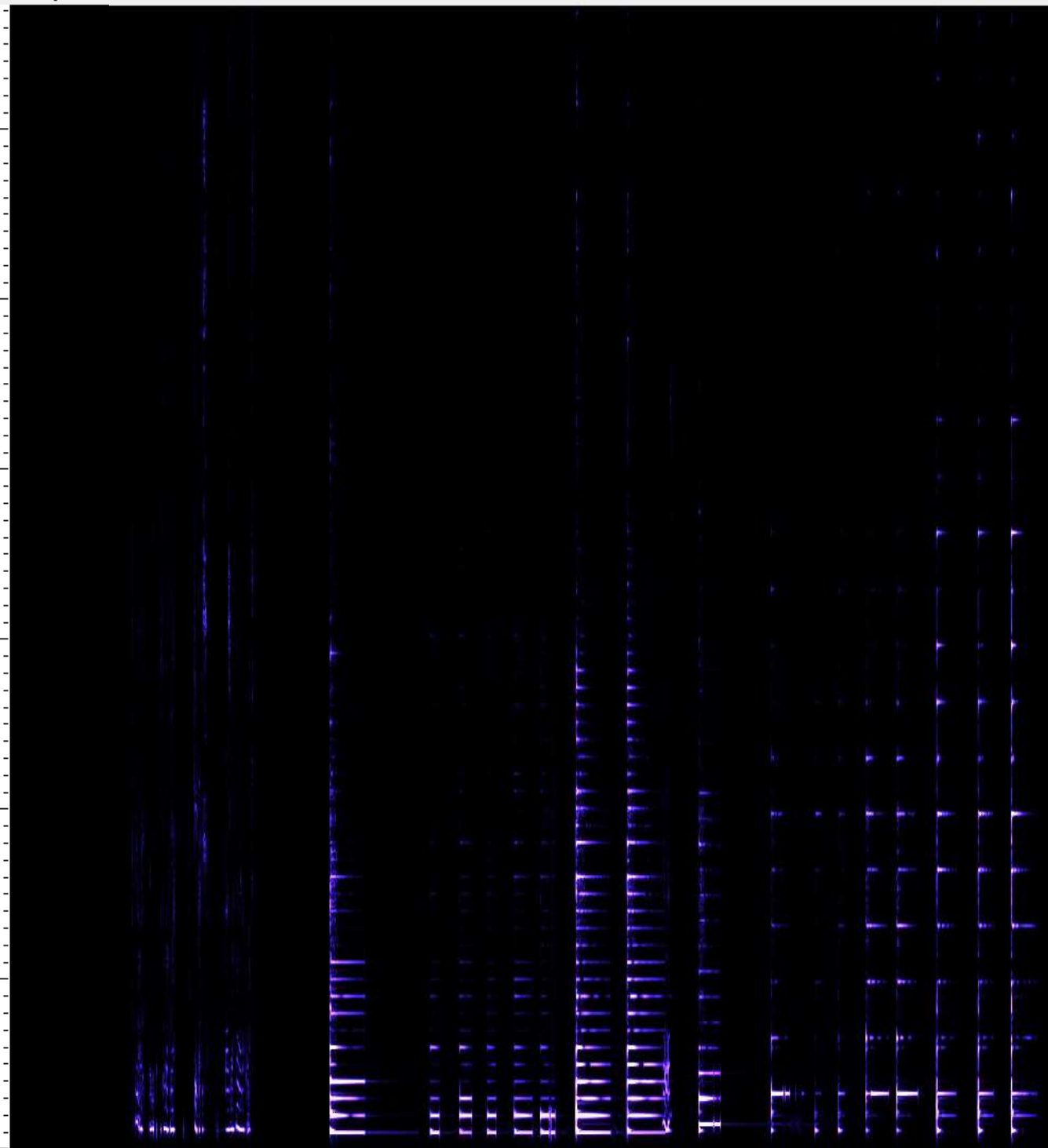
4kHz

3kHz

2kHz

1kHz

0kHz

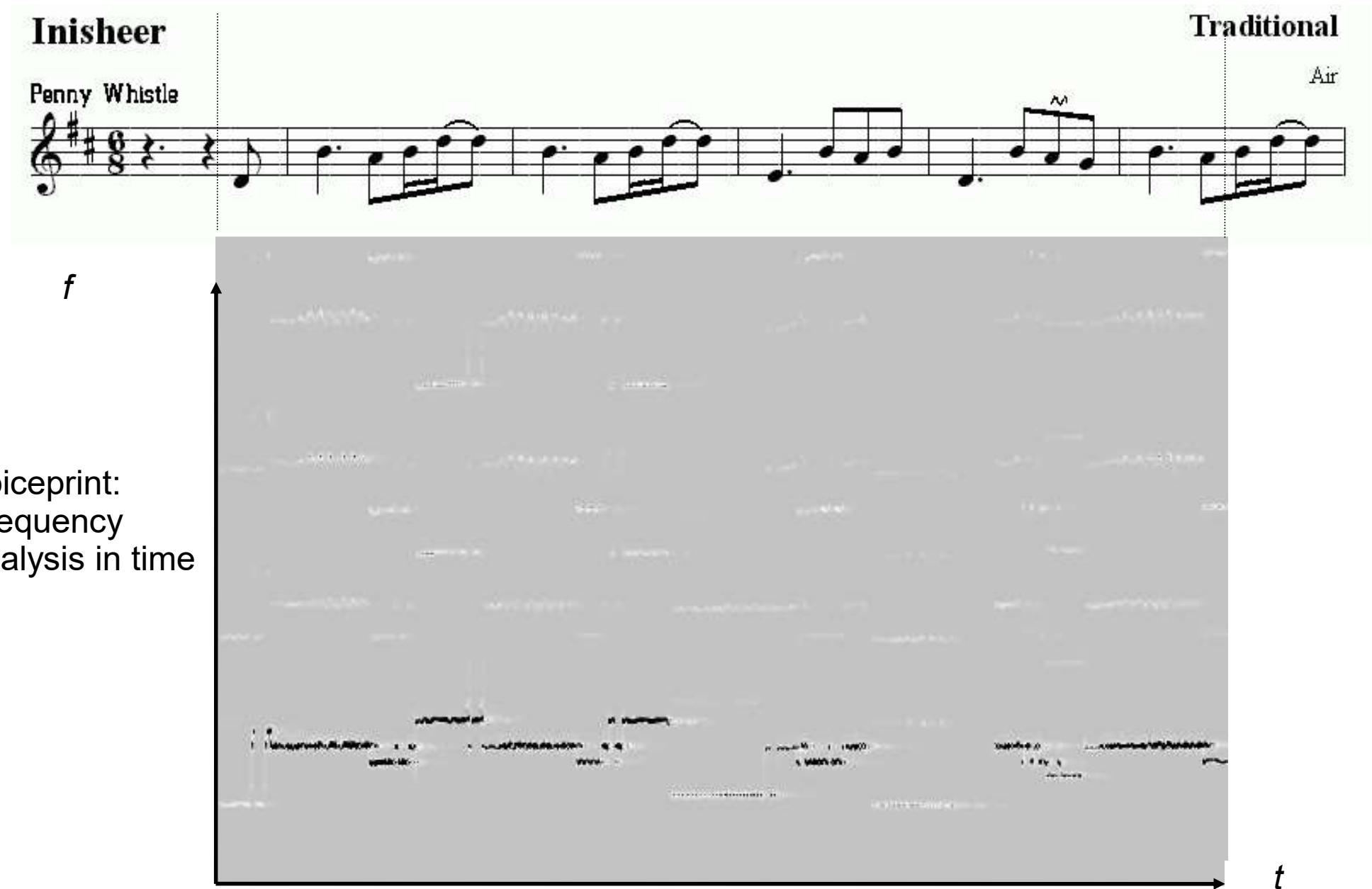


Analysis of amplifiers - Fourier theorem

$$\text{Signal}(t) \leftrightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$

Non-periodic signals: Fourier transform

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



Analysis of amplifiers - Fourier theorem

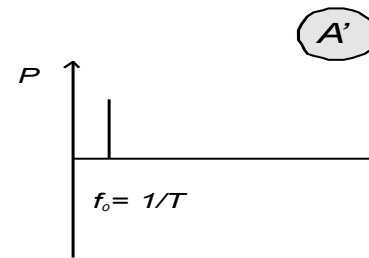
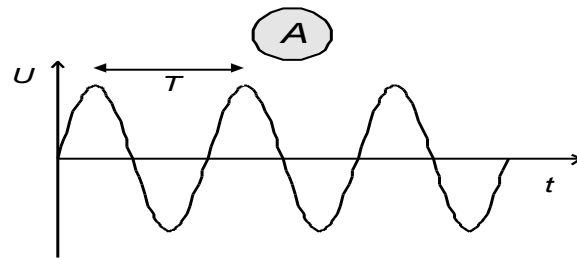
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Non-periodic signals: Fourier transform

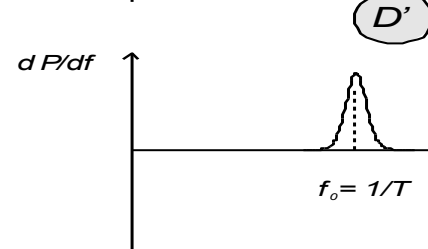
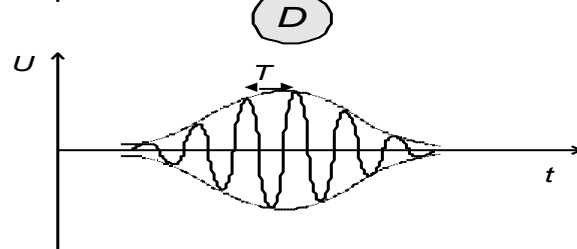
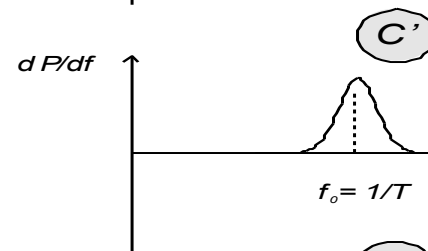
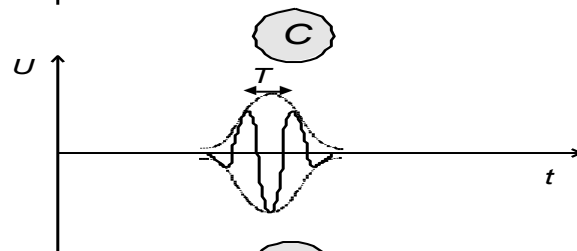
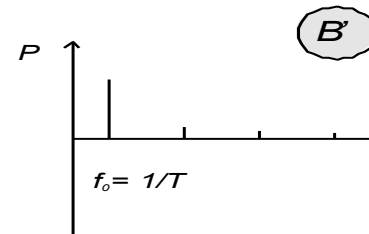
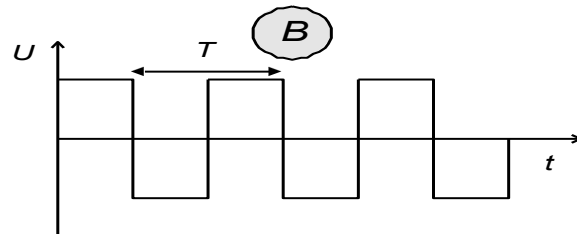
$$F(\omega) = \frac{1}{\sqrt{(2\pi)}} \cdot \int_{-\infty}^{+\infty} f(t) e^{i\omega t} dt$$

Signal in time

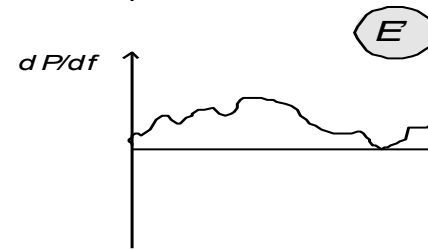
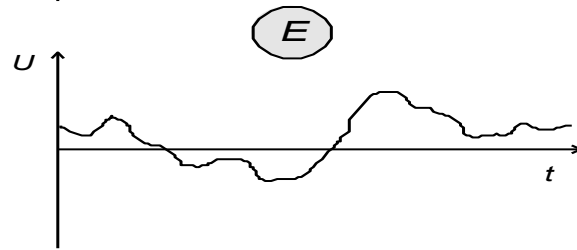
Signal in frequency



Infinite sine wave has a single line as spectrum



Longer sine-signal has narrower spectrum



Analysis of amplifiers - Fourier theorem

Non-periodic signals: Fourier transform

$$\text{Signal}(t) \leftrightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$
$$F(\omega) = \frac{1}{\sqrt{2\pi}} \cdot \int_{-\infty}^{+\infty} f(t) e^{i\omega t} dt$$

Any signal is just a representation of information

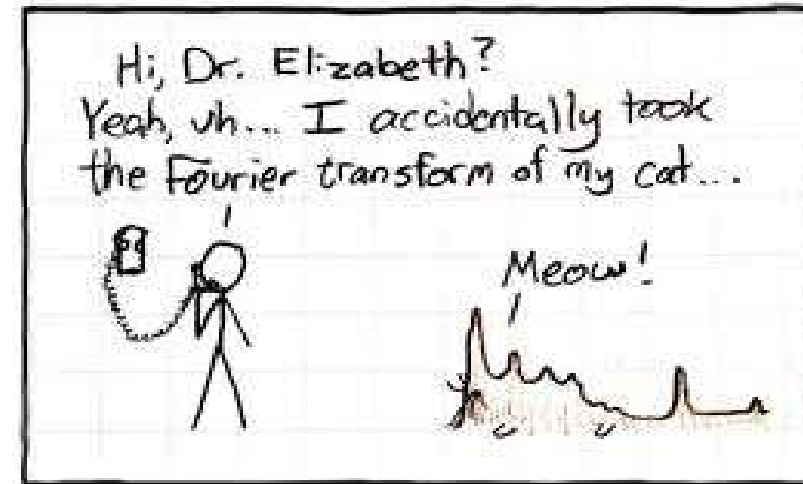
We can have many pictures of the same

Time-based (more conventional)

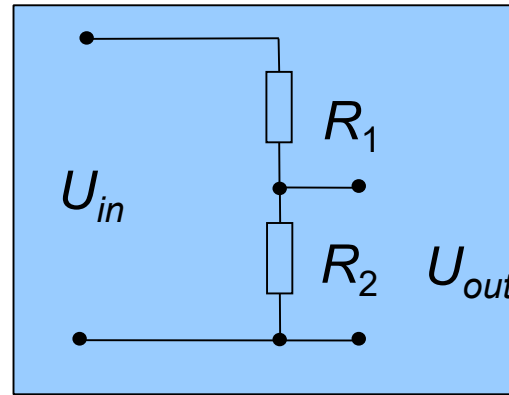
or

Frequency-based
(useful, but a bit abstract)

Fourier-transform is the „art of engineering”
(Picasso: La Crucifixion)

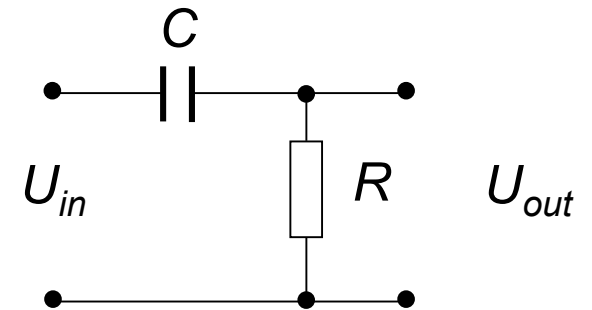
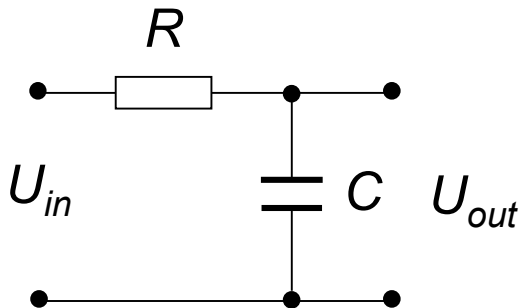
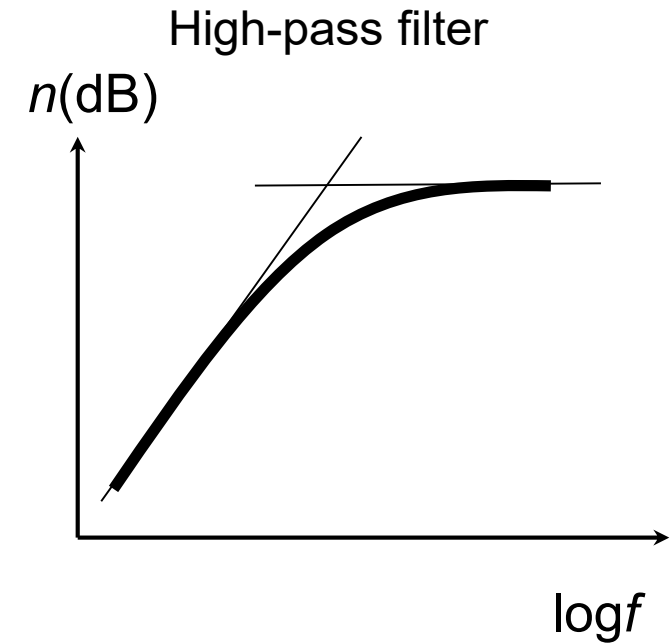
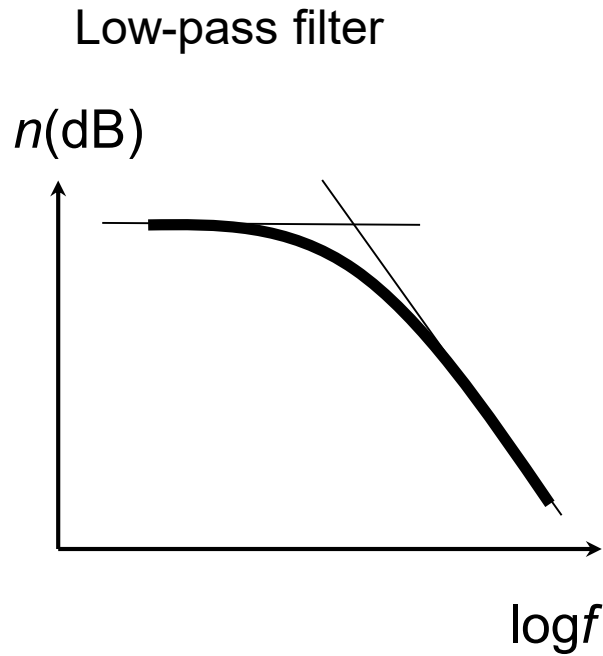


Analysis of amplifiers - Transfer function of filters

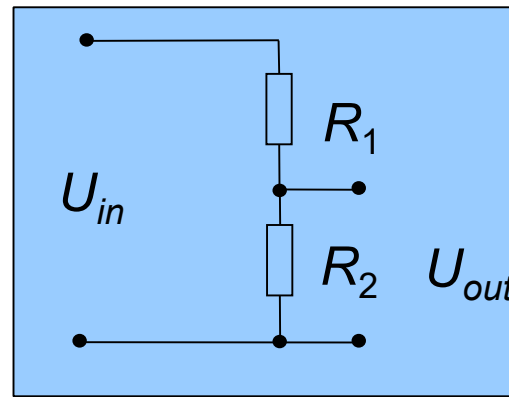


$$U_{output} = U_{input} \cdot \frac{R_2}{R_1 + R_2}$$

Substitute one R with C



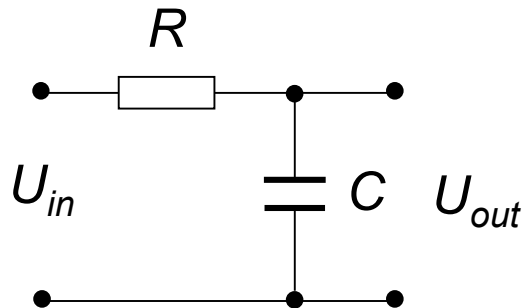
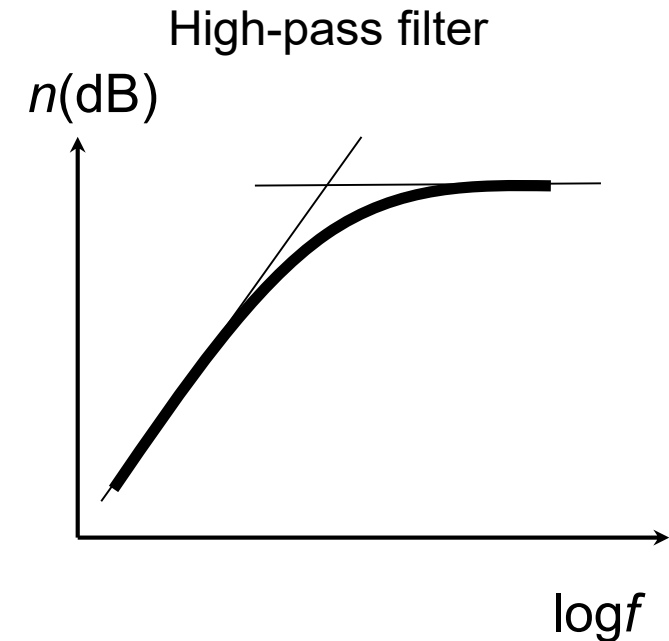
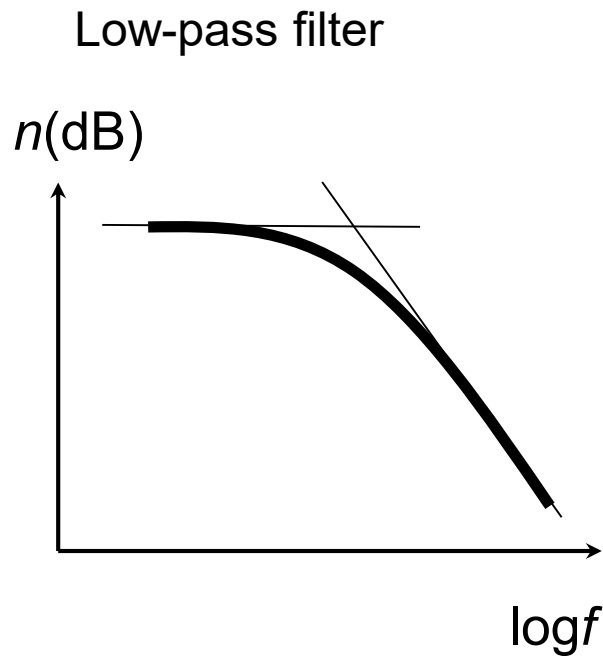
Analysis of amplifiers - Transfer function of filters



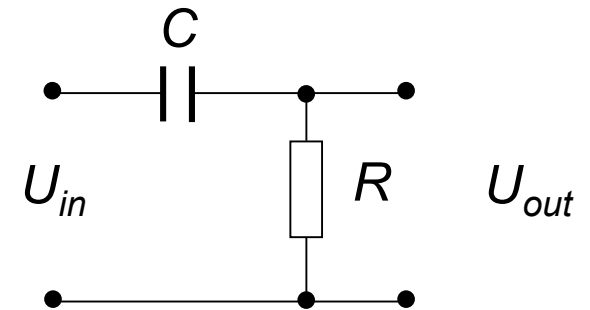
$$U_{output} = U_{input} \cdot \frac{R_2}{R_1 + R_2}$$

Substitute one R with C

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

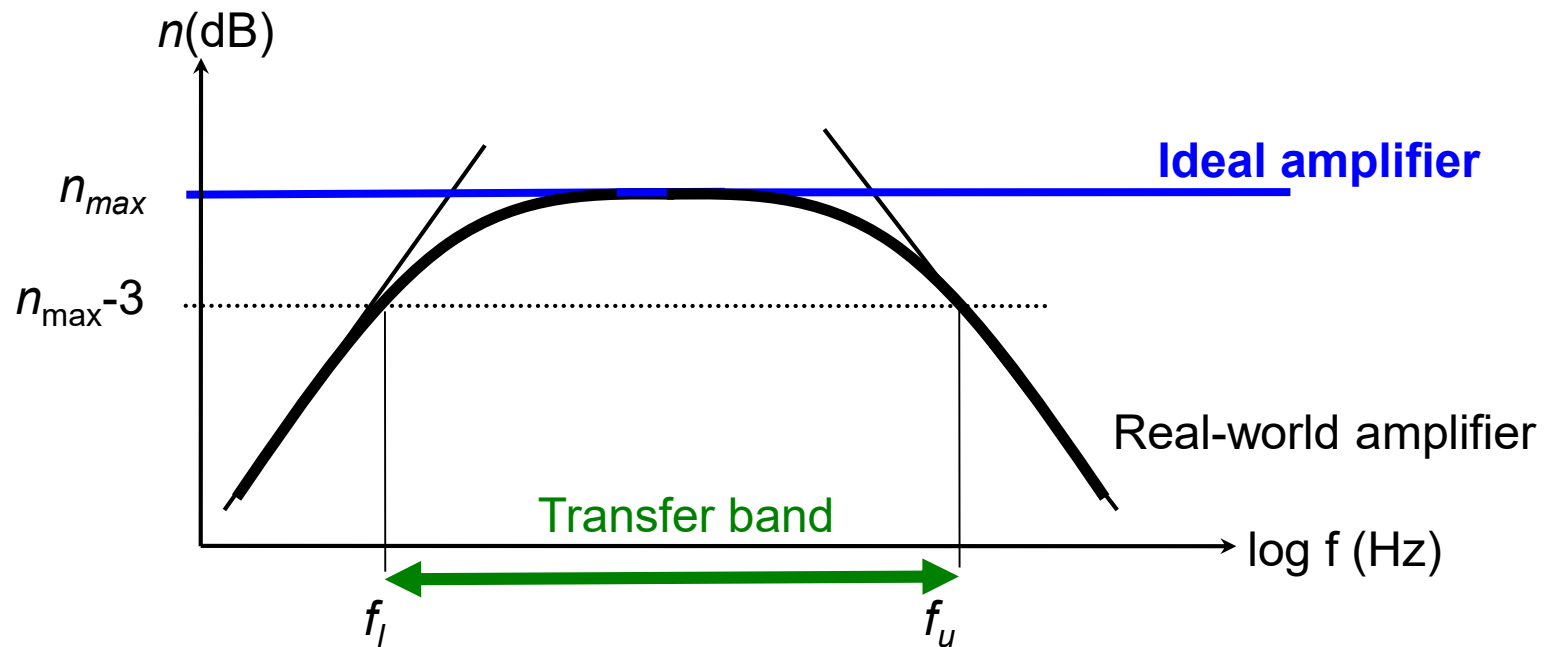
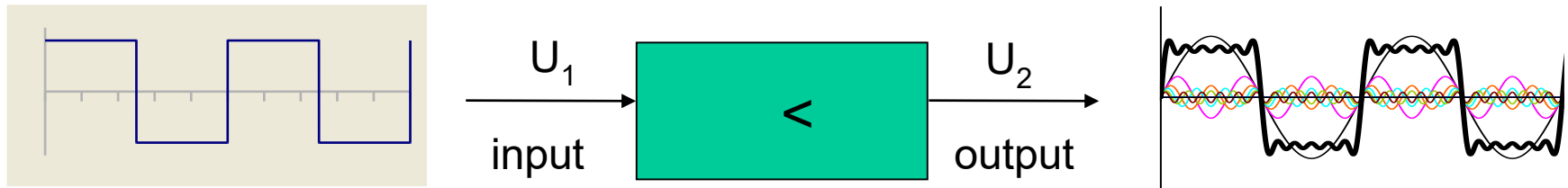


$$U_{out} = \frac{1}{\sqrt{1 + R^2 C^2 \omega^2}} \cdot U_{input}$$



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

Analysis of amplifiers - Transfer function of amplifiers



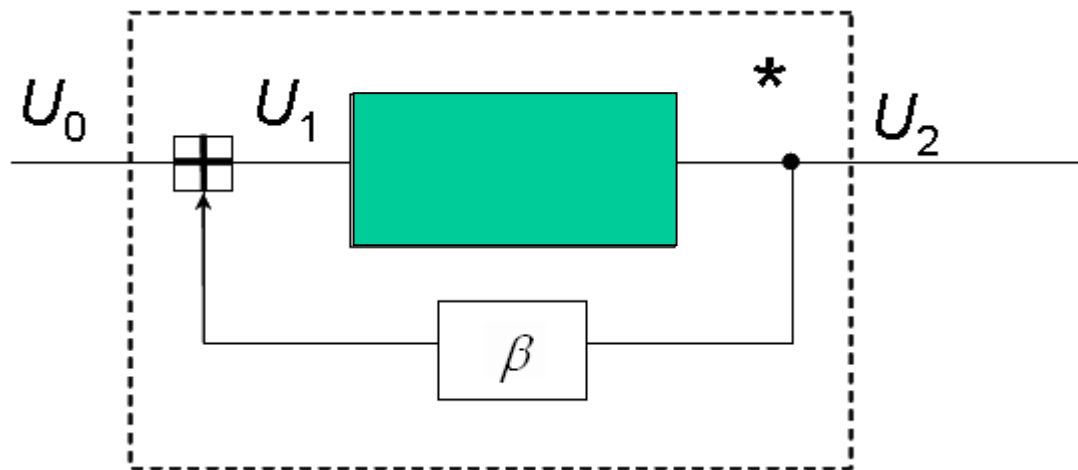
Amplifiers are not ideal, they have input and output capacitance, etc.

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

Amplifier gain

$$A = \frac{U_2}{U_1}$$

$$A = \frac{U_2}{U_0 - U_2 \beta}$$

$$A(1 + \beta A) = \frac{A}{1 - \beta A}$$

$$A^* = \frac{A}{1 - \beta A}$$

Gain with feedback circuit

$\beta > 0$: positive feedback

$\beta < 0$: negative feedback

$A_u \beta = 1$: oscillator (output without input signal: signal generator)

Analysis of amplifiers - Transfer function of amplifiers

Gain Bandwidth Product

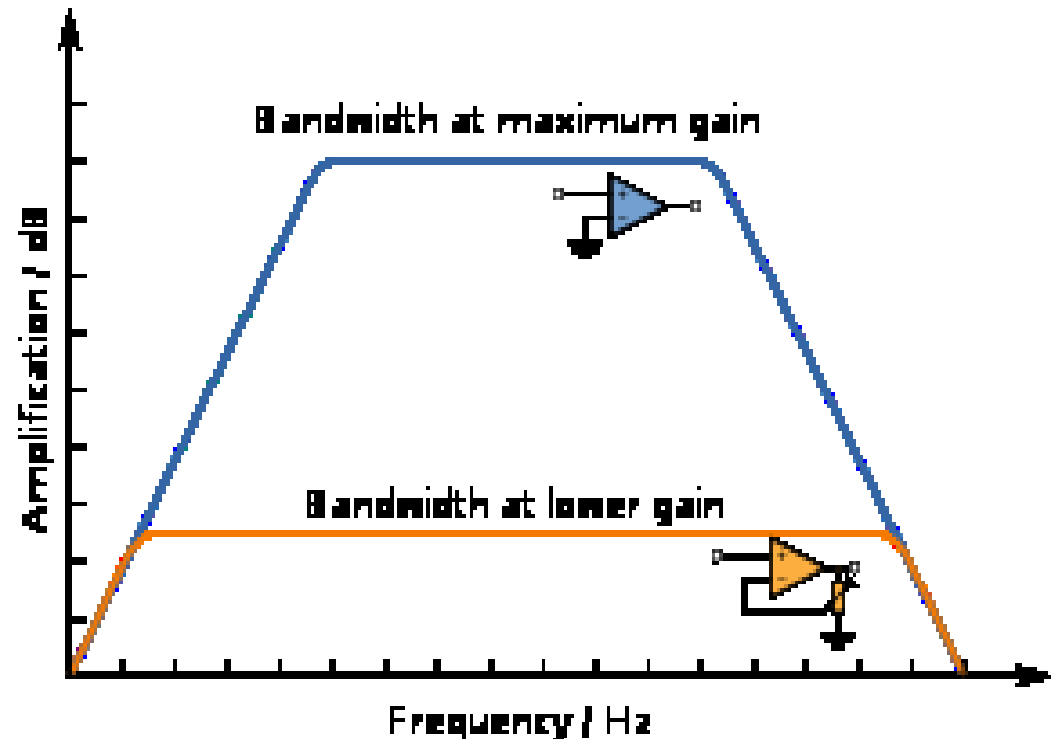
$$\text{Gain} \cdot \text{Bandwidth} = \text{constant}$$

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

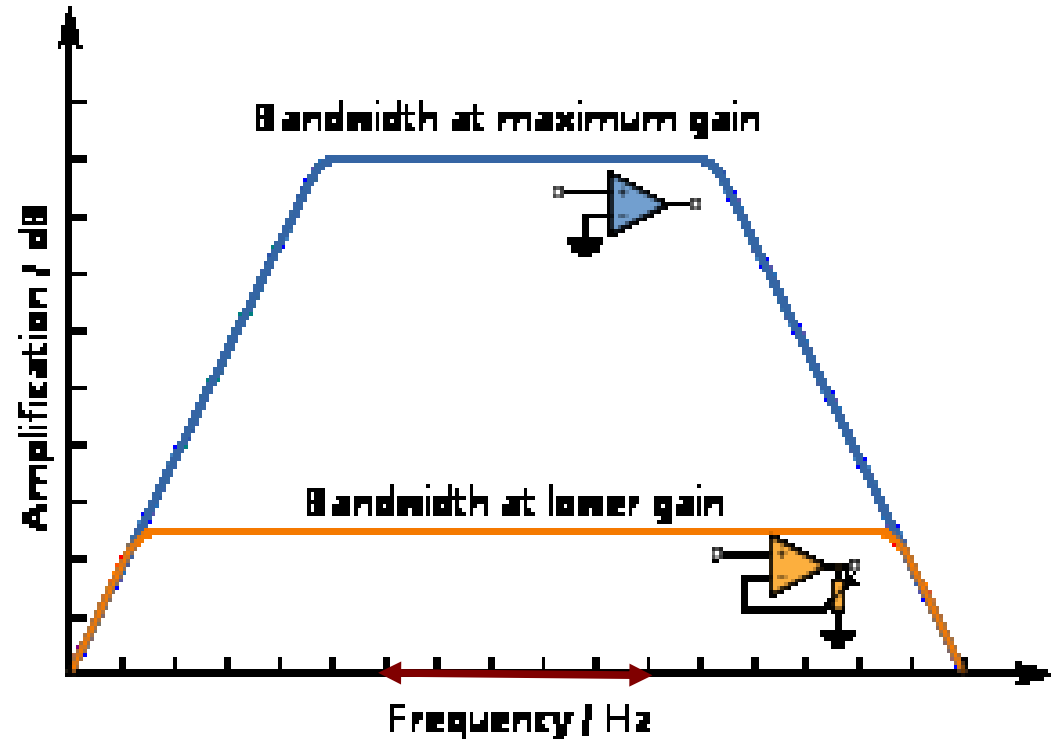
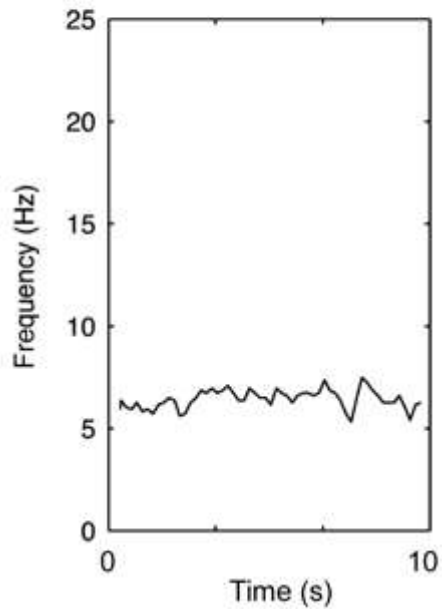
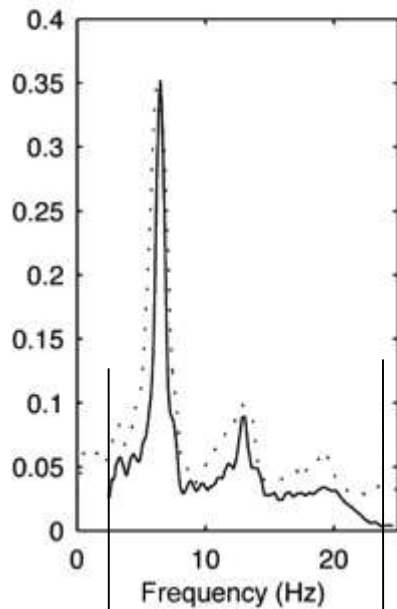
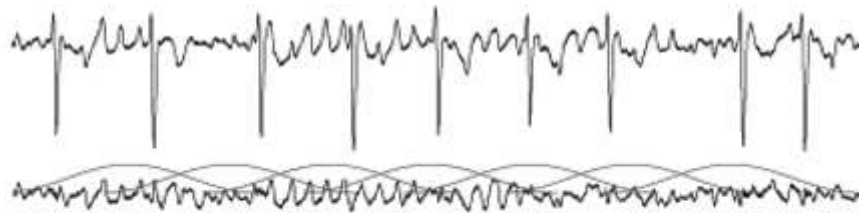
high signal gain over a limited bandwidth

or

limited gain over a wide bandwidth.



Analysis of amplifiers - Transfer function of amplifiers



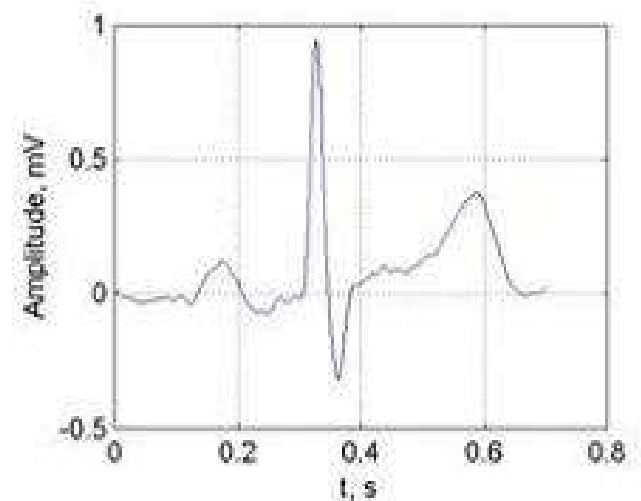
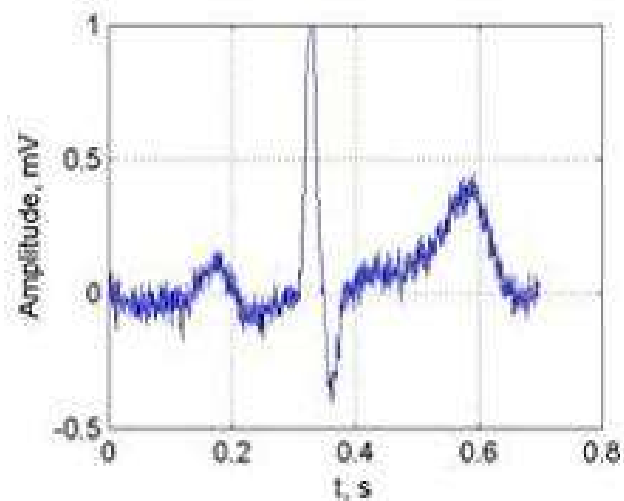
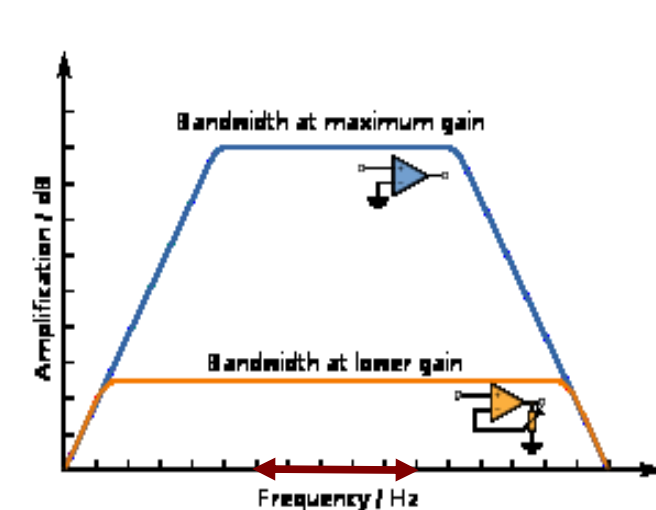
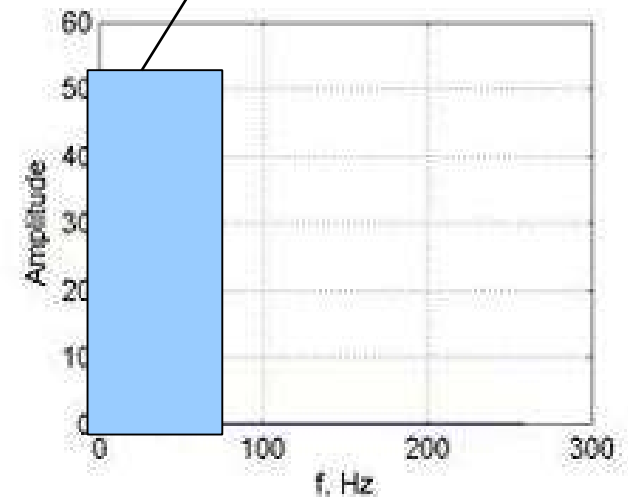
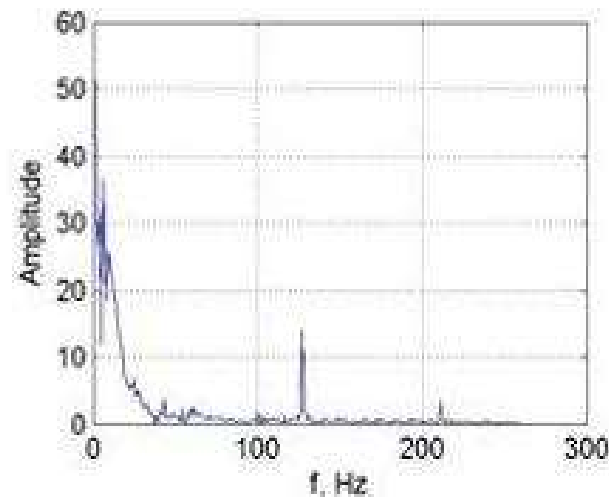
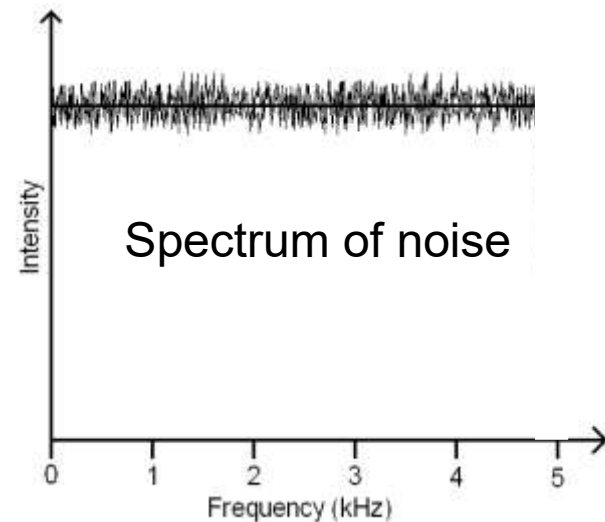
Frequency range of the signal must match the bandwidth!

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 contains the information!



Digital signals – A/D conversion (ADC)

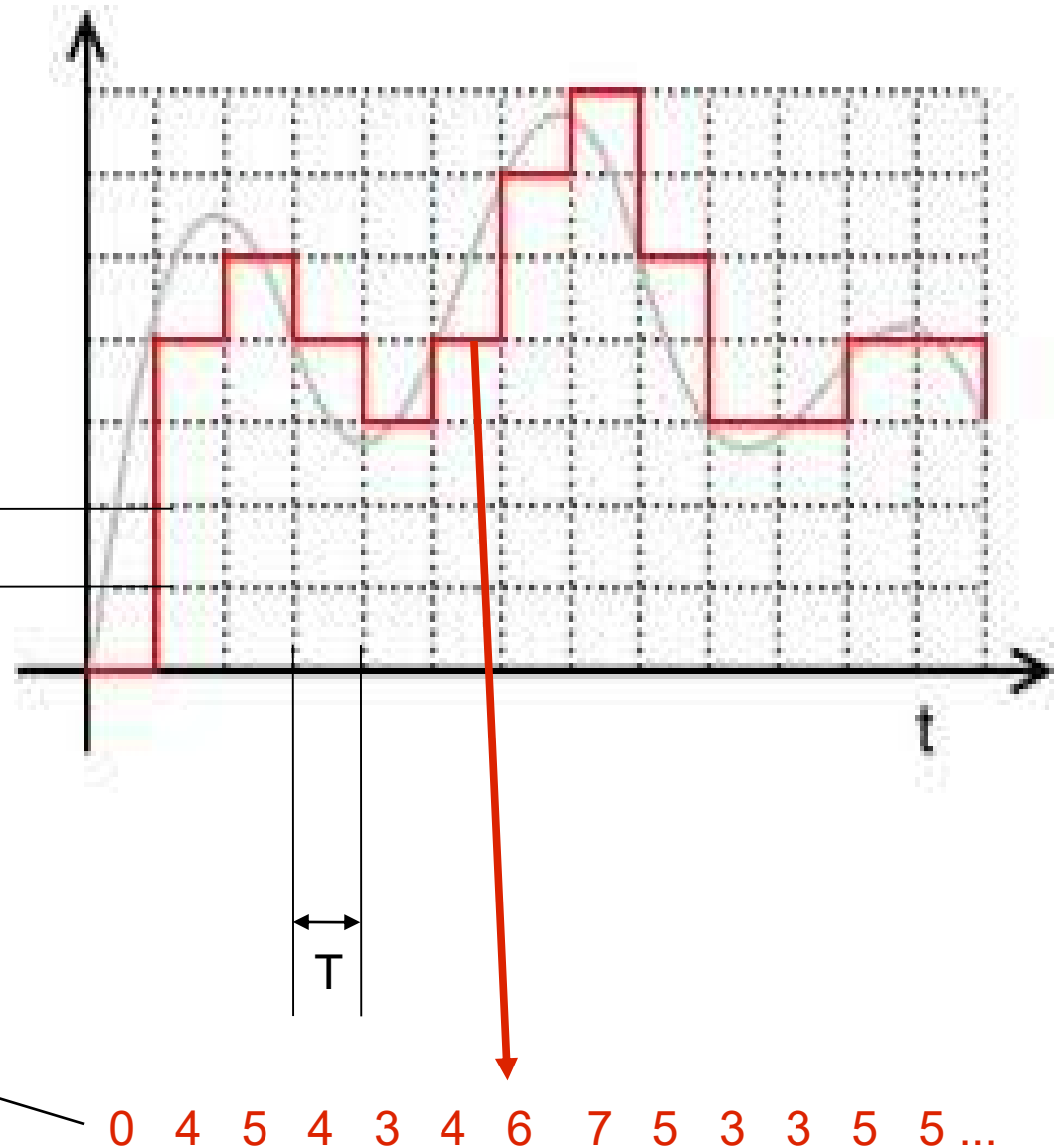
The analog signal can be represented by numbers:

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!

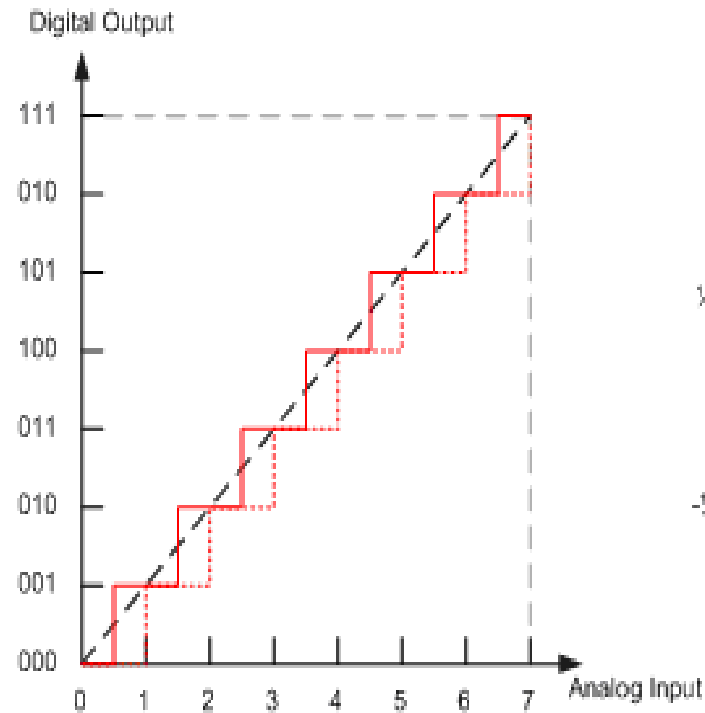


Digital signals - Quantization

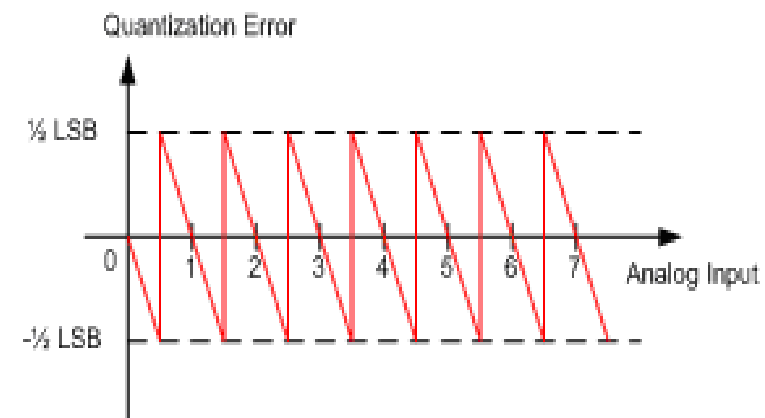
Digital signals are discrete
in time and in value

What happens to the original parts between?

They get lost!



(a)



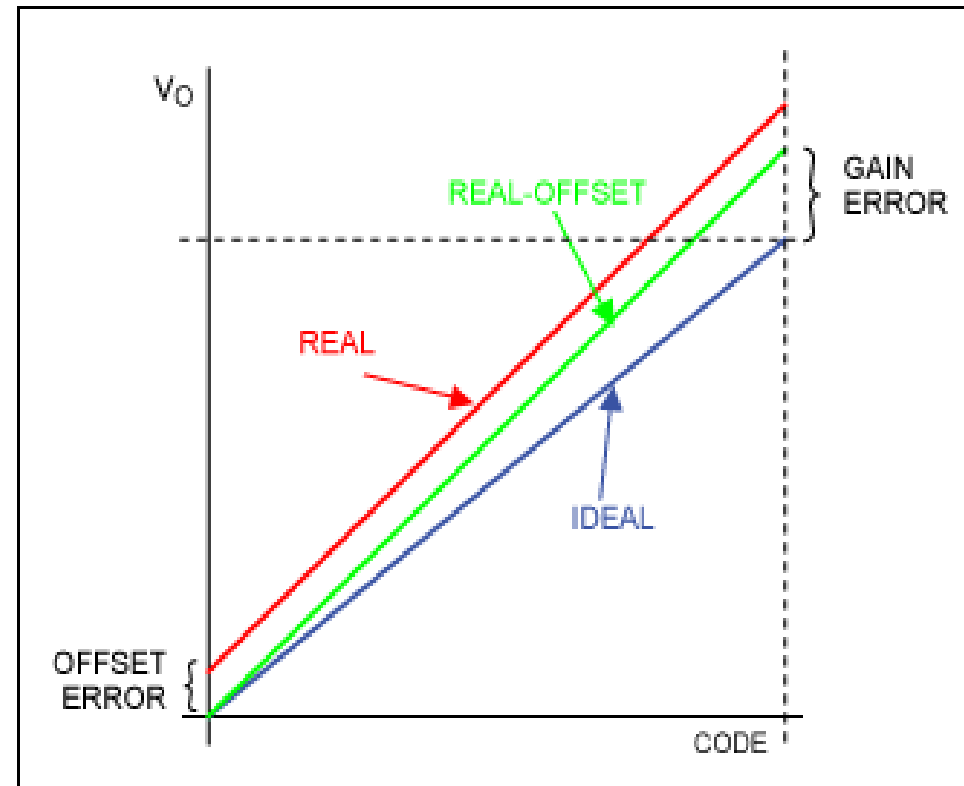
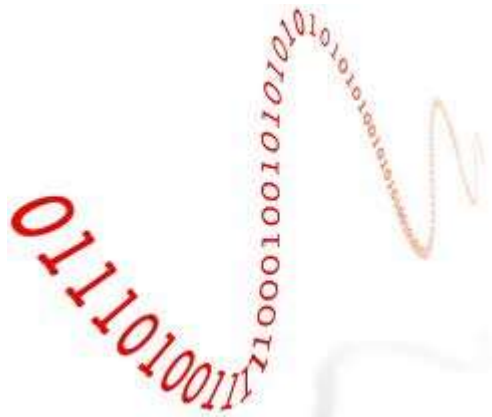
(b)

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

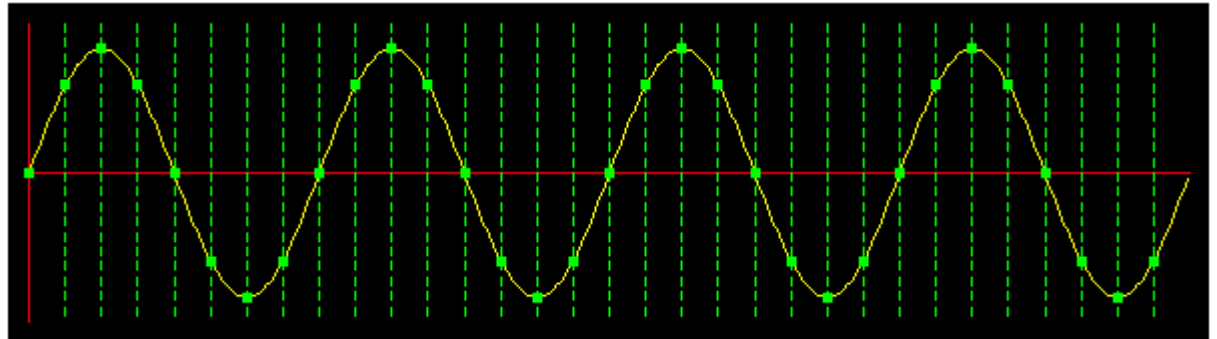
Digital signals – Sampling of sine waves

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

$f = 1000 \text{ Hz}$

$f_s = 8000 \text{ Hz}$

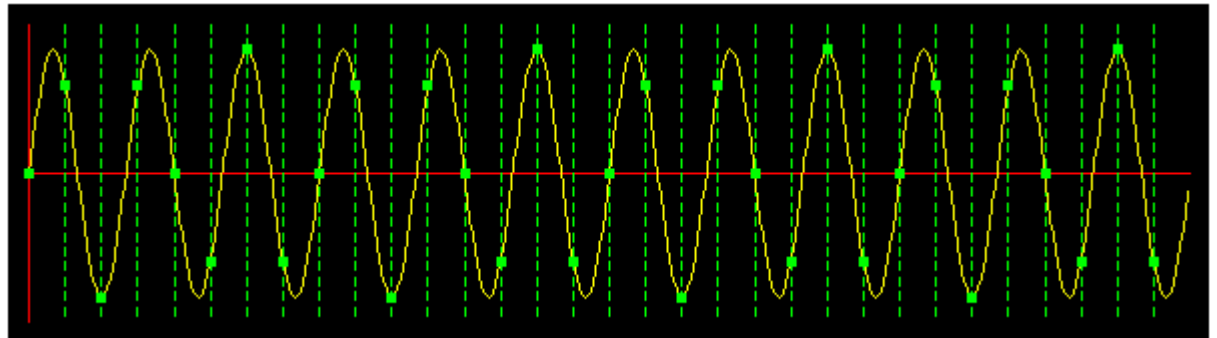
No problem



$f = 3000 \text{ Hz}$

$f_s = 8000 \text{ Hz}$

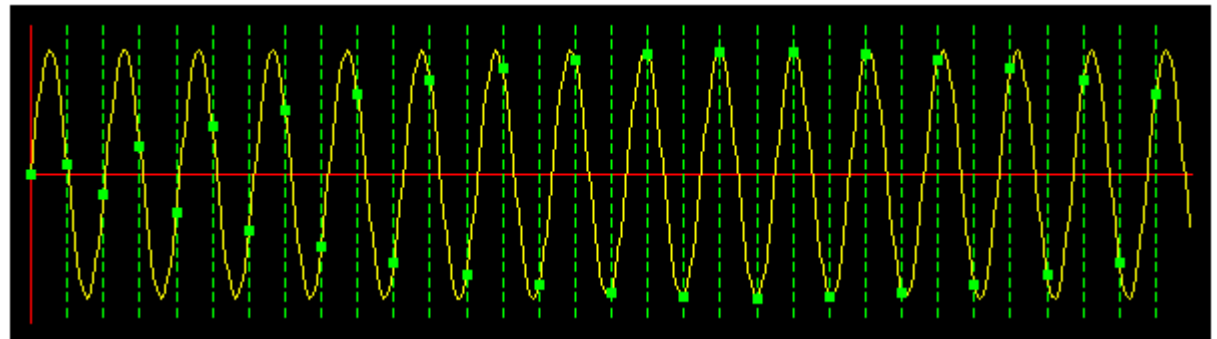
Still no problem



$f = 3900 \text{ Hz}$

$f_s = 8000 \text{ Hz}$

Still no problem



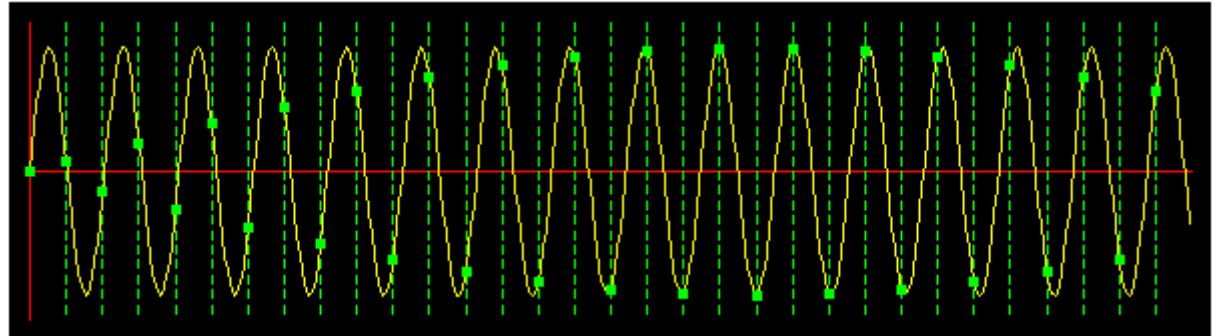
Digital signals – Sampling of sine waves

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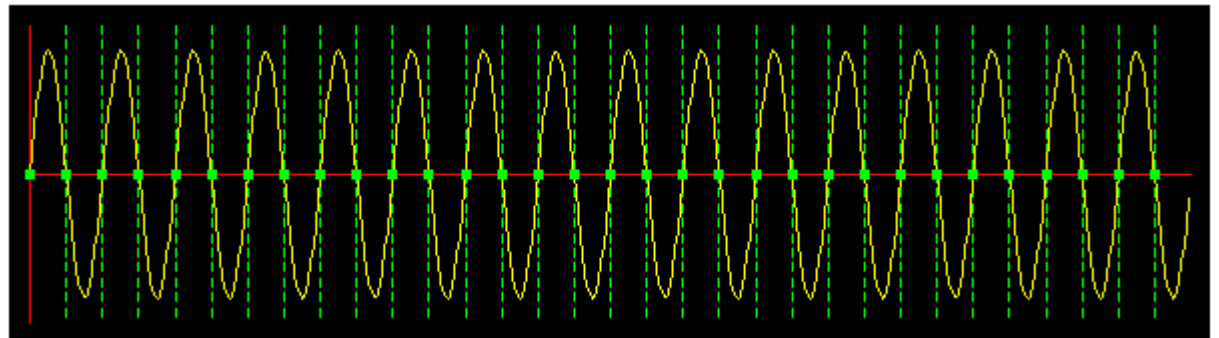
Still no problem



$f = 4000 \text{ Hz}$

$f_s = 8000 \text{ Hz}$

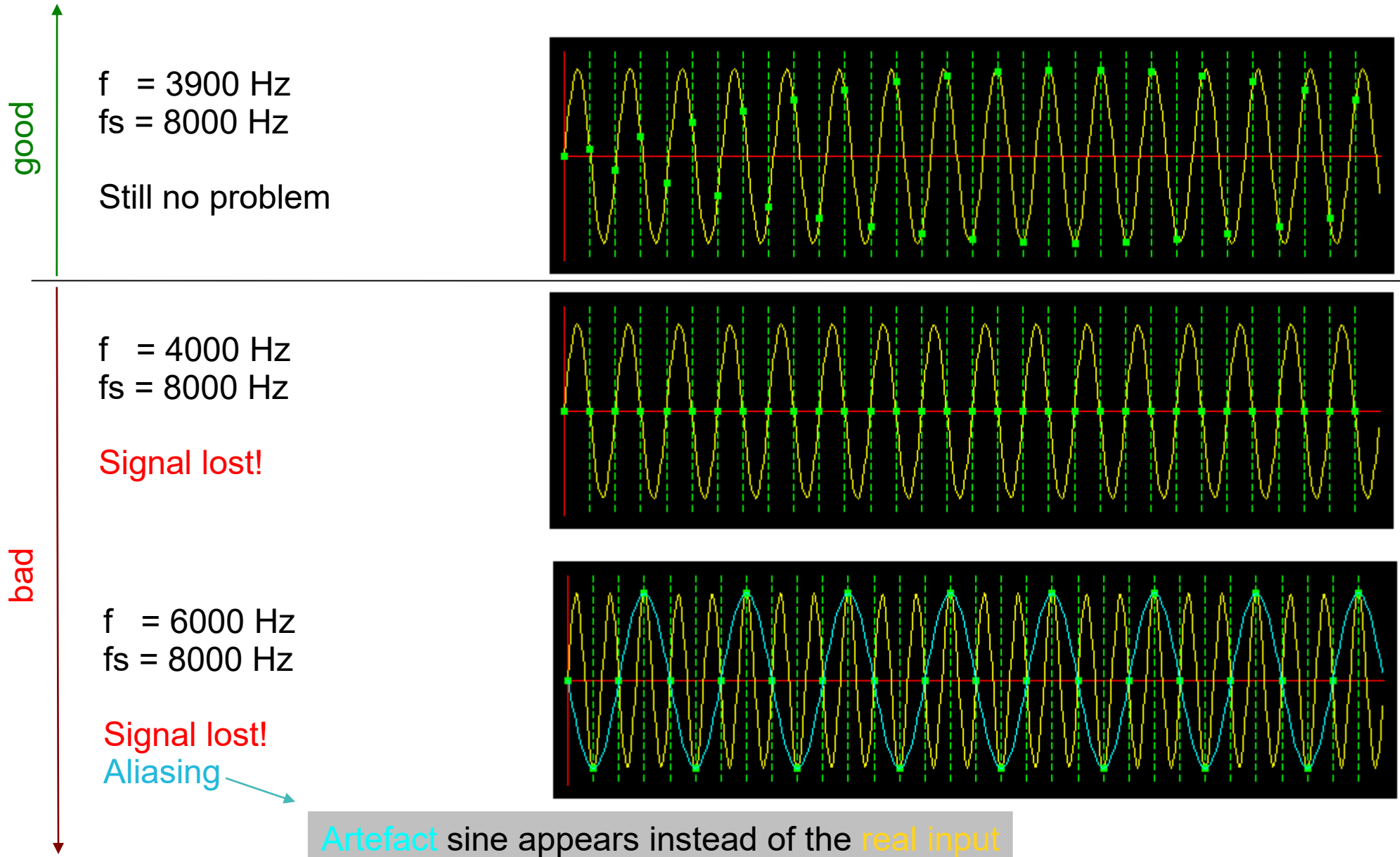
Signal lost!



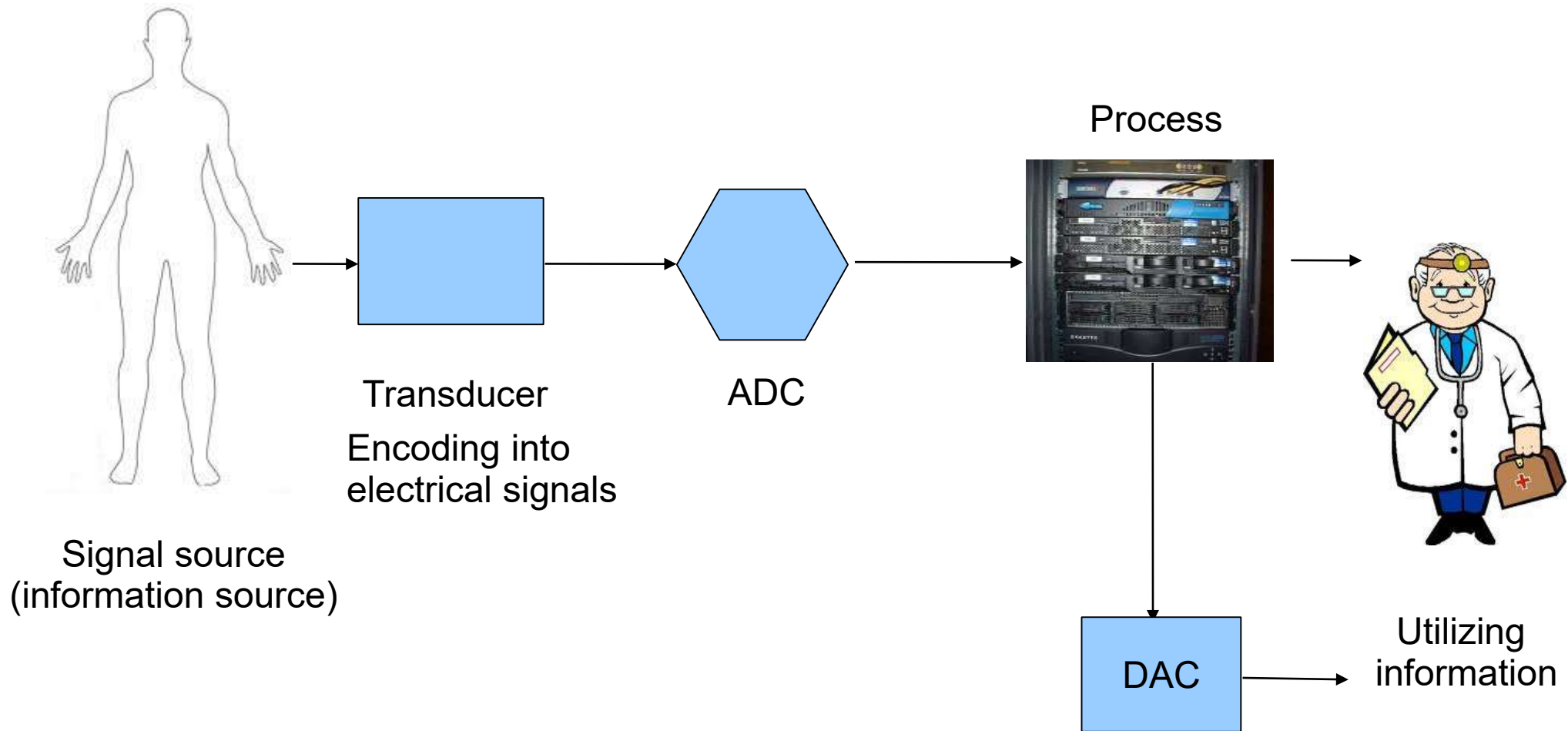
Nyquist theorem: sampling frequency must be at least 2x the frequency of the sine

Digital signals – Nyquist

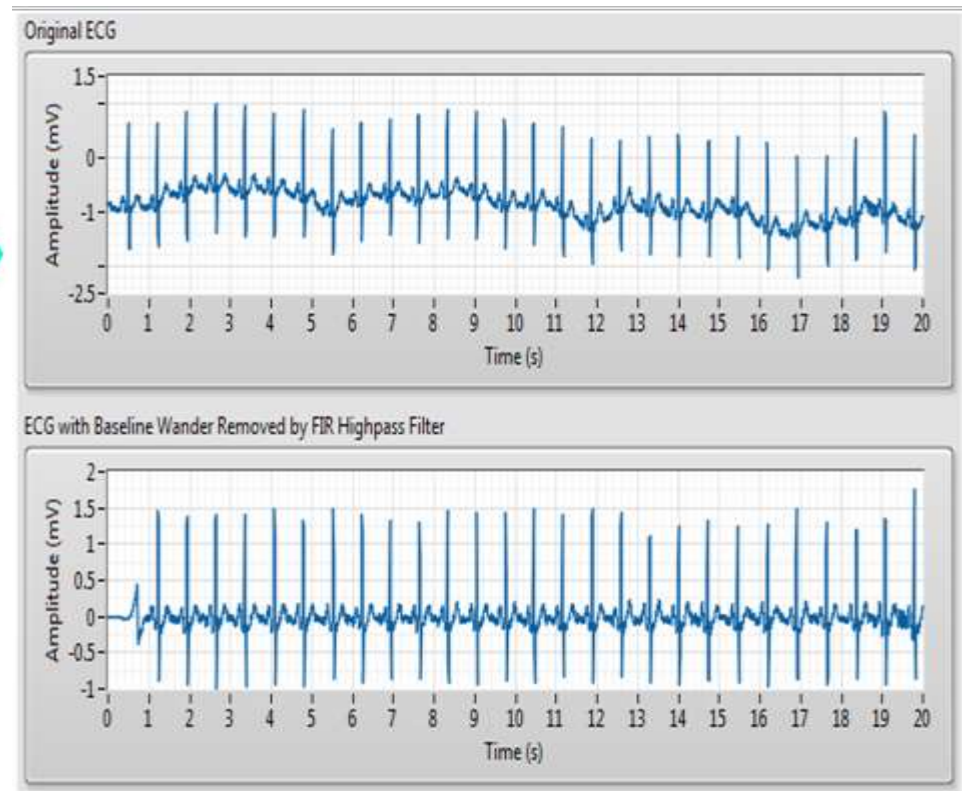
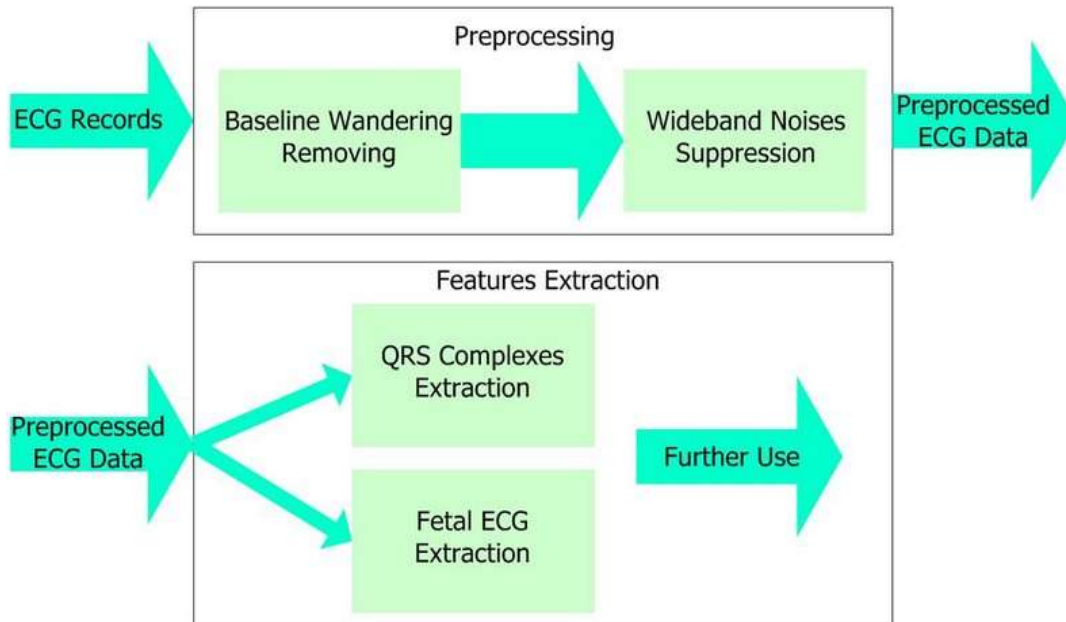
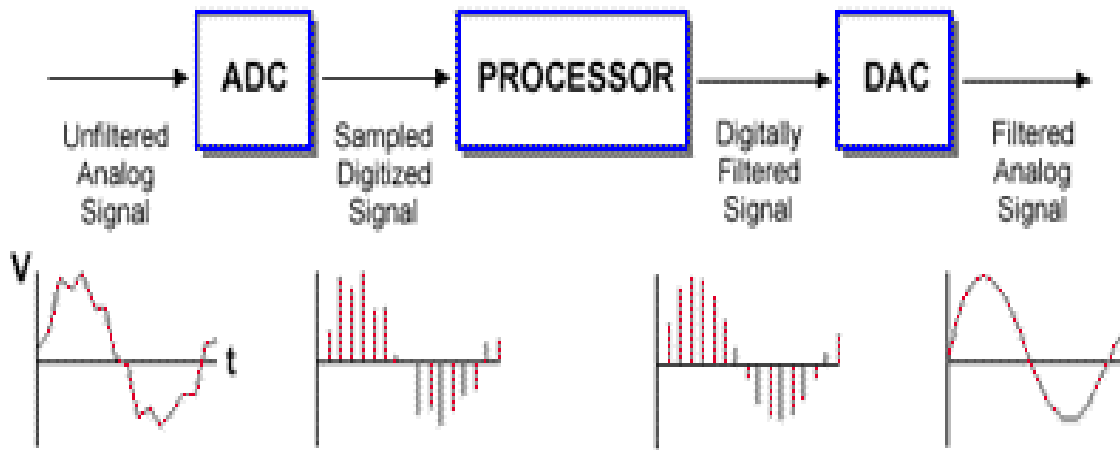
Nyquist theorem: sampling frequency must be at least 2x the frequency of the sine



Digital signals – Digital Signal Processing



Signal processing with DSP units is everywhere around us.

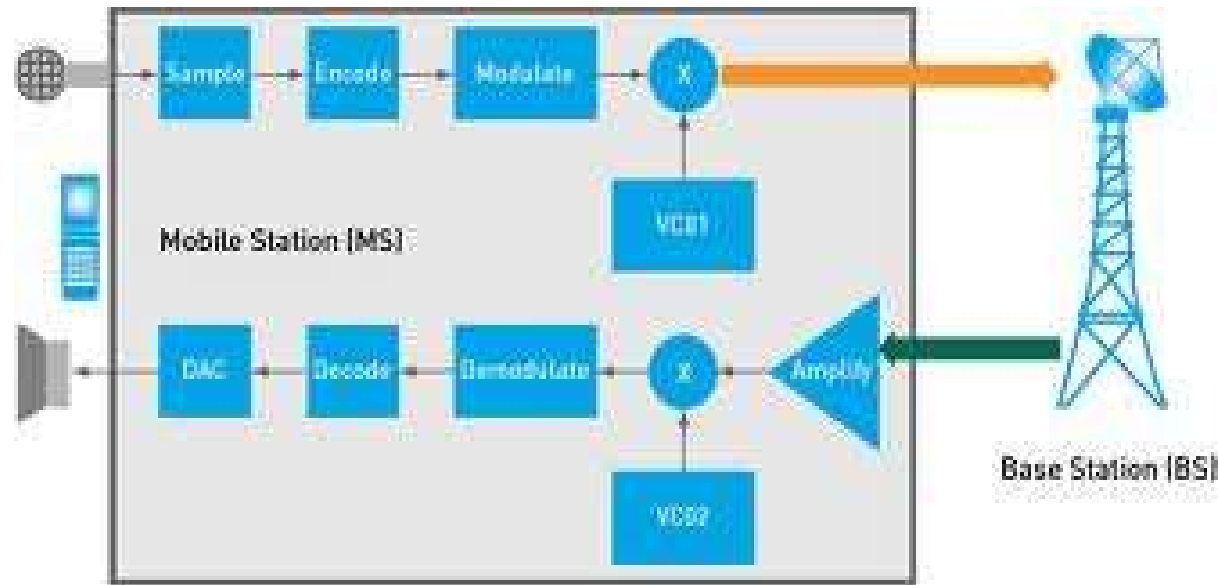


DSP in everyday life

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

