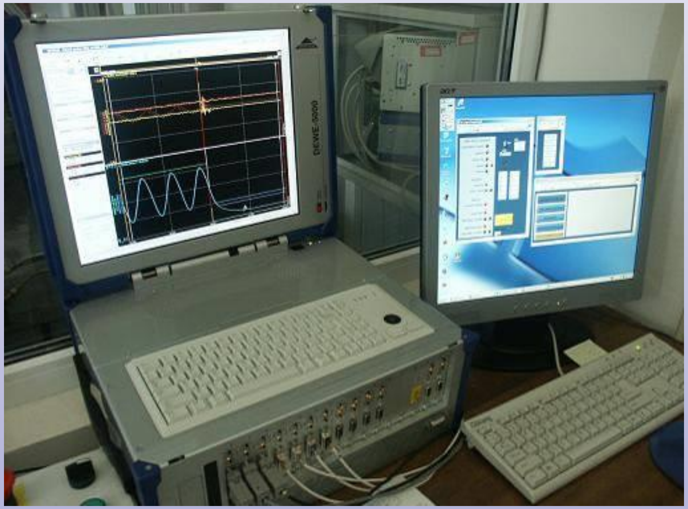
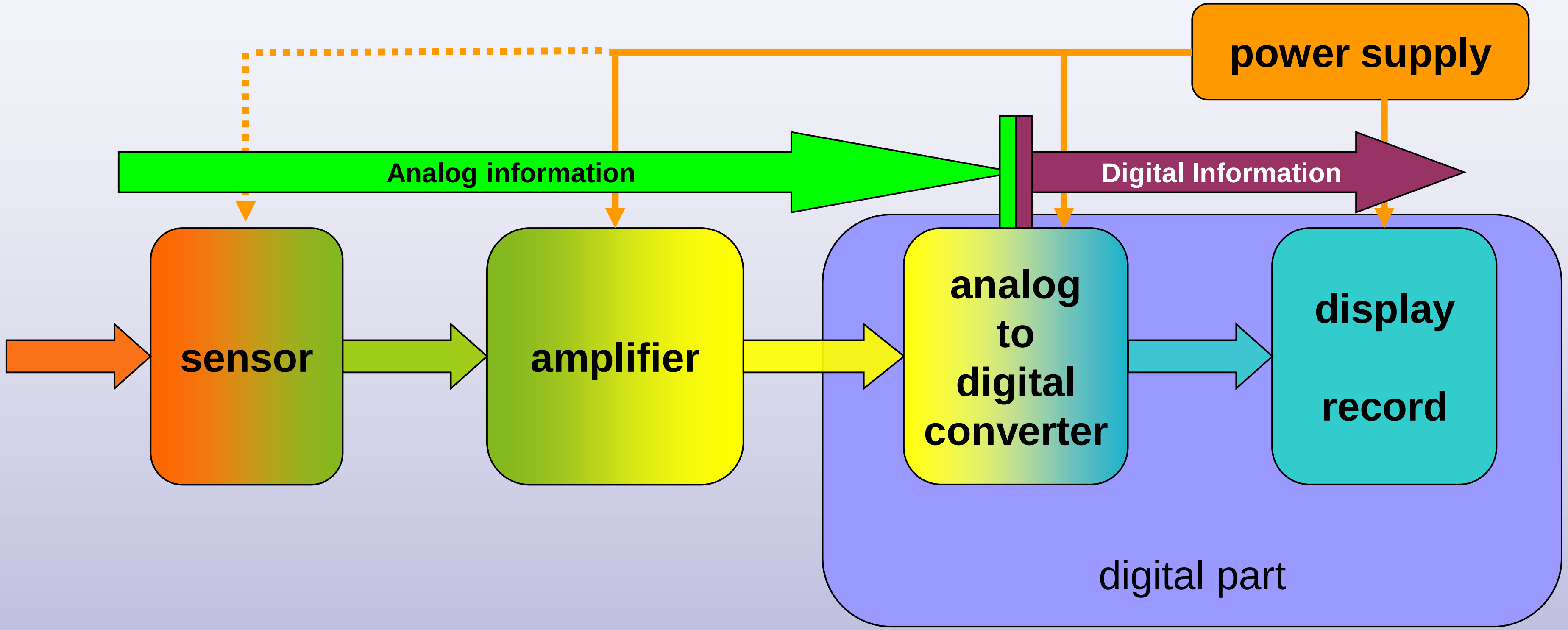
Measurement device component properties

Digital part

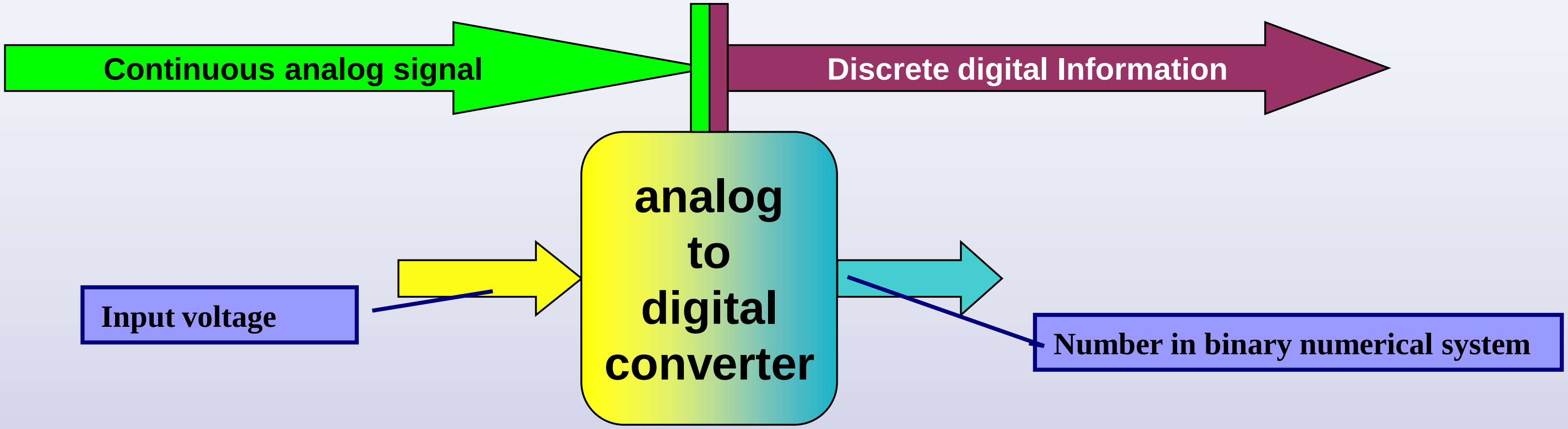


Analogue - digital measurement device



- 1. Analog to digital converter
- 2. Multichannel measuremet device with A/D converters
- 3. Display and record

1.1. A/D converter function principle



- A/D converter converts continuous analog signal to discrete digital information

- A/D converter properties are described by 2 basic parameters
  - number of bits
  - maximum sampling rate

1.1. A/D converter function principle

numerical systems

decimal numerical system
10 symbols = 10 digits

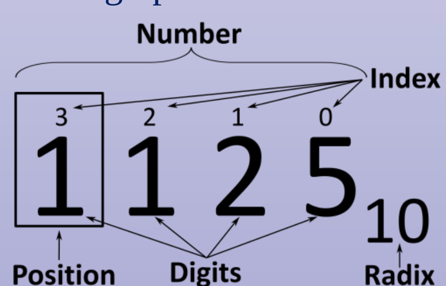
number of expressible levels

$$x = 10^n$$

where
10 is number of used symbols
= 0,1,2,3,4,5,6,7,8,9
(radix of the numerical system)
n is number of used positions

0
1
2
3
4
5
6
7
8
9
10
11
12
…
99
100
101
102
…
998
999
1000

A digit's value is the digit multiplied by the radix raised to the i-th power, where i is the number of digit position:



$1*10^3 + 1*10^2 + 2*10^1 + 5*10^0$
$1000 + 100 + 20 + 5 =$ **1125**

binary numerical system has only 2 symbols = 2 digits

0
1
10
11
100
101
110
111
1000
1001
1010
1011
1100
…

number of expressible levels

$$x = 2^n$$

where
2 is number of used symbols = **0** and **1**
(radix of the numerical system)
n is number of used position

The number of used positions for express a number is called **the number of bits** in computer technology.

number of bits		expressible levels
8	2^8	256
10	2^{10}	1024
12	2^{12}	4096
16	2^{16}	65536
24	2^{24}	16777216

The value calculation is the same as in the decimal system, only the radix is 2: 100 0110 0101 =

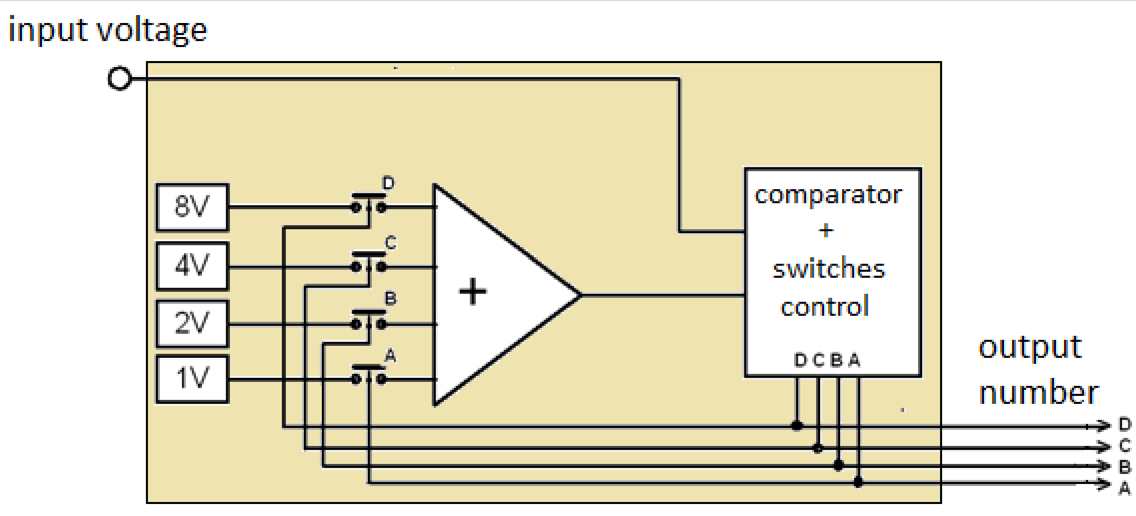
$1*2^{10}+0*2^9+0*2^8+0*2^7+1*2^6+1*2^5+0*2^4+0*2^3+1*2^2+0*2^1+1*2^0$

$1024 + 64 + 32 + 4 + 1 =$ **1125**

1.1. A/D converter function principle

A/D converter is the integral circuit – what is inside?
- voltage sources with values of power 2
- switches
- summing amplifier
- comparator
- control processor

Example - 4bits A/D converter, input voltage 5.5V:



Steps of conversion:
1) turn on 8V switch
   is the input value greater than 8?
   NO -> turn off 8V -> **D=0**
2) turn on 4V switch
   is the input value greater than 4?
   YES -> 4Vswitch stay ON -> **C=1**
3) turn on 2V switch
   is the input value greater than 4+2?
   NO -> turn off 2V -> **B=0**
4) turn on 1V switch
   is the input value greater than 4+1?
   YES -> 1Vswitch stay ON -> **A=1**

conversion result: D C B A
0 1 0 1 = $0*2^3 + 1*2^2 + 0*2^1 + 1*2^0$ = 5

two very important conclusions:
- **conversion result is not accurate**
- **conversion takes some time**

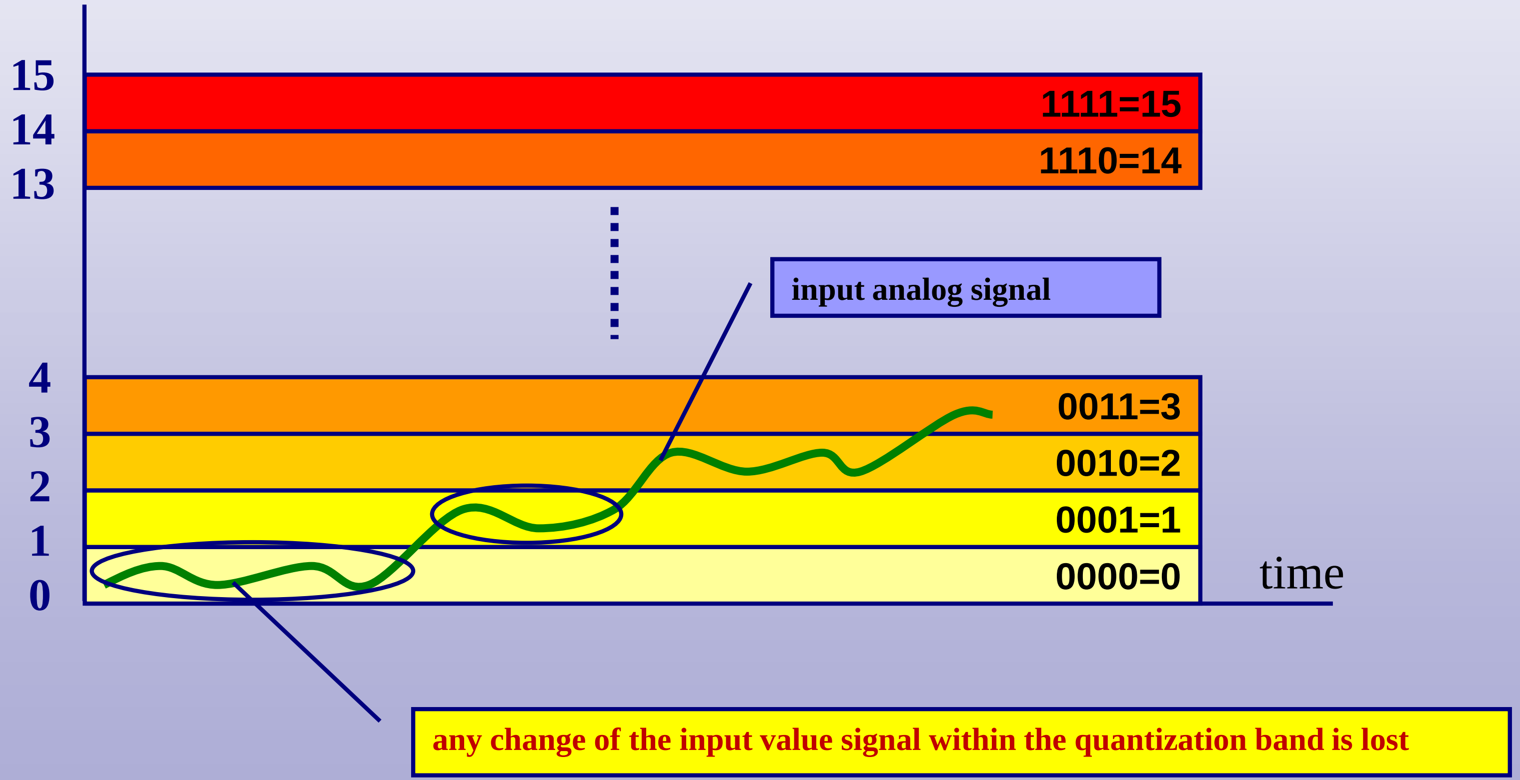
1.2. A/D converter – quantitation principle

quantitation is the transformation of the continuous signal level to discrete values

- **causes loss of information !!!!**

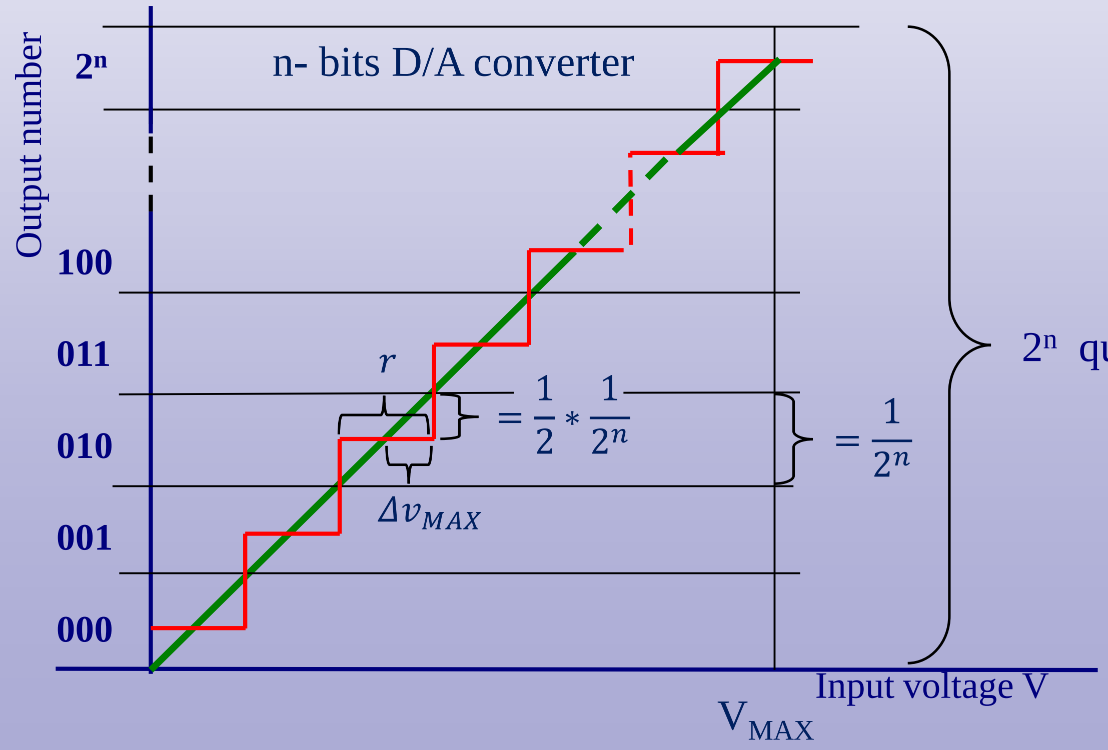
example - 4bits A/D converter

4bits = 2^4 = 16 quantization levels



1.2. A/D converter – quantitation error and resolution

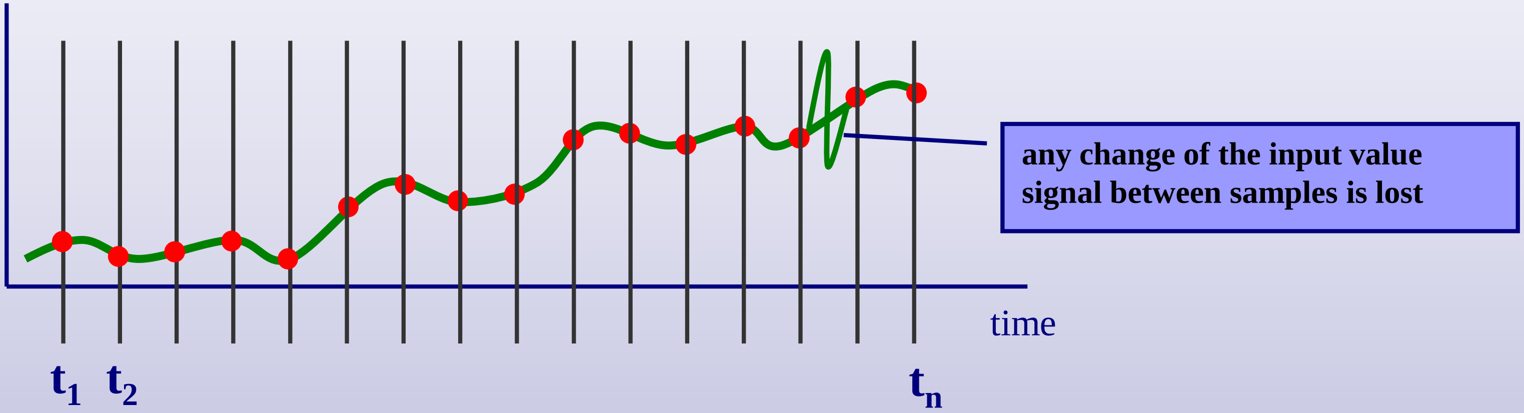
- if the converter has **n-bits**, it has $\mathbf{2^n}$ quantization levels, one level is $\frac{1}{2^n}$
- maximum voltage deviation during conversion : $\Delta v_{MAX} = \frac{1}{2} * \frac{1}{2^n} * v_{MAX}$
- **quantitation error :** $\sigma_Q = \frac{\Delta v_{MAX}}{v_{MAX}} = \frac{1}{2} * \frac{1}{2^n}$
- **resolution:** $r = \frac{1}{2^{n-1}} * v_{MAX} \cong \frac{1}{2^n} * v_{MAX}$



1.3. A/D converter - sampling

Sampling is the transformation of the continuous signal to discrete-time signal, i.e. sequence of samples

- **causes loss of information !!!!**



sample is taken at time points $\mathbf{t_i = T*i}$, where T is sampling period and i = 1, 2, 3, 4, ….

- sampling frequency (sampling rate) is often used instead of sampling period

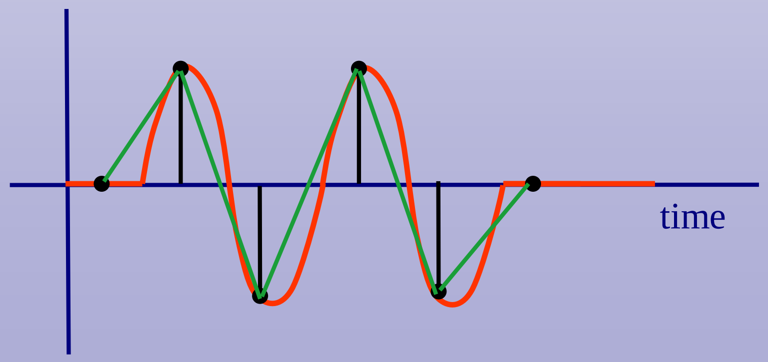
$$f_S = \frac{1}{T} \quad [Hz, s]$$

- sampling frequency
  - maximum is determined by the A/D converter design
  - minimum is determined by
    - Nyquist - Shannon sampling theorem for periodical input signal
    - value of dynamic error for any input signal

1.3. A/D converter - sampling

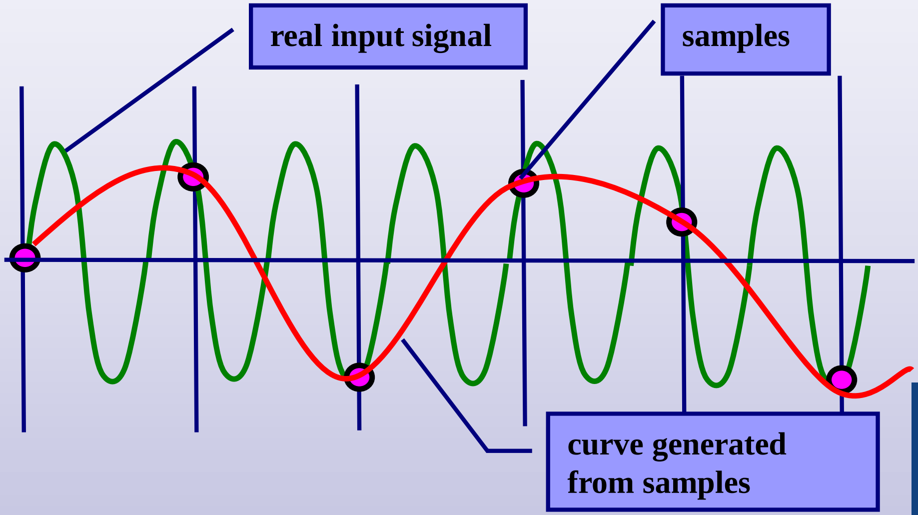
- **sampling frequency setting**
  - the maximum value is given by the possibilities (construction) of the A/D converter
  - the minimum value can be set by
    - **Nyquist - Shanonn's sampling theorem** (only for periodical signals)
    - **the permissible value of the dynamic error**
  - **the sampling frequency should be set between the maximum and minimum value**
    - compromise between the amount of data and the "loss" of information

- **Nyquist - Shanonn's sampling theorem**
  - **sampling frequency** $f_S > 2 * f_{MAX}$ where f_{MAX} is the maximum frequency of the measured signal
  - **the sampling frequency must be at least 2 times greater than the maximum frequency of the measured signal, ie more than two samples per measured signal period**



1.3. A/D converter - sampling

- **the aliasing effect occurs when the Nyquist - Shannon sampling theorem is not observed**
  - output sequence of samples does not correspond to reality



1.3. A/D converter - sampling

Example of the aliasing effect in a film :

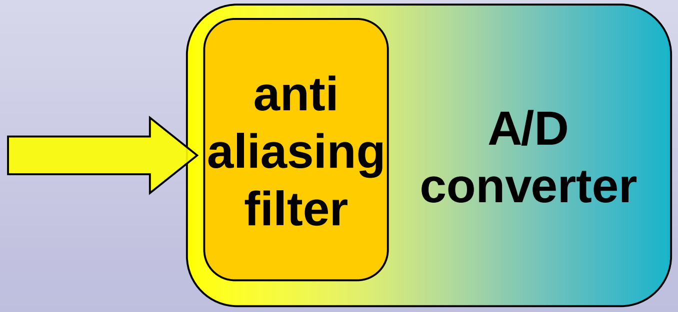
- breaking of the Nyquist - Shannon sampling theorem in the film
    - film is the sequence of static frames, static pictures
    - film sampling frequency is 24Hz (i.e. 24 frames per second)
    - watch the propeller of the plane. Do you think that propeller actually spins like this?

1.3. A/D converter - sampling

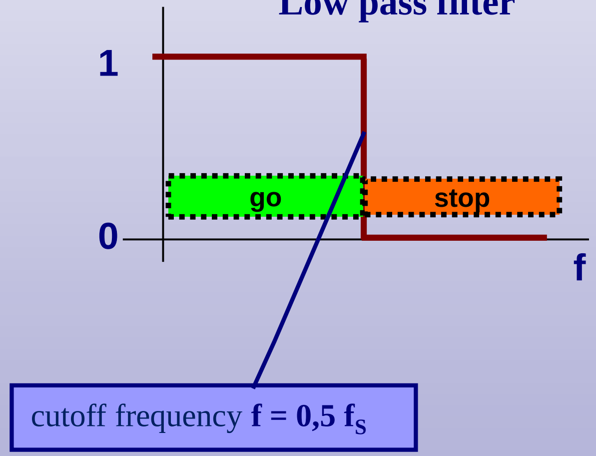
- **Antialiasing filter**

modern A/D converters have **antialiasing filter**

- it is a low pass filter whose cutoff frequency is automatically set to half of the selected sampling frequency
- input signal frequencies over the N-S theorem are automatically stopped



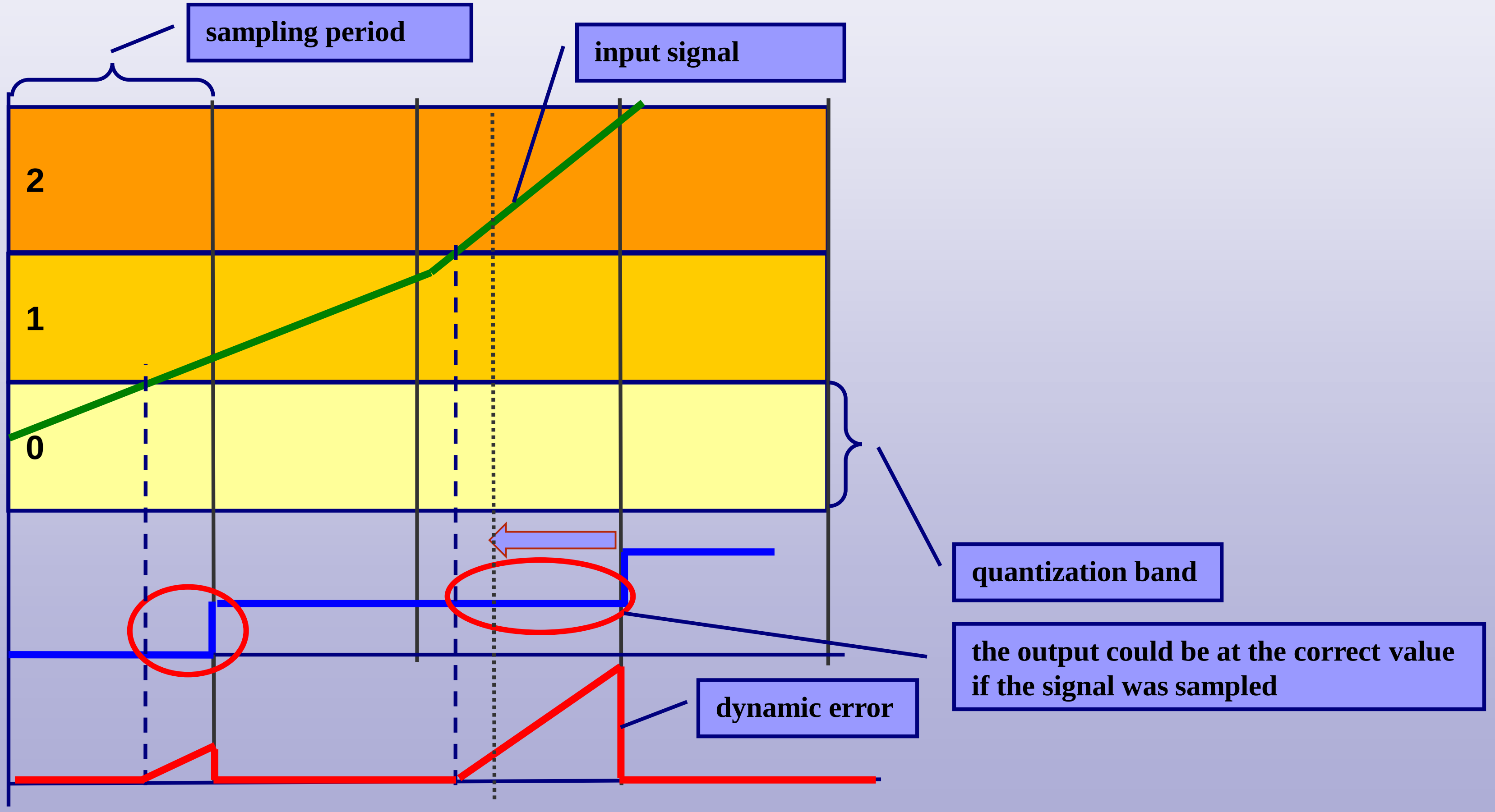
Low pass filter



1.3. A/D converter - sampling

Dynamic error:

- the value at the converter output changes only at the moment of sampling time
- slow sampling creates an output error because the new value of the input signal was not measured



1.3. A/D converter - sampling

Dynamic error:

if the permissible conversion error value is determined
the sampling period must be so short that the fastest change of the input signal is not greater than the allowed conversion error

sampling period $\boldsymbol{T \leq \frac{\Delta v_{MAX}}{max\left|\frac{dv}{dt}\right|}}$ where Δv_{MAX} is the maximal permissible conversion error

$\max\left|\frac{dv}{dt}\right|$ is the maximum signal change rate

Example:
- input signal range is **10V**
- max. input signal change rate is **5V/s**
- permissible conversion error is **0.1%**

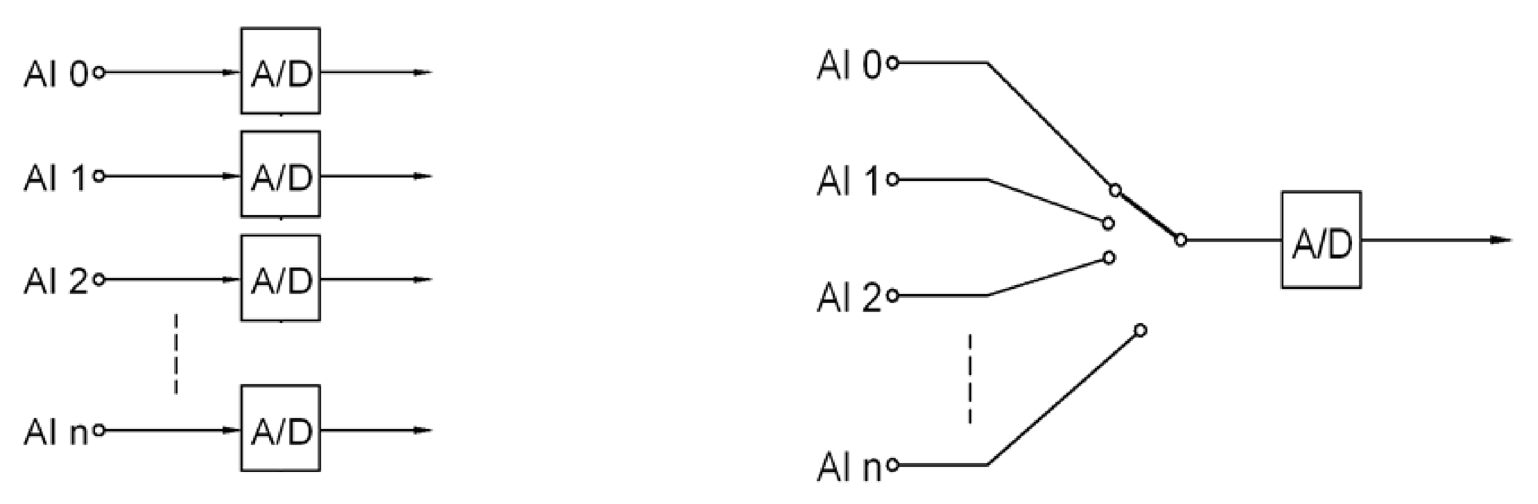
- 0.1% from input range 10V is 0.01V, so permissible conversion error is **0.01V**
- input signal is changed by 0.01V in its max. speed at **0.002s**

minimum sampling rate = 0.002s = 2ms
min. sampling frequency = 500Hz

2. Multichannel measuremet device with A/D converters

two variants

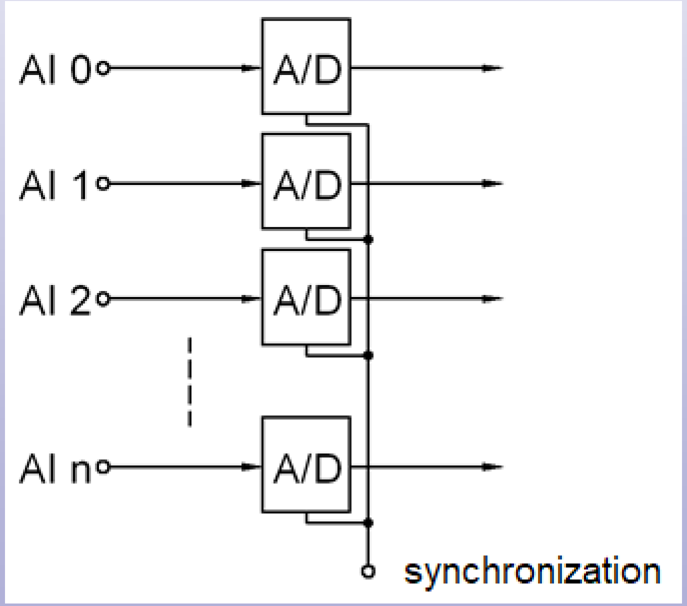
- synchronously sampled inputs
- multiplexed inputs

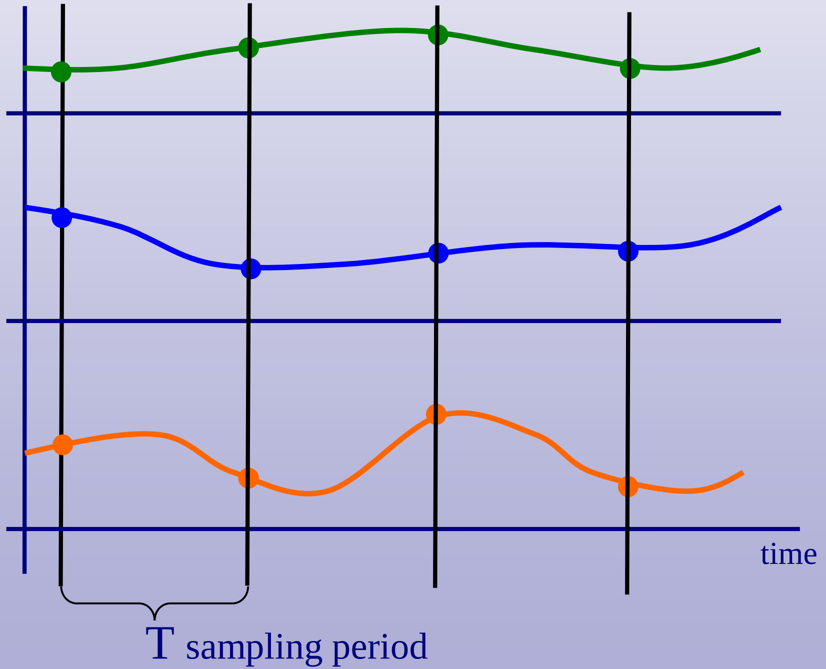


- the maximum sampling frequency of the signal for multi-channel measuring devices is given in **S/s** (samples per second)
- because the frequency is usually high, often the value is in **kS/s**
- for example, 200kS/s means that the device is capable of producing a maximum of 200,000 samples per second
- the time required for A/D conversion of one channel can be calculated from this value, as its inverse value, ie for 200kS/s it is 1/200 000 = 5μs
- the maximum sampling frequency of the individual channels then depends on the variant of connection of the inputs to the A/D converter

2. Multichannel measuremet device with A/D converters

- **synchronously sampled inputs**
  - each input channel has its own A/D converter, all A/D converters are controlled together
  - the sampling time is the same for all channels
  - the maximum specified sampling frequency of the measurement device is applied to each input channel, ie. all channels can be sampled at this maximum frequency simultaneously
  - **this is the only possible solution for measurement of fast events**



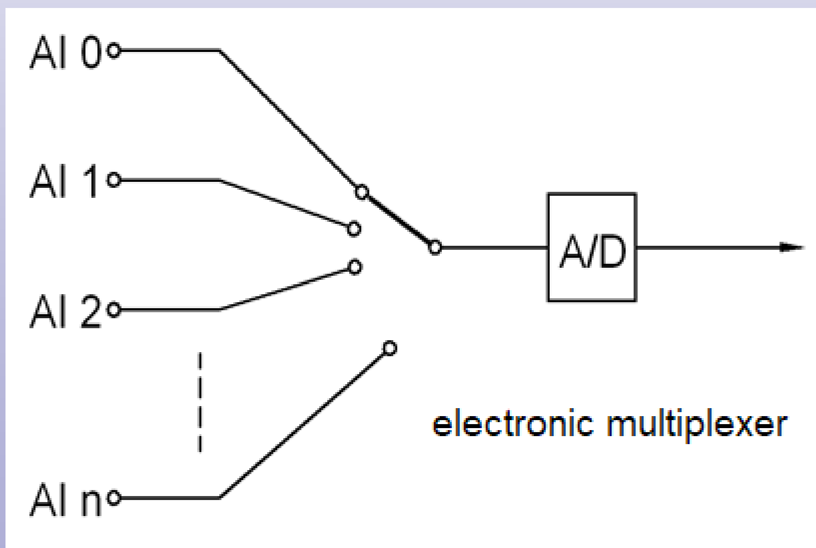


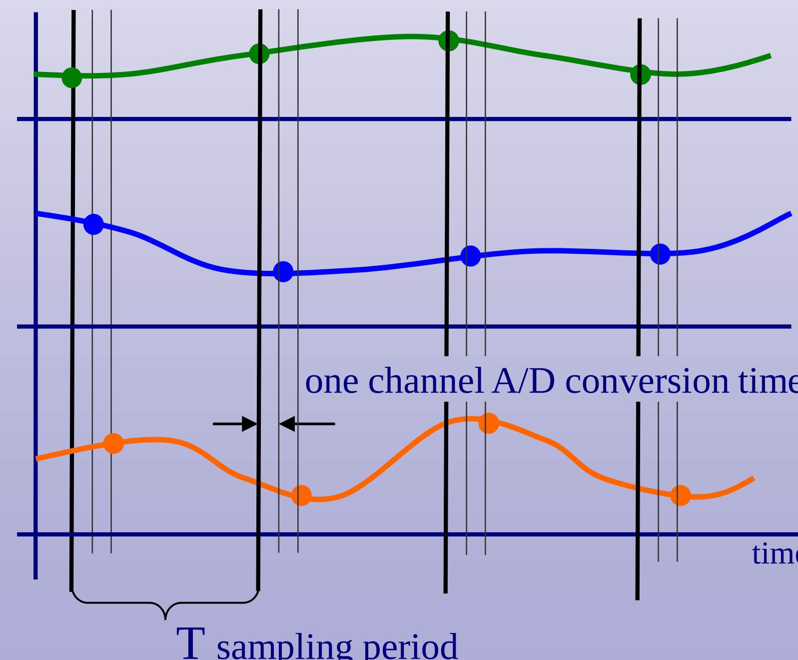
advantage: all input channels are sampled at the same time

disadvantage: large number of A / D converters = higher price

2. Multichannel measuremet device with A/D converters

- **multiplexed inputs**
  - measurement device has only one A/D converter
  - the input channels are gradually switched to the A/D converter by electronics multiplexer
  - the channels have the sampling time shifted by the time required to one channel A/D conversion time
  - the maximum specified sampling frequency of the measuring device is applied together for all input channels, ie. that the resulting sampling rate for one channel is this number divided the number of used channels
  - **this solution is unusable for measurement of fast events**



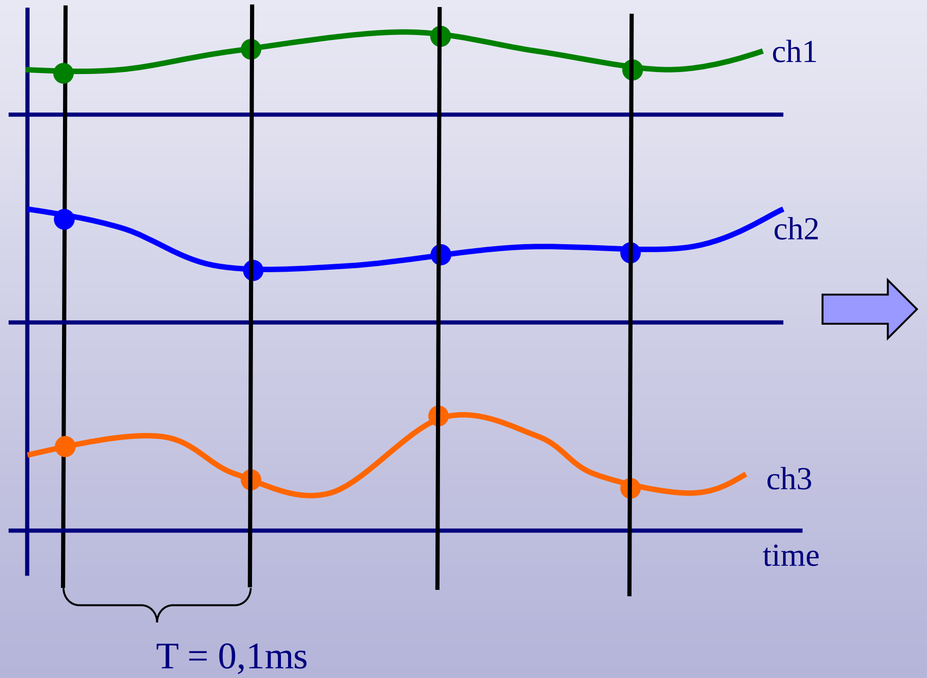


advantage: only one A/D converter = low price

disadvantage: all input channels are not sampled at the same time

2. Multichannel measuremet device with A/D converters

- **synchronously sampled inputs example**
  - measurement device with maximum sampling frequency 200kS/s
  - 3 input channels are used for measurement
  - user set sampling frequency is 10kHz i.e. sampling period is 0,1ms



output data file:

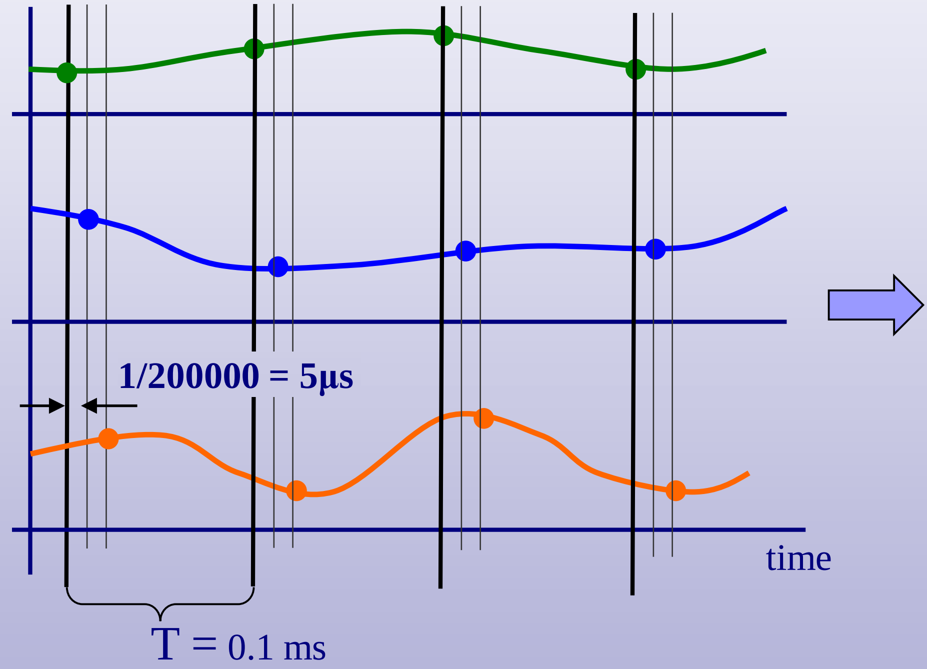
time[ms]	ch1	ch2	ch3
0	10.2	28.3	14.3
0.1	14.8	15.2	18.5
0.2	16.1	6.8	21.3
0.3	11.3	12.3	25.4

note: numeric values are for illustration only

All channels are measured at the same time, so the channel values in the output file exactly match the time in the first column.

2. Multichannel measuremet device with A/D converters

- **multiplexed inputs example**
  - measurement device with maximum sampling frequency 200kS/s
  - 3 input channels are used for measurement
  - user set sampling frequency is 100kHz i.e. sampling period is 0.1ms



output data file:

time[ms]	ch1	ch2	ch3
0	10.2	28.3	14.3
0.1	14.8	15.2	18.5
0.2	16.1	6.8	21.3
0.3	11.3	12.3	25.4

note: numeric values are for illustration only

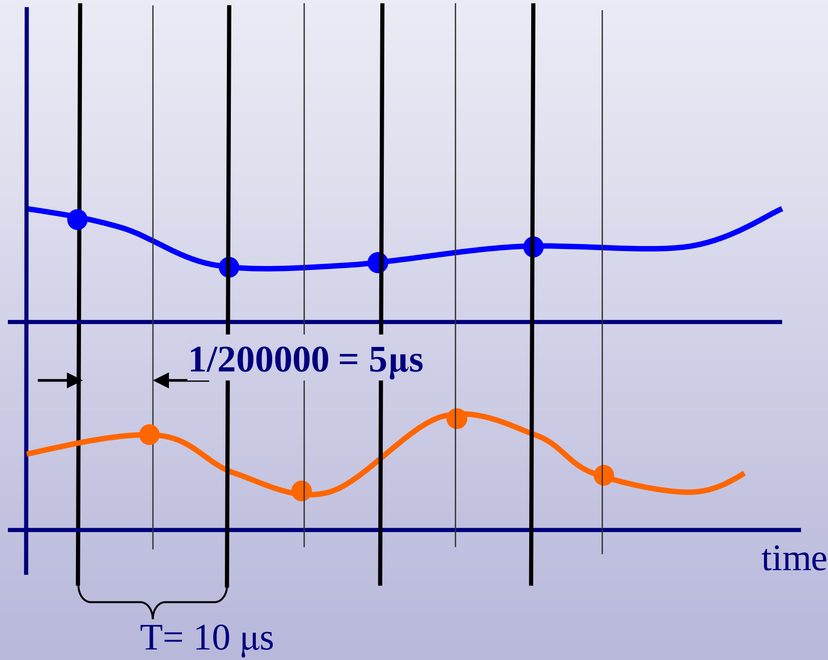
the output data file looks the same as in the previous example, but is not true !!!!

- only the first channel was measured at the times given in the first column
- the second channel was actually measured 5us later, so it should have a different timeline of **0.005, 0.105, 0.205, 0.305**, etc.
- the third another 5us later, so its timeline is **0.01, 0.11, 0.21, 0.31,** etc.

The output file is simplified, the user does not have the exact time values of channels sampling !!

2. Multichannel measuremet device with A/D converters

- **multiplexed inputs extreme example**
  - measurement device with maximum sampling frequency 200kS/s
  - 2 input channels are used for measurement
  - user set sampling frequency is 100kHz i.e. sampling period is 10µs



output data file:

time[µs]	ch1	ch2
0	10.2	28.3
10	14.8	15.2
20	16.1	6.8
30	11.3	12.3

note: numeric values are for illustration only

- only the first channel was measured at the times given in the first column
- the second channel was actually measured 5us later, so its actually timeline is **5, 15, 25, 35, etc.**
- **the second channel is measured with the time shift of 50%!!!!!!!**

By simplifying the output file, there was a complete loss of information about the time relationship between the channels!!!!
ATTENTION to cheap measurement devices with multiplexed inputs operated at limit sampling frequencies

3. Display and record

- **most measuring devices have the ability to customize the format of display and record of measured data**
  - the display and record format of measured data should correspond to the accuracy of the whole measurement device!!

- **example**
  - universal measurement device with **16bit** A/D converter
  - the force sensor with range **1kN** has the relative error **0.1%** and it is connected to the measurement device input

  - sensor error: 0.1% from range 1kN is 1N, so the maximum sensor force deviation is **±1N**

  - A/D quantitation error: $\frac{1}{2} * \frac{1}{2^n} * 1\text{kN} = 0{,}0076\text{N}$, so the maximum A/D conversion deviation is $\pm\mathbf{0{,}0076N}$

  - **the measurement error** is therefore mainly determined by the accuracy of the sensor and is therefore **±1N**

  - **the displayed and stored value should have no decimal place !!**
  - the correct displayed value is therefore eg **force = 478N**
  - to display in this case force for example **478.25N is nonsense**, because in fact it can be **478±1N**, so the uncertainty is already in the order of Newtons and any other decimal places are nonsense

- keep this in mind when giving measured values !!
- each test report should have the specified measurement error of the individual quantities and the displayed values should correspond to this

Exam questions

- A/D converter function principle
  - function principle, two basic parametres (p. 3)
  - binary numerical system, number of bits and formula for number of expressible levels (p. 4)
- quantitation
  - quantitation principle (p. 6)
  - quantitation error and resolution (p. 7)
- sampling
  - sampling principle, sampling frequency or period (p. 8)
  - Nyquist - Shanonn‘s sampling theorem (p. 9)
  - aliasing effect, antialiasing filter (p. 10, 12)
  - dynamic error (p. 13)
- multichannel measuremet device
  - principle of two variants, maximal sampling frequency (p.15)
  - synchronously sampled inputs, advantage, disadvantage (p. 16)
  - multiplexed inputs, advantage, disadvantage, maximal sampling frequency for one cannel (p. 17)
  - multiplexed inputs, the biggest data files problem (p.19, 20)
- display and record
  - the display and record format and the accuracy of the measurement device (p. 21)