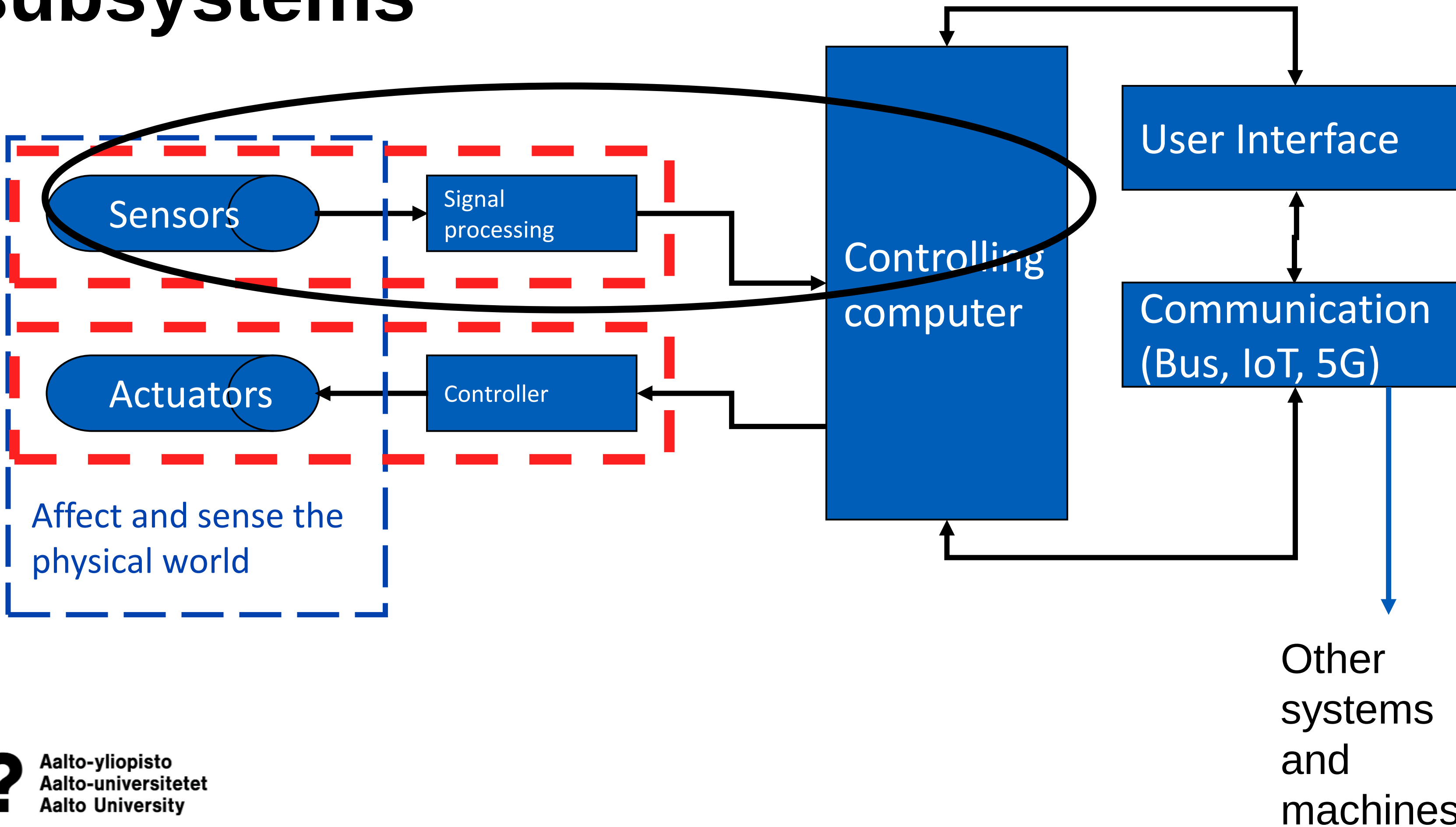
Measurement systems & Data acquisition

KON-C2004 Mechatronics Basics
12.11.2024 Raine Viitala & Panu Kiviluoma

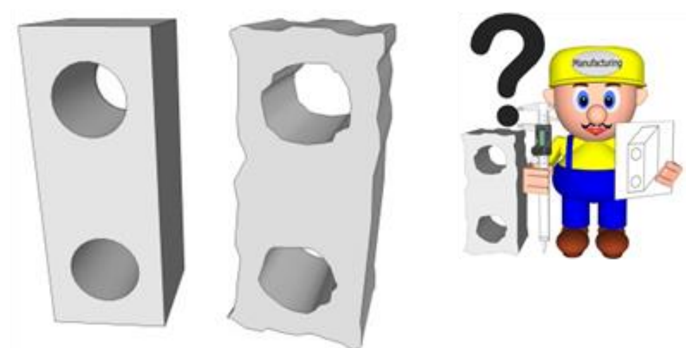
Aalto University
School of Engineering

Mechatronic machine - subsystems



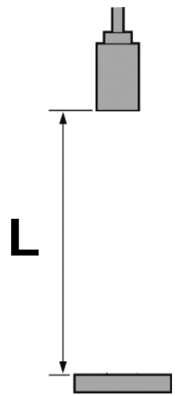
Philosophy of measurements

- **Measurement is always an estimate of the true value**
  - *Nobody* can find out the true value
- **The real value exists only on the computer screen (CAD, signal analysing etc.)**
  - In the real world all the objects, measured signals and physical magnitudes are erroneous



Architecture of a measurement system

Measurand



Sensor

Voltage
Current
Charge
…

Conversion to another, typically electric physical quantity

Measurement Device

Signal Conditioning

Analog-to-Digital Converter

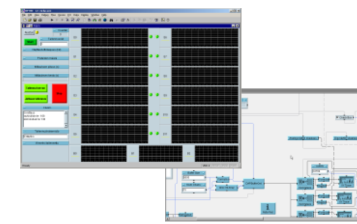
Texas instruments
Bosch PLC
Arduino etc.

National Instruments
Measurement Computing
Data Translation etc.

Software

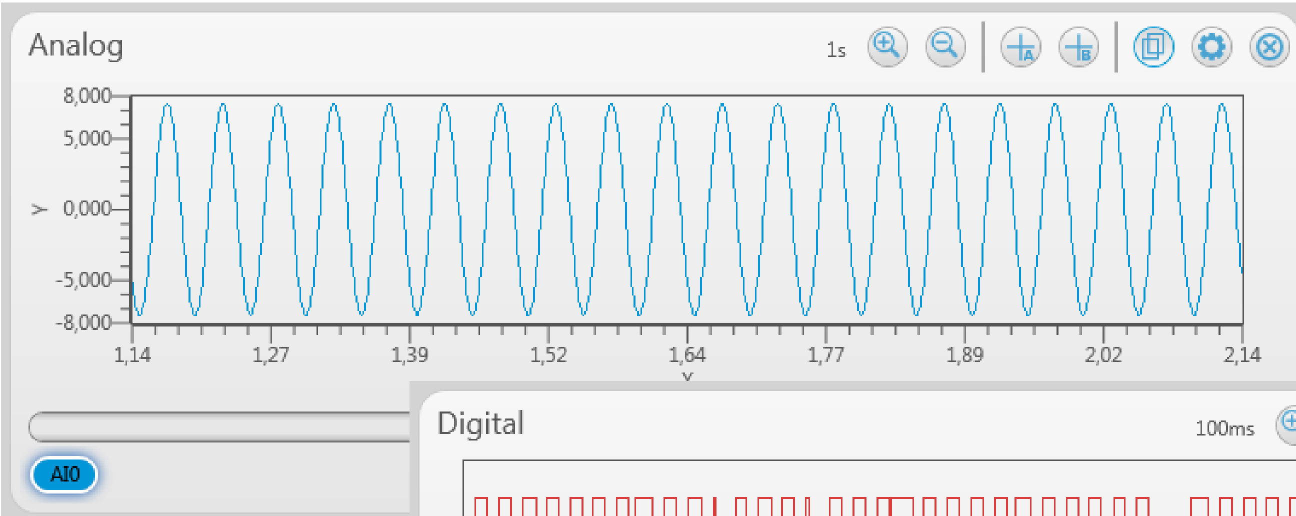
Driver

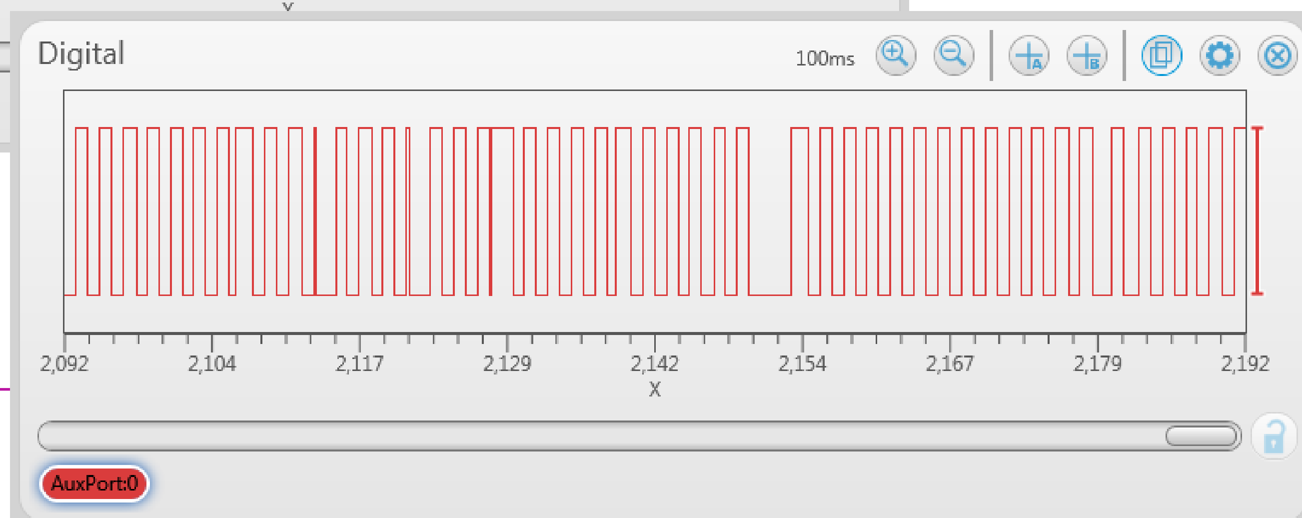
Application



Visual C++/Basic
Arduino
Labview
Matlab
…

Signals Come in Two Forms: Digital and Analog





Signals

Analog

Voltage

- Standard ranges
  - 0…10V
  - 0…5V
  - 1…5V
  - -5…+5V
  - -10…+10V
- Easy and cheap, susceptible to disturbance

Current

- Standard ranges
  - 0…20mA
  - 4…20mA
- Better immunity to disturbance

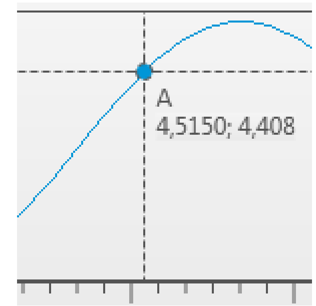
Digital

- 0 or 1
- 0 or 5 V
- 0 or 3.3 V
- Easy to process further
- The best immunity to disturbance
- “Computer proof”

Analog Terminology

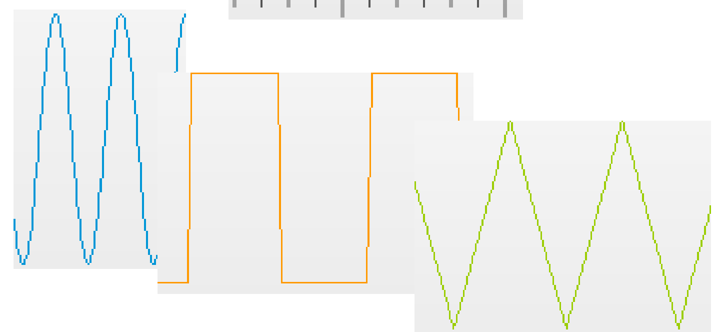
Level

- The instantaneous value of the signal at a given point in time



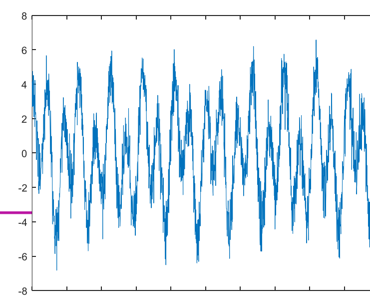
Shape

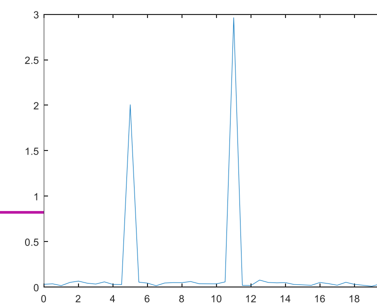
- The form that the analog signal takes, which often dictates further analysis that can be performed on the signal



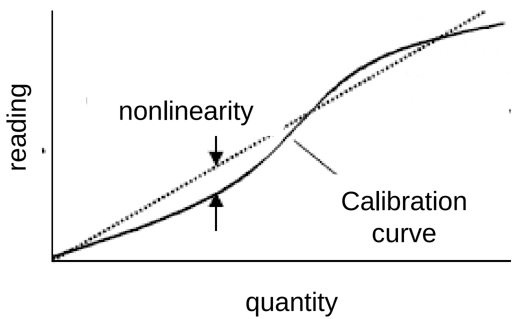
Frequency

- The number of occurrences of a repeating event over time

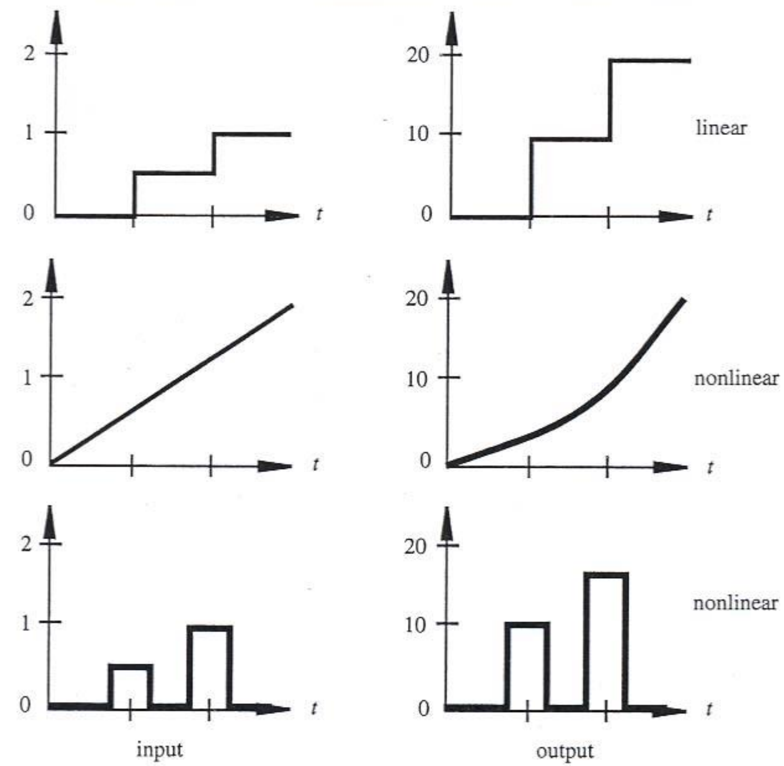




Linearity



$$V_{out}(t) - V_{out}(0) = \alpha[V_{in}(t) - V_{in}(0)]$$



Analog to Digital

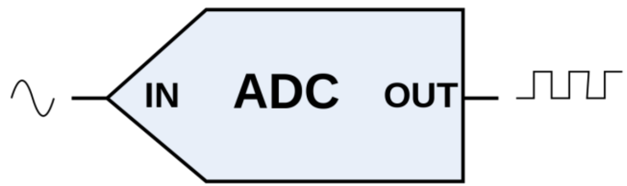
Selection criteria

- Number of bits
  - Resolution, quantization noise
- Sampling frequency
  - Dictates the highest measurable frequency
- Input range
  - 0…1V, ±5V, …
- Number of channels
  - Multichannel
  - Sample and Hold / Multiplexer

8bit → 2^8 = 256

16bit → 2^16 = 65536

22bit → 2^22 = 4194304



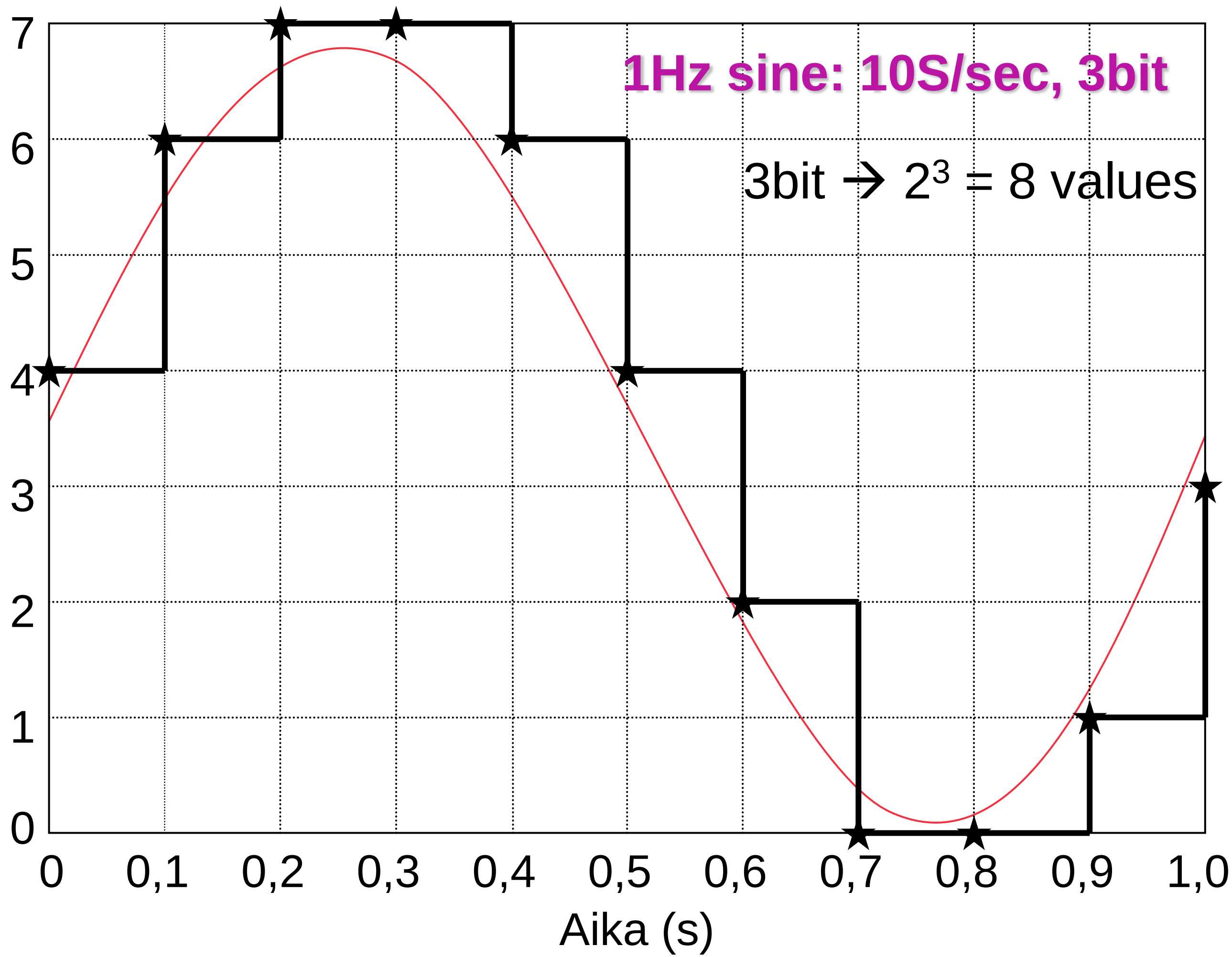
Digitized signal

AD conversion

Outputted "signal"

Time	Value
0	4 (100)
0,1	6 (110)
0,2	7 (111)
0,3	7 (111)
0,4	6 (110)
0,5	4 (100)
0,6	2 (010)
0,7	0 (000)
0,8	0 (000)
0,9	1 (001)
1,0	3 (011)
…	

Resolution?



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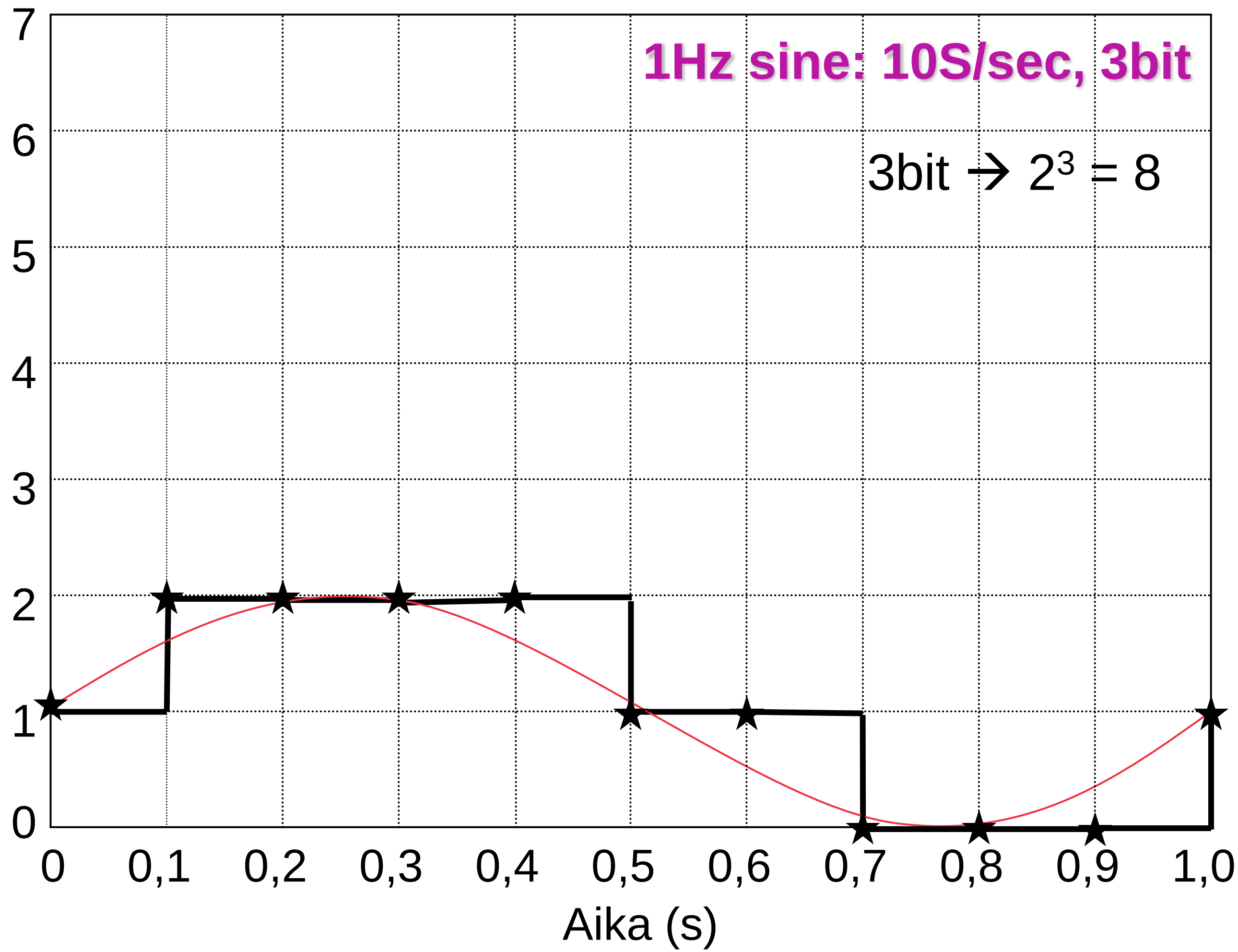
Range?



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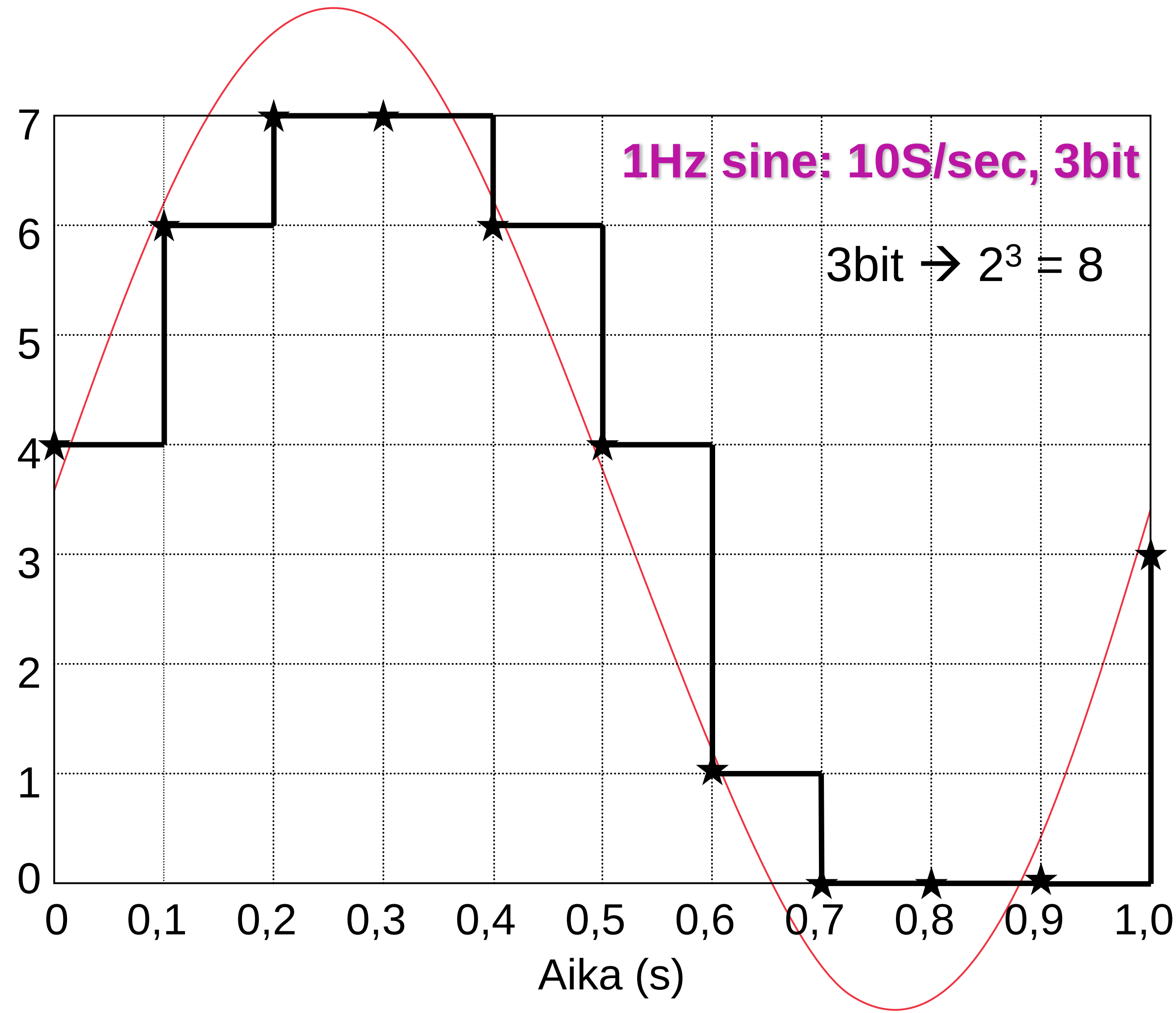

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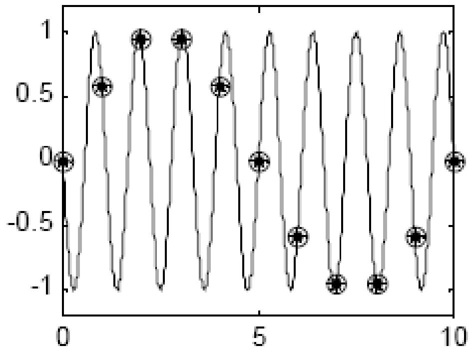
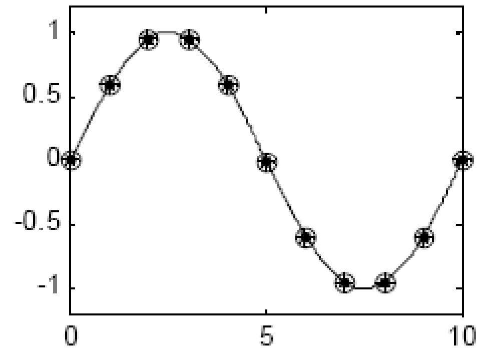
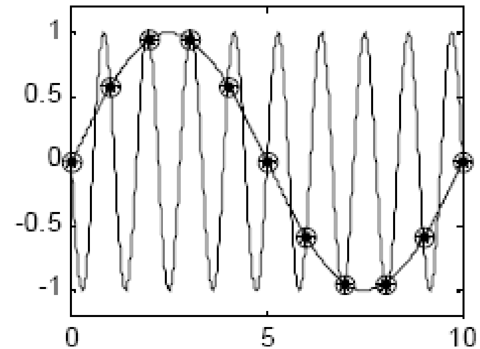
Sampling frequency



Sampling

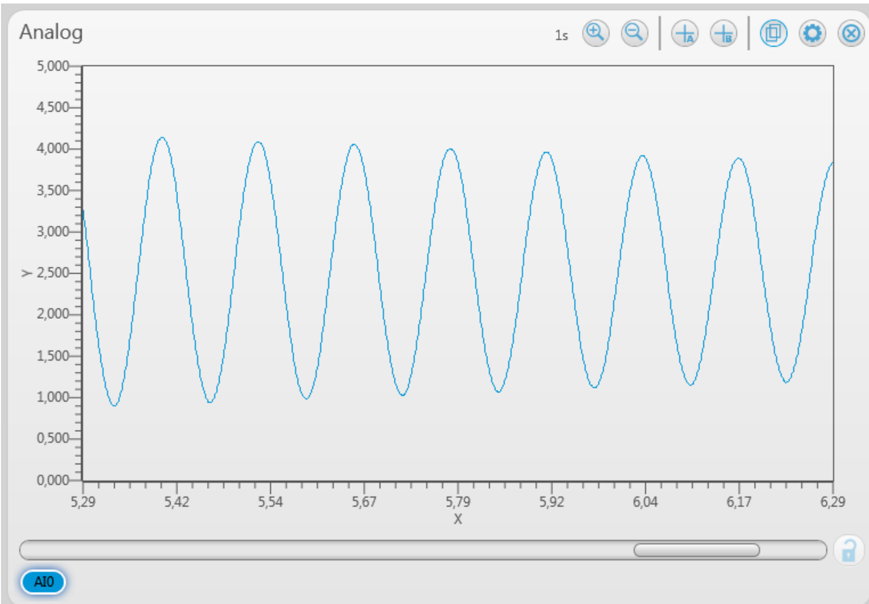


Generated signal

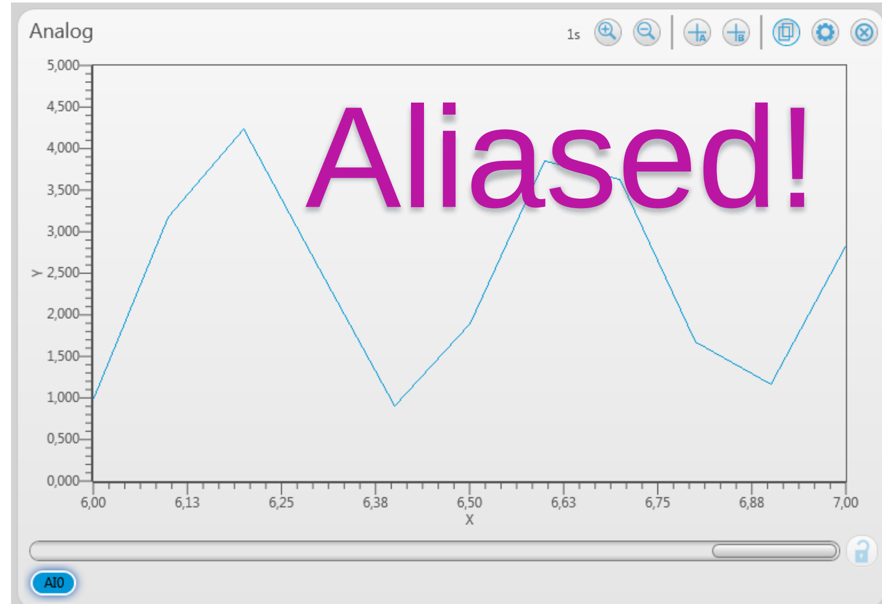


!!??

Effects of sampling rate vs. signal frequency



f_s=1000 Hz



f_s=10 Hz

How to Prevent Aliasing
Nyquist Theorem

Frequency

- To accurately represent the frequency of your original signal…
  - *You must sample at <u>greater than 2 times the maximum frequency</u> component of your signal*

Shape

- To accurately represent the shape of your original signal…
  - *You must sample between <u>5–10 times greater than the maximum frequency</u> component of your signal .*

Common Signal Conditioning for Voltage Measurements

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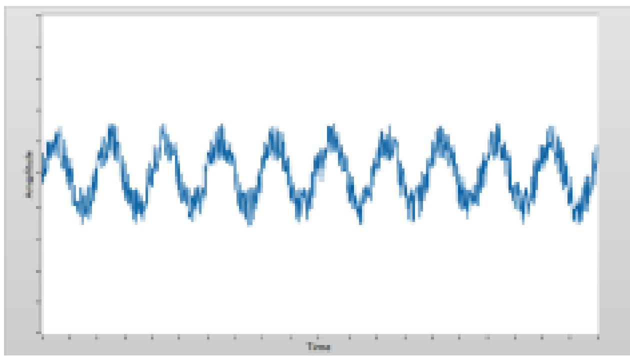
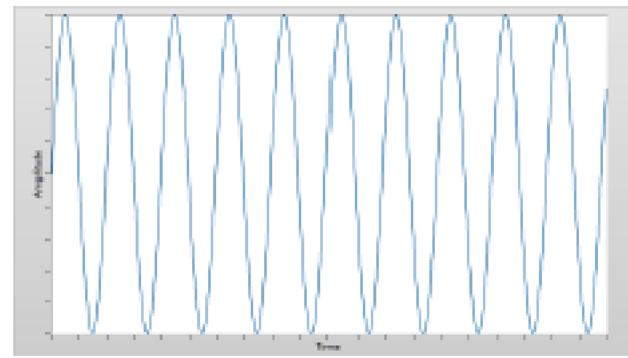
Conditioning Signals

Signal conditioning improves a signal that is difficult for your DAQ device to measure

Signal conditioning is not always required



Noisy, Low-Level Signal



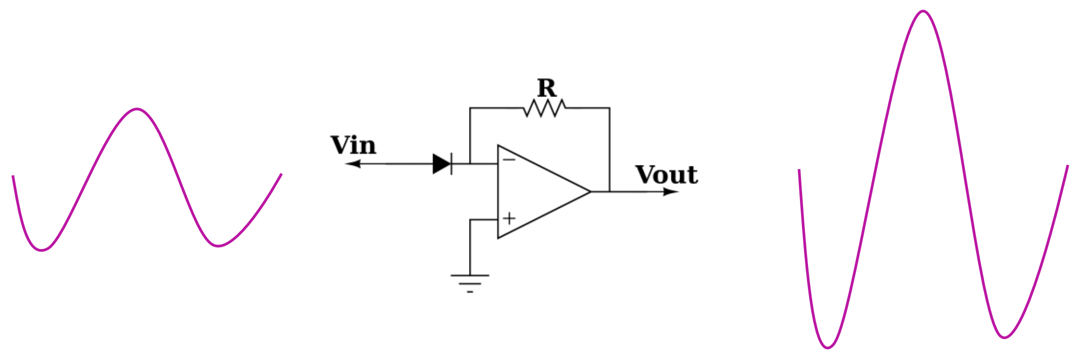
Filtered, Amplified Signal

Amplification

Used on low-level signals

Maximizes use of analog-to-digital converter (ADC) range and increases accuracy

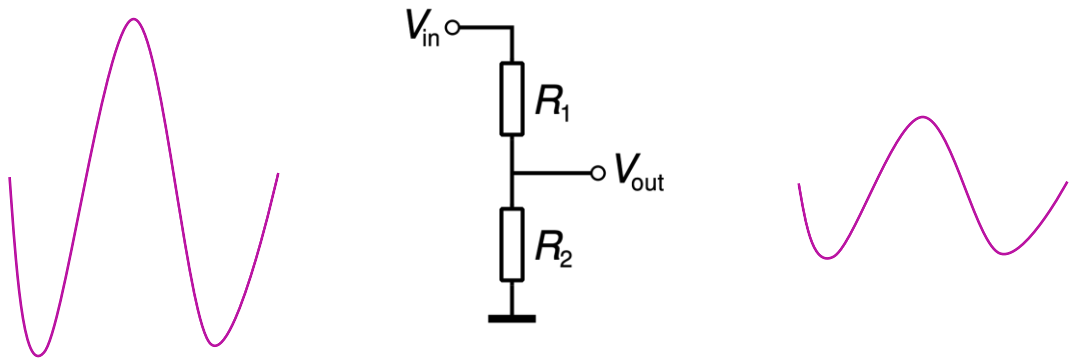
Increases signal-to-noise ratio (SNR)



Attenuation

Decreases the input signal amplitude to fit within the range of the DAQ device

Necessary when input signal voltages are beyond the range of the DAQ device

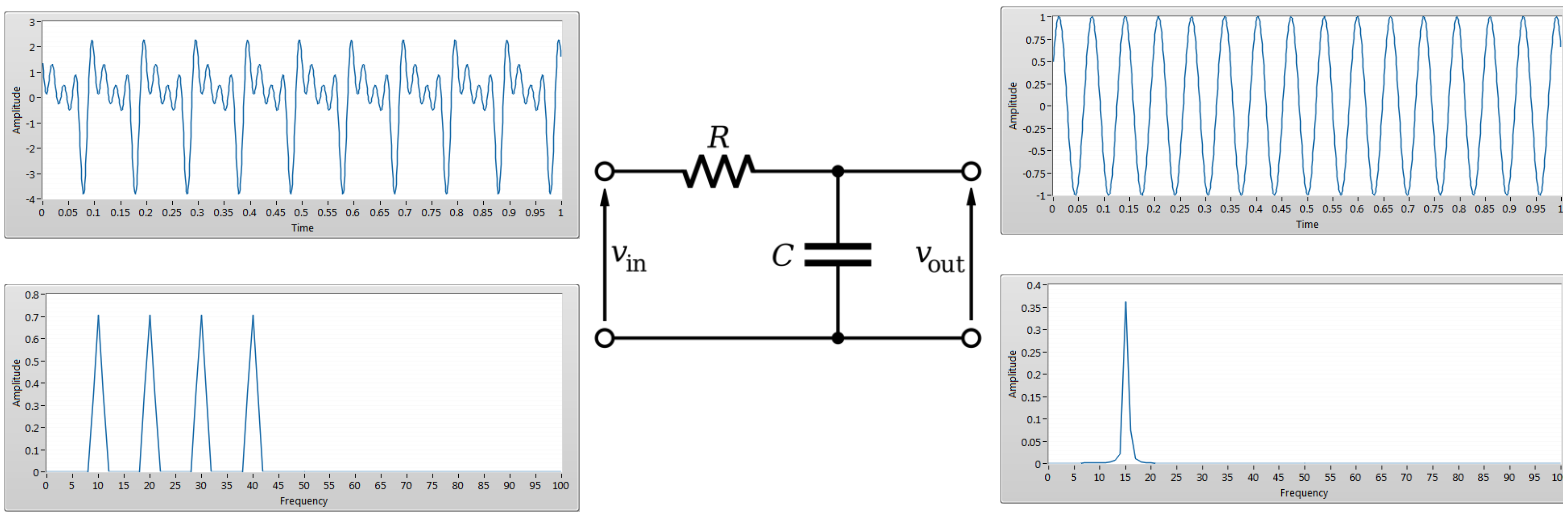


Filtering

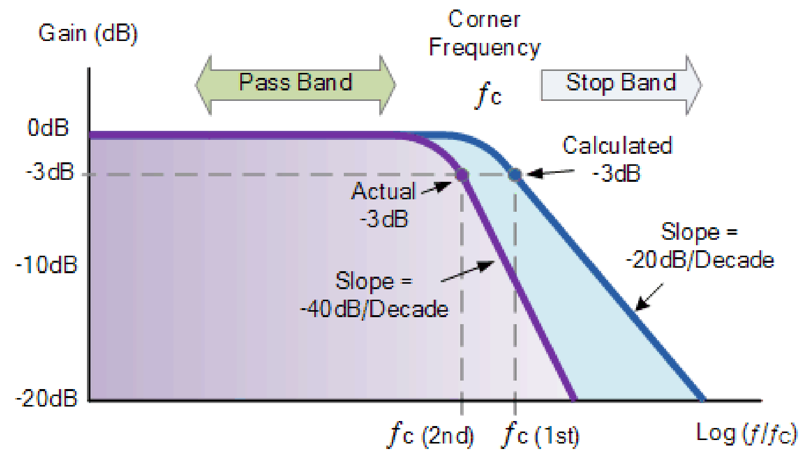
Filters remove unwanted noise from a measured signal and block unwanted frequencies

Time domain

Frequency domain



Low pass filter



Passband = low frequencies

Stopband = high frequencies

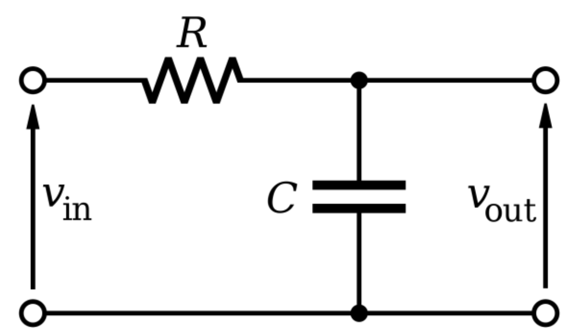
Cutoff frequency

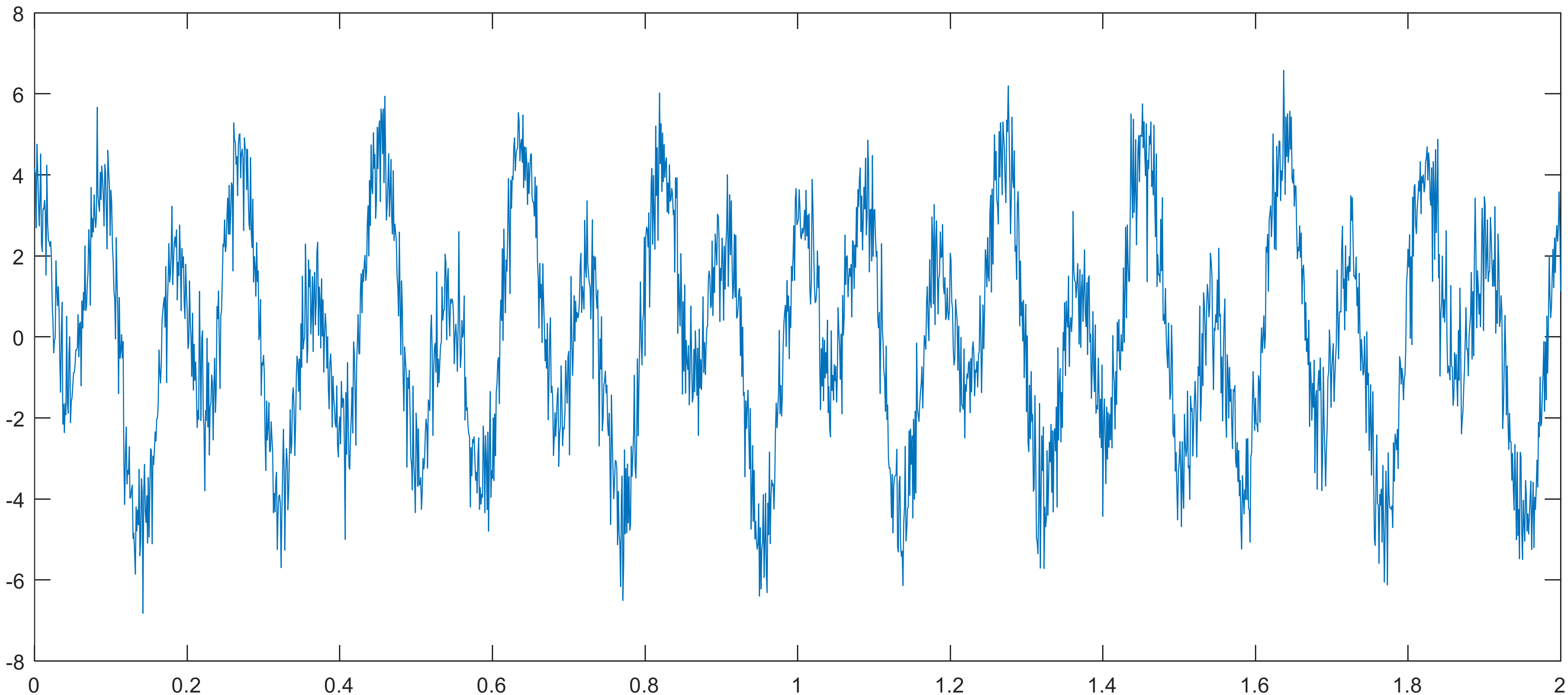
- *Amplitude -3 dB i.e. gain ~0.7*

Example: RC filter

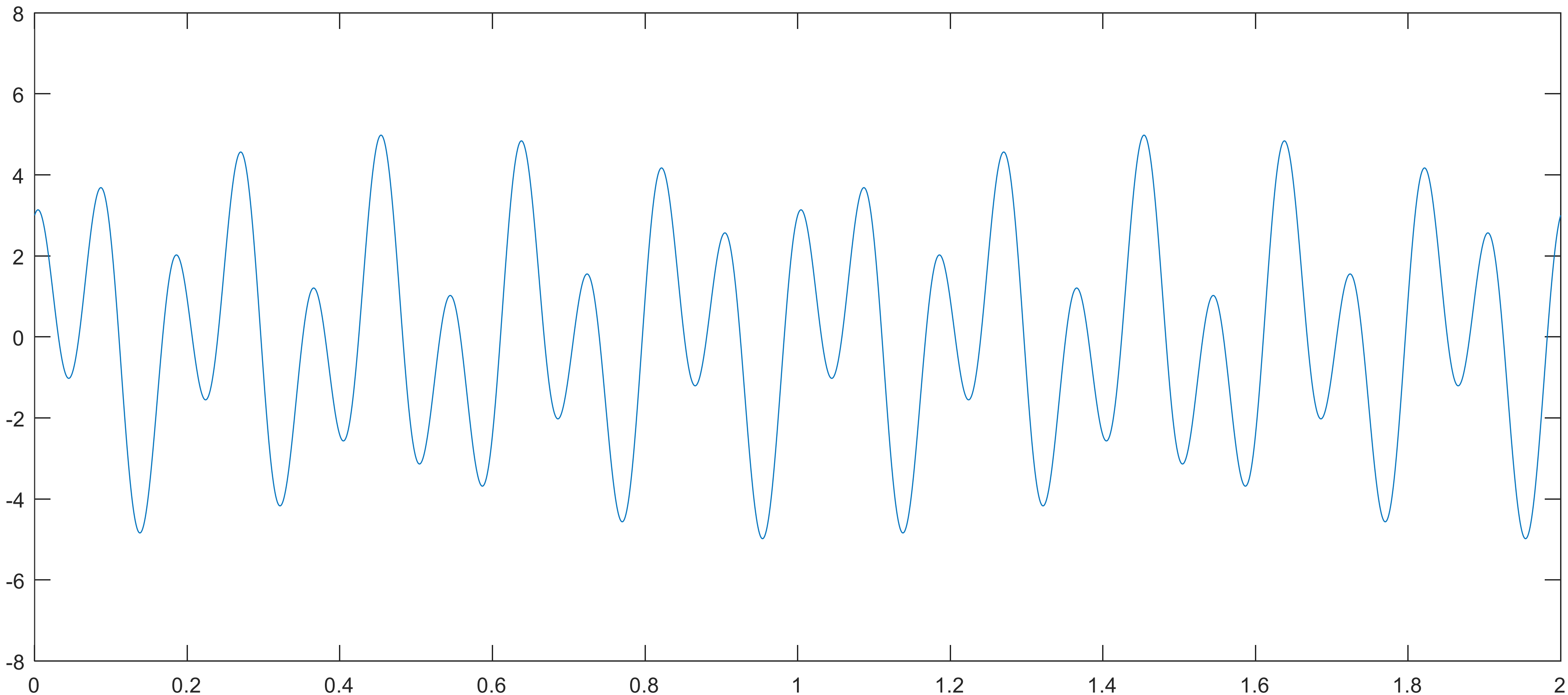
- *1st order low pass filter*
- *Simple to implement, not very effective*
- *1 resistor, 1 capacitor*
- *Cut off frequency:*

$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$$





8
6
4
2
0
-2
-4
-6
-8
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


8
6
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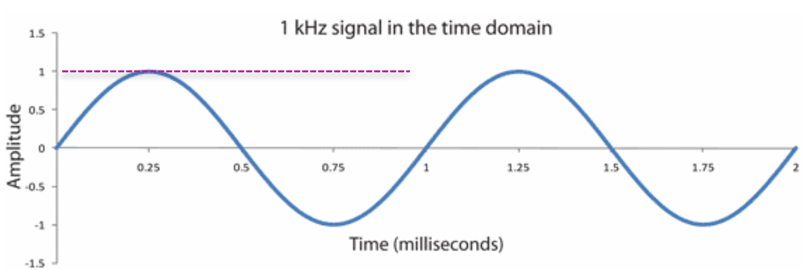
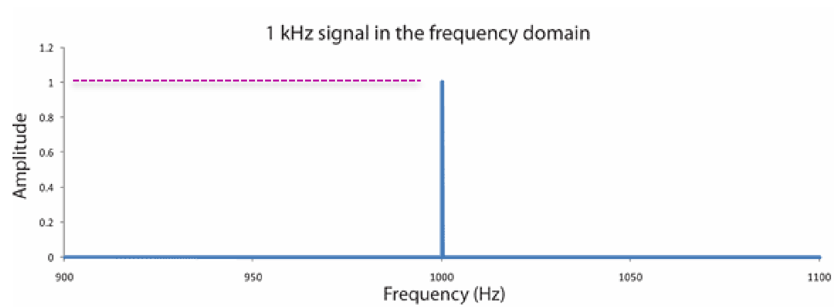
0
-2
-4
-6
-8
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Fourier transform

Decomposing a signal into its sinusoidal frequency components



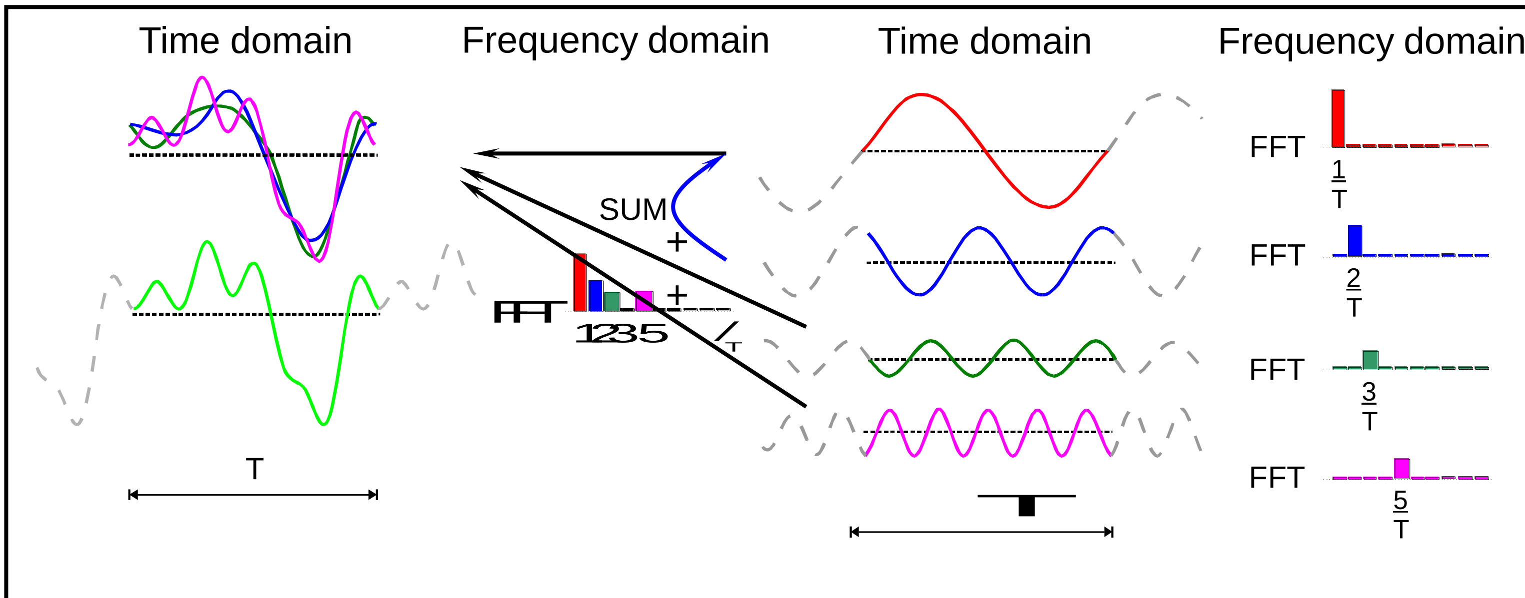


Signal in time domain

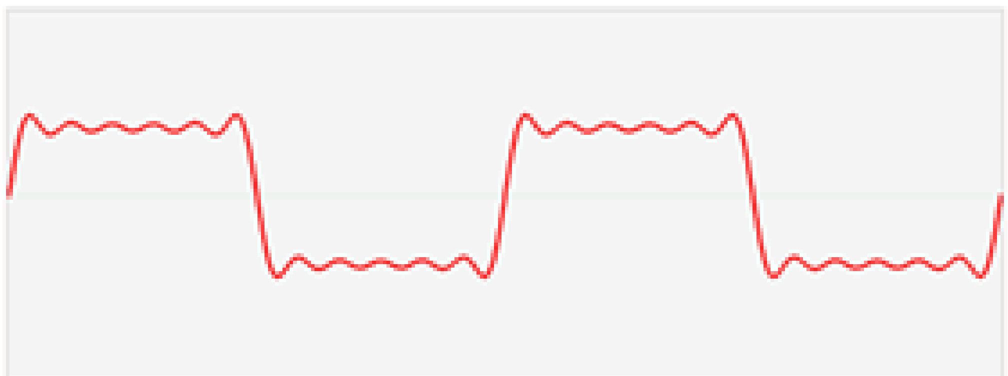
Signal in frequency domain

Frequency domain analysis

- Can be done easily using for example Matlab built-in function fft()
- FFT = Fast Fourier Transform



Fourier transform



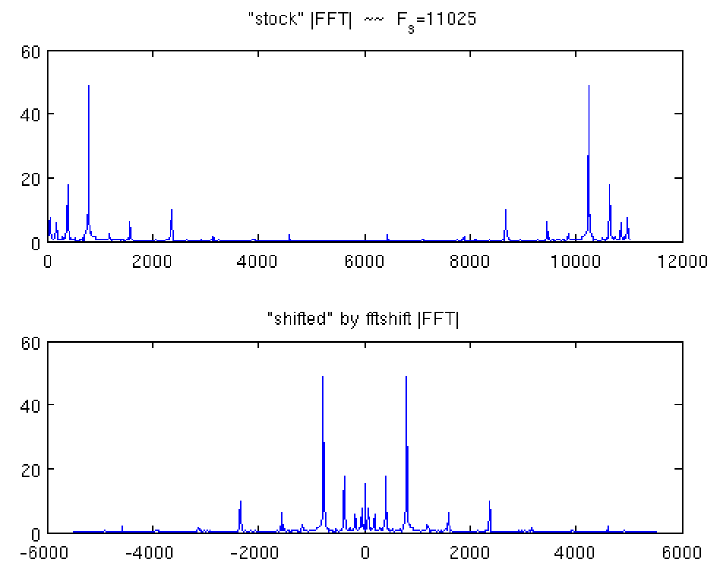
Discrete Fourier transform

Returns the amplitude of bands (or bins) of frequencies as complex numbers

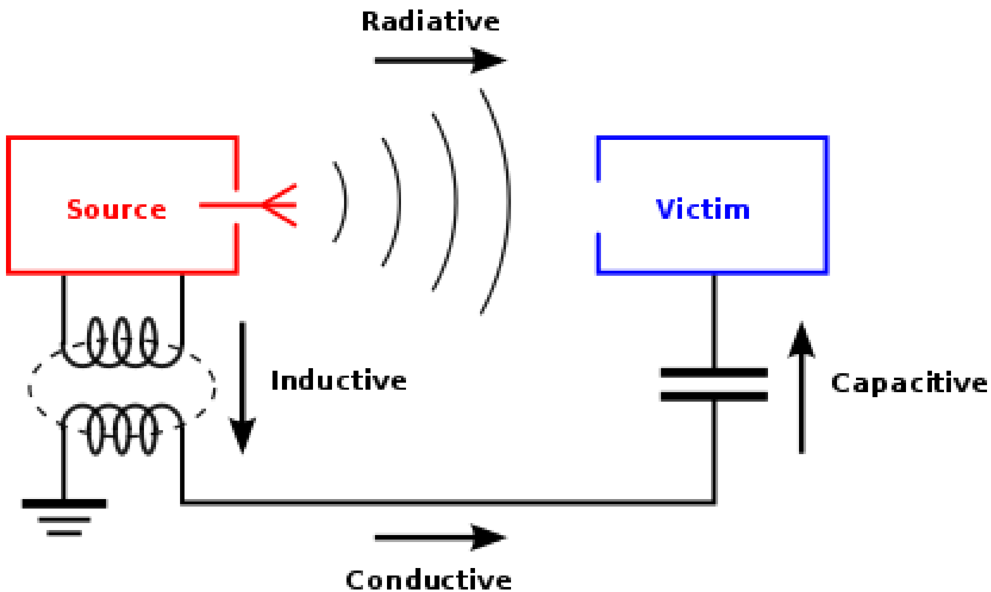
- *0 Hz = DC offset*
- *Magnitude = absolute value of complex number -> abs()*
- *Phase = angle of the complex number -> angle() or atan2()*

FFT – Fast Fourier transform algorithm

- *Matlab function fft(data)*



Electromagnetic interference
can ruin your measurements



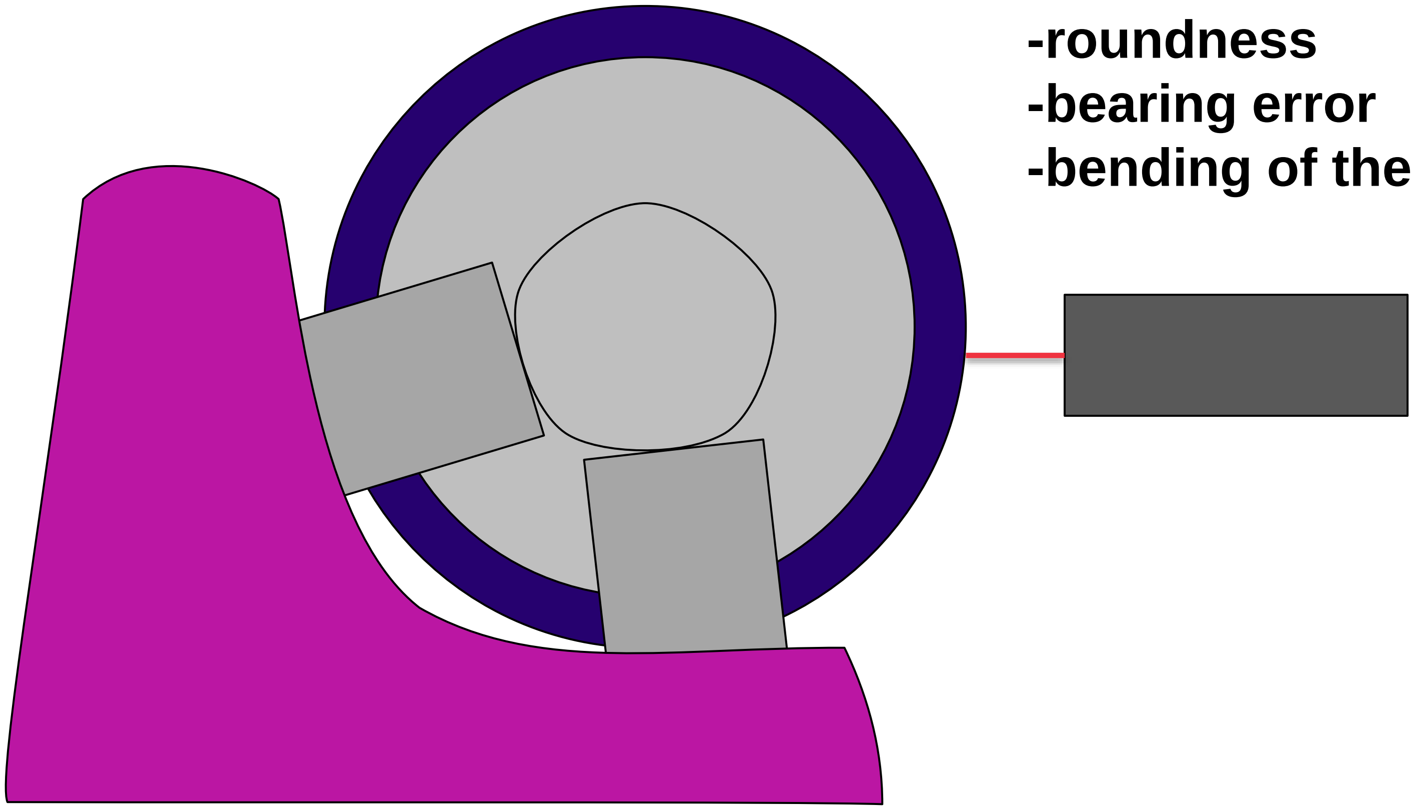
Eliminate ground loops
Wire condition and quality
- **Coaxial**
- **Twisted pair**
- **Shielding (Eg. CAT 6)**

Isolation
- **Galvanic**
- **Inductive**
- **optical**

Case: paper machine roll run-out

- **Dynamic run-out**
  - run-out as a function of the roll rotating frequency
- **Measurement objectives**
  - Measure run-out of the roll
  - Measure angular velocity and angular position of the roll

Run-out

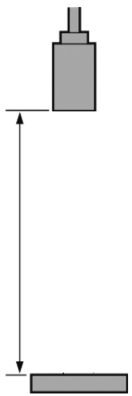


-roundness
-bearing error
-bending of the roll

Architecture of a measurement system

Measurand

L



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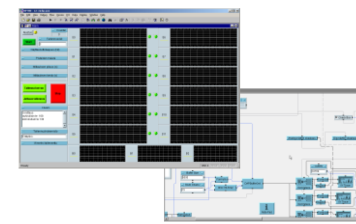


Labview
DASYLab
Matlab
Visual C++/Basic
…

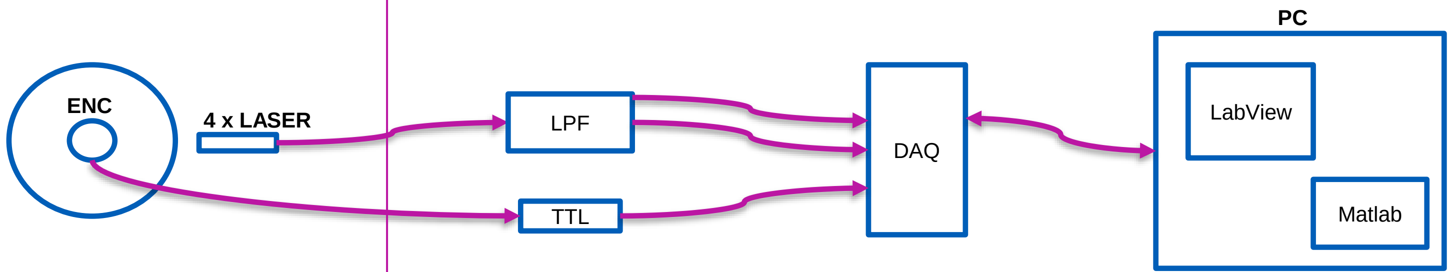
Measurement setup

Sensors
- Laser (displacement)
- Encoder (angle & speed)

Filtering
- LPF
- Line receiver

Data acquisition
- DAQ-card

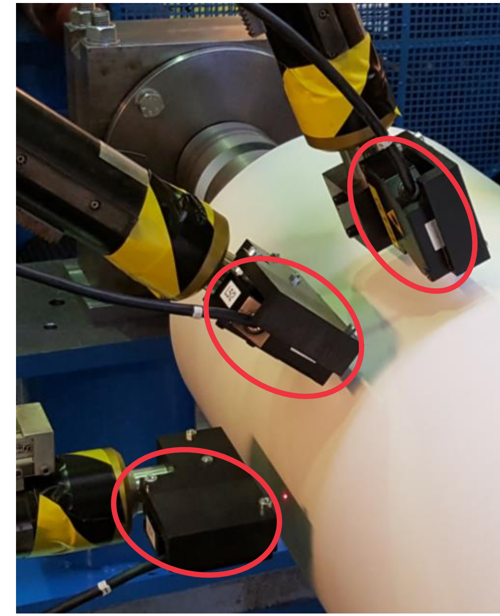
Data processing and analysis
- Labview
- Matlab

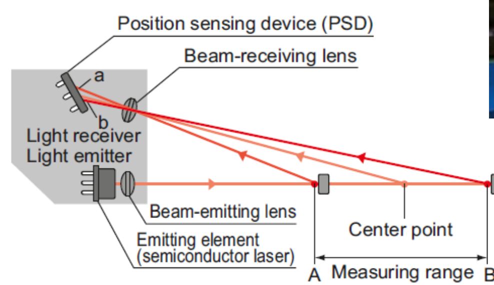


Sensors

Displacement (run-out)

- **Laser**
- **Triangulation**
- **Resolution 0.2μm**
- **Sample rate 50kHz**
- **Amplifier converts the distance to voltage: 1V ≡ 1mm**

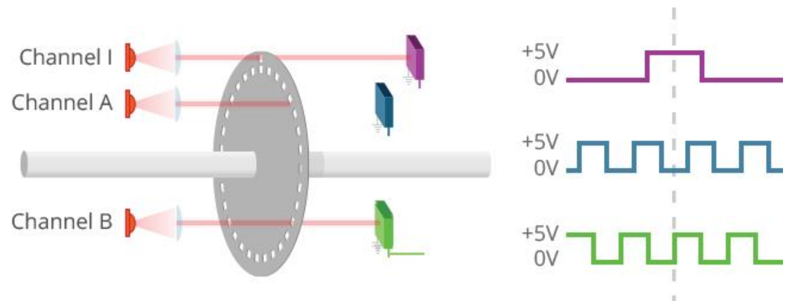




Sensors

Angle (position and velocity)

- **encoder**
- **Roll angle at each disp. value**
- **1024 pulses/rev**
  - **Resolution 0,35˚**
- **Digital: 0V=0, 5V=1**
- **2 channels + zero channel**



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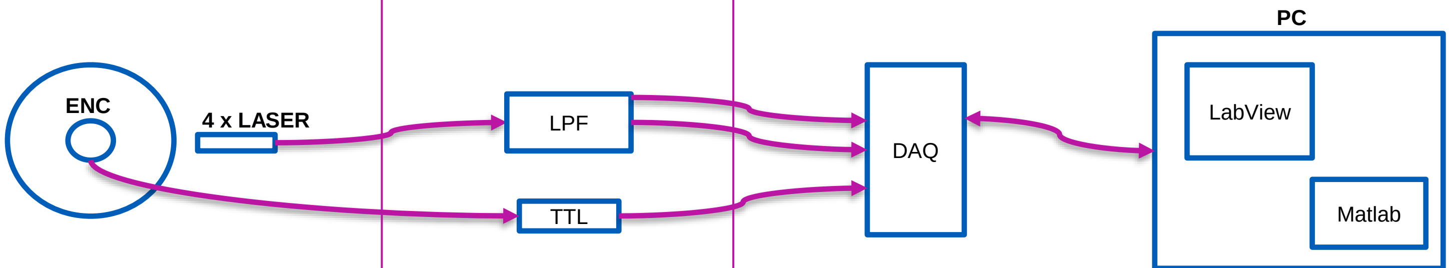
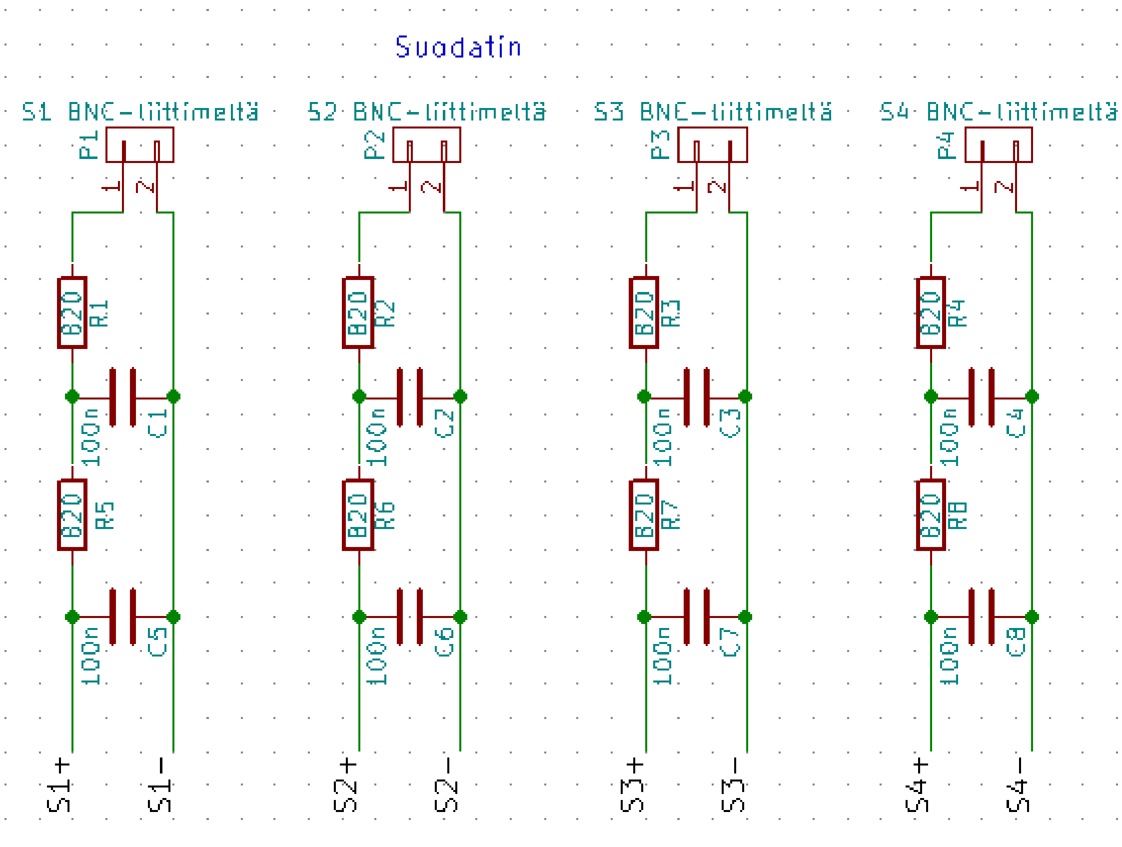
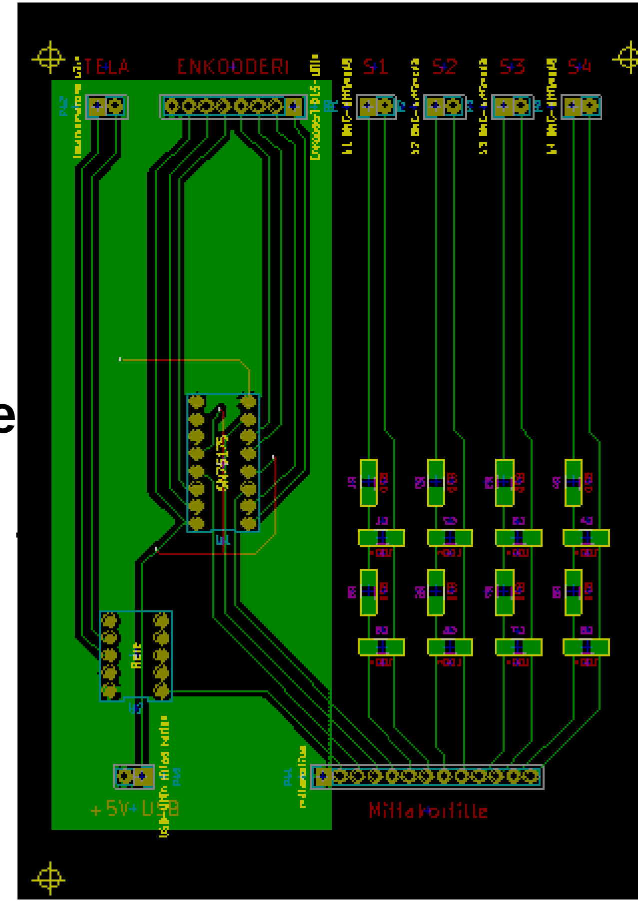



Suodatin
S1 BNC-liittimeltä
S2 BNC-liittimeltä
S3 BNC-liittimeltä
S4 BNC-liittimeltä
P1
P2
P3
P4
820 R1
820 R2
820 R3
820 R4
100n C1
100n C2
100n C3
100n C4
820 R5
820 R6
820 R7
820 R8
100n C5
100n C6
100n C7
100n C8
S1+
S1-
S2+
S2-
S3+
S3-
S4+
S4-

ne

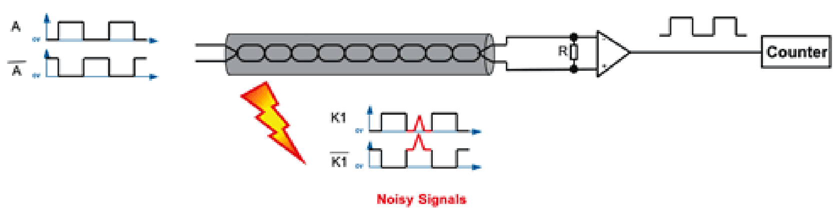
s


TELA
ENKOODERI
S1
S2
S3
S4
SN75175
Rele
+5V USB
Mittakortille

Differential digital signal trasmission

- Electromagnetic coupling based disturbance
  - Variable frequency drive, electric motors, power supply units…

- Differential signal transmission
- TTL receiver (digital signals)



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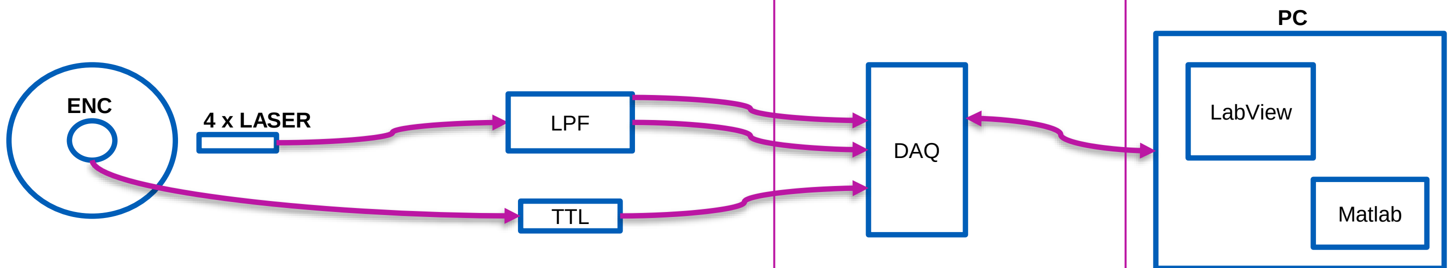

Data Acquisition

Measurement card – analog voltages and digital pulses are measured and converted to a computer-friendly format

- **NI USB-6215 USB**
- **16 analog inputs (voltage, ±10V), resolution 16 bit**
- **2 analog outputs (voltage, ±10V), resolution 16 bit**
- **4 digital inputs/outputs (0…5V)**
- **Max. Sample rate 250 kHz**
- **Multiplexer -> only one A/D-conversion unit ->converts voltages in turns from channel to channel**

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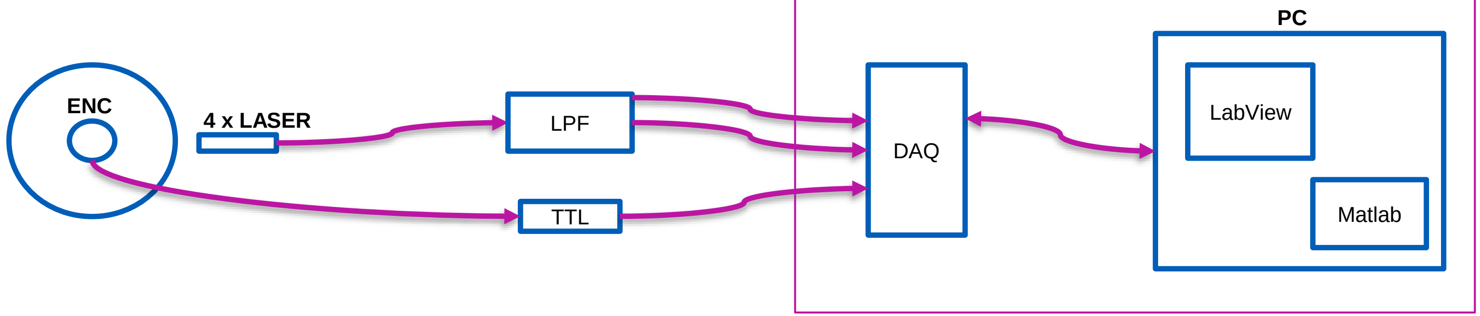
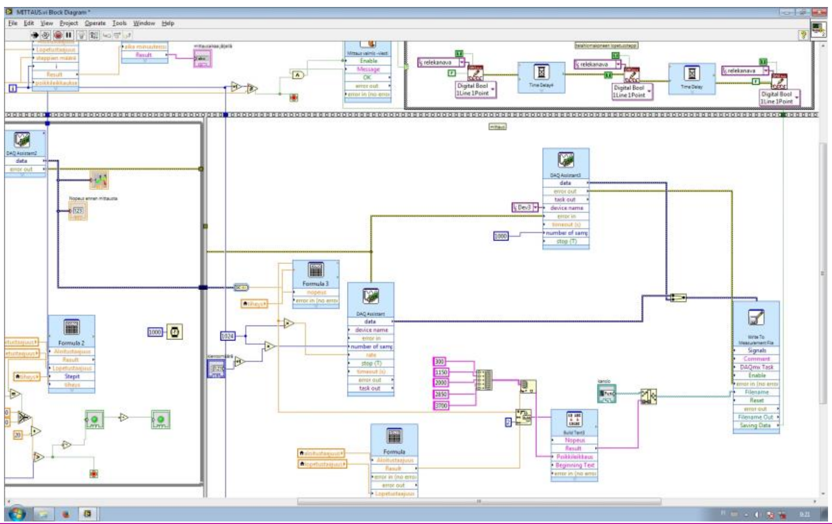


Measurement programming

- Measurement task must be programmed to the DAQ-card
- What is measured, which channel, how often…
- Labview, Matlab, C++, arduino…



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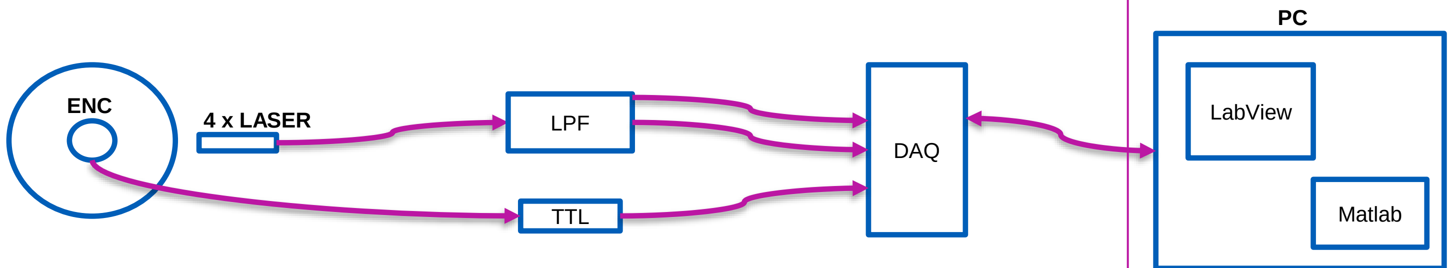
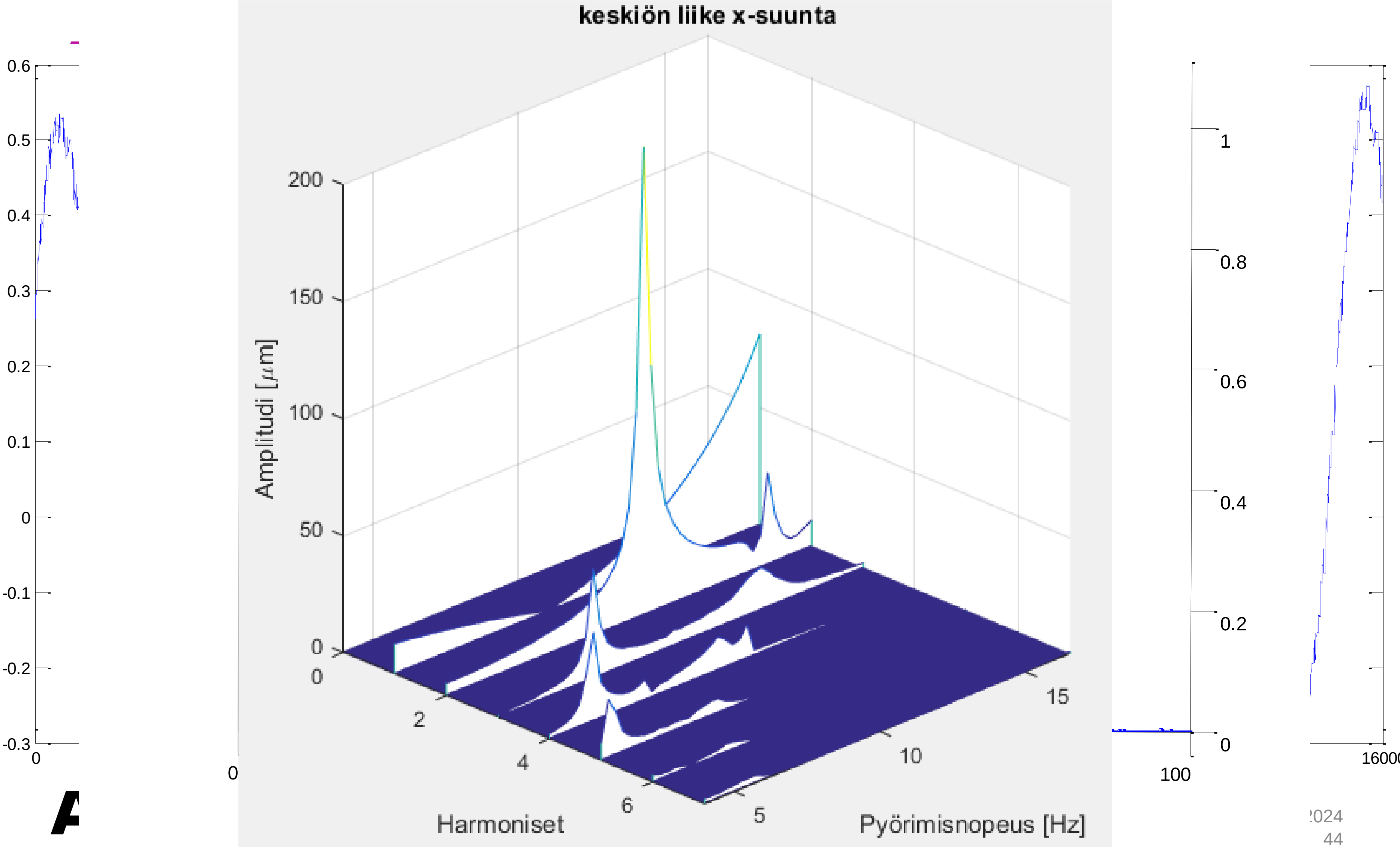


Analysis

- From data to information
- LabView, Matlab,…:
  - Data usually in text or binary forms
  - Data manipulation
  - Averaging
  - Frequency domain analysis (Fast Fourier Transform, FFT)
  - Charts and graphs

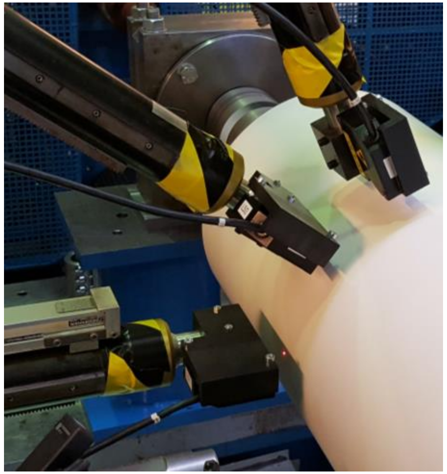

keskiön liike x-suunta
Amplitudi [μm]
Harmoniset
Pyörimisnopeus [Hz]
200
150
100
50
0
0
2
4
6
5
10
15

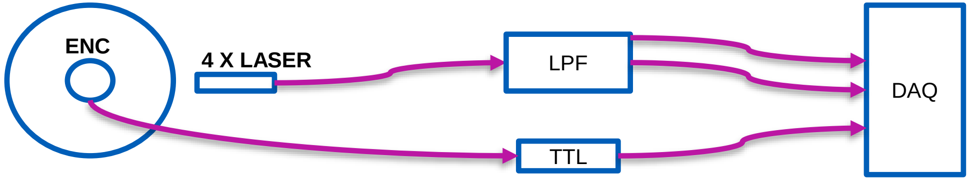
Measurement uncertainty

- **True value not reachable**
  - How to find out the error??? (measured – true value)
    - *Not possible!*
  - Measured values and Measurement uncertainty are both statistical variables: the result is within certain limits with certain probability
- **Systematic error -> calibration**
  - For example constant error in a meter
- **Random error -> uncertainty**
  - For example noise, vibration, stresses, temperature, measurer…
  - Harder to control!

Case: error sources – laser

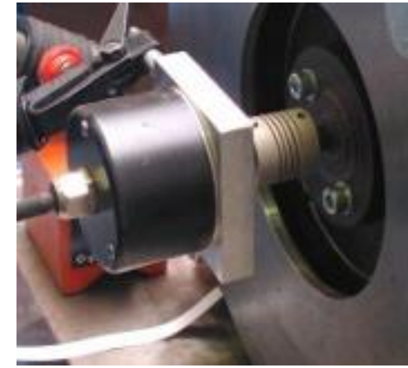
- Positioning error of the sensors (syst.)
- Nonlinearity (syst.)
- Noise and other EMC disturbance before DAQ

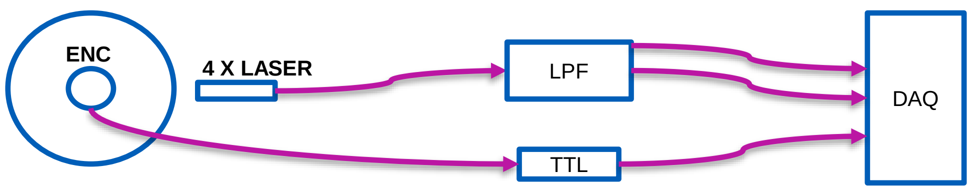




Case: error sources - encoder

- **Angular positioning error (syst.):**






A!