Measurement Techniques

Anders Sjöström
Juan Negreira Montero

Department of Construction Sciences.
Division of Engineering Acoustics.
Lund University

Disposition

- Introduction
- Errors in Measurements
- Signals
- Measurement Devices

Introduction

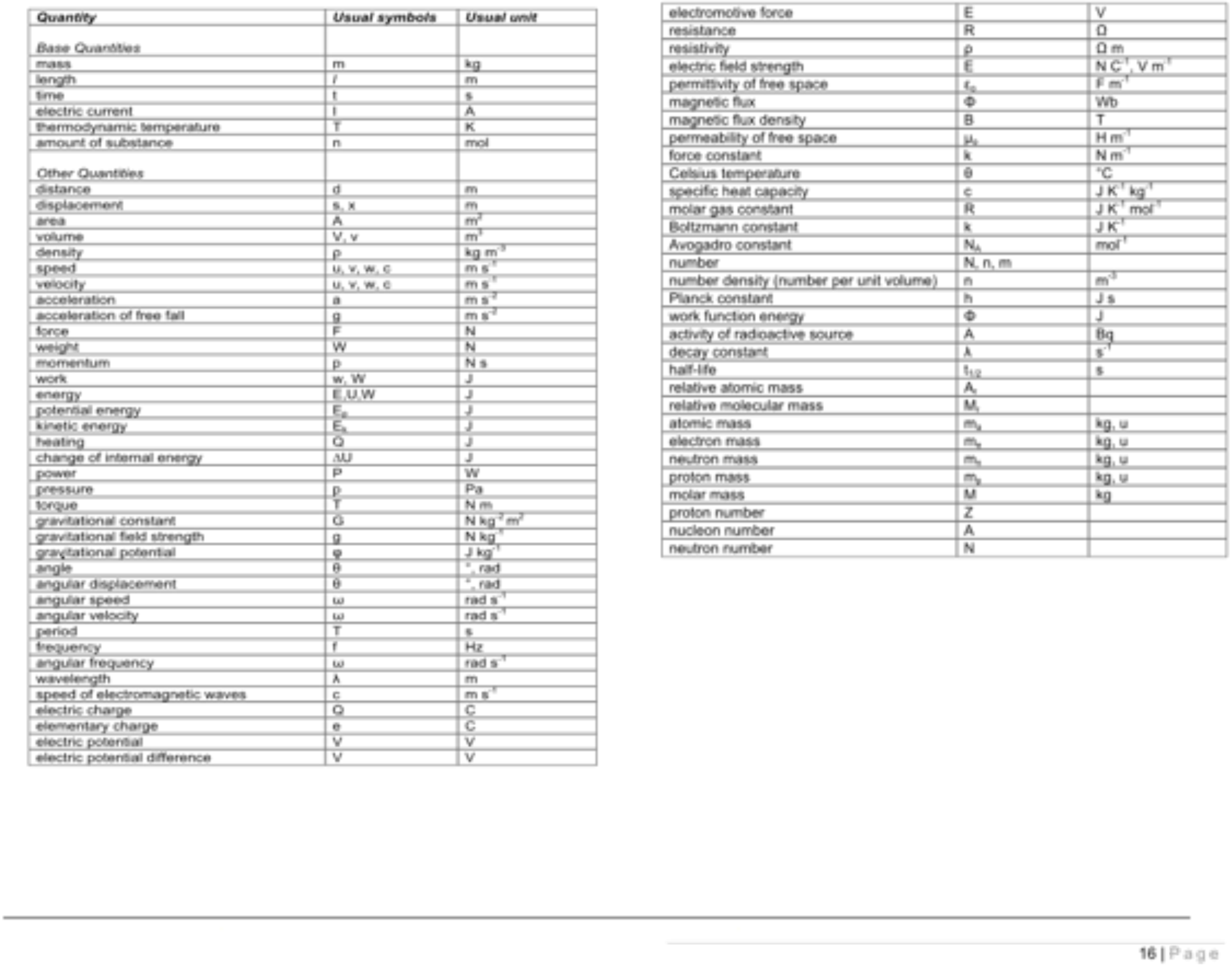
Introduction

- Experimental process to acquire new knowledge of a “product”
- The process must consist of planned actions for quantitative comparison of a measurand with an unit
- Measurand: Physical quantity to be measured
- Measurement equipment: software, measurement standard, reference material or auxiliar aparatus needed

SI-units

kilogram	The mass of a piece of platinum-iridium alloy kept under standard conditions near Paris.
second	The duration of 9192613770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesiurn-133 atom.
metre	The distance travelled in 1/299792458 of a second by plane EM waves in a vacuum.
Ampere	The electric current which, if maintained in two straight parallel conductors of infinite length and negligible circular cross-section, when placed one metre apart in a vacuum would produce, per metre of length, a force of 2 x 107N between the two conductors.
Kelvin	The fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
mole	A mole the amount of substance of a system which contains as many molecules, atoms or elementary entities as there are carbon atoms in 0.012kg of carbon-12.

Some examples of quantities



Quantity	***Usual symbols***	***Usual unit***
Base Quantities		
mass	m	kg
length	*l*	m
time	t	s
electric current	I	A
thermodynamic temperature	T	K
amount of substance	n	mol
Other Quantities		
distance	d	m
displacement	s, x	m
area	A	m^{2}
volume	V, v	m^{3}
density	ρ	kg m^{-3}
speed	u, v, w, c	m s^{-1}
velocity	u, v, w, c	m s^{-1}
acceleration	a	m s^{-2}
acceleration of free fall	g	m s^{-2}
force	F	N
weight	W	N
momentum	p	N s
work	w, W	J
energy	E,U,W	J
potential energy	E_p	J
kinetic energy	E_k	J
heating	Q	J
change of internal energy	ΔU	J
power	P	W
pressure	p	Pa
torque	T	N m
gravitational constant	G	N kg^{-2} m^{2}
gravitational field strength	g	N kg^{-1}
gravitational potential	φ	J kg^{-1}
angle	θ	°, rad
angular displacement	θ	°, rad
angular speed	ω	rad s^{-1}
angular velocity	ω	rad s^{-1}
period	T	s
frequency	f	Hz
angular frequency	ω	rad s^{-1}
wavelength	λ	m
speed of electromagnetic waves	c	m s^{-1}
electric charge	Q	C
elementary charge	e	C
electric potential	V	V
electric potential difference	V	V
electromotive force	E	V
resistance	R	Ω
resistivity	ρ	Ω m
electric field strength	E	N C^{-1}, V m^{-1}
permittivity of free space	ε_0	F m^{-1}
magnetic flux	Φ	Wb
magnetic flux density	B	T
permeability of free space	μ_0	H m^{-1}
force constant	k	N m^{-1}
Celsius temperature	θ	°C
specific heat capacity	c	J K^{-1} kg^{-1}
molar gas constant	R	J K^{-1} mol^{-1}
Boltzmann constant	k	J K^{-1}
Avogadro constant	N_A	mol^{-1}
number	N, n, m	
number density (number per unit volume)	n	m^{-3}
Planck constant	h	J s
work function energy	Φ	J
activity of radioactive source	A	Bq
decay constant	λ	s^{-1}
half-life	$t_{1/2}$	s
relative atomic mass	A_r	
relative molecular mass	M_r	
atomic mass	m_a	kg, u
electron mass	m_e	kg, u
neutron mass	m_n	kg, u
proton mass	m_p	kg, u
molar mass	M	kg
proton number	Z	
nucleon number	A	
neutron number	N	

Errors in Measurements

Errors in Measurements

- Measurements under ideal conditions have no errors. Real ones always do
- Clearly defined processes are needed to identify every source of error
- Measurement system errors can only be defined in relation to the solution of a real specific measurement task

Errors in Measurements

- Measurement Error: Difference between true value of the measurand (measured quantity) and the measured value

$$\Delta x = x_r - x_i$$

- Precision is the closeness of agreement between independent measurements of a quantity under the same conditions

- Uncertainty: Component of a reported value that characterizes the range whithin with the true value is asserted to lie.

Actual (absolute) uncertainty

- The value obtained when a measurement is made always carries an uncertainty that is dependent on the precision of the instrument.
- The *absolute uncertainty,* is usually either the smallest division or half the smallest division in the calibration of the instrument.
- The instrument used determines the number of decimal places that should be quoted for all measurements made with it.

Errors in Measurements

- Measurement system type. Common errors:
  - Input error
  - Sensor error
  - Signal Transmission error 1
  - Transducer error
  - Signal Transmission error 2
  - Converter error
  - Signal Transmission error 3
  - Computer error
  - Signal Transmission error 4
  - Indication error

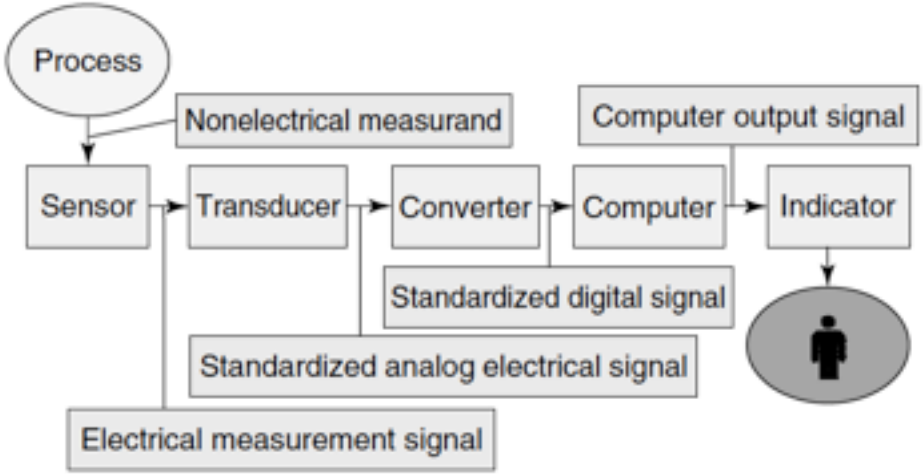
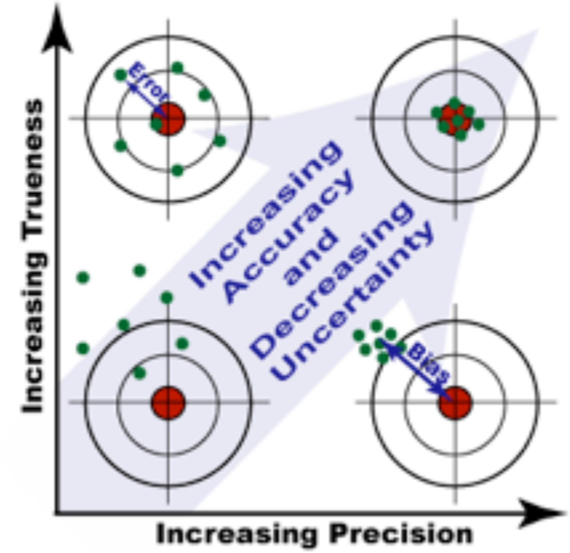


Figure 1. Measurement chain.

Types of Errors

- Systematic error (bias)
  - Permanent deflection in same direction from true value
  - It can be corrected
  - Types:
    - Lack of gauge resolution
    - Lack of linearity
    - Drift
    - Hysteresis



Types of Errors

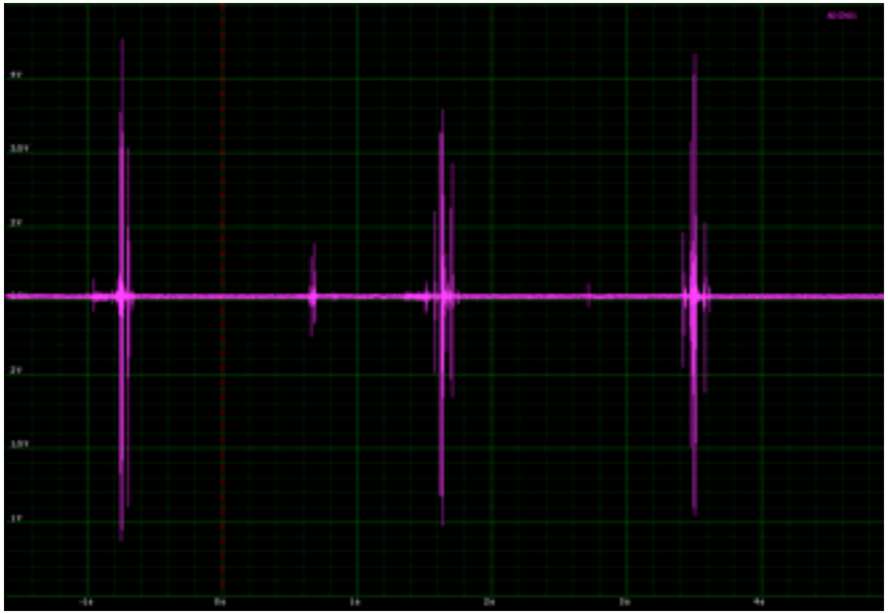
- Random error
  - Short-term scattering of values around a mean value.
  - Varies in an unpredictable way
  - Expressed by statistical methods
  - It cannot be corrected
  - Reasons
    - Lack of equipment sensitivity
    - Noise
    - Imprecise definition
- Gross errors
  - Human mistakes

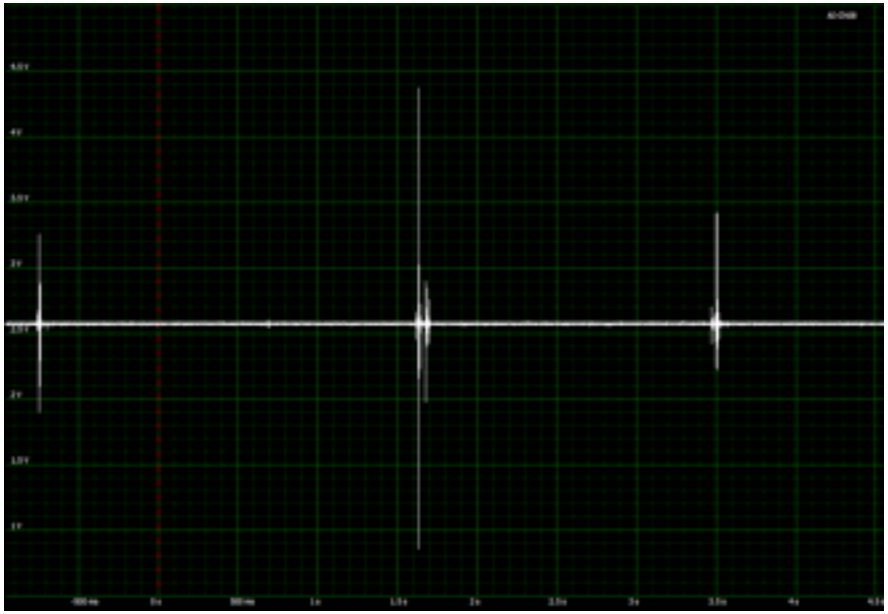
$$X_{true} = X_{measured} + e_{syst} + e_{random}$$

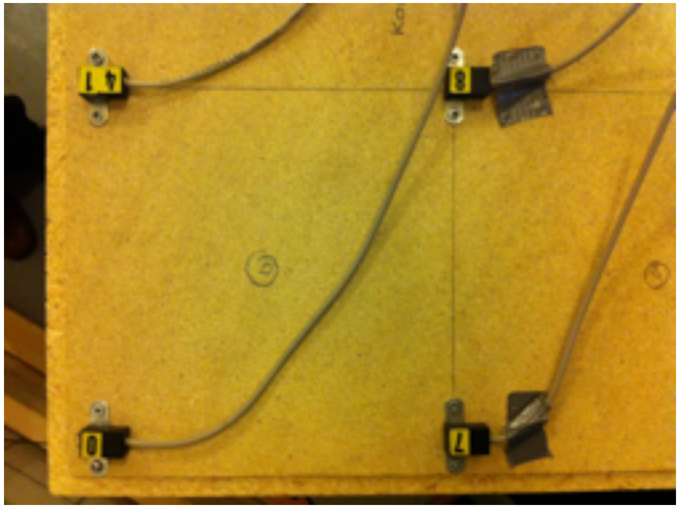
Difference between errors

	Random errors	**Systematic errors**
Magnitude of errors	Variable	Constant
Sign of errors	Equally likely to be positive or negative	Same
Can be reduced by taking more readings and average	Yes	No
Can be totally eliminated	No	Yes

Examples of Errors

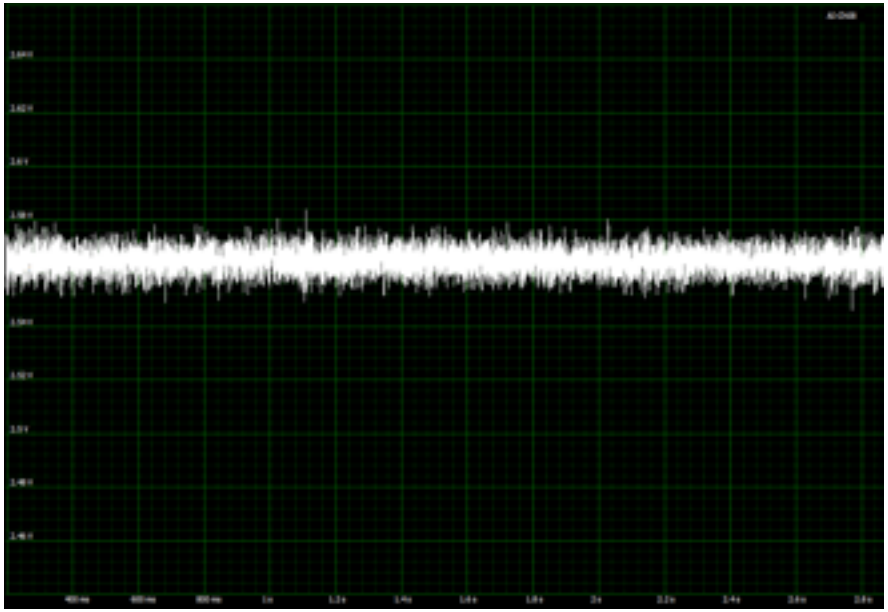






- Wire-Error

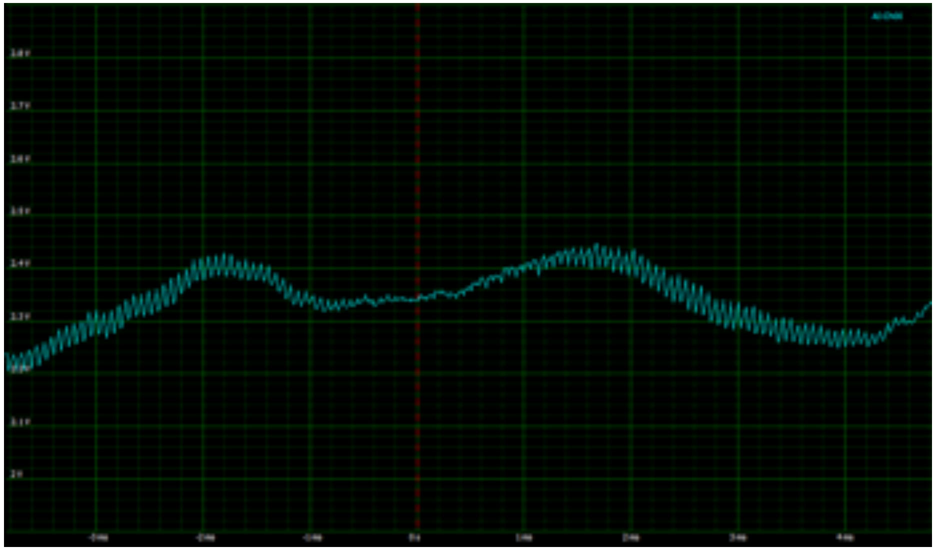
Examples of Errors



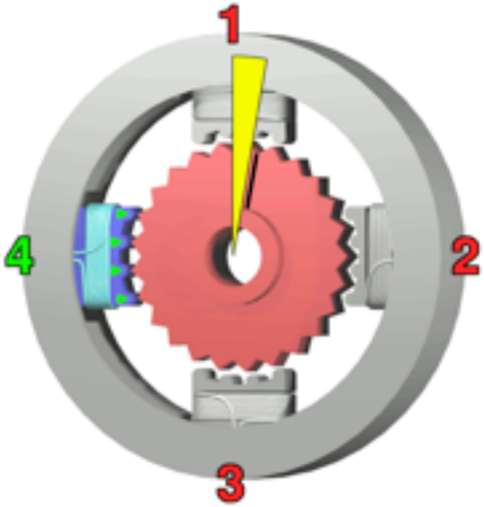
- Music

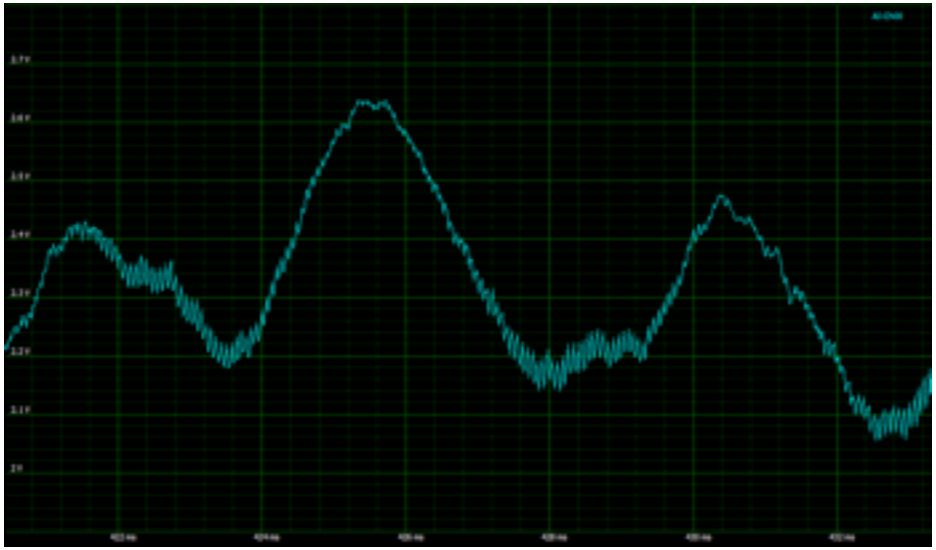
- External impact

Examples of Errors



- Step motor (2 Hz)



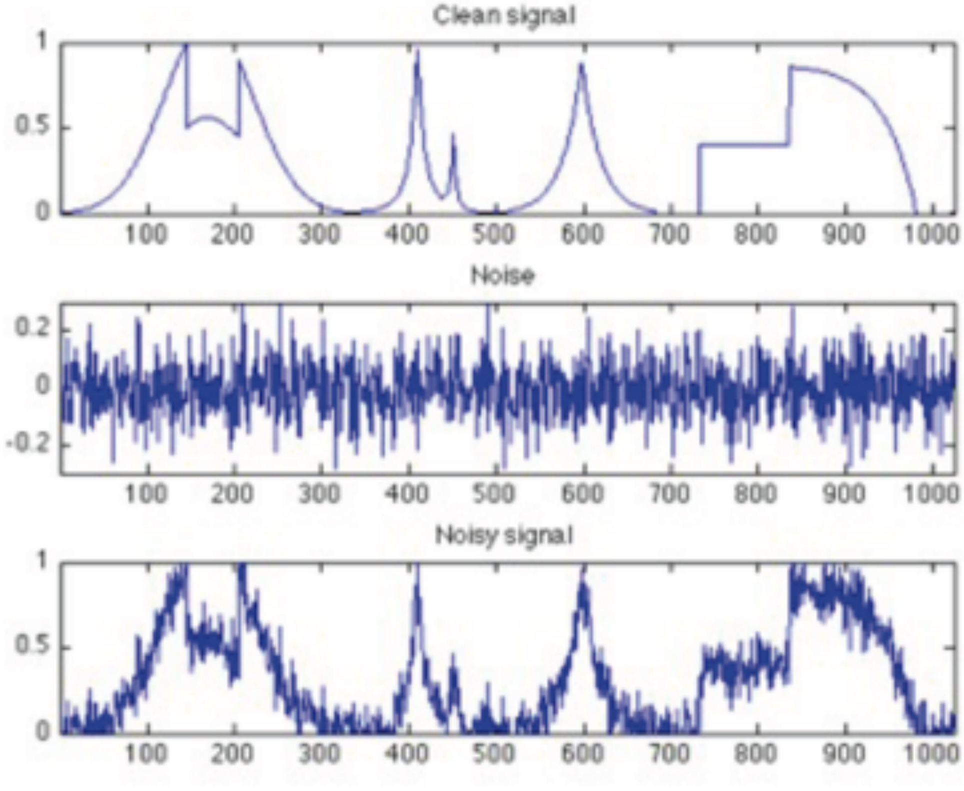


- Step motor (4,5 Hz)

Signals

Signals

- Signal produced by the acquisition system is a voltage signal varying with time. Unequivocally related to the measurand
- Noise added makes the signal change from a smooth curve to a “jagged” one.
- Signal to noise ratio is defined as the ratio of signal power to the noise power corrupting the signal.
- A ratio higher than 1:1 indicates that it exits more signal than noise

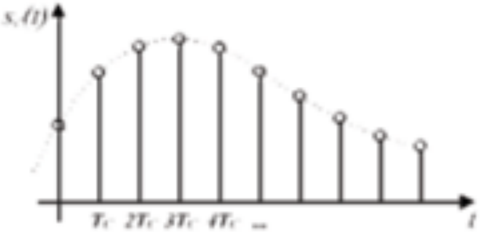


$$SNR = \frac{P_{signal}}{P_{noise}}$$

$$SNR_{dB} = 10\log_{10}\frac{P_{signal}}{P_{noise}}$$

Getting Ready for the Analysis

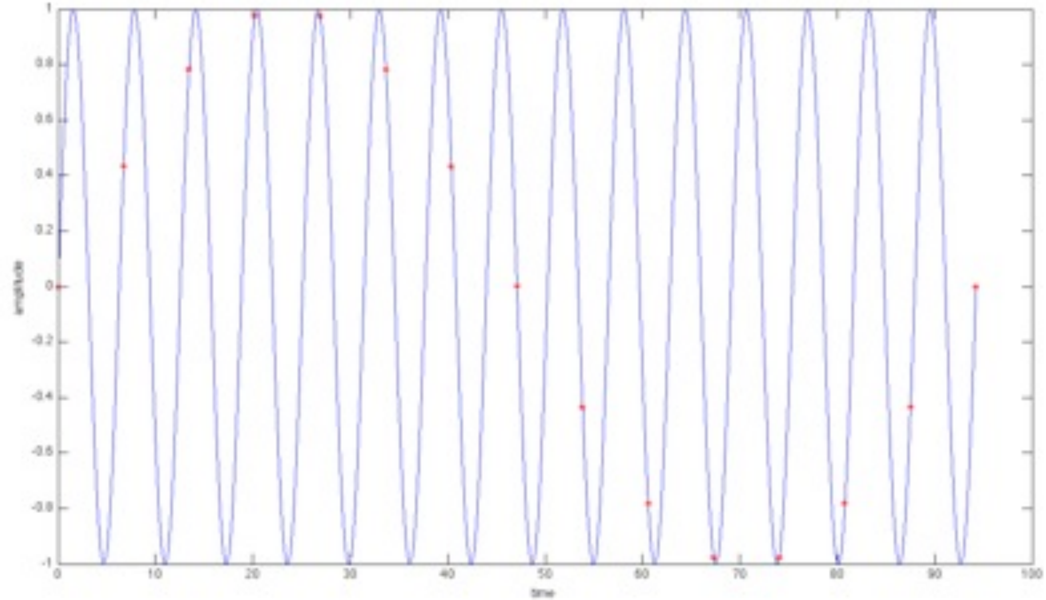
- To get the signal into a computer we need to digitalize it
- Digitize is the process of convert the analogue signal to a stream of discrete values (numbers) by assigning a value *x* to the signal level at a time *t*
- The time Δt between two consecutive values is given by the sampling frequency.



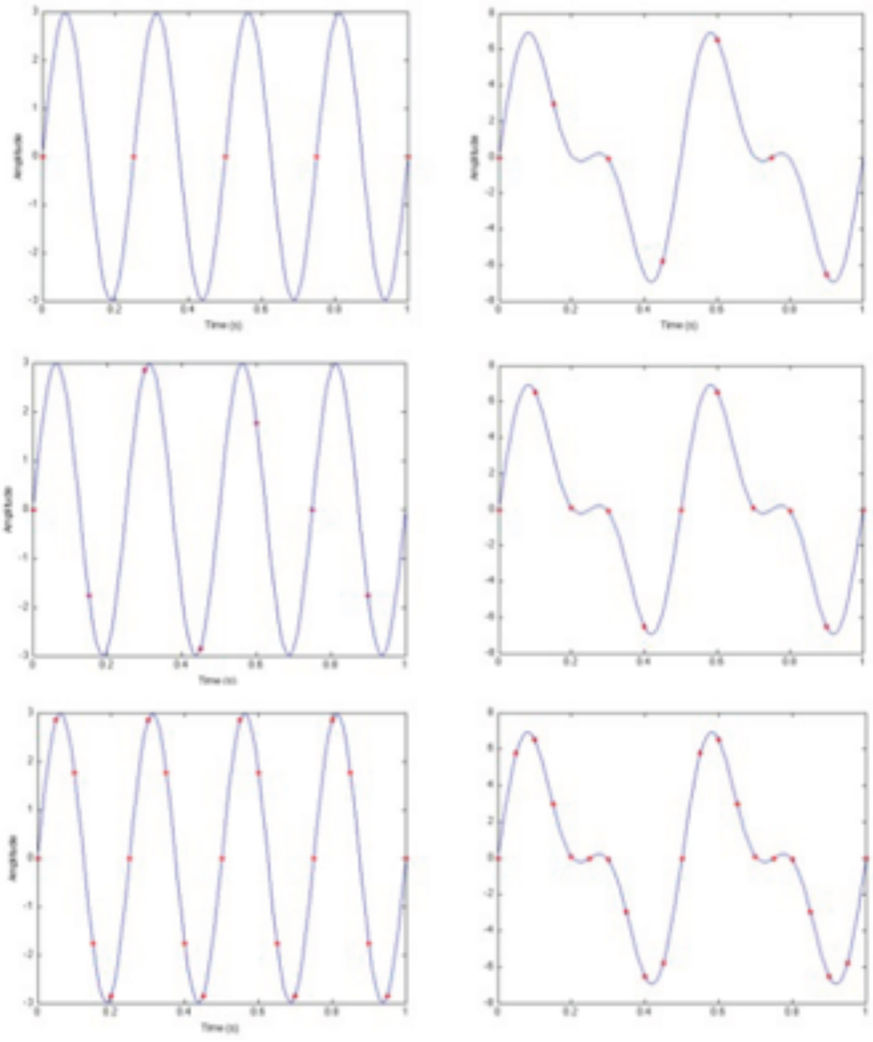
A/D conversion – data sampling

- The continuous analog signal is *sampled* at regular *intervals – the sampling interval h* [s]
  The analog signal is thus represented by a number of discrete – digital – values (numbers)
- The quality of the digital representation of the signal depends on:
  The sampling frequency f=1/h [Hz]
  The accuracy of the number representing the analog value
    - The accuracy means the number of bits representing the number
    - 8 bit means only 2^8=256 different values => poor accuracy
    - 20 bit means 2^20=1048576 different values => good accuracy
  The measurement *range* vs. the *range* of values in the experiment
  High sampling frequency and high accuracy => large data files!
- The reason not to use high sampling frequency is mainly to reduce file size

Sampling frequency



Sampling Frequency



- Note that the red dots (samples) do not truly represent the original signal.

- In order to do that, the sampling frequency must be twice the higher frequency in the signal

↓

NYQUIST-SHANNON CRITERIA

Nyquist-Shannon Sampling Criteria

Let x(t) be a continuous-time signal and X(t) the Fourier transform of that signal

$$X(t) \overset{Def}{=} \int_{-\infty}^{+\infty} x(t) e^{j2\pi ft} dt$$

x(t) is said to be bandlimited to a one-sided baseband bandwidth, B, if:

$$X(F) = 0 \qquad \forall \qquad f$$

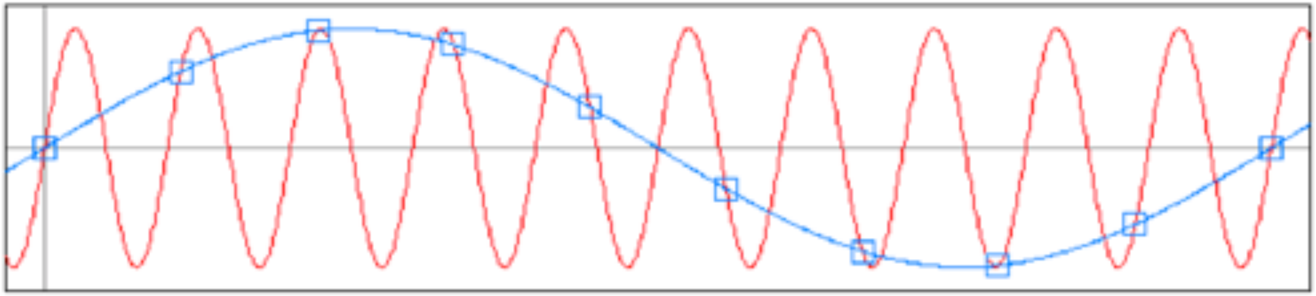
The the sufficient condition for “exact” reconstructability from samples at uniform sample rate is:

$$f_s > 2B \Leftrightarrow B < \frac{f_s}{2}$$

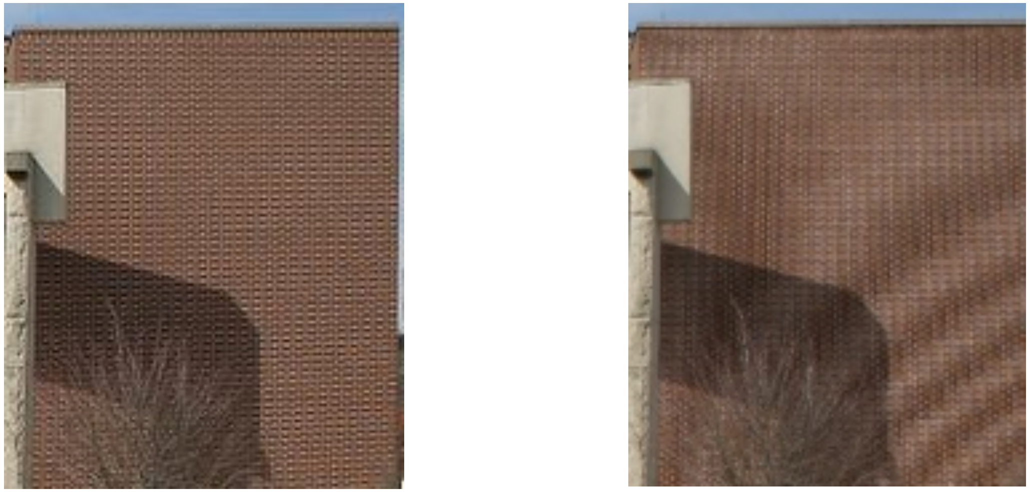
2B is called the Nyquist rate and it is a property of the bandlimited signal, while (f_s/2) is called the Nyquist frequency and is a property of the sampling system

Aliasing

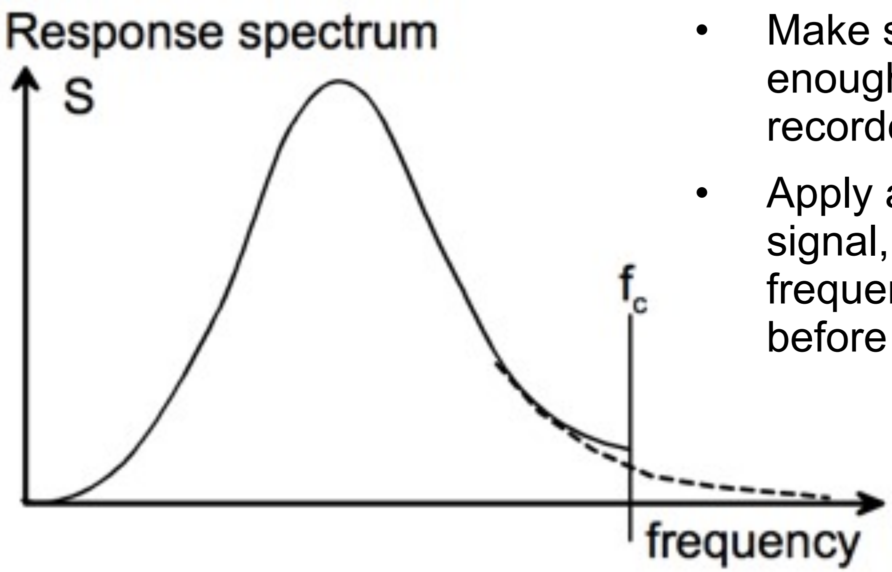
- When two different continuous signals become indistinguishable due to bad sampling (Nyquist-Shannon criteria is not fulfilled)



- Example: Image aliasing (Sampling resolution / Pixel density wrong)

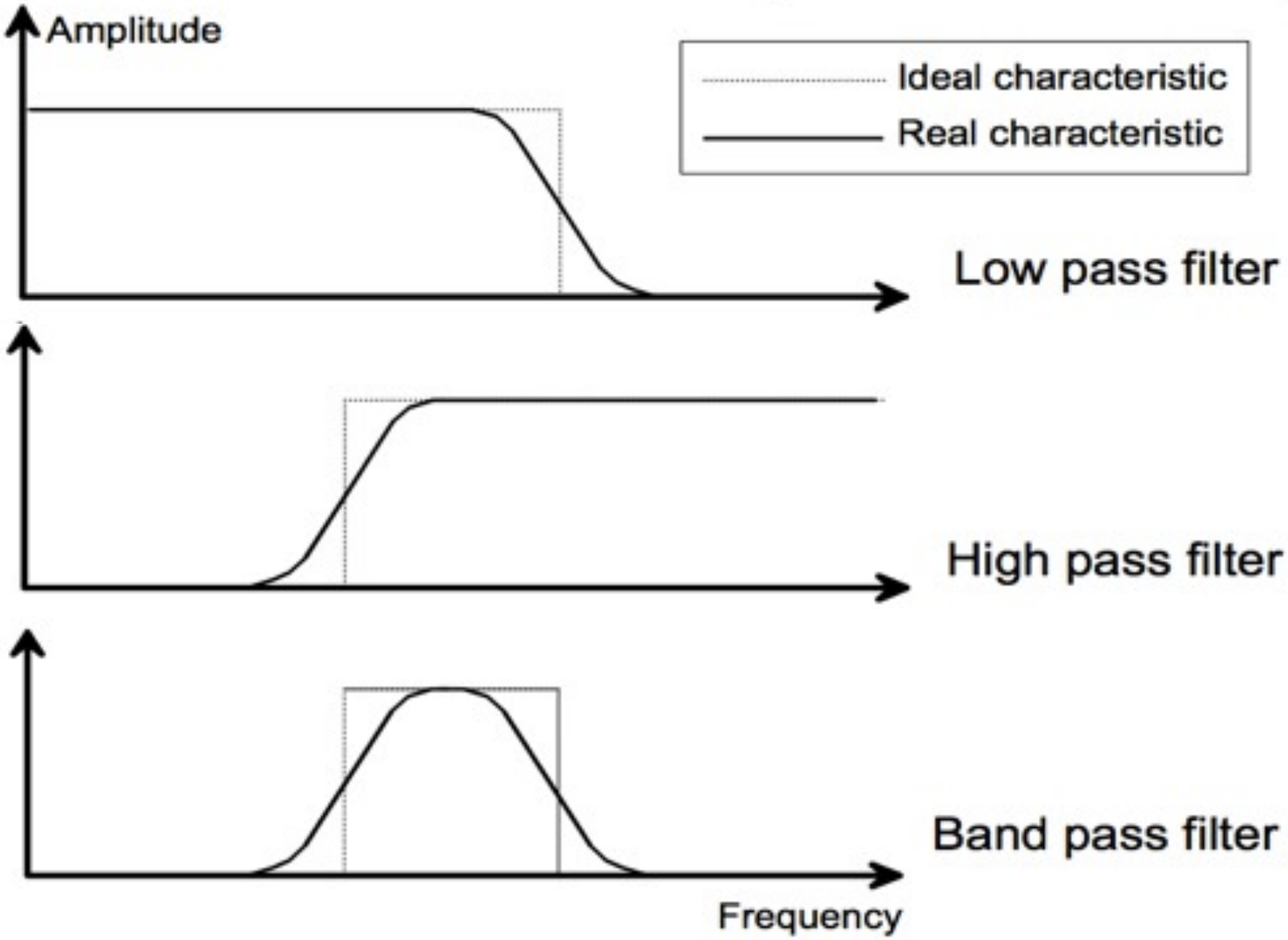


More on aliasing



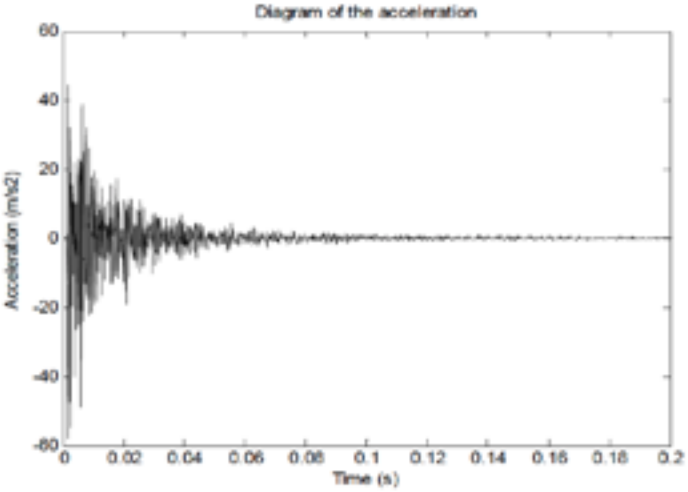
- Make sure the nyquist frequency is high enough that all frequencies are correctly recorded
- Apply analogue low-pass filtering of the signal, removing all signal components at frequency above the nyquist frequency before the signal is sampled

Filters – remove parts of the signal

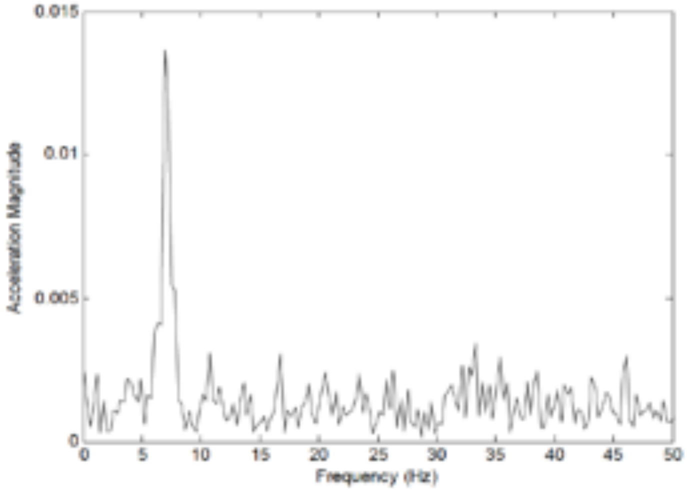


How to Analyze the Data

- The waveform of a sound: amplitude as a function of time
- Spectrum of the signal shows the frequencies contained in the signal
- The leap between both domains can be done by applying FT
- In practice, software apply FFT (Fast Fourier Transformation)



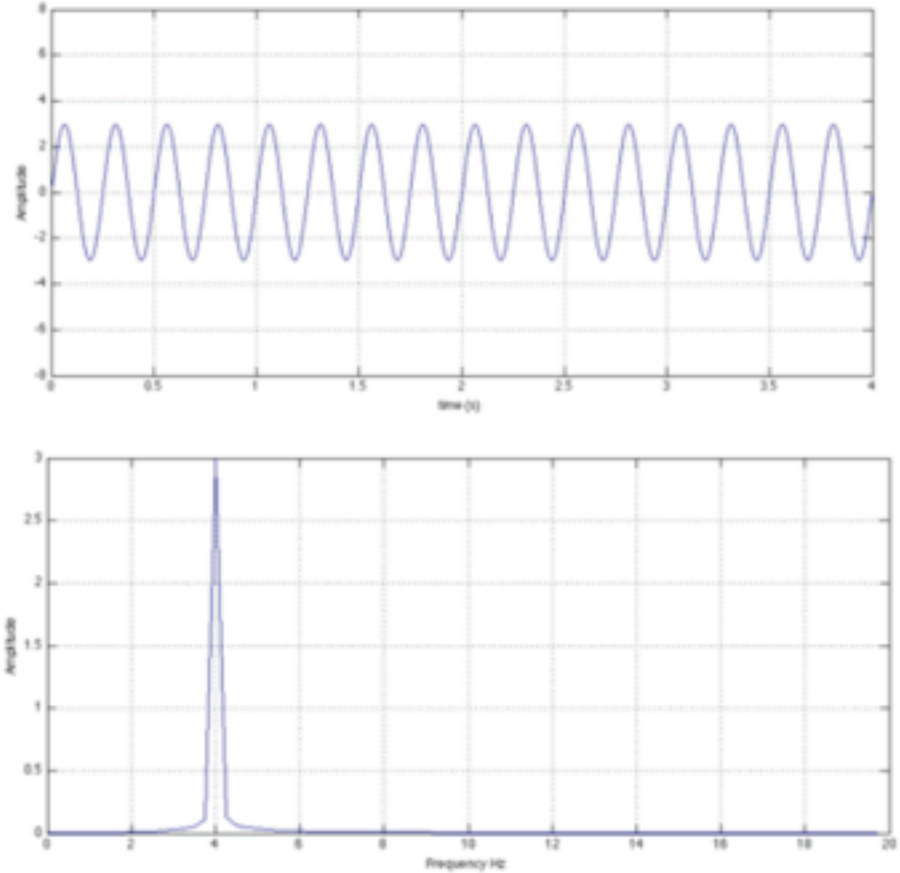
(a) Time domain.



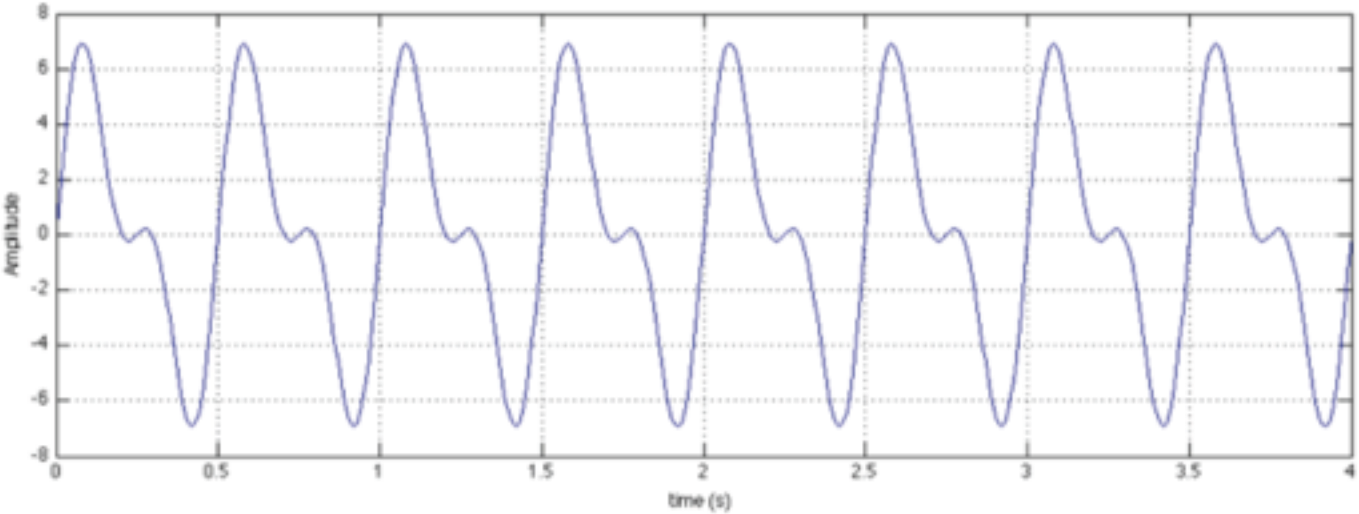
(b) Frequency domain.

FFT Example (Matlab)

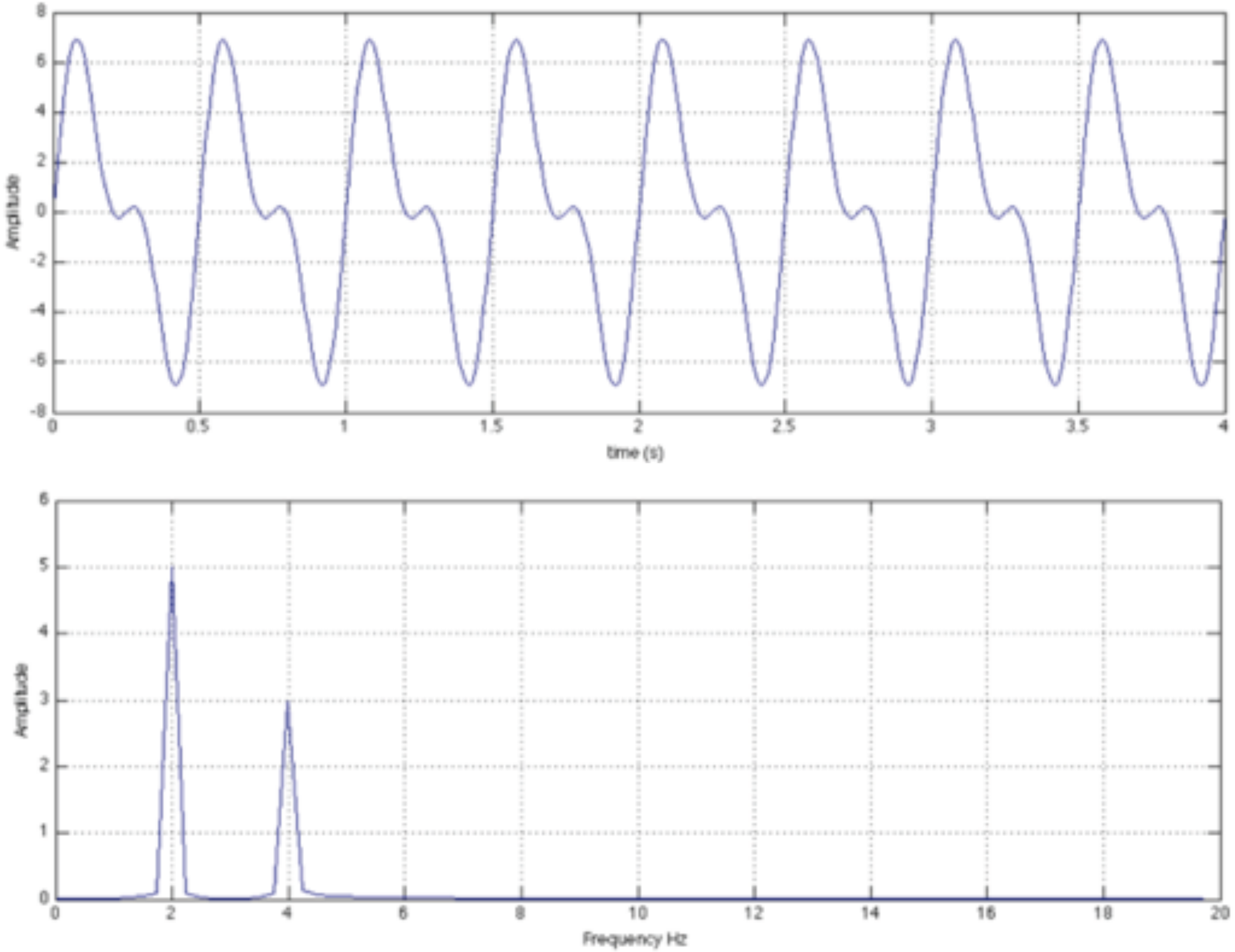
```
dt = 1/100;
et = 4;
t = 0:dt:et;
y = 3*sin(4*2*pi*t);
subplot(2,1,1);
plot(t,y); grid on
axis([0 et -8 8]);
xlabel('time (s)')
ylabel('Amplitude')
Y = fft(y);
n = size(y,2)/2;
amp_spec = abs(Y)/n;
subplot(2,1,2);
freq = (0:79)/(2*n*dt);
plot(freq,amp_spec(1:80)); grid on
xlabel('Frequency Hz');
ylabel('Amplitude')
```



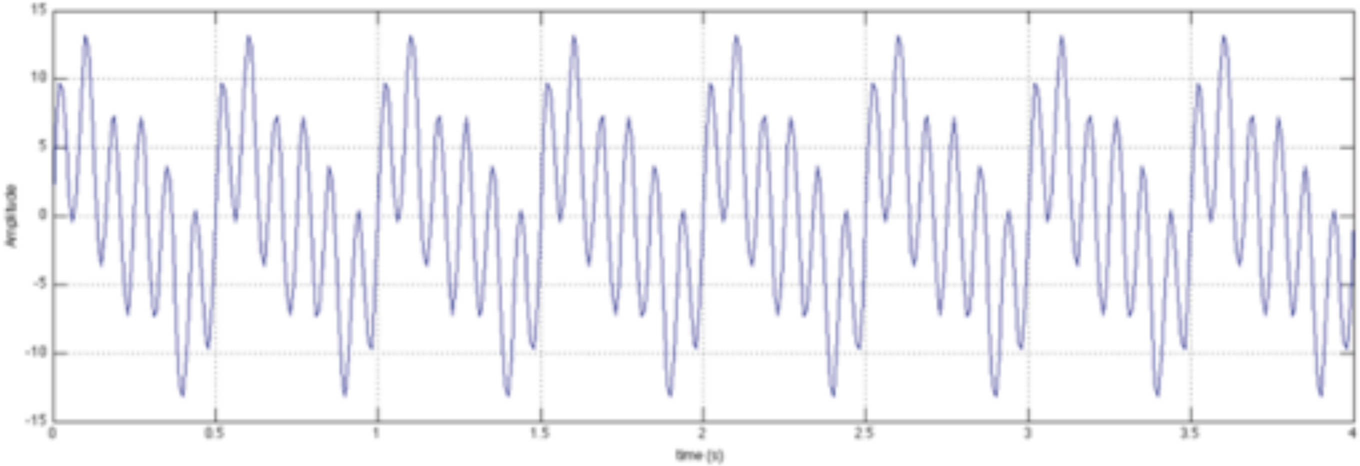
Examples FFT



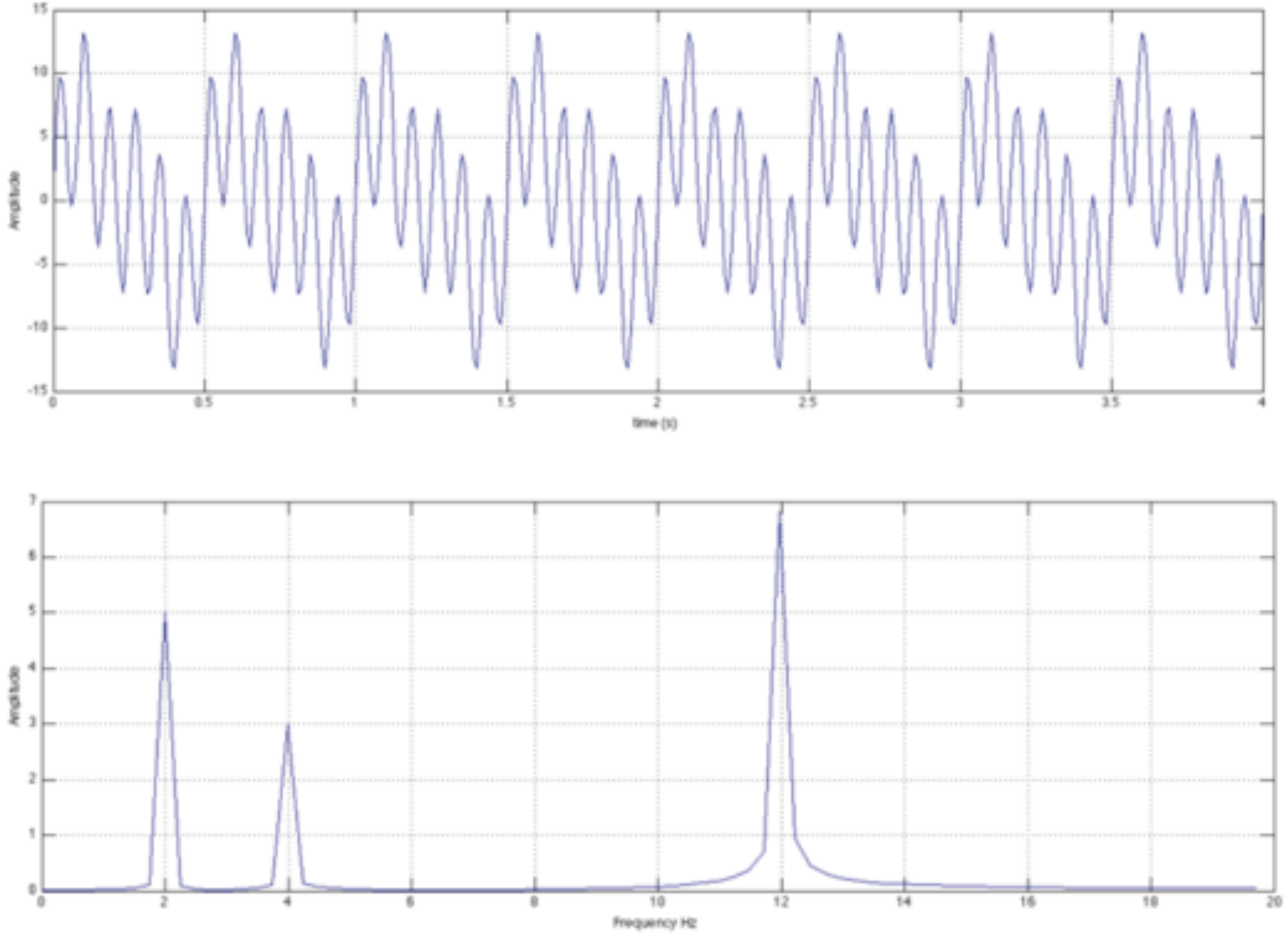
Examples FFT



Examples FFT



Examples FFT



Measurement Devices

Types of Measurement Devices

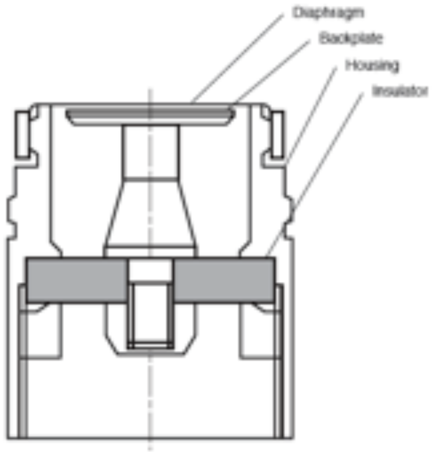
- Microphones:
  - Acoustical-to-electric transducer which converts sound into a electric signal

Types of Measurement Devices

- Microphones:
  - Acoustical-to-electric transducer which converts sound into a electric signal
  - Calibrated transducers with specified performance (sensitivity) over a frequency spectra
  - Measurement microphones are usually scalar sensors of pressure with an omnidirectional response
  - If particle velocity or sound intensity are to be determined, pressure sensing microphones can be used. Those quantities are worked out from pressures measured simultaneously at two points.

Types of Measurement Devices

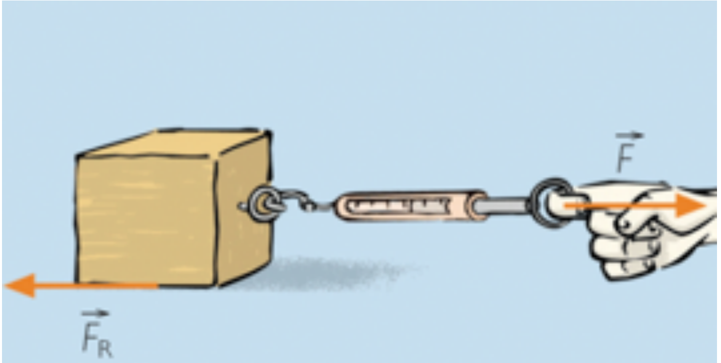
- Microphone:
  - Requirements

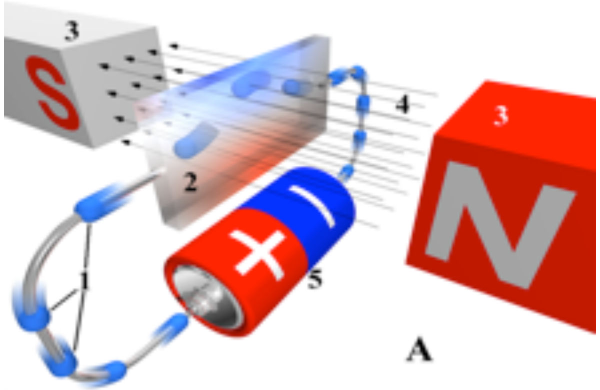


- Good acoustic and electric performance
- Minor influence from the enviroment
- High stability of sensitivity and frequency response
- High suitability for measurement and calculation of properties
- Comprehensive specifications and performance description.

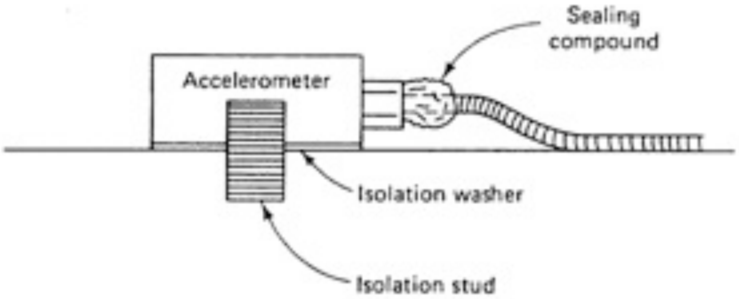
Types of Measurement Devices

- Accelerometers:
  - Mechanical
  - Hall Effect



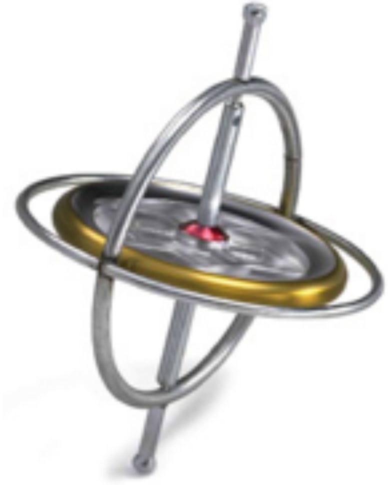


  - Piezoelectric
  - Capacitive

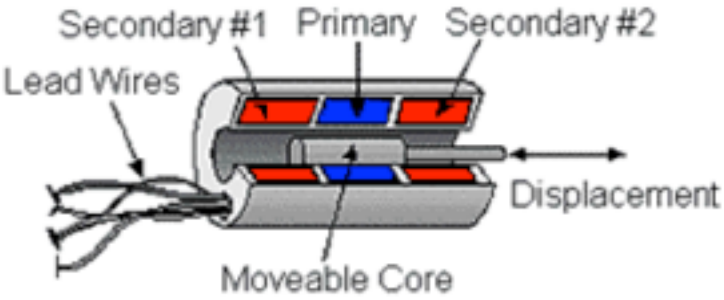


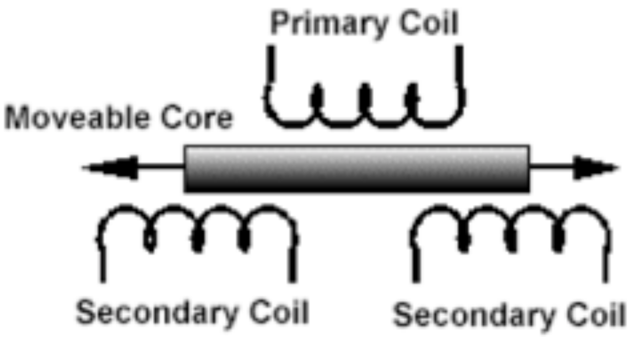
Types of Measurement Devices

- Other type of devices:
  - Gyroscopes
    - Measure or mantaining orientation
    - Based on conservation of angular momentum



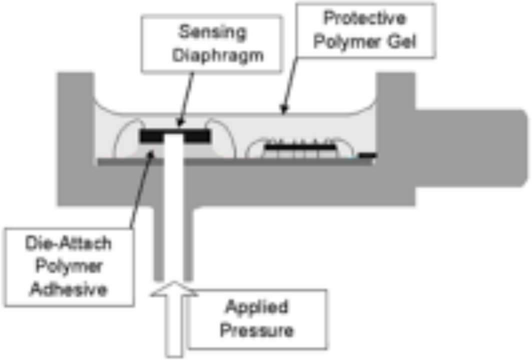
  - LVDT Sensors
    - Linear Variable Differential Transformers
    - Output voltage proportional to the displacement of the core



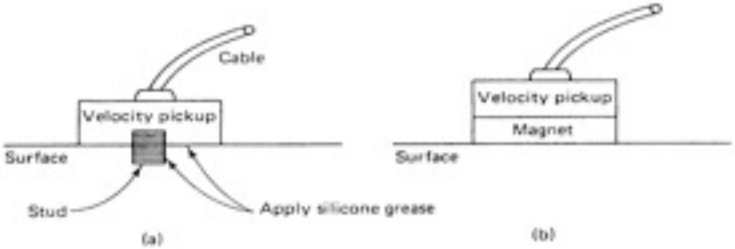


Types of Measurement Devices

- Other type of devices:
  - Pressure Sensors
    - Output voltage proportional to the pressure

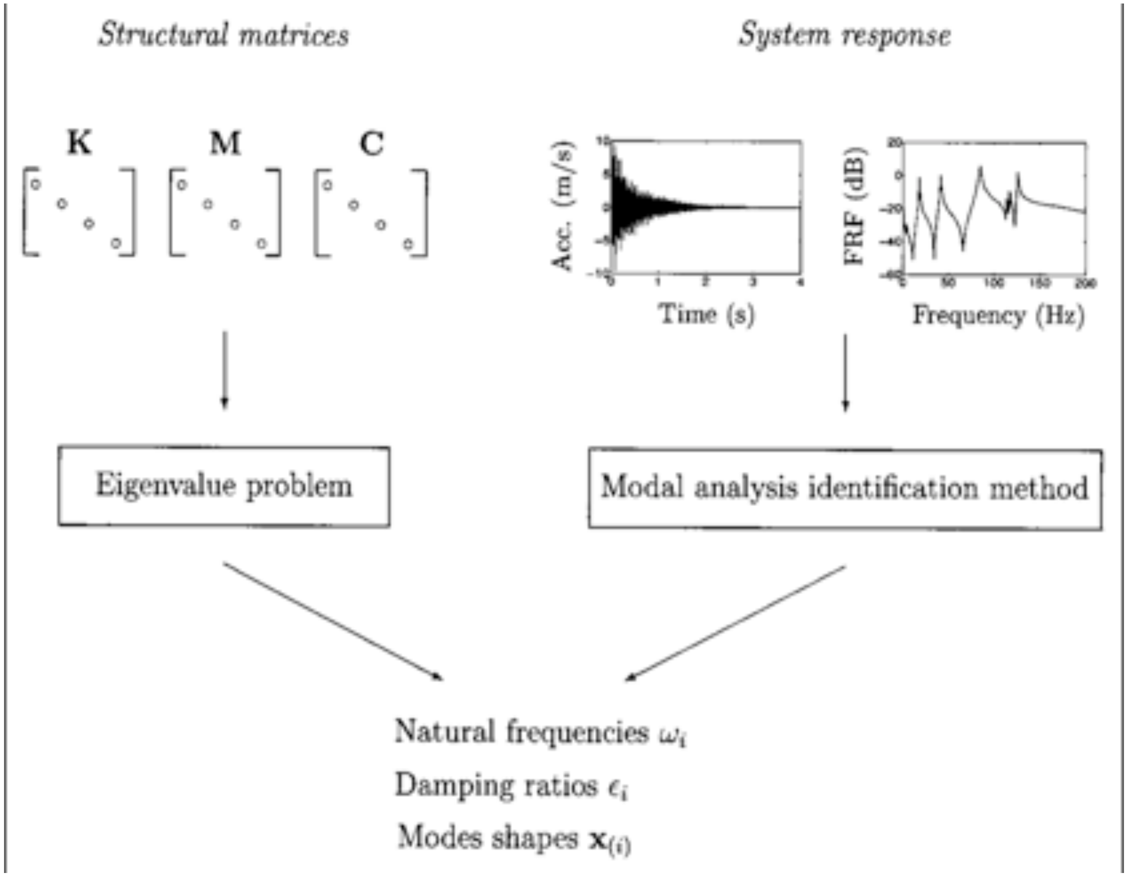


  - Interferometers
    - Sends out a voltage in case of detection of an obstacle
  - Velocity Pickups
    - Generates a voltage proportional to the relative velocity between two elements of the sensor



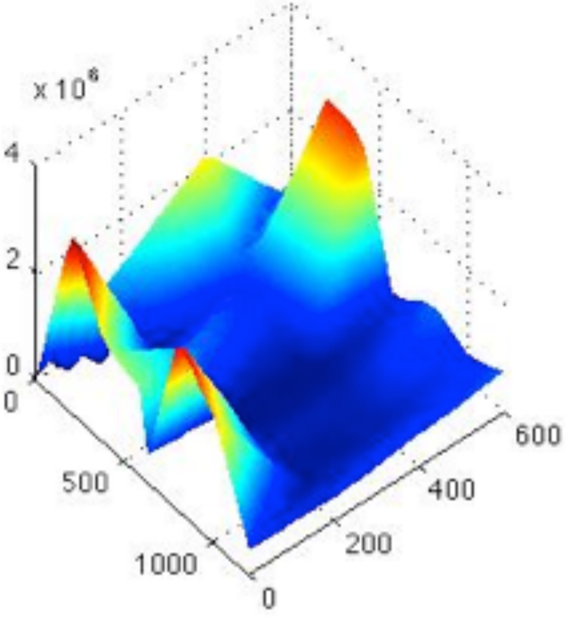
Example with Accelerometers

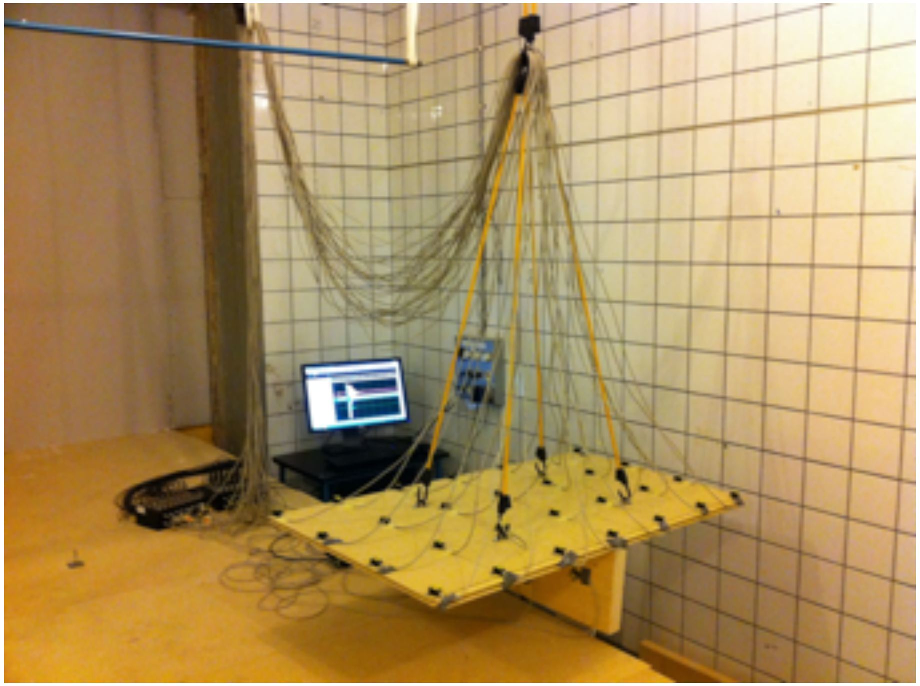
- Modal analysis: analysis modal behavior of structure
  - Two ways to calculate the modal parameters (theoretic and experim)

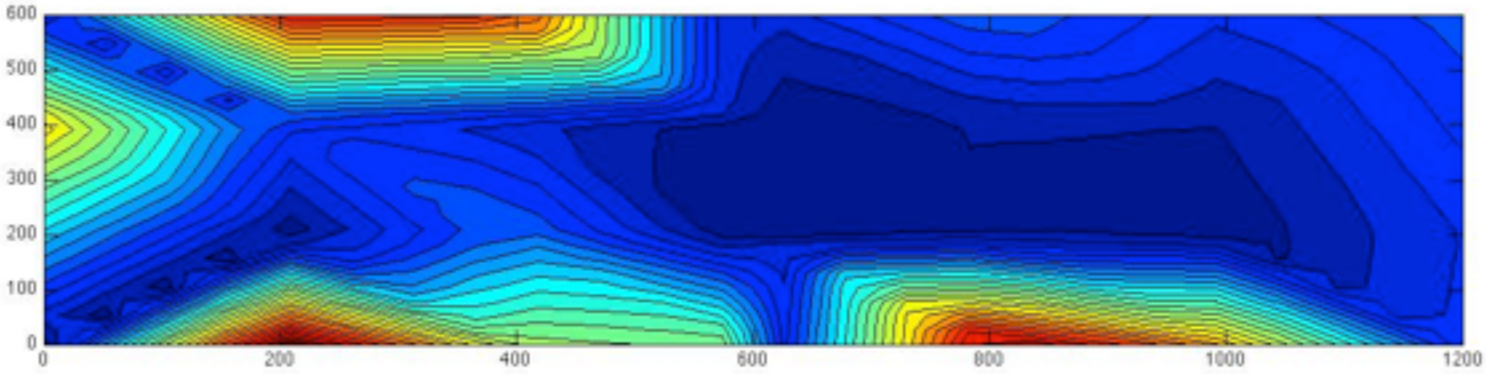


Example with Accelerometers

- Set-up investigation







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Questions?