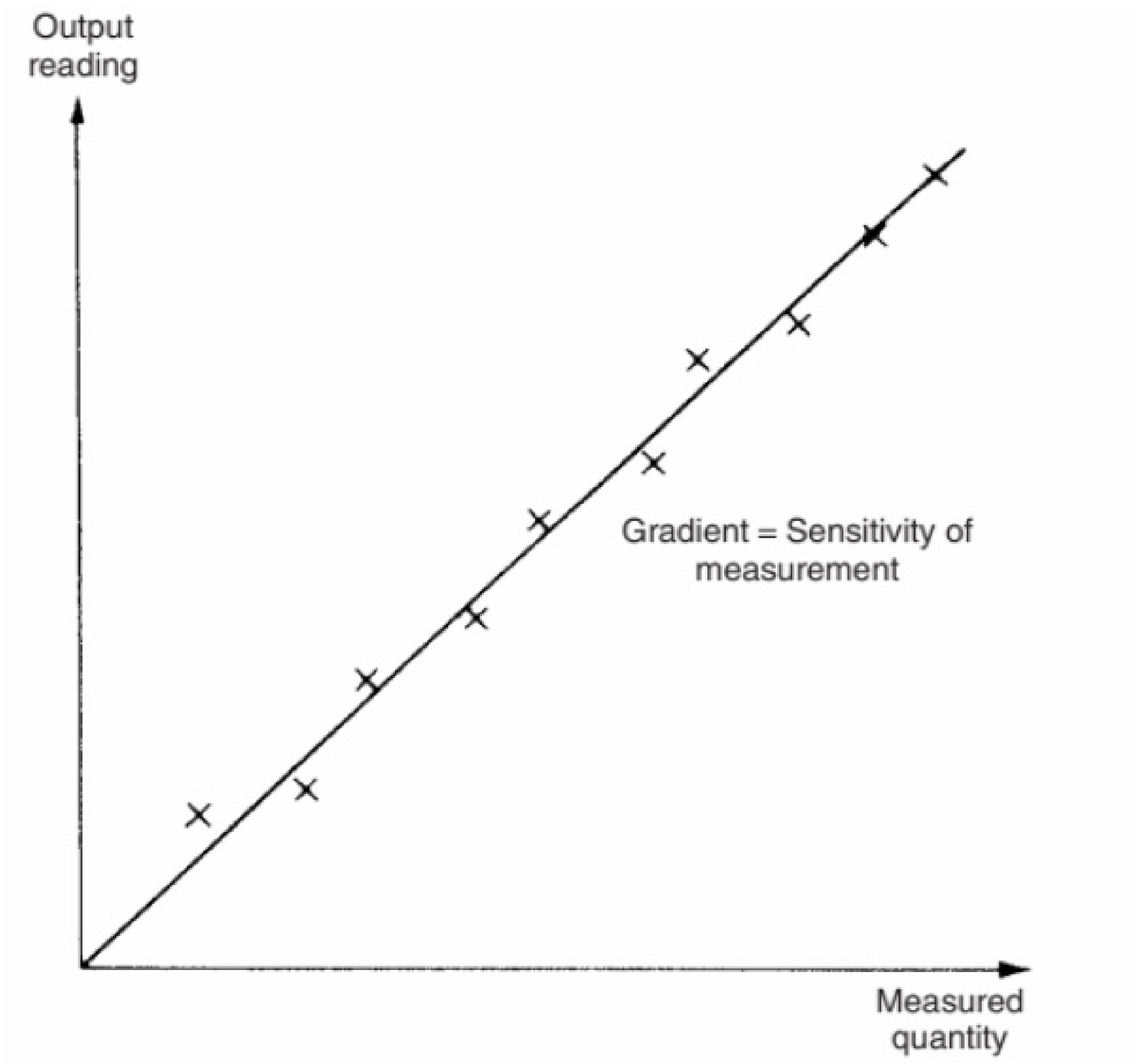
Measurement and Data Aquisition



Ádám Schiffer

Measurement and Data Aquisition

Pécs

2019

The Measurement and Data Aquisition course material was developed under the project EFOP 3.4.3-16-2016-00005 "Innovative university in a modern city: open-minded, value-driven and inclusive approach in a 21st century higher education model".

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A Measurement and Data Aquisition tananyag az EFOP-3.4.3-16-2016-00005 azonosító számú,
„Korszerű egyetem a modern városban: Értékközpontúság, nyitottság és befogadó szemlélet egy 21. századi felsőoktatási modellben” című projekt keretében valósul meg.

EFOP-3.4.3-16-2016-00005 Korszerű egyetem a modern városban:
Értékközpontúság, nyitottság és befogadó szemlélet
egy 21. századi felsőoktatási modellben

MEASUREMENT AND DAQ
LECTURE #1

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Faculty of Engineering and Information Technology

The presentation was supported by EFOP-3.4.3.-16-2016-00005 számú "Korszerű egyetem a modern városban: Értékközpontúság, nyitottság és befogadó szemlélet egy 21. századi felsőoktatási modellben „ programme.

General Measurement System

Standard Units

Physical Quantity	Standard Unit	Definition
Length	Meter	Length of path traveled by light in an interval of 1/299,792,458 seconds
Mass	Kilogram	Mass of a platinum–iridium cylinder kept in the International Bureau of Weights and Measures, Sevres, Paris
Time	Second	9.192631770×10^9 cycles of radiation from vaporized cesium 133 (an accuracy of 1 in 10^{12} or one second in 36,000 years)
Temperature	Degrees	Temperature difference between absolute zero Kelvin and the triple point of water is defined as 273.16 K
Current	Amphere	One ampere is the current flowing through two infinitely long parallel conductors of negligible cross section placed 1 meter apart in vacuum and producing a force of 2×10^{-7} newtons per meter length of conductor
Luminous intensity	Candela	One candela is the luminous intensity in a given direction from a source emitting monochromatic radiation at a frequency of 540 terahertz ($Hz \times 10^{12}$) and with a radiant density in that direction of 1.4641 mW/steradian (1 steradian is the solid angle, which, having its vertex at the centre of a sphere, cuts off an area of the sphere surface equal to that of a square with sides of length equal to the sphere radius)
Matter	Mole	Number of atoms in a 0.012-kg mass of carbon 12

General Measurement System

information variables which are commonly generated by processes

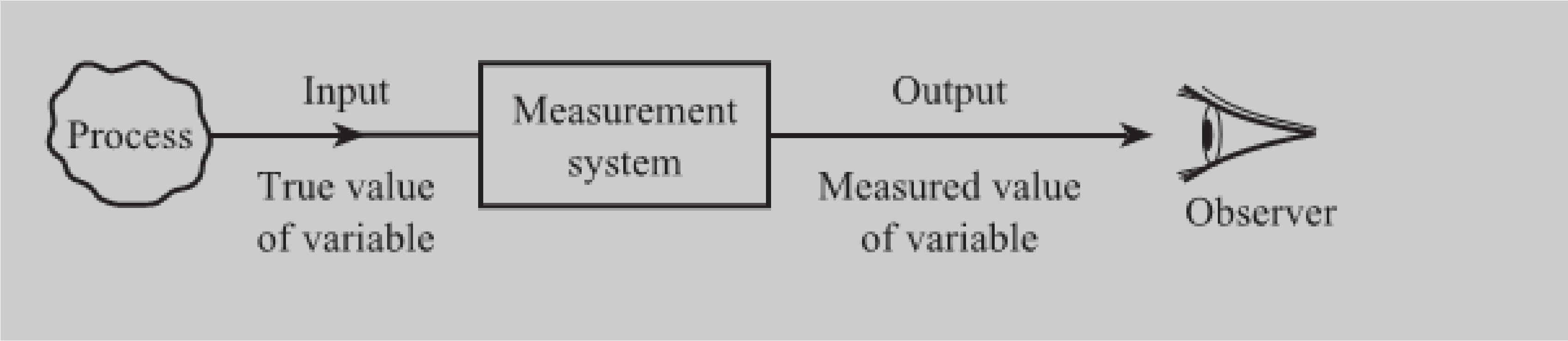
Acceleration	Density
Velocity	Viscosity
Displacement	Composition
Force–Weight	pH
Pressure	Humidity
Torque	Temperature
Volume	Heat/Light flux
Mass	Current
Flow rate	Voltage
Level	Power

General Measurement System

process as a system which generates **information**

observer as a person who needs this information from the process

measurement system is to link the observer to the process



General Measurement System

The **accuracy** of the system can be defined as the closeness of the measured value to the true value.

measurement system error *E:*

E = measured value − true value

E = system output − system input

Example1: reference standard: 100 kg, the measured value 101 kg.
E=?
Solution: x_t=100 kg, x_m=101 kg, E=101-100 =1 kg

Example2 : The accurate weigh of a truck is 10 000 kg, when it is measured the balance shows 10001 kg.
E=?
Solution: x_t=10001 kg, x_m=101 kg, E=10001-10000 =1 kg

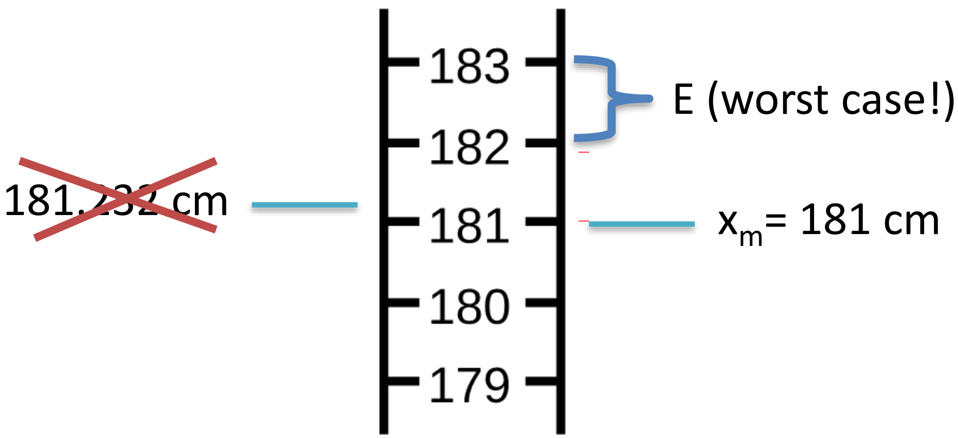
General Measurement System

Example3 : The pressure gauge shows 6.1 bars while the pressure is 6.5 bars.

E=?

Solution: x_t=6.5 bars, x_m= 6.1 bars, E=6.1 – 6.5 =-0.4 bars

Example4 : We want to measure the height of a person with a tape measure of 1 cm scale. We have measured x_m= 181 cm. E=?



Relative error

E_r = E/ x_t (%) (if the true value is known)
Er = E/ x_m (%) (only the measured value is known)

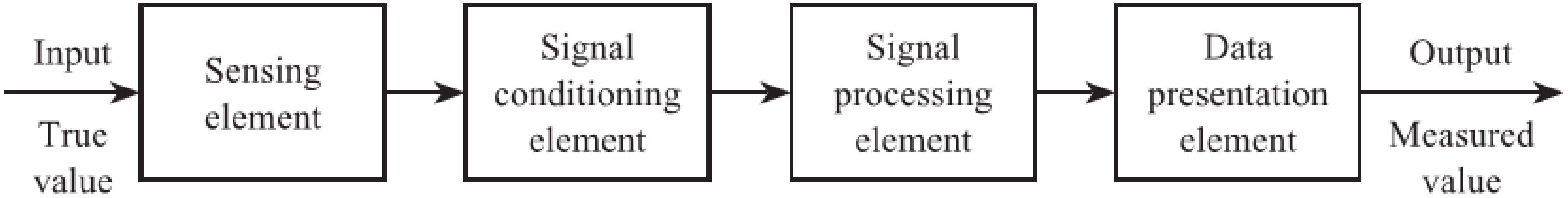
Example1: reference standard: 100 kg, the measured value 101 kg. E=1 kg
E_r = E/ x_t=1 kg/100 kg = 0.01 = 1%

Example2 : The accurate weigh of a truck is 10 000 kg, when it is measured the balance shows 10001 kg. E=1kg.
E_r = E/ x_t=1 kg/10000 kg = 0.0001 = 0.01%

Example3 : The pressure gauge shows 6.1 bars while the pressure is 6.5 bars.
E=-0.4 bars. E_r = E/ x_t=-0.4 bars kg/6.5 bars = -0.0615 = -6.15%

Example4 : We want to measure the height of a person with a tape measure of 1 cm scale. E=1 cm.
E_r = E/ x_m= 1 cm/6.5 bars = -0.0615 = -6.15%

General structure of measurement system.

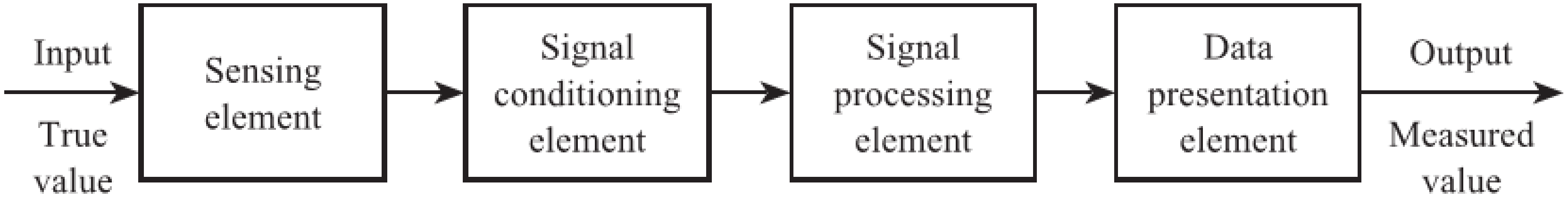


Sensing element

This is in contact with the process and gives an output which depends in some way
on the variable to be measured. Examples are:

- Thermocouple where millivolt e.m.f. depends on temperature
- Strain gauge where resistance depends on mechanical strain
- Orifice plate where pressure drop depends on flow rate

General structure of measurement system.



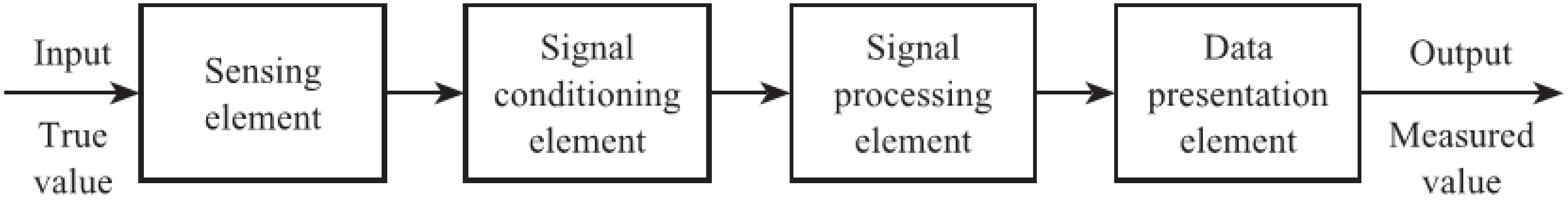
Signal conditioning element

This takes the output of the sensing element and converts it into a form more suitable for further processing, usually a d.c. voltage, d.c. current or frequency signal.

Examples are:

- Deflection bridge which converts an impedance change into a voltage change
- Amplifier which amplifies millivolts to volts
- Oscillator which converts an impedance change into a variable frequency voltage

General structure of measurement system.

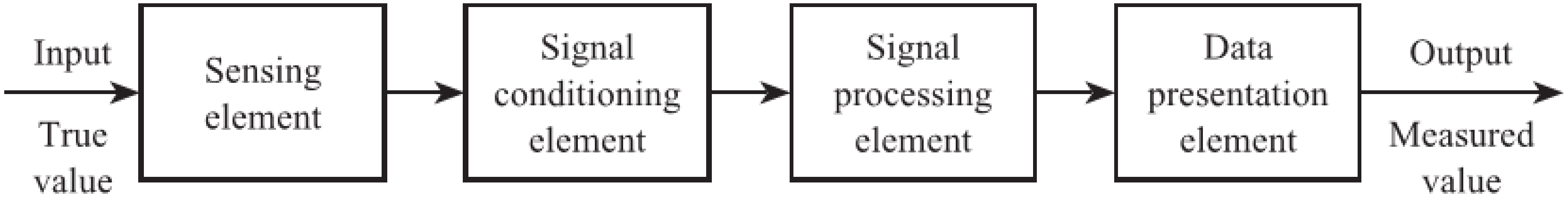


Signal processing element

This takes the output of the conditioning element and converts it into a form more
suitable for presentation. Examples are:

- Analogue-to-digital converter (ADC) which converts a voltage into a digital form for input to a computer
- Computer which calculates the measured value of the variable from the incoming digital data.

General structure of measurement system.

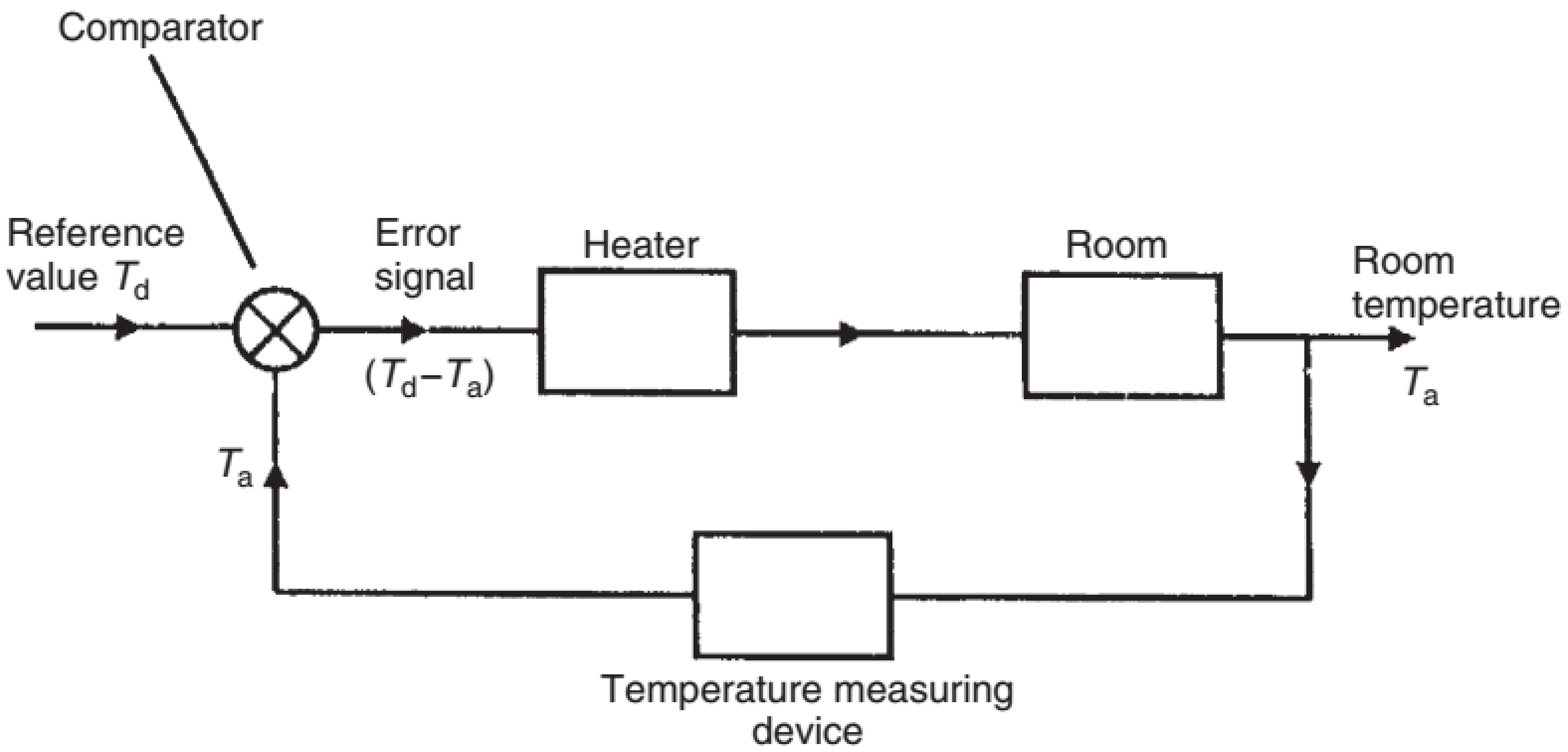


Data presentation element

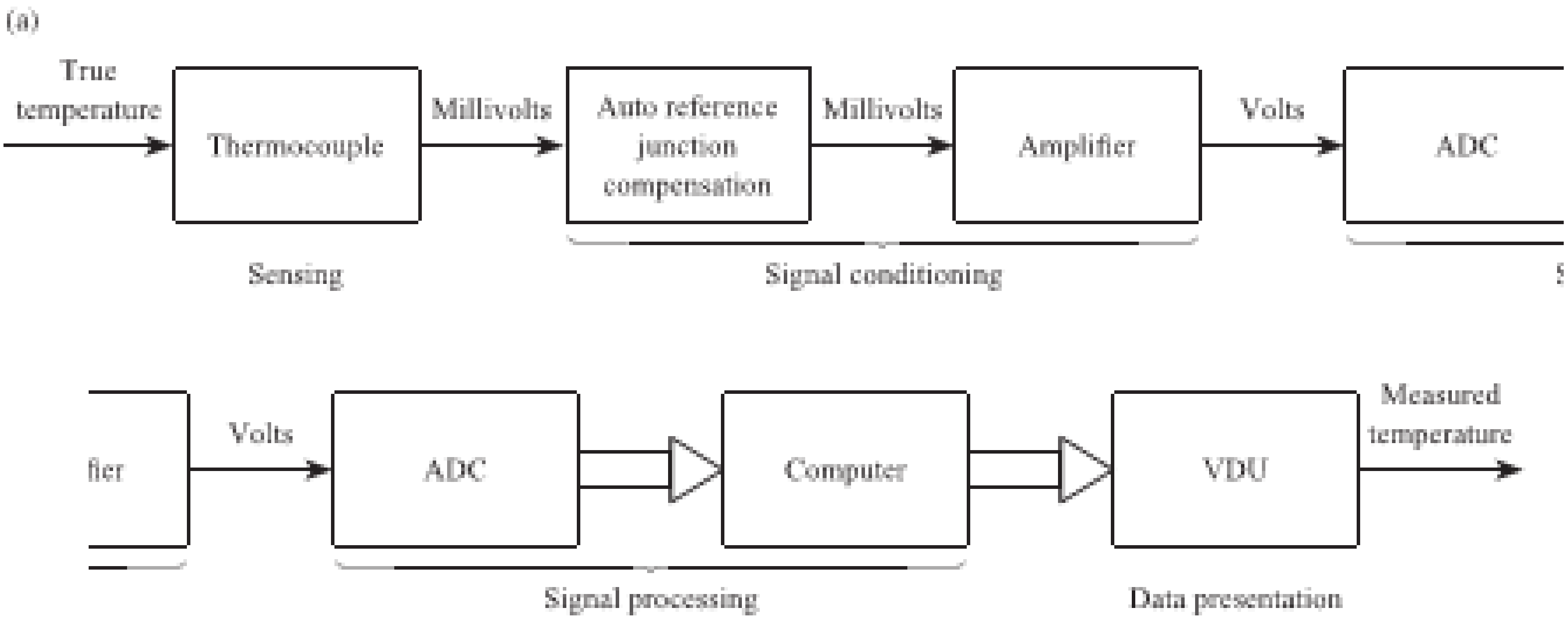
This presents the measured value in a form which can be easily recognised by the
observer. Examples are:

- Simple pointer–scale indicator
- Chart recorder
- Alphanumeric display
- Visual display unit (VDU)

Measurement system application



EXAMPLE

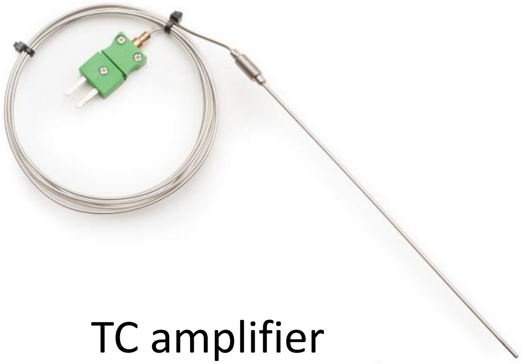

(a)
True temperature
Thermocouple
Millivolts
Auto reference junction compensation
Millivolts
Amplifier
Volts
ADC
Sensing
Signal conditioning
fier
Volts
ADC
Computer
VDU
Measured temperature
Signal processing
Data presentation

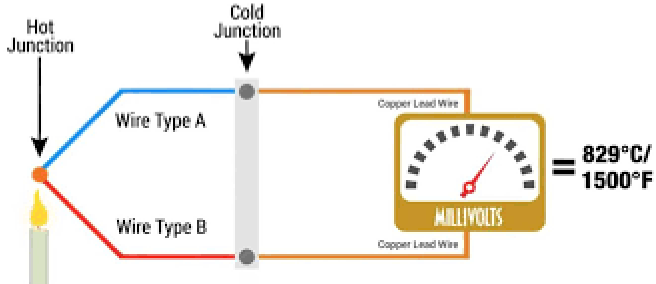
EXAMPLE

Thermocouple

Junction compensation

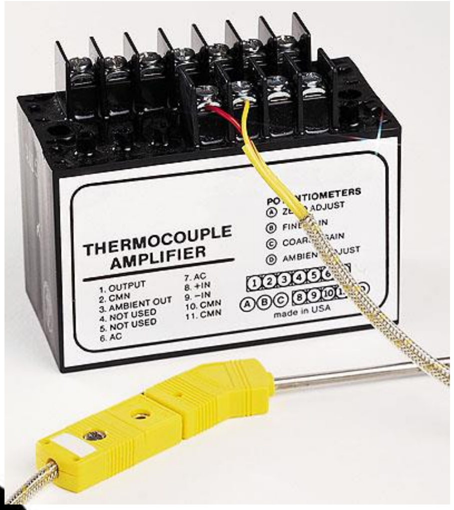
VDU

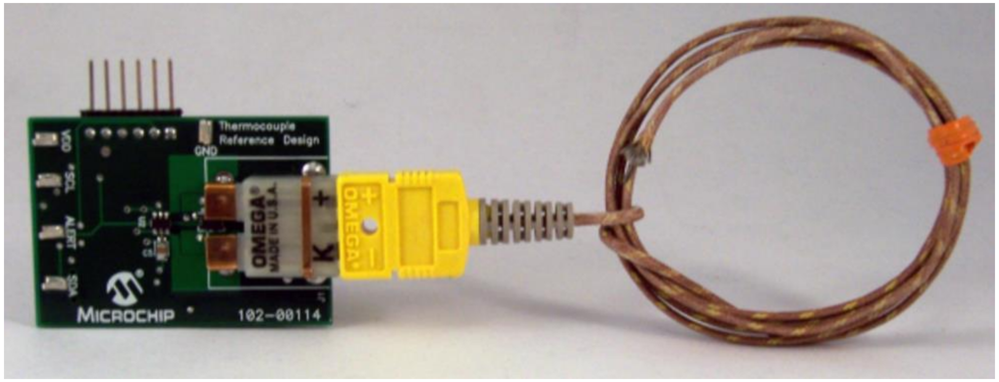




TC amplifier

ADC





Static Characteristics of Measurement System Elements

Range

The input range of an element is specified by the minimum and maximum values of *I*, i.e. I_{MIN} to I_{MAX}. The output range is specified by the minimum and maximum values of *O*, i.e. O_{MIN} to O_{MAX}. Thus a pressure transducer may have an input range of 0 to 10^4 Pa and an output range of 4 to 20 mA; a thermocouple may have an input
range of 100 to 250 °C and an output range of 4 to 10 mV.

Span

Span is the maximum variation in input or output, i.e. input span is $I_{MAX} - I_{MIN}$, and output span is $O_{MAX} - O_{MIN}$. Thus in the above examples the pressure transducer has an input span of 10^4 Pa and an output span of 16 mA; the thermocouple has an input span of 150 °C and an output span of 6 mV.

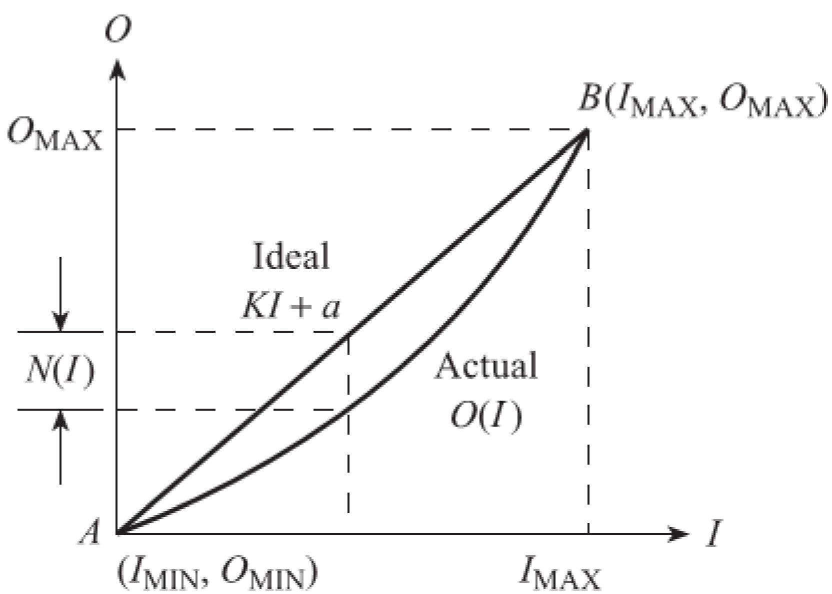
Ideal Straight Line

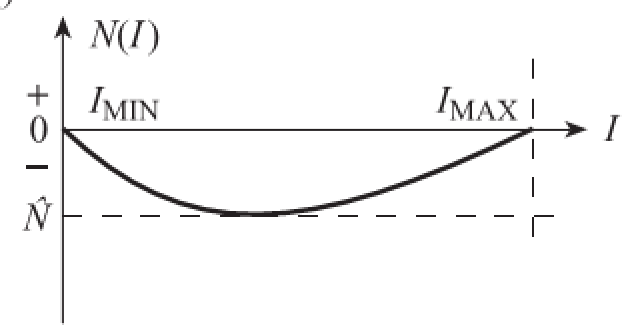
$$O - O_{MIN} = \left[\frac{O_{MAX} - O_{MIN}}{I_{MAX} - I_{MIN}}\right](I - I_{MIN})$$

$$O_{IDEAL} = KI + a$$

$$K = \text{ideal straight-line slope} = \frac{O_{MAX} - O_{MIN}}{I_{MAX} - I_{MIN}}$$

$$a = \text{ideal straight-line intercept} = O_{MIN} - KI_{MIN}$$





Non-linearity

Linear case:

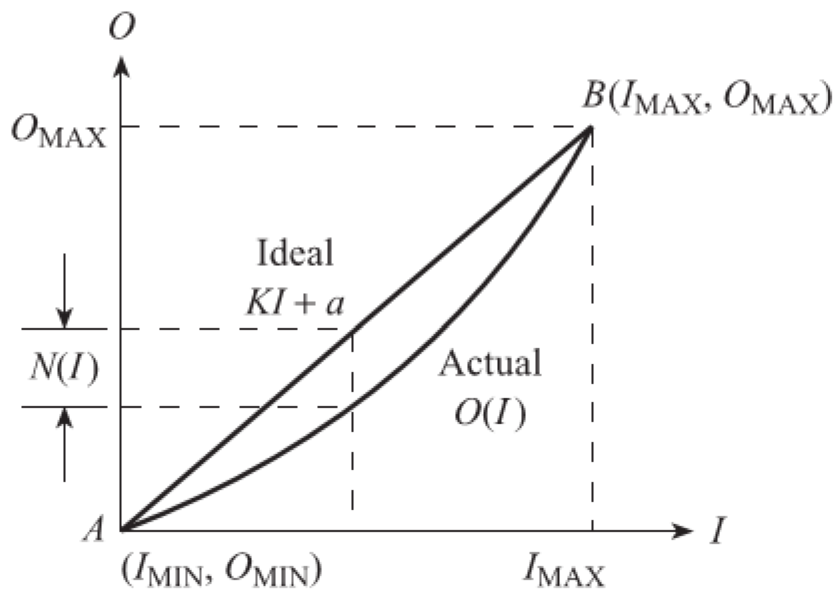
$$O_{\mathrm{IDEAL}} = KI + a$$

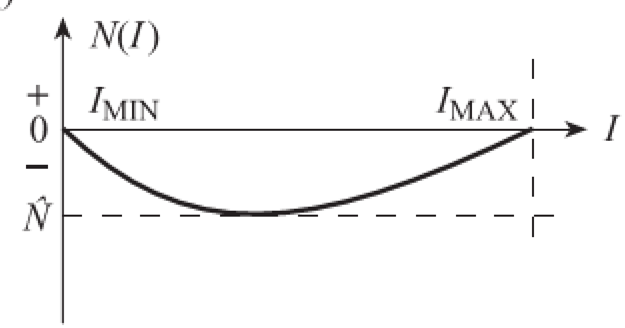
Non-linear case:

$$N(I) = O(I) - (KI + a)$$

or

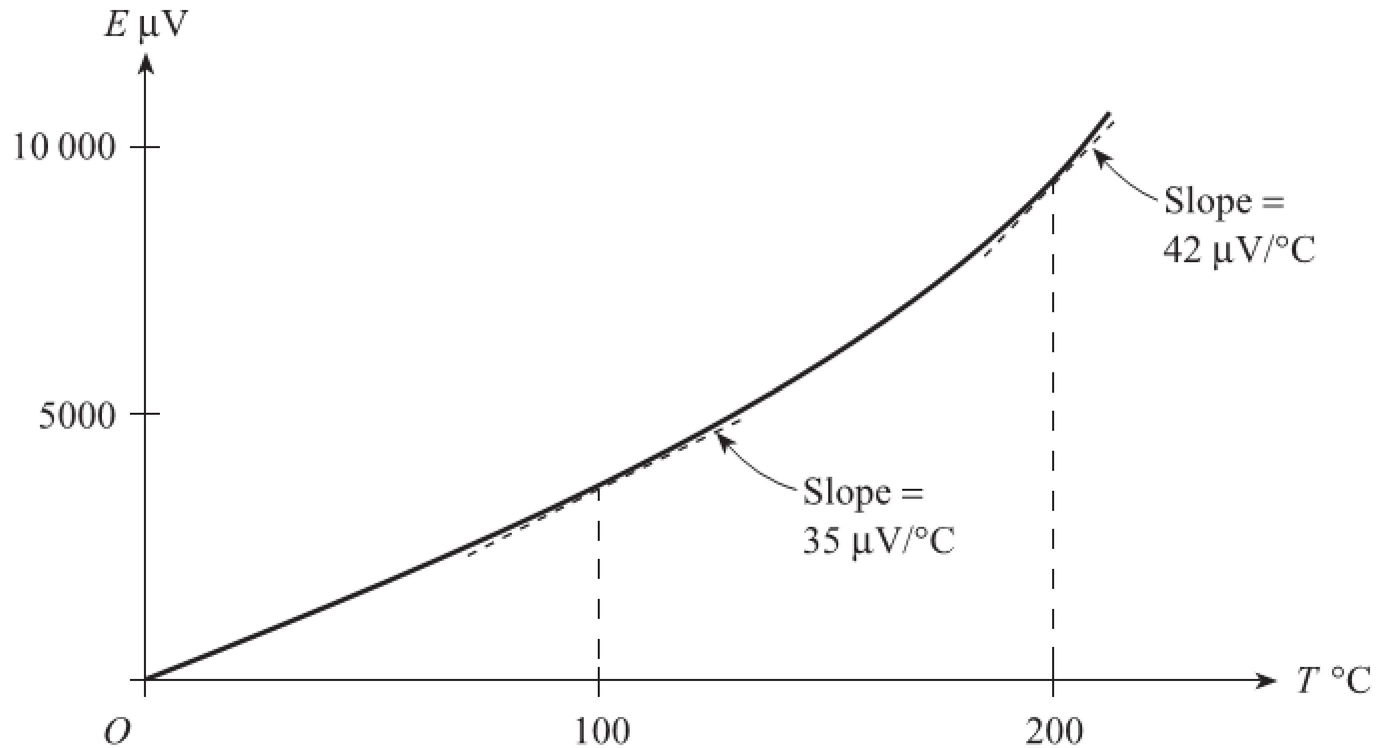
$$O(I) = KI + a + N(I)$$



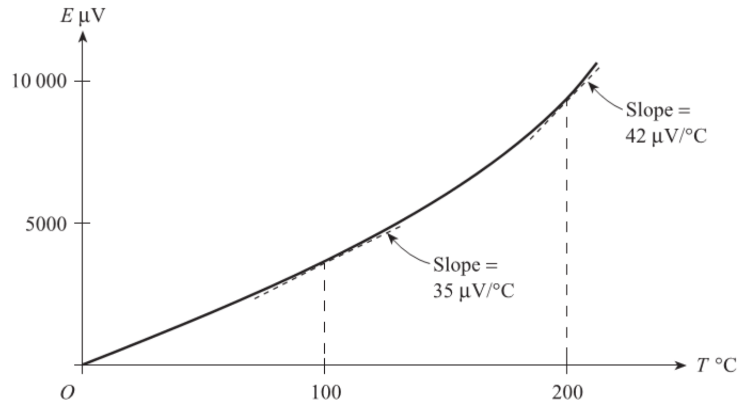


Environmental Effects

- In general, the output *O* depends not only on the signal input *I* but on environmental inputs such as ambient temperature, atmospheric pressure, relative humidity, supply voltage.
-

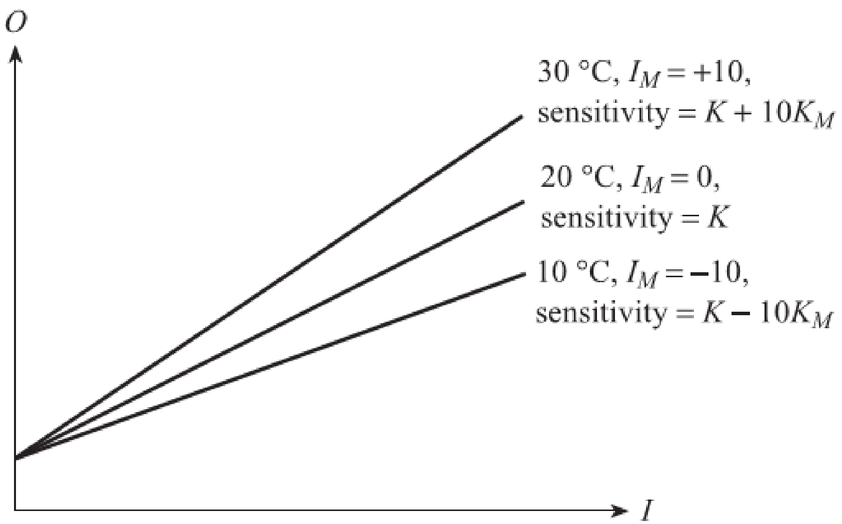


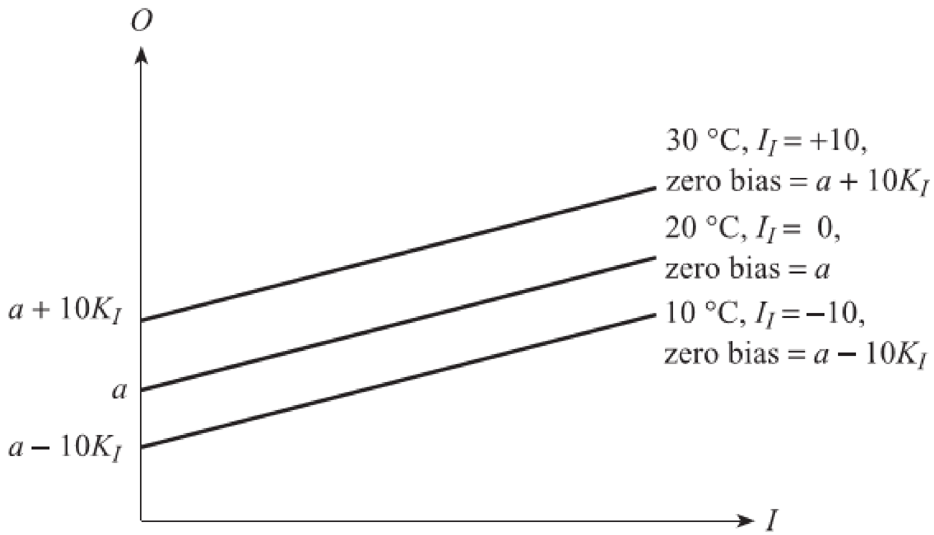
Environmental Effects



A **modifying** input I_M causes the linear sensitivity of an element to change. K is the sensitivity at standard conditions when $I_M = 0$. If the input is changed from the standard value, then I_M is the **deviation** from standard conditions

STANDARD: Tstd = 20°C, Pstd = 1000 mbar; Hstd = 50%; Ustd = 10 VDC



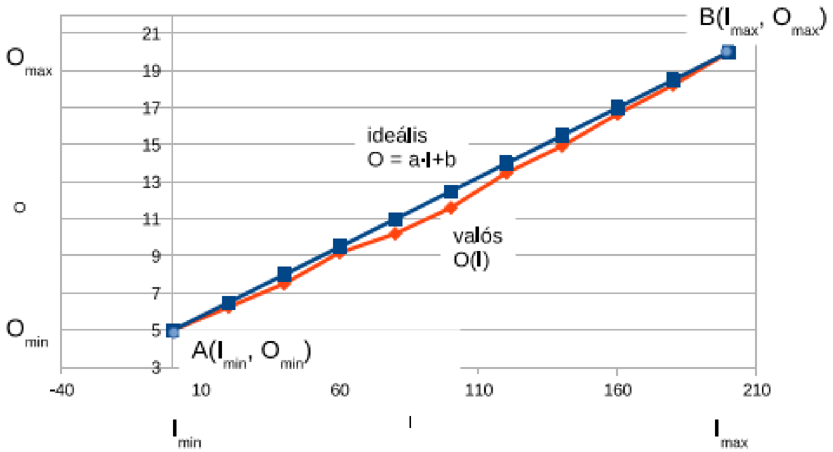


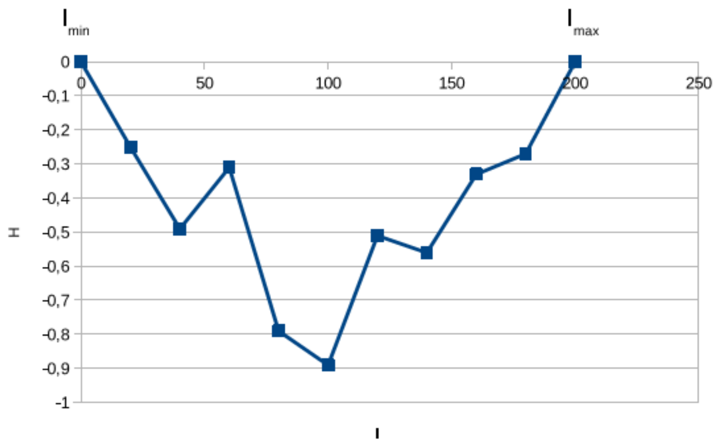
Non-linearity

$$N(I) = O(I) - (KI + a)$$

or

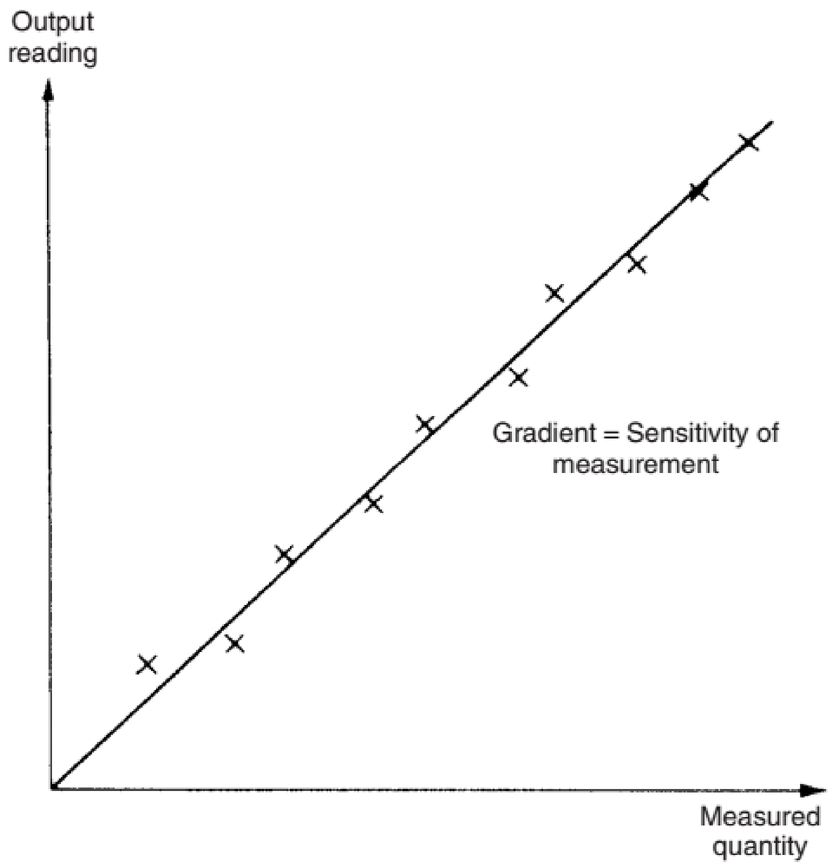
$$O(I) = KI + a + N(I)$$





Sensitivity

This is the change ΔO in output O for unit change ΔI in input I, i.e. it is the ratio $\Delta O/\Delta I$



Sensitivity EXAMPLE

The following resistance values of a platinum resistance thermometer were measured at a range of temperatures. Determine the measurement sensitivity of the instrument in ohms/°C.

Resistance (Ω)	*Temperature* (°C)
307	200
314	230
321	260
328	290

Solution

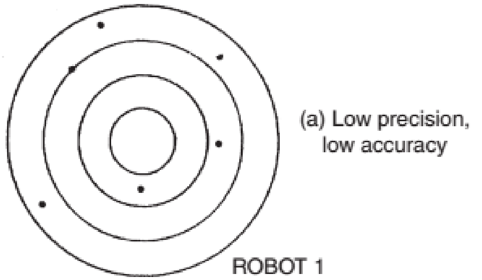
If these values are plotted on a graph, the straight-line relationship between resistance change and temperature change is obvious.

For a change in temperature of 30°C, the change in resistance is 7 Ω. Hence the measurement sensitivity $= 7/30 = 0.233\ \Omega/°C$.

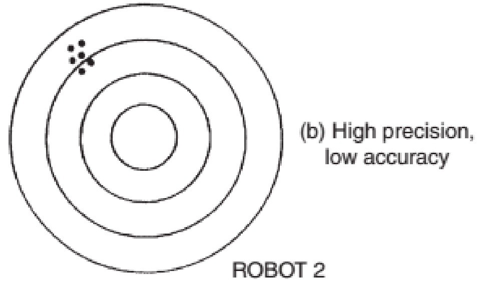
For a non-linear element $dO/dI = K + dN/dI$, i.e.
sensitivity is the **slope** or **gradient** of the output versus input characteristics $O(I)$

Precision/Repeatability/Reproducibility

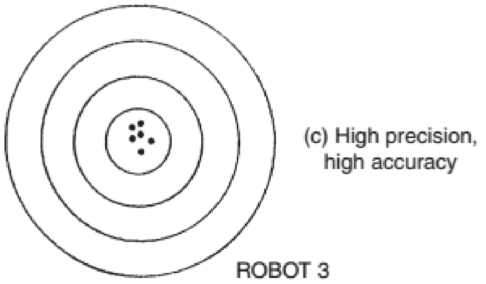
Precision is a term that describes an instrument's degree of freedom from random errors.



Repeatability describes the closeness of output readings when the same input is applied repetitively over a short period of time



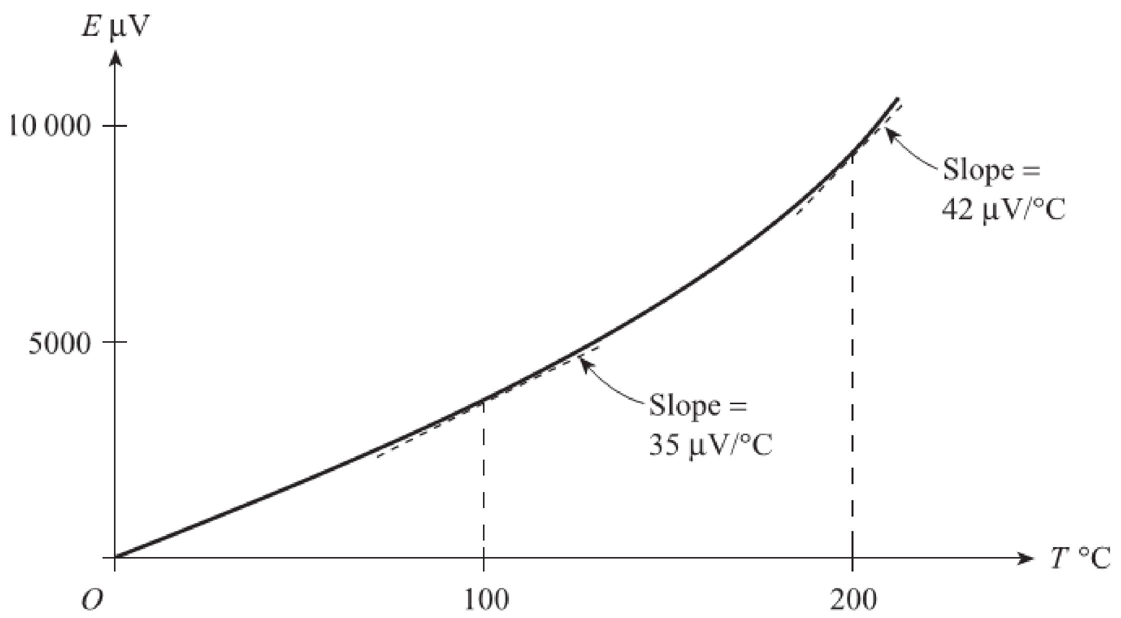
Reproducibility describes the closeness of output readings for the same input when there are changes ir the method of measurement, observer, measuring instrument, location, conditions of use, and time of measurement.



Environmental effects

In general, the output *O* depends not only on the signal input *I* but on environmental inputs such as ambient temperature, atmospheric pressure, relative humidity, supply voltage, etc.

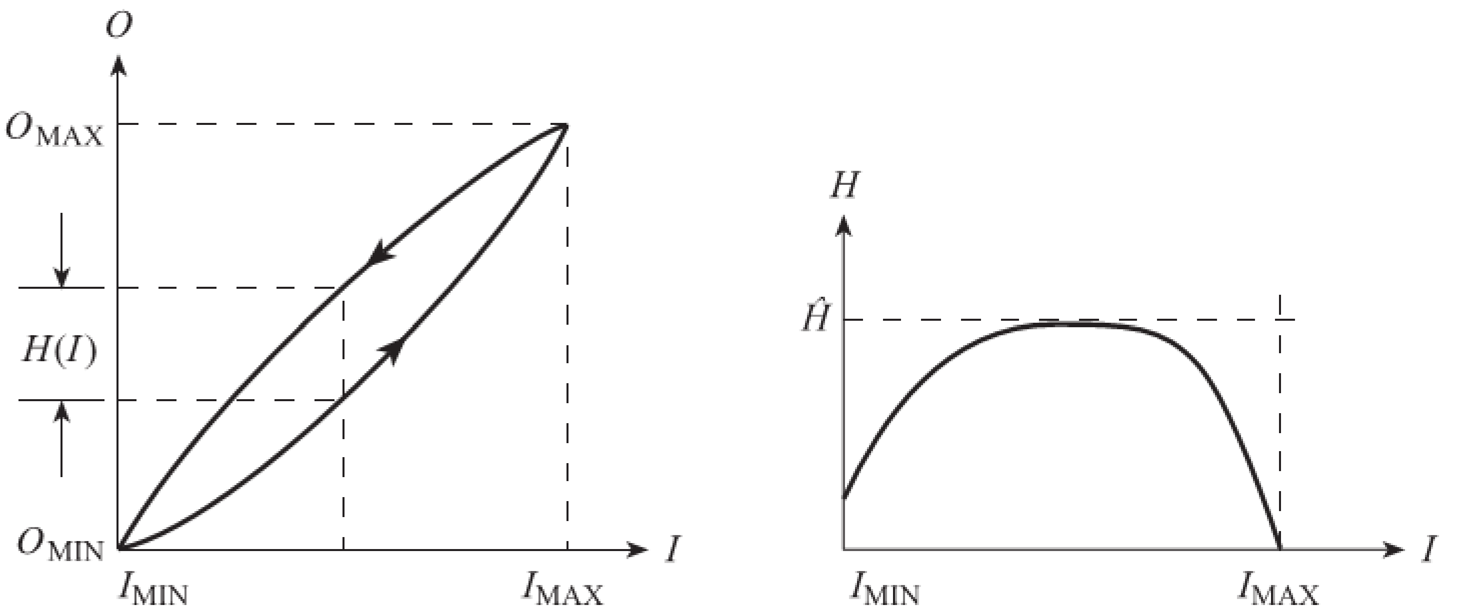
‘standard’ environmental conditions: 20 °C ambient temperature, 1000 millibars atmospheric pressure, 50% RH and 10 V supply voltage



Thermocouple sensitivity.

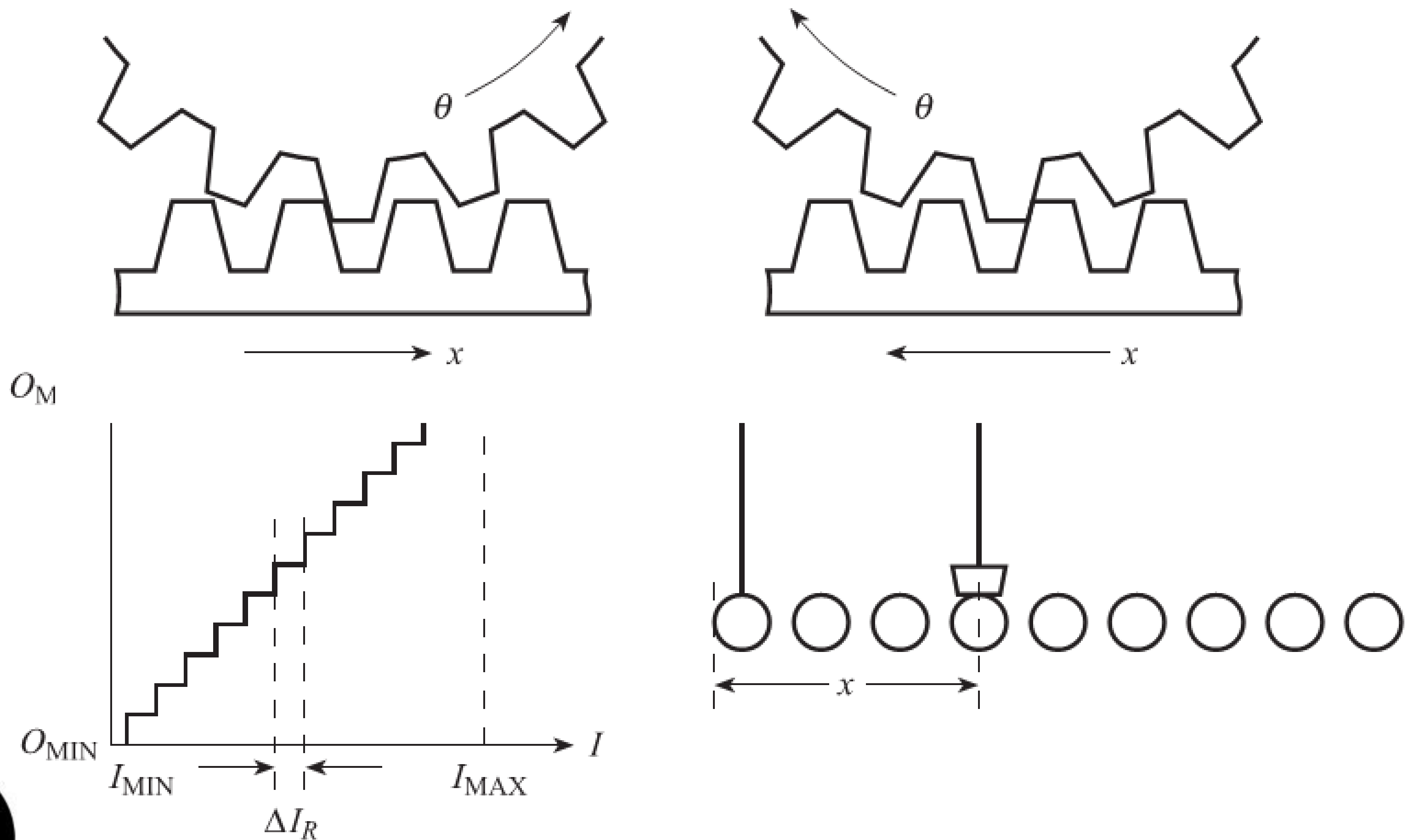
Hysteresis

For a given value of *I*, the output *O* may be different depending on whether *I* is increasing or decreasing.



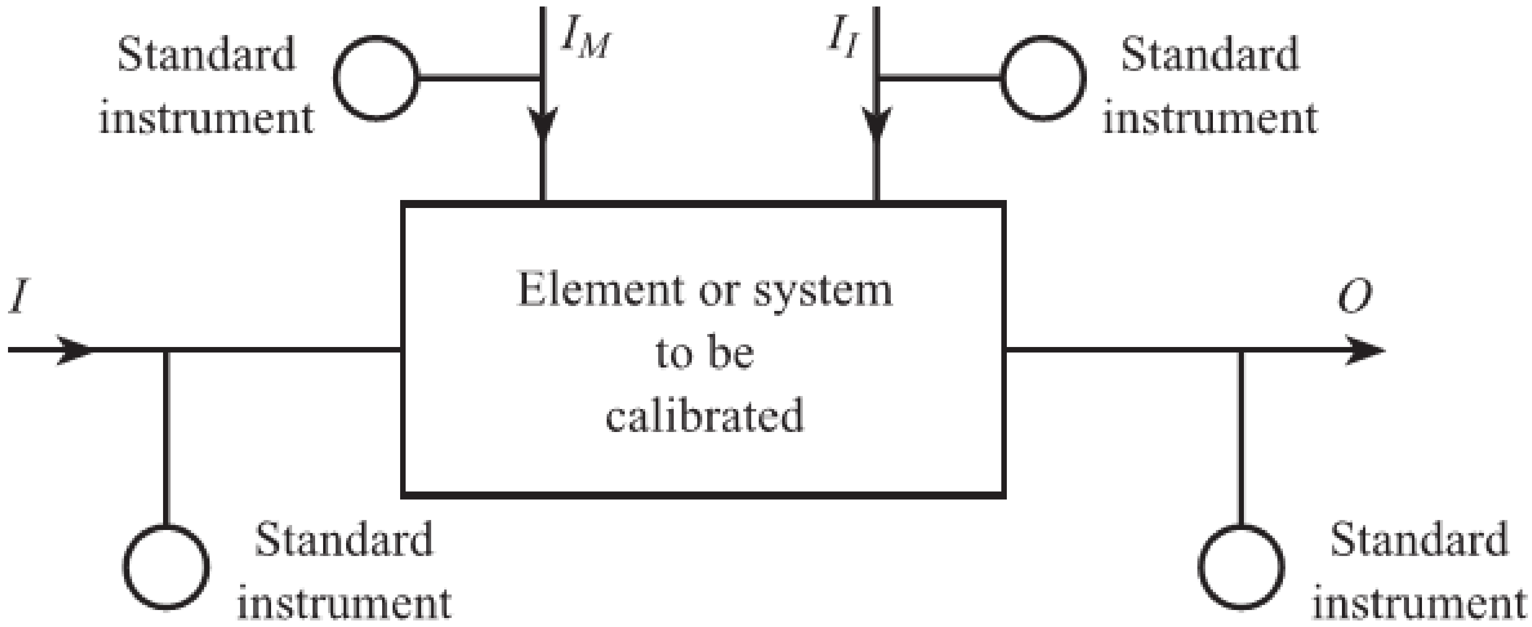
Resolution

Some elements are characterised by the output increasing in a series of discrete steps or jumps in response to a continuous increase in input

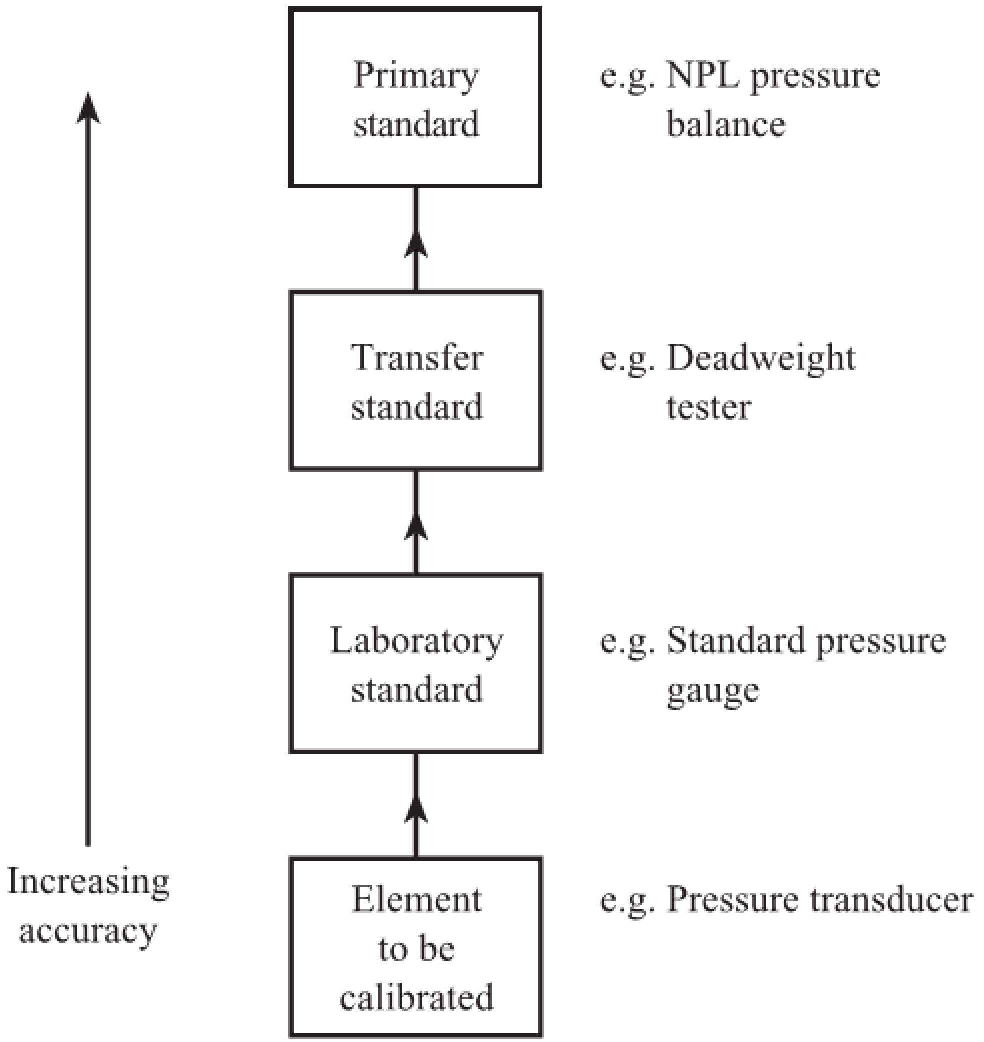


CALIBRATION – STANDARD SYSTEM

The static characteristics of an element can be found experimentally by measuring corresponding values of the input *I*, the output *O* and the environmental inputs I_M and I_I, when *I* is either at a constant value or changing slowly.



CALIBRATION – STANDARD SYSTEM



CALIBRATION

Linear case:

$$O_{IDEAL} = KI + a$$

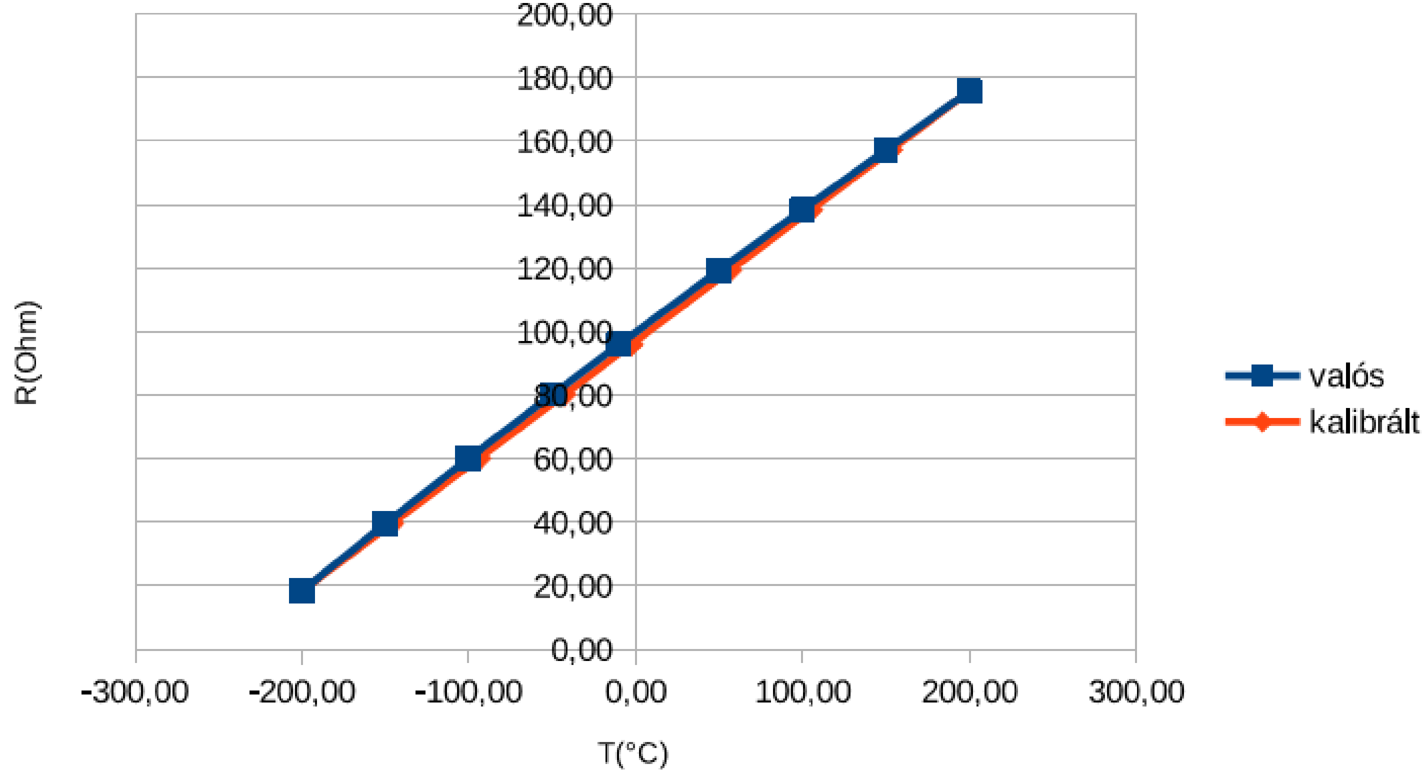
I=(O-a)/K

$$K = \text{ideal straight-line slope} = \frac{O_{MAX} - O_{MIN}}{I_{MAX} - I_{MIN}}$$

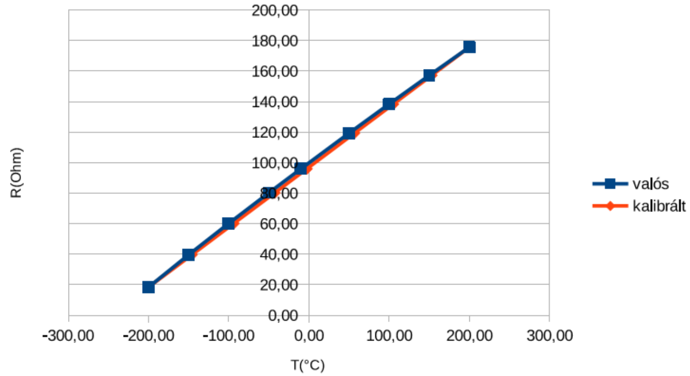
$$a = \text{ideal straight-line intercept} = O_{MIN} - KI_{MIN}$$

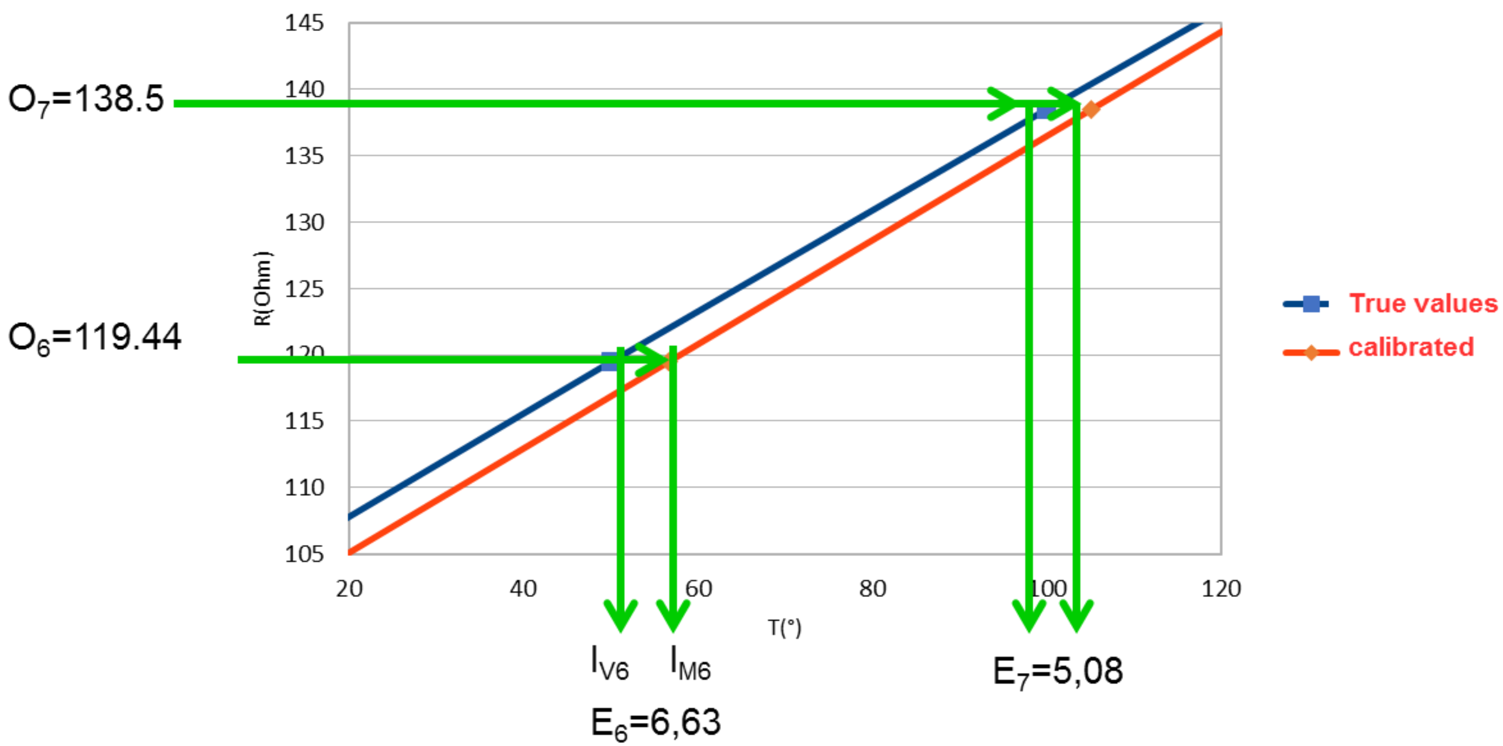
#	T(°C); I_v	R(Ohm), O	T*(°C); I_m	H(°C)	h(%)
1	-200,00	18,49	-200,00	0,00	0,00%
2	-150,00	39,71	-146,06	3,94	-2,63%
3	-100,00	60,25	-93,84	6,16	-6,16%
4	-50,00	80,31	-42,85	7,15	-14,31%
5	-10,00	96,09	-2,73	7,27	-72,67%
6	50,00	119,44	56,63	6,63	13,25%
7	100,00	138,50	105,0	8 5,08	5,08%
8	150,00	157,31	152,8	9 2,89	1,93%
9	200,00	175,84	200,0	0 0,00	0,00%

CALIBRATION

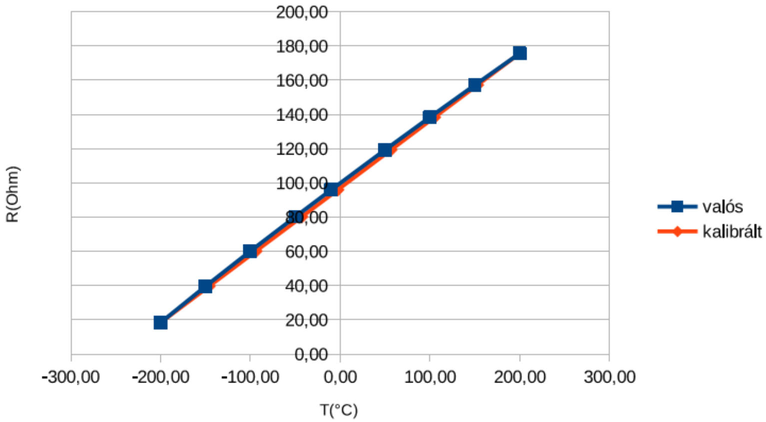


CALIBRATION





CALIBRATION



#	$\mathbf{T(^\circ C); I_v}$	R(Ohm), O	$\mathbf{T^*(^\circ C); I_m}$	H(°C)	h(%)
1	-200,00	18,49	-200,00	0,00	0,00%
2	-150,00	39,71	-146,06	3,94	-2,63%
3	-100,00	60,25	-93,84	6,16	-6,16%
4	-50,00	80,31	-42,85	7,15	-14,31%
5	-10,00	96,09	-2,73	7,27	-72,67%
6	50,00	119,44	56,63	6,63	13,25%
7	100,00	138,50	105,0	8 5,08	5,08%
8	150,00	157,31	152,8	9 2,89	1,93%
9	200,00	175,84	200,0	0 0,00	0,00%

$$K = \text{ideal straight-line slope} = \frac{O_{MAX} - O_{MIN}}{I_{MAX} - I_{MIN}}$$

$$a = \text{ideal straight-line intercept} = O_{MIN} - KI_{MIN}$$

I=(O-a)/K

$A(-200;18, 49)$ and $B(200;175, 84)$

K=0.39; a=99.17

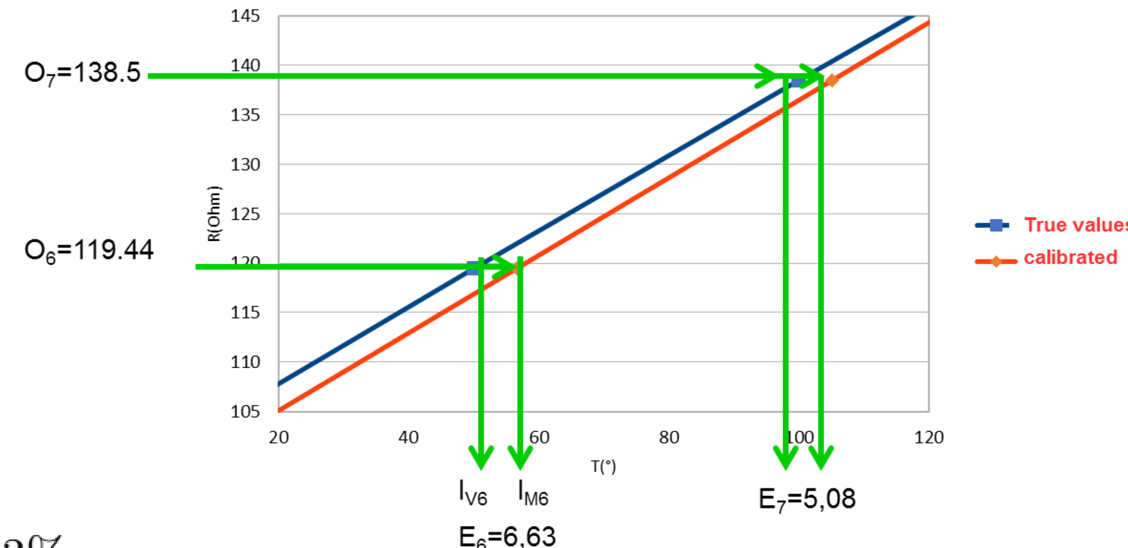
#	T(°C); I_v	R(Ohm), O	T*(°C); I_m	H(°C)	h(%)
1	-200,00	18,49	-200,00	0,00	0,00%
2	-150,00	39,71	-146,06	3,94	-2,63%
3	-100,00	60,25	-93,84	6,16	-6,16%
4	-50,00	80,31	-42,85	7,15	-14,31%
5	-10,00	96,09	-2,73	7,27	-72,67%
6	50,00	119,44	56,63	6,63	13,25%
7	100,00	138,50	105,0	8 5,08	5,08%

The error values (E) are known.

E_{max}= 7.27 °C

I_{max}=200°C

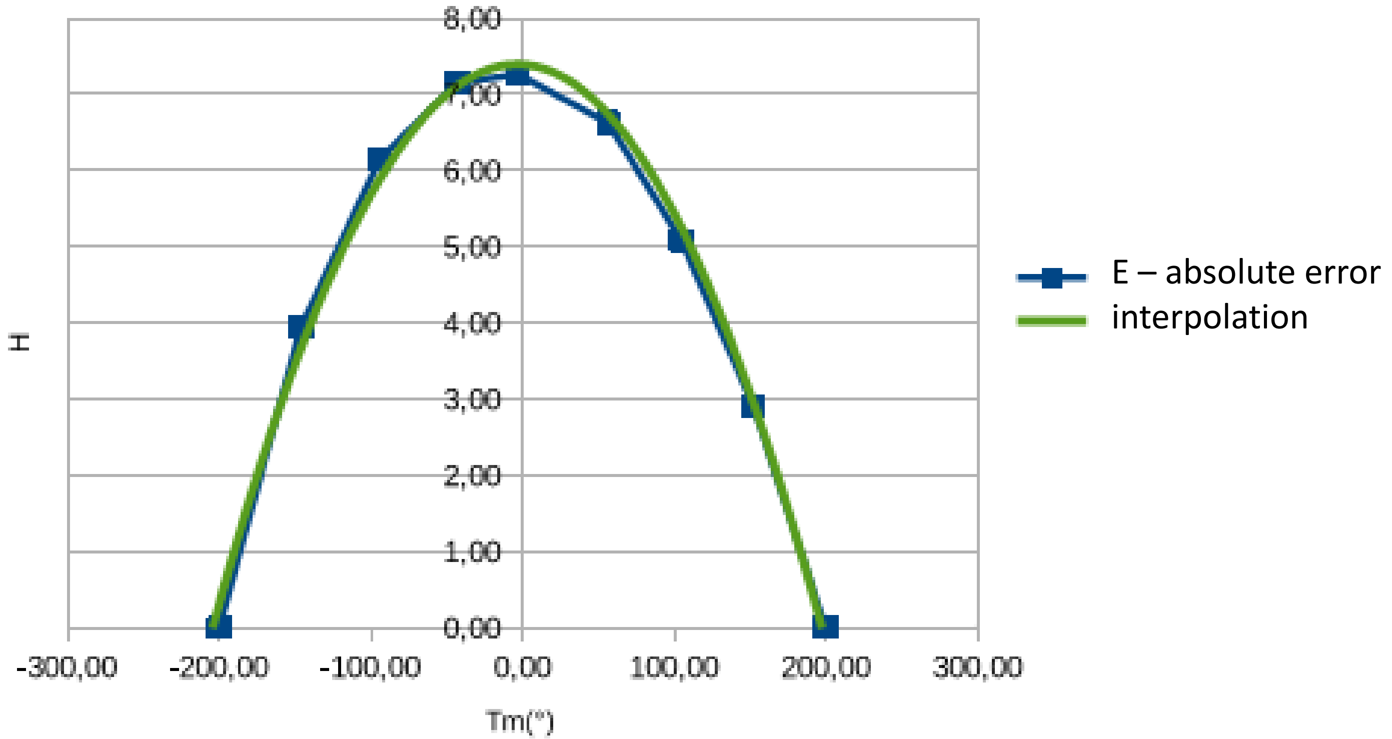
$\beta = |E_{max}| / I_{max}$ (%)

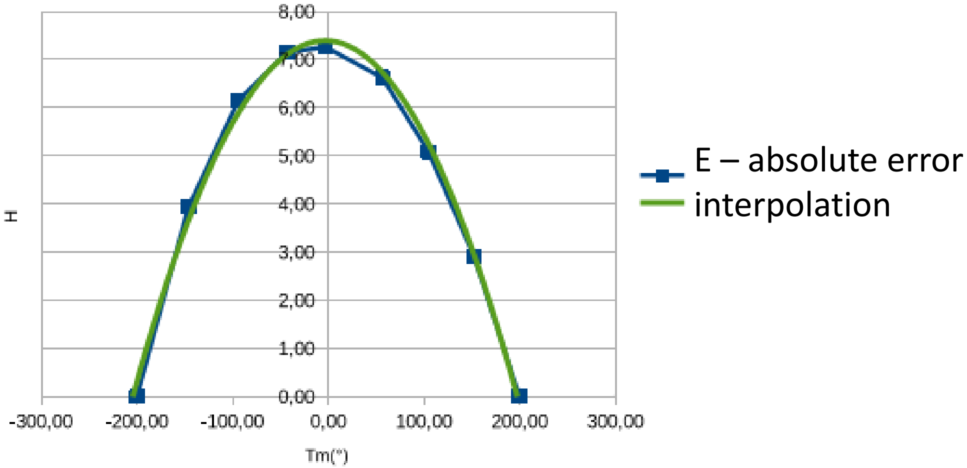


$$\beta = \frac{7,27\ °C}{200\ °C} \cdot 100 = 3,63\%.$$

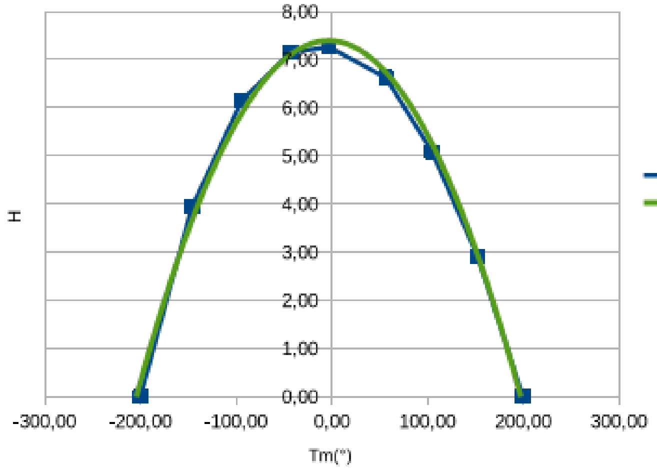
CALIBRATION – ERROR + INTERPOLATION

$$f(x) = -0,0001832542x^2 - 0,0012046545x + 7,3967711312$$





#	T(°C) I_v	R(Ohm) O	T^*(°C) I_m	H(°C)	h(%)	H_{int}(°C)	T^*_K(°C) I_{km}	h_k(%)
1	-200,00	18,49	-200,00	0,00	0,00	0,31	-200,31	-0,31
2	-150,00	39,71	-146,06	3,94	-2,63	3,66	-149,72	0,28
3	-100,00	60,25	-93,84	6,16	-6,16	5,90	-99,74	0,26
4	-50,00	80,31	-42,85	7,15	-14,31	7,11	-49,96	0,04
5	-10,00	96,09	-2,73	7,27	-72,67	7,40	-10,13	-0,13
6	50,00	119,44	56,63	6,63	13,25	6,74	49,88	-0,12
7	100,00	138,50	105,08	5,08	5,08	5,25	99,83	-0,17
8	150,00	157,31	152,89	2,89	1,93	2,93	149,97	-0,03
9	200,00	175,84	200,00	0,00	0,00	0,17	200,17	0,17



#	T(°C) I_v	R(Ohm) O	T^*(°C) I_m	H(°C)	h(%)	H_{int}(°C)	T^*_K(°C) I_{km}	h_k(%)
1	-200,00	18,49	-200,00	0,00	0,00	0,31	-200,31	-0,31
2	-150,00	39,71	-146,06	3,94	-2,63	3,66	-149,72	0,28
3	-100,00	60,25	-93,84	6,16	-6,16	5,90	-99,74	0,26
4	-50,00	80,31	-42,85	7,15	-14,31	7,11	-49,96	0,04
5	-10,00	96,09	-2,73	7,27	-72,67	7,40	-10,13	-0,13
6	50,00	119,44	56,63	6,63	13,25	6,74	49,88	-0,12
7	100,00	138,50	105,08	5,08	5,08	5,25	99,83	-0,17
8	150,00	157,31	152,89	2,89	1,93	2,93	149,97	-0,03
9	200,00	175,84	200,00	0,00	0,00	0,17	200,17	0,17

MEASUREMENT AND DAQ
LECTURE #2

Adam Schiffer, PhD

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The presentation was supported by EFOP-3.4.3.-16-2016-00005 számú "Korszerű egyetem a modern városban: Értékközpontúság, nyitottság és befogadó szemlélet egy 21. századi felsőoktatási modellben „ programme.

Statistical Analysis of Measurement Subject

Problem

- Repeatability – most important factor
- Random errors in measurements are caused by unpredictable variations in the measurement system
- Therefore, random errors can largely be eliminated by calculating the average of a number of repeated measurements
- The unaccuracy of the measurement device is normal
- Repeated measurements results different values in the same environmental conditions
-

Questions

- What is the measured value if the repeated measurements show different outputs?

Ie: R = 10.0012, 10.0014, 10.0011, 10.0012, 90.0013 Ohm

- What is the error interval of the next measurement?
- What is the probability that the next measurement will be in the defined range?
- How the probability changes if the range changes as well?

Questions

- What is the measured value if the repeated measurements show different outputs?

Ie: R = 10.0012, 10.0014, 10.0011, 10.0012, 90.0013 Ohm

- What is the error interval of the next measurement?
- What is the probability that the next measurement will be in the defined range?
- How the probability changes if the range changes as well?

Median, Mean

- The average value of a set of measurements of a constant quantity can be expressed as either the mean value or the median value.
- set of n measurements x1, x2 …. xn

$$x_{\text{mean}} = \frac{x_1 + x_2 + \cdots x_n}{n}$$

- For a set of n measurements x1, x2…. xn of a constant quantity, written down in ascending order of magnitude, the median value is given by:

$$x_{\text{median}} = x_{n+1}/2$$

Median, Mean

398 420 394 416 404 408 400 420 396 413 430 (Measurement set A)

$$\text{mean} = 409.0 \text{ and median} = 408$$

409 406 402 407 405 404 407 404 407 407 408 (Measurement set B)

$$\text{mean} = 406.0 \text{ and median} = 407$$

409 406 402 407 405 404 407 404 407 407 408 406 410 406 405 408
406 409 406 405 409 406 407 (Measurement set C)

$$\text{mean} = 406.5 \text{ and median} = 406$$

median value tends towards the mean value as the number of measurements increases

Median, Mean

deviation (error) d_i of each measurement x_i from the mean value x_{mean}:

$$d_i = x_i - x_{\text{mean}}$$

The *variance* (V) is then given by:

$$V = \frac{d_1^2 + d_2^2 \cdots d_n^2}{n-1}$$

The *standard deviation* σ

$$\sigma = \sqrt{V} = \sqrt{\frac{d_1^2 + d_2^2 \cdots d_n^2}{n-1}}$$

Median, Mean - EXAMPLES

Measurement	398	420	394	416	404	408	400	420	396	413	430
Deviation from mean	−11	+11	−15	+7	−5	−1	−9	+11	−13	+4	+21
$(\text{deviations})^2$	121	121	225	49	25	1	81	121	169	16	441

n=11, V=1310/10=137, σ=11.7

Measurement	409	406	402	407	405	404	407	404	407	407	408
Deviation from mean	+3	0	−4	+1	−1	−2	+1	−2	+1	+1	+2
$(\text{deviations})^2$	9	0	16	1	1	4	1	4	1	1	4

n=11, V=4.2, σ=2.05

Median, Mean - EXAMPLES

Measurement	409	406	402	407	405	404	407	404
Deviation from mean	+2.5	−0.5	−4.5	+0.5	−1.5	−2.5	+0.5	−2.5
$(\text{deviations})^2$	6.25	0.25	20.25	0.25	2.25	6.25	0.25	6.25

Measurement	407	407	408	406	410	406	405	408
Deviation from mean	+0.5	+0.5	+1.5	−0.5	+3.5	−0.5	−1.5	+1.5
$(\text{deviations})^2$	0.25	0.25	2.25	0.25	12.25	0.25	2.25	2.25

Measurement	406	409	406	405	409	406	407
Deviation from mean	−0.5	+2.5	−0.5	−1.5	+2.5	−0.5	+0.5
$(\text{deviations})^2$	0.25	6.25	0.25	2.25	6.25	0.25	0.25

$n=24$, $V=3.53$, $\sigma=1.88$

Interval estimation

$$x_m = \overline{X}_{-L_2}^{+L_1},$$

a) RANGE:
Xmax, Xmin are defined.

$$L_1 = x_{max} - \overline{X} \qquad L_2 = \overline{X} - x_{min}$$

b) Average of the absolute deviation:

$$x_m = \overline{X} \pm \delta \qquad \delta = \frac{1}{n}\sum_{k=1}^{n} |d_k|.$$

c) Standard deviation:

$$x_m = \overline{X} \pm \sigma$$

Interval estimation - EXAMPLE

k	1	2	3	4	5	6	7	8	9	10
l_k	100,1	99,6	100,3	100,0	99,8	100,5	100,1	100,0	100,1	99,7
d_k	0,08	-0,42	0,28	-0,02	-0,22	0,48	0,08	-0,02	0,08	-0,32
d_k^2	0,01	0,18	0,08	0,00	0,05	0,23	0,01	0,00	0,01	0,10
$\|d_k\|$	0,08	0,42	0,28	0,02	0,22	0,48	0,08	0,02	0,08	0,32

$$\sum_{k=1}^{10} d_k^2 = 0,656;$$

$$V_s = \frac{\sum_{k=1}^{10} d_k^2}{9} = 0,0729;$$

$$\sigma = \sqrt{V_s} = 0,27;$$

$$\delta = \frac{1}{10}\sum_{k=1}^{10} |d_k| = 0,2.$$

a) range:

$$L_1 = x_{max} - \overline{X} = 100,5 - 100,02 = 0,48$$

$$L_2 = \overline{X} - x_{min} = 100,02 - 99,6 = 0,42$$

$$x_m = \overline{X}_{-L_2}^{+L_1} = \overline{X}_{-0,42}^{+0,48}$$

Interval estimation - EXAMPLE

k	1	2	3	4	5	6	7	8	9	10
l_k	100,1	99,6	100,3	100,0	99,8	100,5	100,1	100,0	100,1	99,7
d_k	0,08	-0,42	0,28	-0,02	-0,22	0,48	0,08	-0,02	0,08	-0,32
d_k^2	0,01	0,18	0,08	0,00	0,05	0,23	0,01	0,00	0,01	0,10
$\|d_k\|$	0,08	0,42	0,28	0,02	0,22	0,48	0,08	0,02	0,08	0,32

$$\sum_{k=1}^{10} d_k^2 = 0,656;$$

$$V_s = \frac{\sum_{k=1}^{10} d_k^2}{9} = 0,0729;$$

$$\sigma = \sqrt{V_s} = 0,27;$$

$$\delta = \frac{1}{10} \sum_{k=1}^{10} |d_k| = 0,2.$$

b) Average of the absolute deviation:

$$x_m = \overline{X} \pm \delta = \overline{X} \pm 0,27$$

Interval estimation - EXAMPLE

k	1	2	3	4	5	6	7	8	9	10
l_k	100,1	99,6	100,3	100,0	99,8	100,5	100,1	100,0	100,1	99,7
d_k	0,08	-0,42	0,28	-0,02	-0,22	0,48	0,08	-0,02	0,08	-0,32
d_k^2	0,01	0,18	0,08	0,00	0,05	0,23	0,01	0,00	0,01	0,10
$\|d_k\|$	0,08	0,42	0,28	0,02	0,22	0,48	0,08	0,02	0,08	0,32

c) Standard deviation:

$$\sum_{k=1}^{10} d_k^2 = 0,656;$$

$$V_s = \frac{\sum_{k=1}^{10} d_k^2}{9} = 0,0729;$$

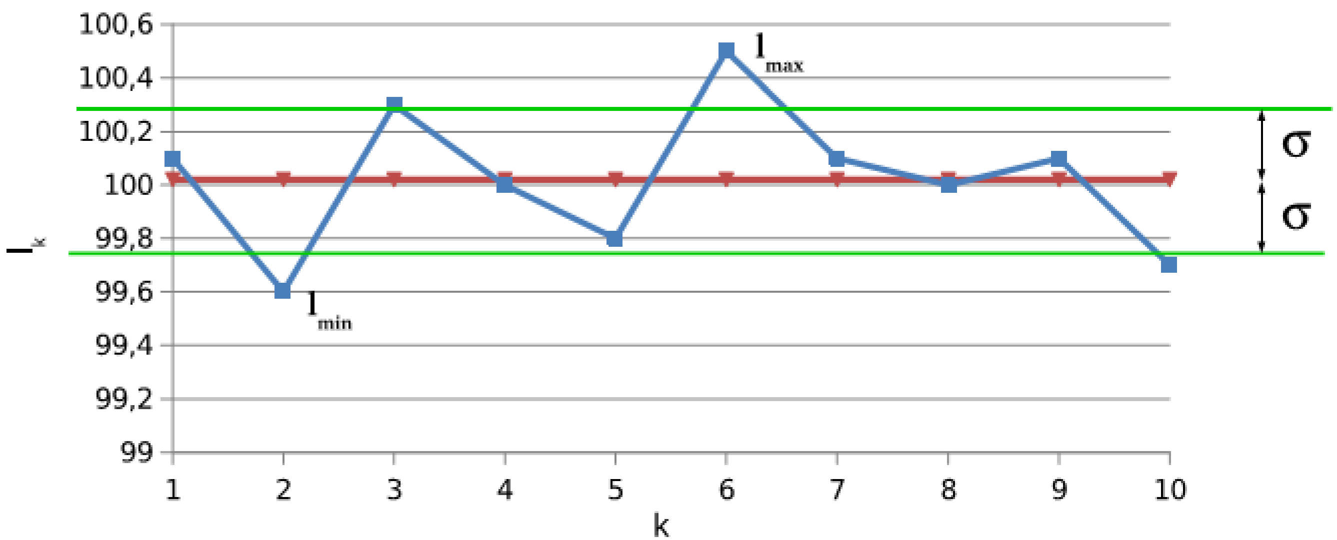
$$\sigma = \sqrt{V_s} = 0,27;$$

$$\delta = \frac{1}{10}\sum_{k=1}^{10} |d_k| = 0,2.$$

$$x_m = \overline{X} \pm \sigma = \overline{X} \pm 0,27$$

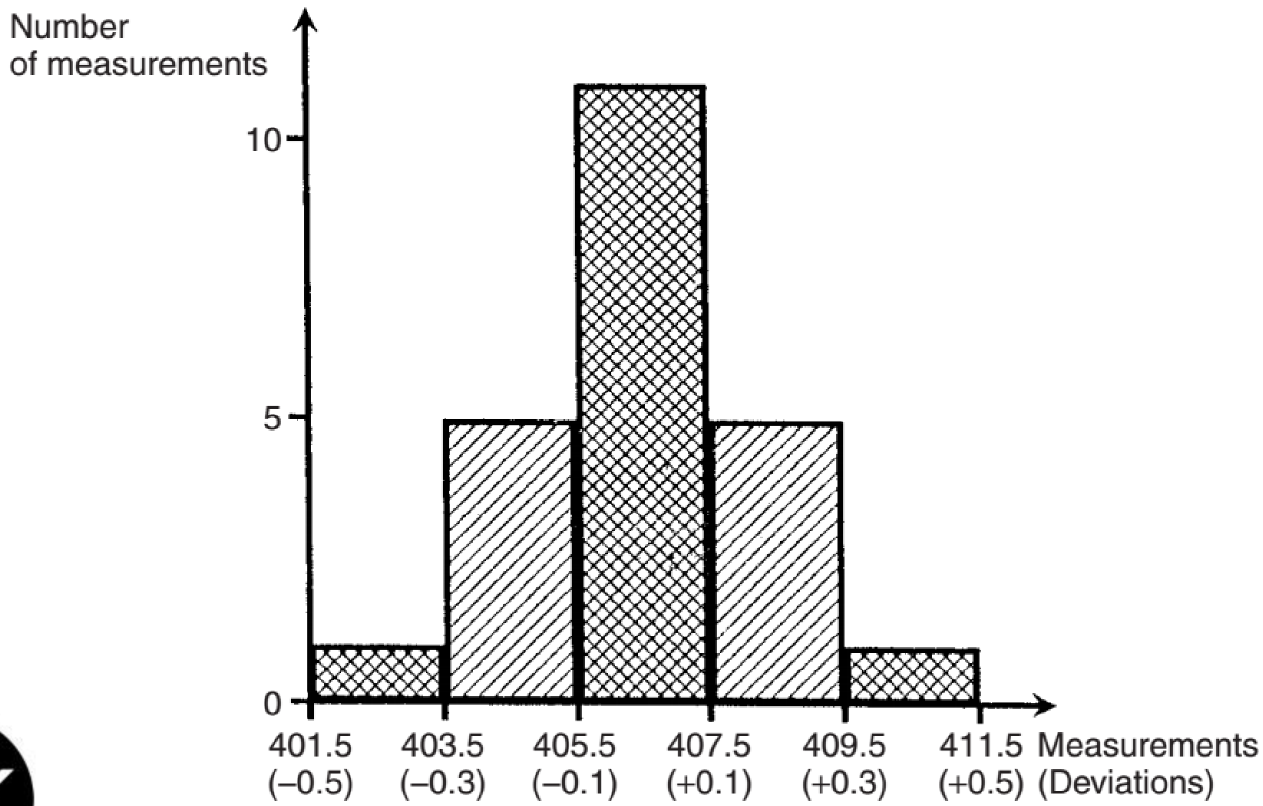
Interval estimation - EXAMPLE

k	1	2	3	4	5	6	7	8	9	10
l_k	100,1	99,6	100,3	100,0	99,8	100,5	100,1	100,0	100,1	99,7
d_k	0,08	-0,42	0,28	-0,02	-0,22	0,48	0,08	-0,02	0,08	-0,32
d_k^2	0,01	0,18	0,08	0,00	0,05	0,23	0,01	0,00	0,01	0,10
$\|d_k\|$	0,08	0,42	0,28	0,02	0,22	0,48	0,08	0,02	0,08	0,32



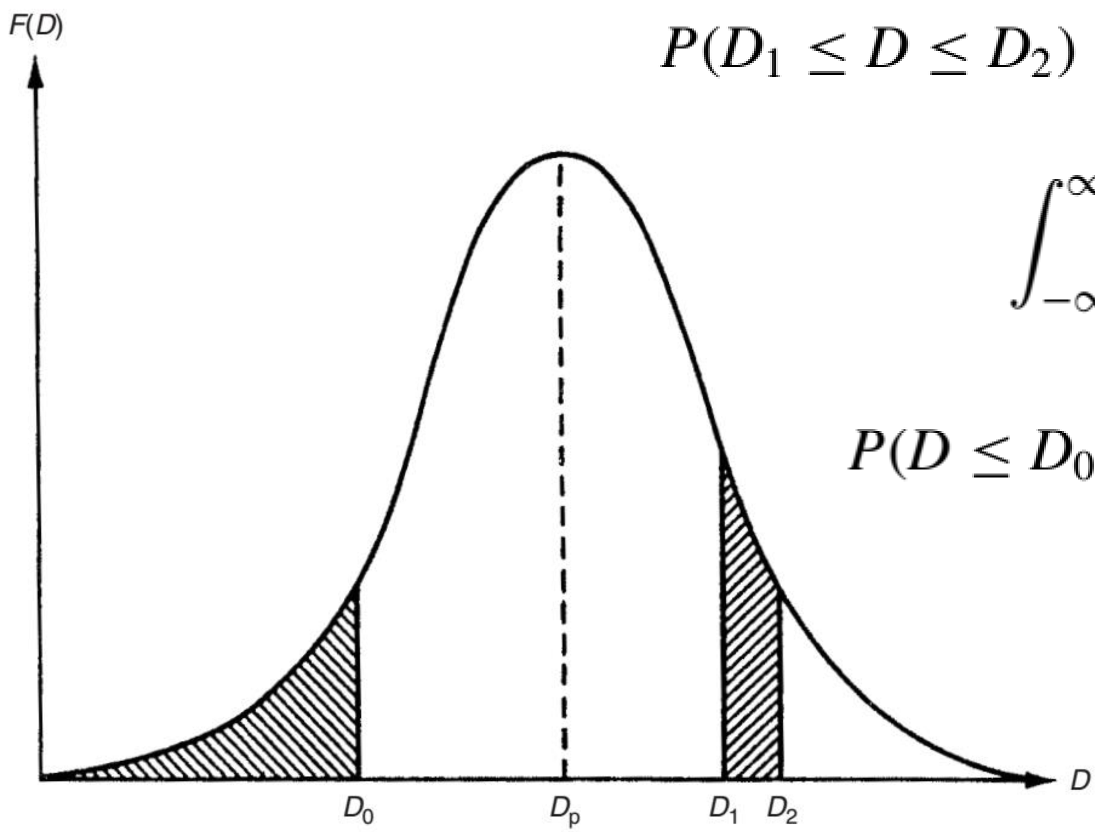
Frequency distribution - HISTOGRAM

- Graphical techniques are a very useful way of analysing the way in which random measurement errors are distributed.
- *histogram*, in which bands of equal width across the range of measurement values are defined and the number of measurements within each band is counted.



Frequency distribution - HISTOGRAM

- what happens to the histogram of deviations as the number of measurements increases?
- as the number of measurements approaches infinity, the histogram becomes a smooth curve known as a *frequency distribution curve*



$$P(D_1 \leq D \leq D_2) = \int_{D_1}^{D_2} F(D)\,\mathrm{d}D$$

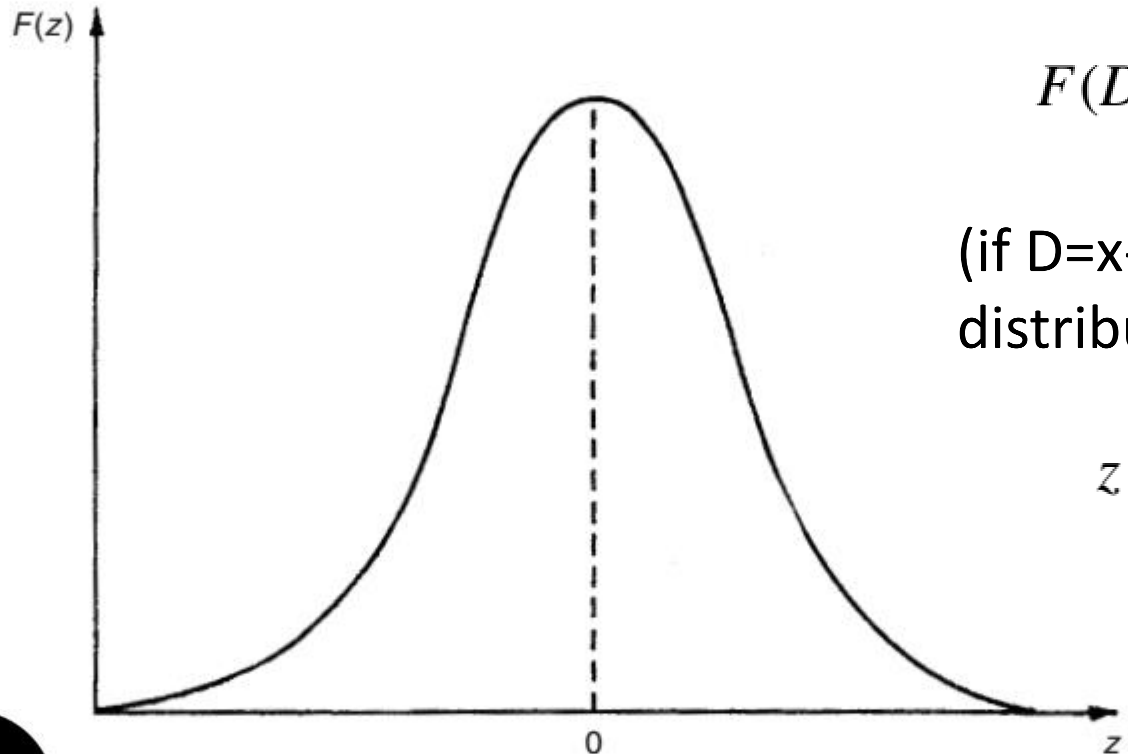
$$\int_{-\infty}^{\infty} F(D)\,\mathrm{d}D = 1$$

$$P(D \leq D_0) = \int_{-\infty}^{D_0} F(D)\,\mathrm{d}D$$

Gaussian Distribution

$$F(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{[-(x-m)^2/2\sigma^2]}$$

m is the mean value of the data set x



$$F(D) = \frac{1}{\sigma\sqrt{2\pi}} e^{[-D^2/2\sigma^2]}$$

(if D=x-m, the errors are distributed)

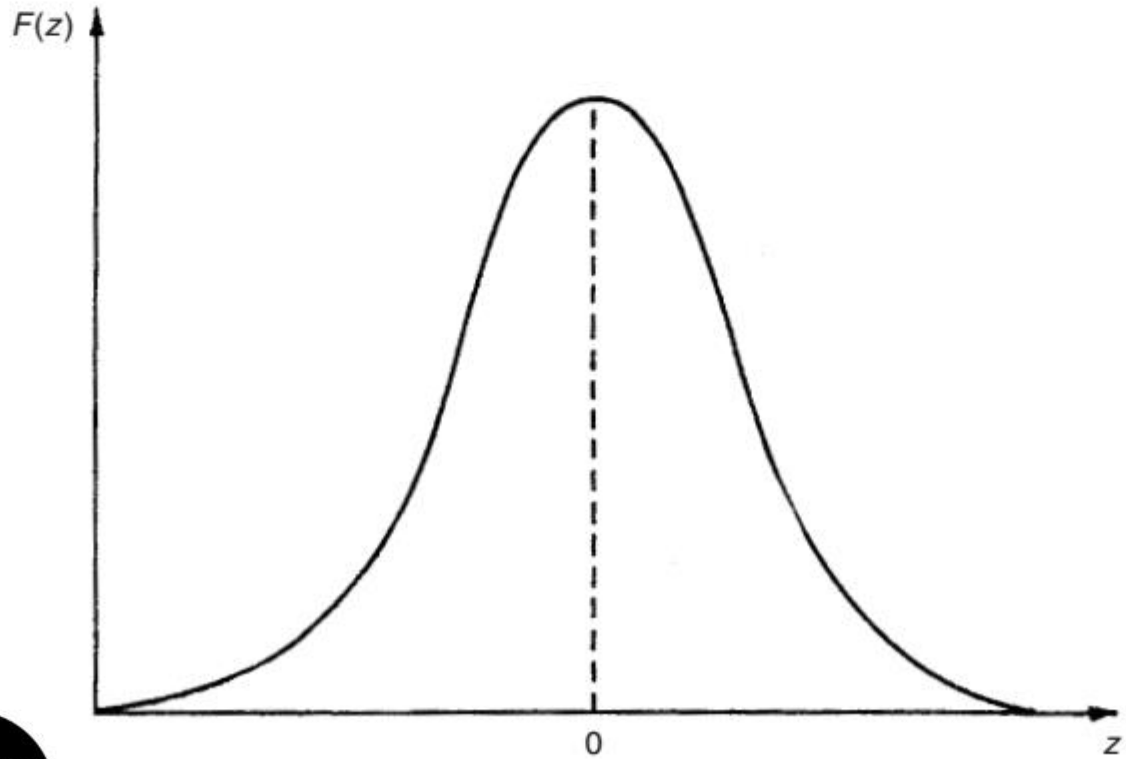
$$z = D/\sigma$$

σ=1, m=0

Gaussian Distribution

$$P(D_1 \leq D \leq D_2) = P(z_1 \leq z \leq z_2) = \int_{z_1}^{z_2} \frac{1}{\sigma\sqrt{2\pi}} e^{(-z^2/2)}\,\mathrm{d}z$$

$$F(-z) = 1 - F(z)$$

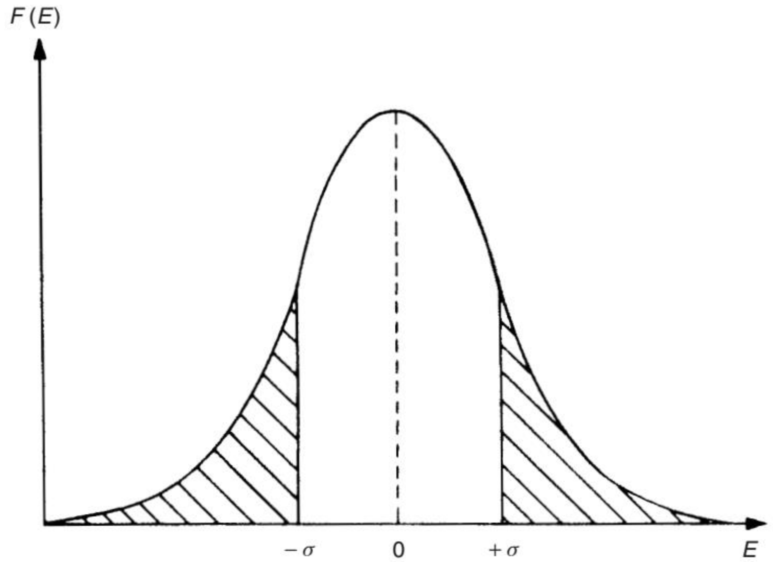


Gaussian Distribution

$$P(D_1 \leq D \leq D_2) = P(z_1 \leq z \leq z_2) = \int_{z_1}^{z_2} \frac{1}{\sigma\sqrt{2\pi}} e^{(-z^2/2)}\,\mathrm{d}z$$

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
					$F(z)$					
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998
3.5	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
3.6	0.9998	0.9998	0.9998	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999

Probability for Interval Estimations



a) range:

$$P(-0,42 < D < 0,48) = 90,23\%$$

b) Average of the absolute deviation:

$$P(-0,2 < D < 0,2) = 54,11\%$$

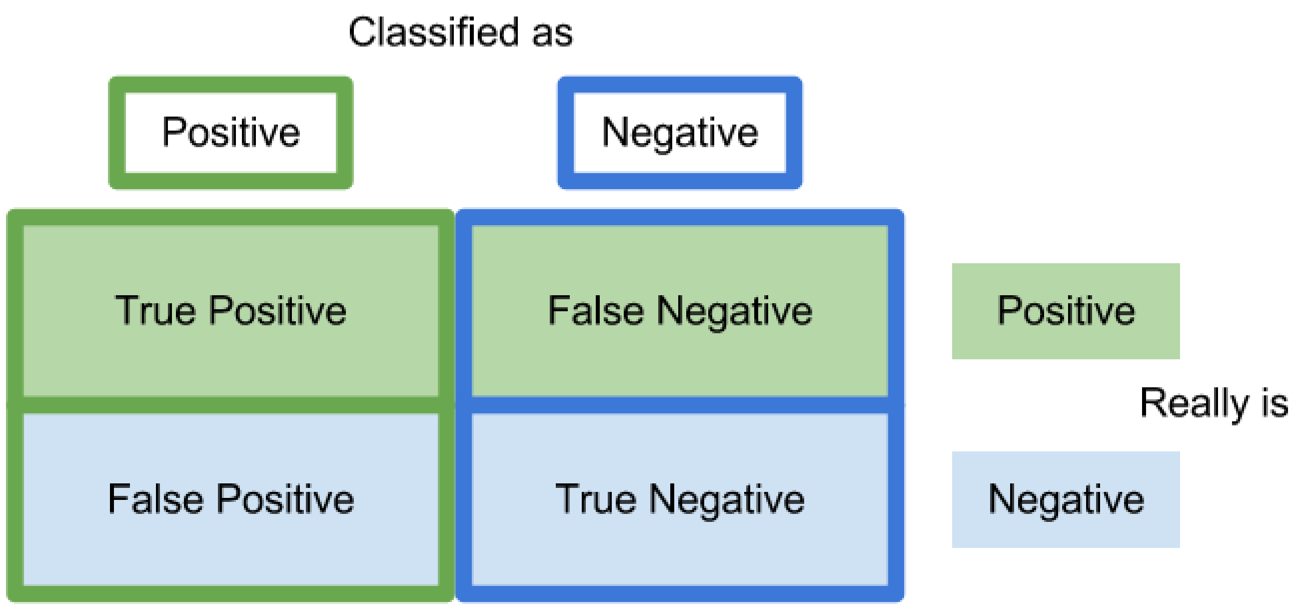
c) Standard deviation:

$$P(-0,27 < D < 0,27) = 68,27\%$$

Deviation boundaries	*% of data points within boundary*	*Probability of any particular data point being outside boundary*
$\pm\sigma$	68.0	32.0%
$\pm 2\sigma$	95.4	4.6%
$\pm 3\sigma$	99.7	0.3%

Sensitivity Specificity

confusion matrix:



Sensitivity Specificity

E.g. we have a measurement test that classifies pieces as in the range (positive) or not in the range (negative).

•True positive – measurement: the piece is in the range and this is TRUE

•True negative – measurement: the piece is NOT in the range and this is TRUE

•False negative – measurement: the piece is NOT in the range and this is FALSE

•False positive – measurement: the piece is in the range and this is FALSE

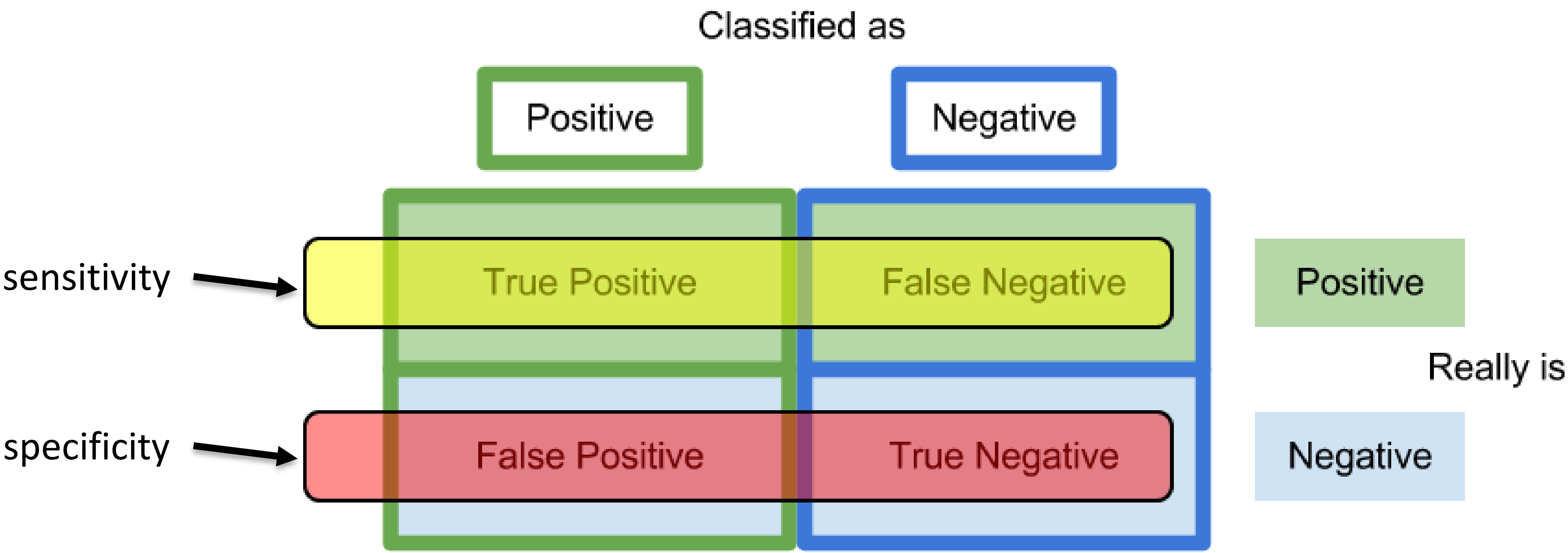
D=120 mm ± 0.5 mm

?

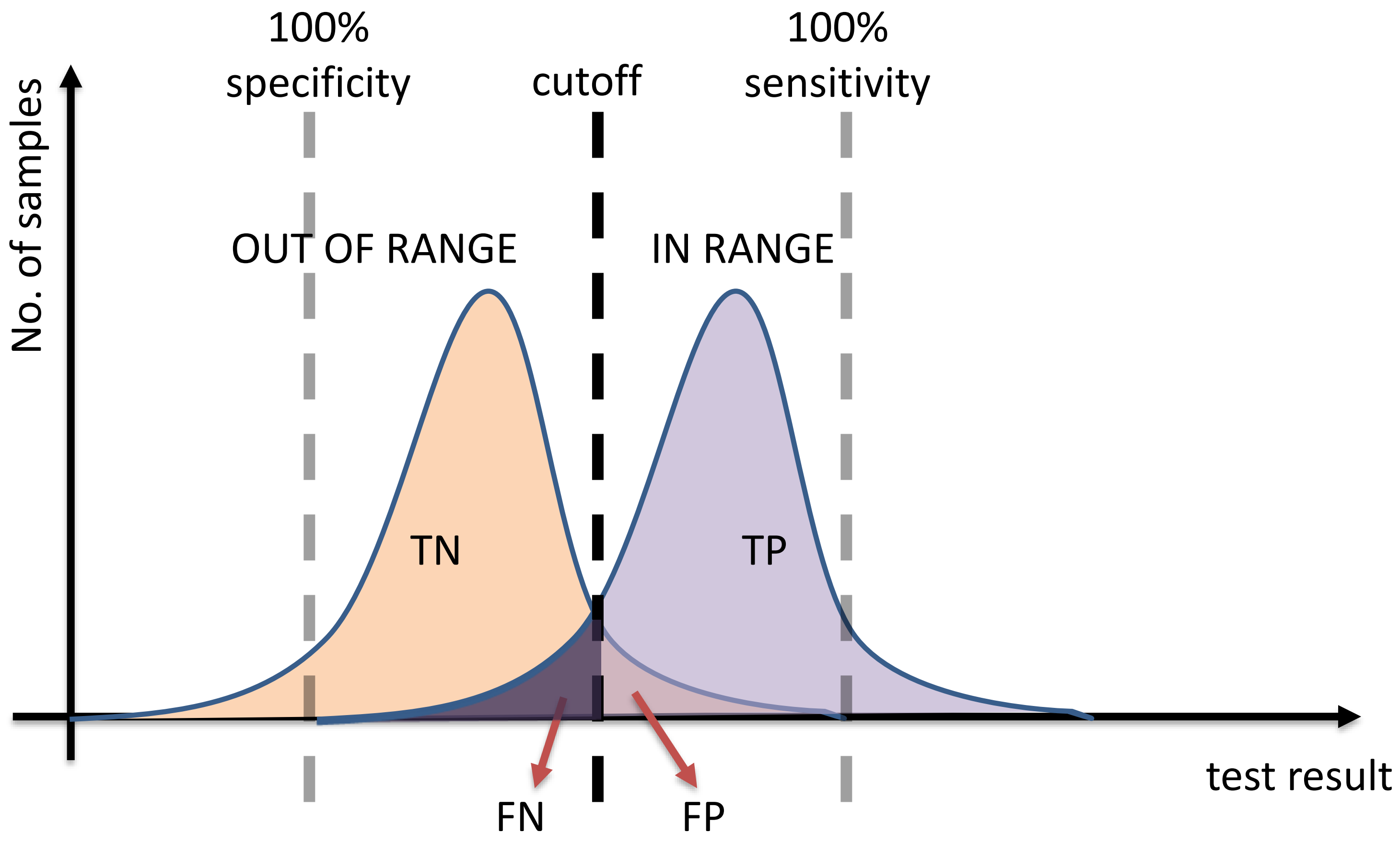
Sensitivity Specificity

$$\text{sensitivity} = \frac{\text{number of true positives}}{\text{number of true positives} + \text{number of false negatives}}$$

$$\text{specificity} = \frac{\text{number of true negatives}}{\text{number of true negatives} + \text{number of false positives}}$$



Sensitivity Specificity



$$\text{sensitivity} = \frac{\text{number of true positives}}{\text{number of true positives} + \text{number of false negatives}}$$

$$\text{specificity} = \frac{\text{number of true negatives}}{\text{number of true negatives} + \text{number of false positives}}$$

Precision, Accuracy

Accuracy = (TP+TN)/(TP+FP+FN+TN)

Precision = TP/(TP+FP)

Sensitivity = TP/(TP+FN)

Specificity = TN/(TN+FP)

EXAMPLE

Accuracy = (TP+TN)/(TP+FP+FN+TN)

Sensitivity = TP/(TP+FN)

Precision = TP/(TP+FP)

Specificity = TN/(TN+FP)

REALITY (mm)	**98**	**99**	**103**	**105**	**96**	**98**	**100**	RANGE:	98-102 mm
MEASURED (mm)	**100**	**103**	**99**	**103**	**98**	**99**	**103**		
REALITY (mm)	**T**	**T**	**F**	**F**	**F**	**T**	**T**		
MEASURED (mm)	**T**	**F**	**T**	**F**	**T**	**T**	**F**		

		CLASSIFIED AS	
		POSITIVE	NEGATIVE
REALITY	POSITIVE	TP	FN
	NEGATIVE	FP	TN

		CLASSIFIED AS	
		POSITIVE	NEGATIVE
REALITY	POSITIVE	2	2
	NEGATIVE	2	1

Accuracy	(2+1)/7	43%
Precision	2/(2+2)	50%
Sensitivity	2/(2+2)	50%
Specificity	1/(1+2)	33%

MEASUREMENT AND DAQ LECTURE #3

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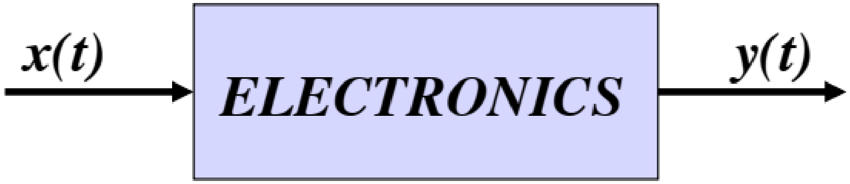
SAMPLING THEORY

Sampling theory

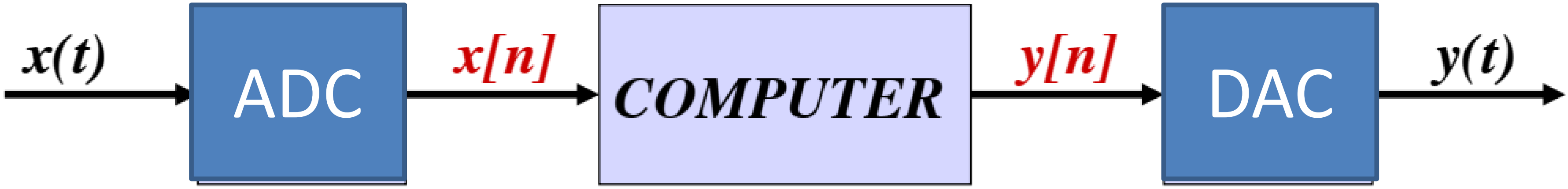
Continuous time system

- Good for analogue & general understanding
- Appropriate mostly to analogue electronic systems



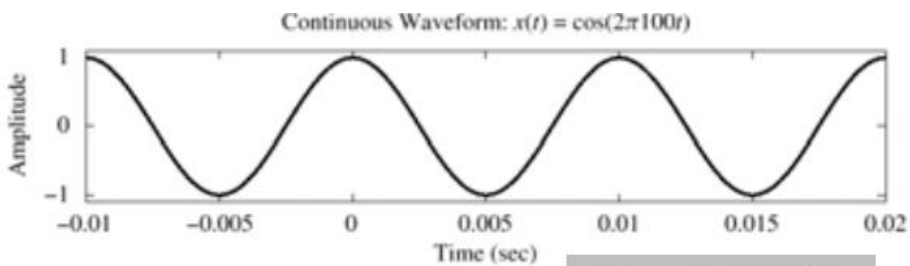
Digital systems

- Signals are converted to numbers, processed, and converted back

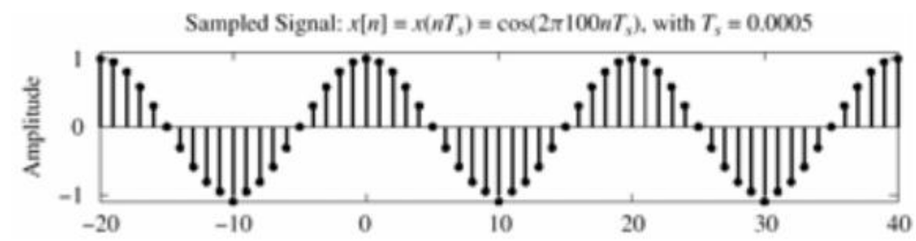


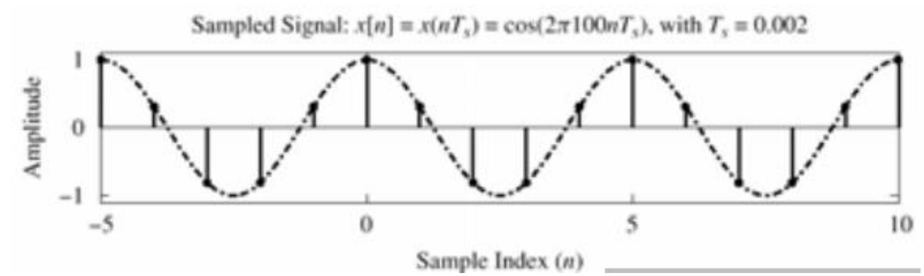
Sampling theory

Use A-to-D converters to turn x(t) into numbers x[n]
Take a sample every sampling period T_s – uniform sampling
$x[n] = x(nT_s)$

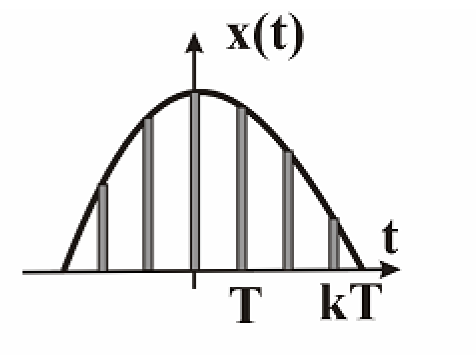


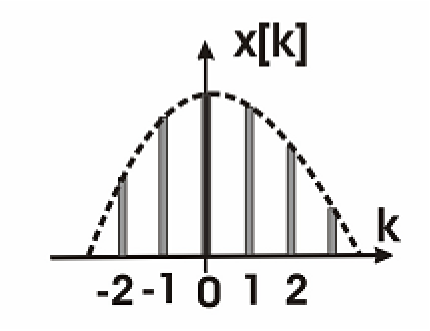
$$f = 100\text{Hz}$$

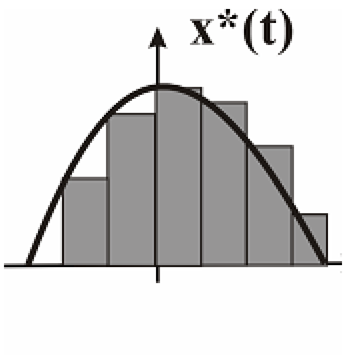




Sampling theory







T_s-sampling time

f_s-sampling frequency

f_{max}-max frequency of the signal

T_p-period time

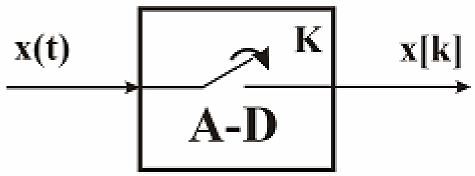
n- number of the samples per one period

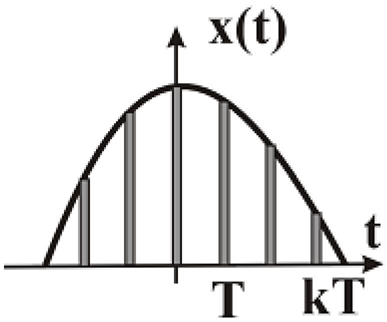
$f_s=1/T_s$

$n=T_p/T_s$

$n=f_s/f_{signal}$

Sampling theory





K is closed if: kT<t<kT+dt

K is open if: kT+dt<t<(k+1)T

Sampling theory

- Example 1

T_p = 20ms; T_s=10ns. f_s=?

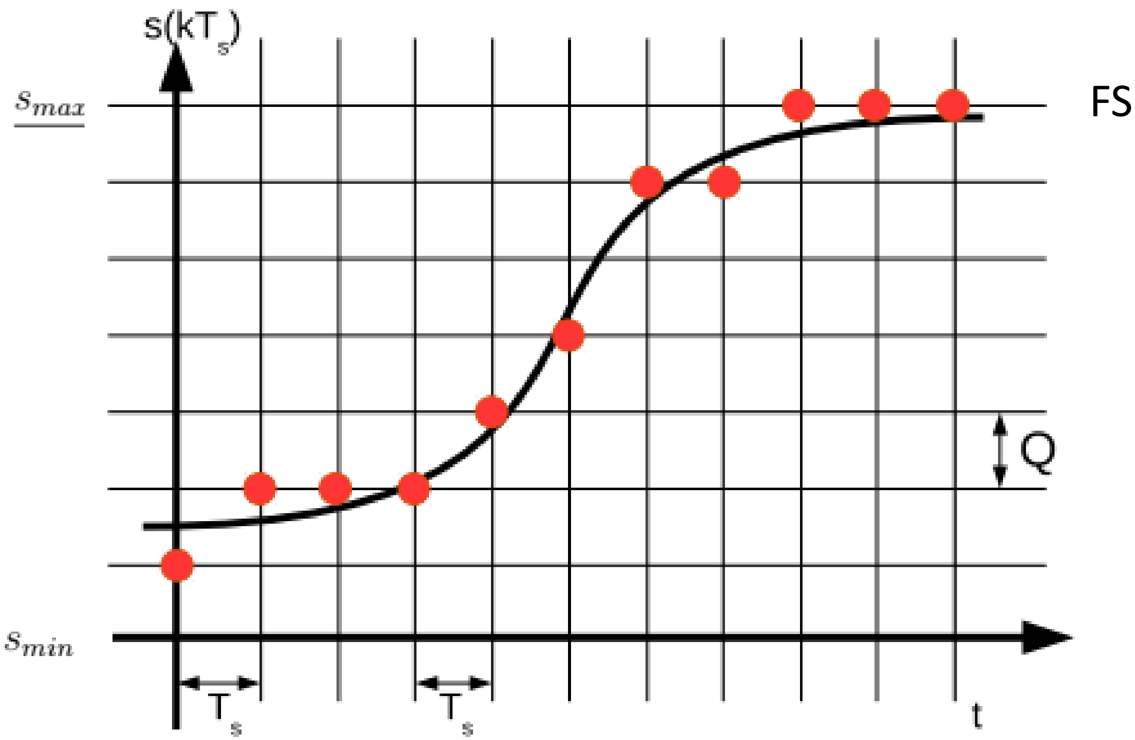
f_s=1/ T_s =10^8Hz = 100 MHz

- Example 2

T_p = 20ms; f_s=100 kHz; n=?

n= T_p / T_s= T_p f_s =2000 samples

Sampling theory



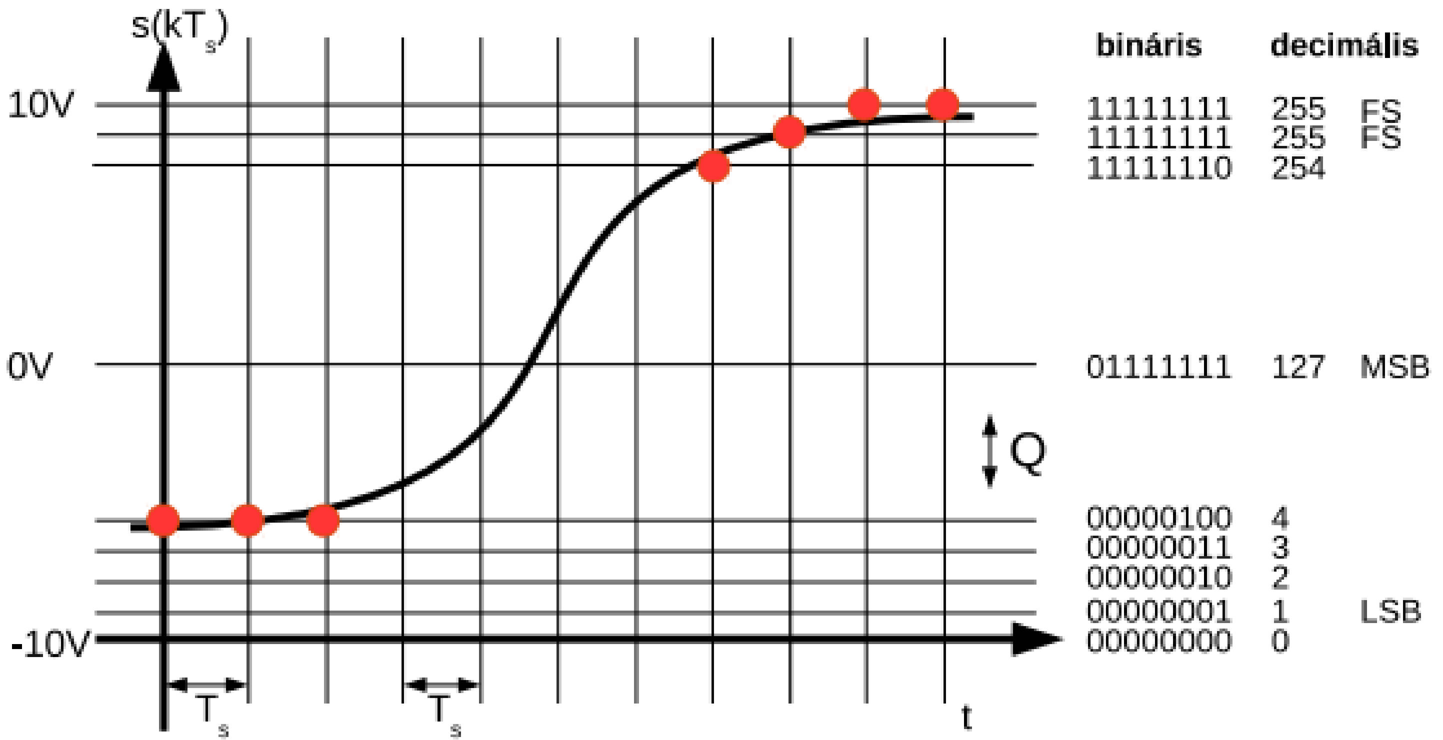
$$Q = \frac{s_{max} - s_{min}}{n_q - 1}.$$

n_q- number of quantums
(q=8 ; n_q=256)

FS (Full Scale), *FS* = 2^{res},
binary: *FS* = 0*b*11111*:::*1111;
LSB (least significant bit),
LSB =0*b*00000*:::*0001
MSB (most significant bit),
MSB = 0*b*10000*:::*0000.

Sampling theory

Example: Umax =10V, Umin = -10V, q=8 bits,



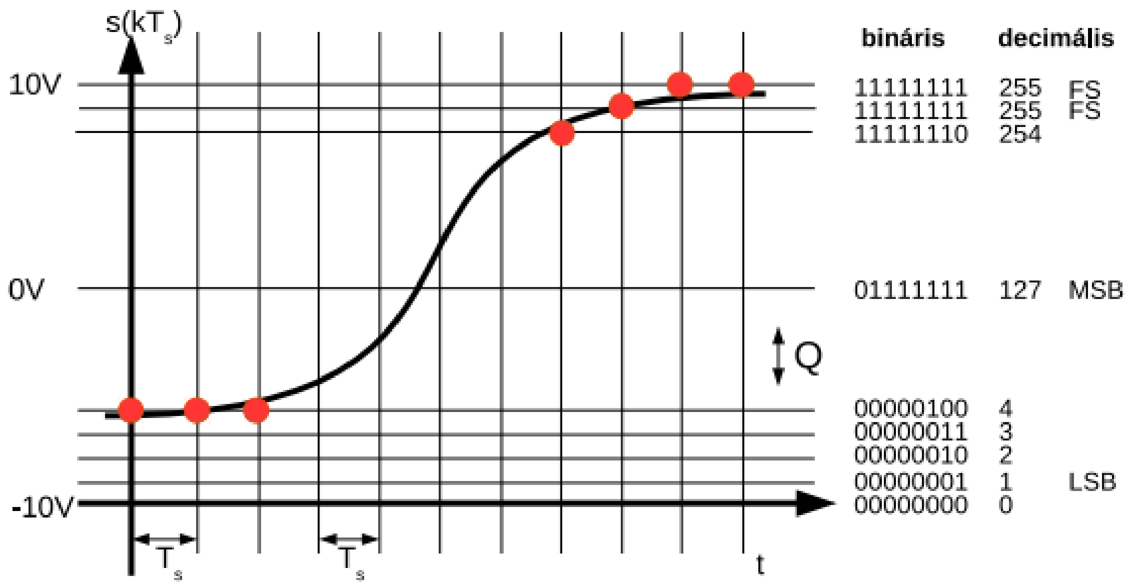
$Q = (10V-(-10V)) / 256 = 0.078\ V = 78\ mV$

$U_{FS} = 10V$

$U_{MSB} = 5V$

$U_{LSB} = -10V+Q = -9.92\ V$

Sampling theory



Quantitisation error = E_q = Q/2

Q = (10V-(-10V)) / 256 = 0.078 V = 78 mV

E_q = 78mV/2 = 39 mV

Relative quantitisation error e_q (%); $e_q = E_q/U_x$; U_x – measured voltage

@10 V -> e_q= 0.078/10 = 0.0078 = 0.78%

@5V ->e_q= 0.078/5 = 0.0039 = 0.39%

@0.1V ->e_q= 0.078/0.1 = 0.78 = 78%

Sampling theory

DC value

$$x_a^e = \frac{1}{T_p}\int_0^{T_p} x(t)dt, \quad x_d^e = \frac{1}{n_{s/p}}\sum_{k=0}^{n_{s/p}-1} x[k], \quad \left|\frac{x_a^e - x_d^e}{x_a^e}\right| \le \varepsilon$$

Absolute Value

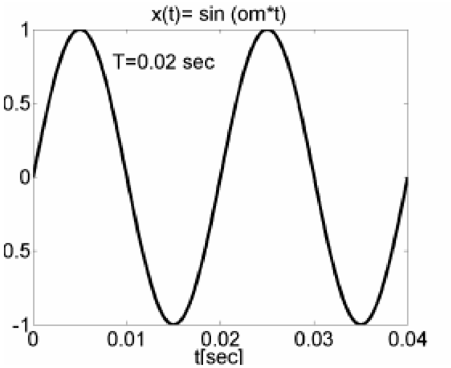
$$x_a^{abs} = \frac{1}{T_p}\int_0^{T_p} |x(t)|dt, \quad x_d^{abs} = \frac{1}{n_{s/p}}\sum_{k=0}^{n_{s/p}-1} |x[k]|, \quad \left|\frac{x_a^{abs} - x_d^{abs}}{x_a^{abs}}\right| \le \varepsilon$$

RMS Value

$$x_a^{eff} = \sqrt{\frac{1}{T_p}\int_0^{T_p} x(t)^2 dt}, \quad x_d^{eff} = \sqrt{\frac{1}{n_{s/p}}\sum_{k=0}^{n_{s/p}-1} x[k]^2}, \quad \left|\frac{x_a^{eff} - x_d^{eff}}{x_a^{eff}}\right| \le \varepsilon$$

Példa

$$x_a(t)=\hat{X}\sin\omega t,\quad \omega=\frac{2\pi}{T_p}$$



$$x_a^e=\frac{1}{T_p}\int_0^{T_p}x(t)dt=\frac{1}{T_p}\int_0^{T_p}\hat{X}\sin\omega t\,dt=0$$

$$x_a^{abs}=\frac{1}{T_p}\int_0^{T_p}|x(t)|dt=\frac{1}{T_p}\int_0^{T_p}\left|\hat{X}\sin\omega t\right|dt=4\frac{\hat{X}}{T_p}\int_0^{T_p/4}\sin\omega t\,dt$$

$$=4\frac{\hat{X}}{T_p}\left[\frac{-\cos\omega t}{\omega}\right]_0^{T_p/4}=4\frac{\hat{X}}{T_p}\frac{1-\cos\left(\frac{2\pi}{T_p}\frac{T_p}{4}\right)}{2\pi/T_p}=\frac{2}{\pi}\hat{X}$$

$$x_a^{eff}=\sqrt{\frac{1}{T_p}\int_0^{T_p}x(t)^2dt}=\sqrt{\frac{1}{T_p}\int_0^{T_p}\hat{X}^2\underbrace{\sin^2\omega t}_{\frac{1-\cos 2\omega t}{2}}dt}=\sqrt{\frac{1}{T_p}\hat{X}^2\frac{T_p}{2}}=\frac{\hat{X}}{\sqrt{2}}$$

Sampling theory

$$x[k] = \{1; -1,2; -1,8; 2,4; -2,2; 1,9\}$$

$$x_d^e = \frac{1}{n_{s/p}} \sum_{k=0}^{n_{s/p}-1} x[k] = \frac{1}{6}(1 - 1,2 - 1,8 + 2,4 - 2,2 + 1,9) = 0,0167 \;,$$

$$x_d^{abs} = \frac{1}{n_{s/p}} \sum_{k=0}^{n_{s/p}-1} |x[k]| = \frac{1}{6}(1 + 1,2 + 1,8 + 2,4 + 2,2 + 1,9) = 1,7500$$

$$x_d^{eff} = \sqrt{\frac{1}{n_{s/p}} \sum_{k=0}^{n_{s/p}-1} x[k]^2}$$

$$= \sqrt{\frac{1}{6}\left(1^2 + (-1,2)^2 + (-1,8)^2 + (-2,4)^2 + 2,2^2 + 1,9^2\right)} = 1,8207$$

Sampling theory

$$x[k] = \{1; -2; -4; 3; \}$$

$$x_d^e = \frac{1}{n_{s/p}} \sum_{k=0}^{n_{s/p}-1} x[k] = \frac{1}{4}(1-2-4+3) = -3/4$$

$$x_d^{abs} = \frac{1}{n_{s/p}} \sum_{k=0}^{n_{s/p}-1} |x[k]| = \frac{1}{4}(1+2+4+3) = 2,5$$

$$x_d^{eff} = \sqrt{\frac{1}{n_{s/p}} \sum_{k=0}^{n_{s/p}-1} x[k]^2}$$

$$= \sqrt{\frac{1}{4}\left(1^2 + (-2)^2 + (-4)^2 + (3)^2\right)} = \sqrt{30} = 5,4772$$

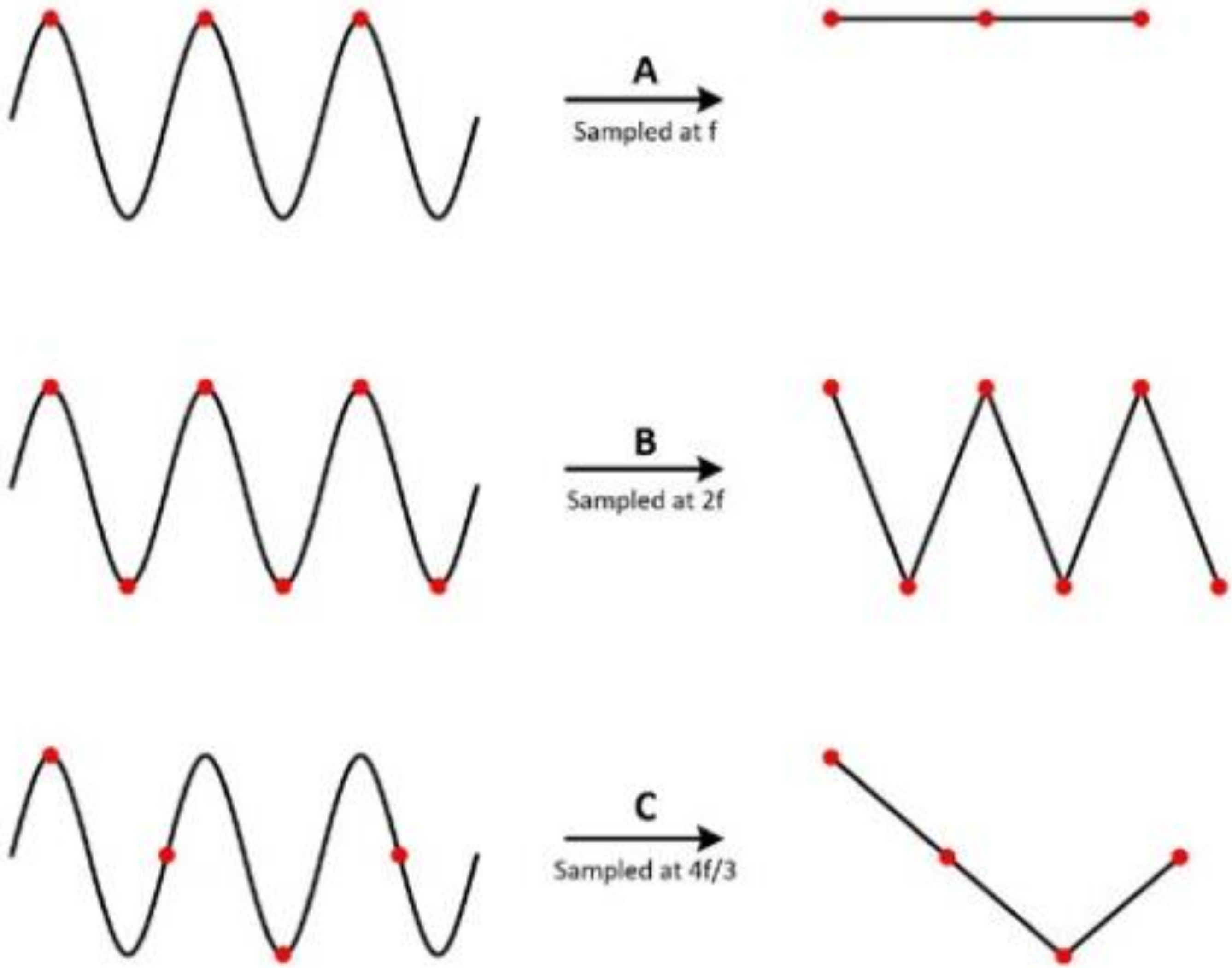
Sampling theory

Bridge between continuous-time and discrete-time
Tell us HOW OFTEN WE MUST SAMPLE in order not to loose any information

Sampling Theorem
A continuous-time signal x(t) with frequencies no higher than f_{max} (Hz) can be reconstructed EXACTLY from its samples $x[n] = x(nT_s)$, if the samples are taken at a rate $f_s = 1/T_s$ that is greater than $2f_{max}$

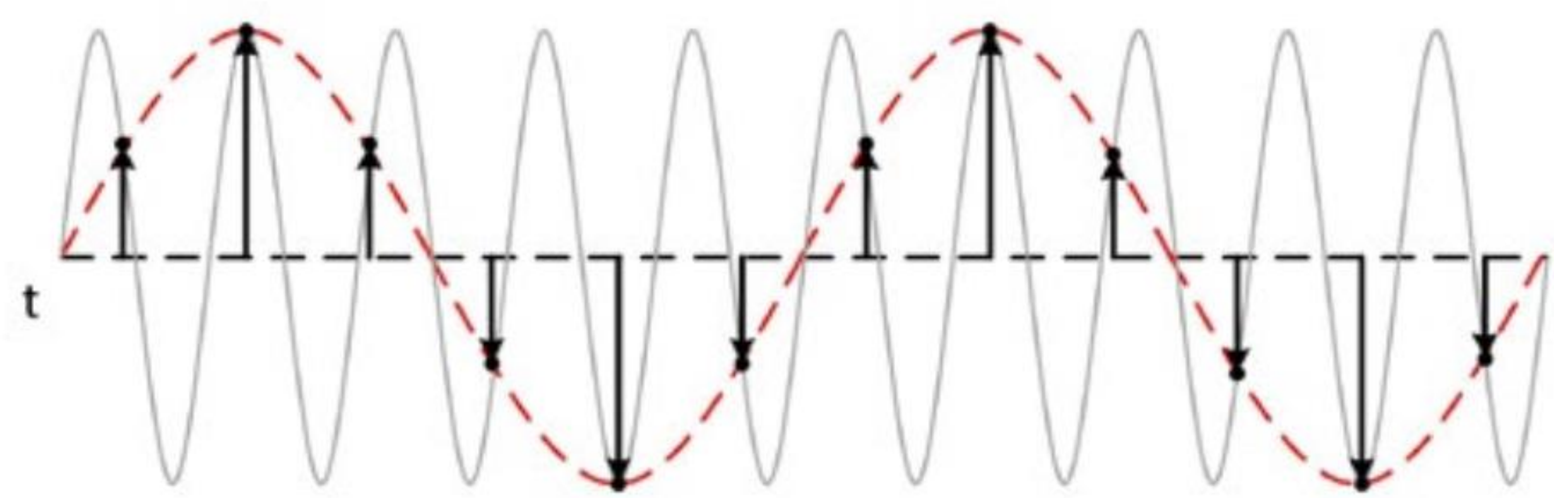
For example, the sinewave on previous slide is 100 Hz. We need to sample this at higher than 200 Hz (i.e. 200 samples per second) in order NOT to loose any data, i.e. to be able to reconstruct the 100 Hz sinewave exactly.
fmax refers to the maximum frequency component in the signal that has **significant** energy.
Consequence of violating sampling theorem is **corruption of the signal** in digital form

Sampling theory



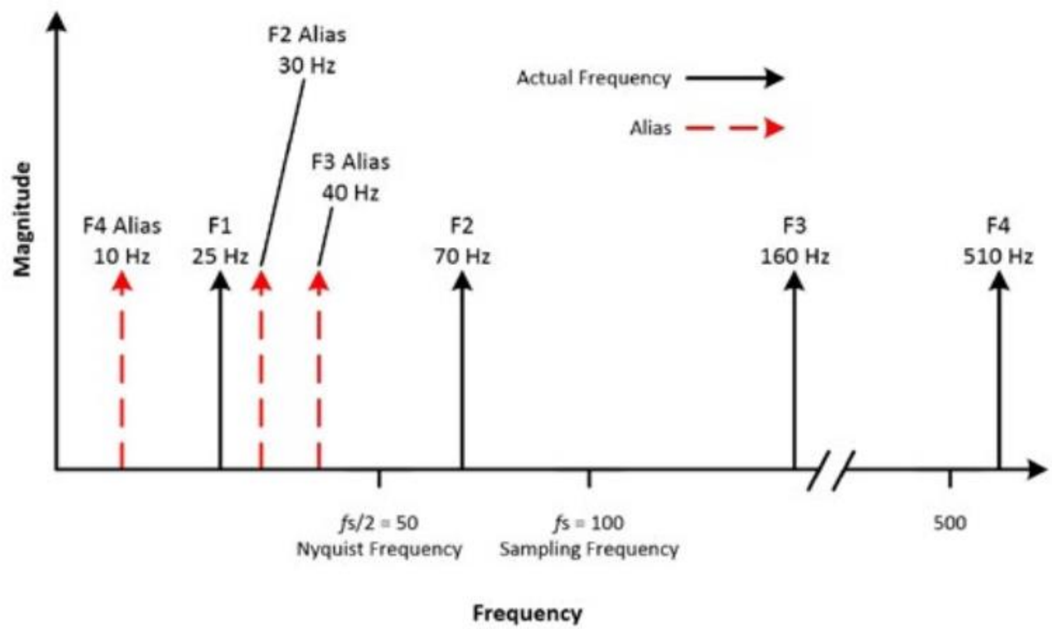
ALIASING

If you need to sample at a certain rate to avoid aliasing, then what exactly is aliasing? If a signal is sampled at a sampling rate smaller than twice the Nyquist frequency, false lower frequency components appear in the sampled data. This phenomenon is referred to as aliasing. The following figure shows an 800 kHz sine wave sampled at 1 MS/s. The dotted line indicates the aliased signal recorded at that sample rate. The 800 kHz frequency aliases back in the passband, falsely appearing as a 200 kHz sine wave.



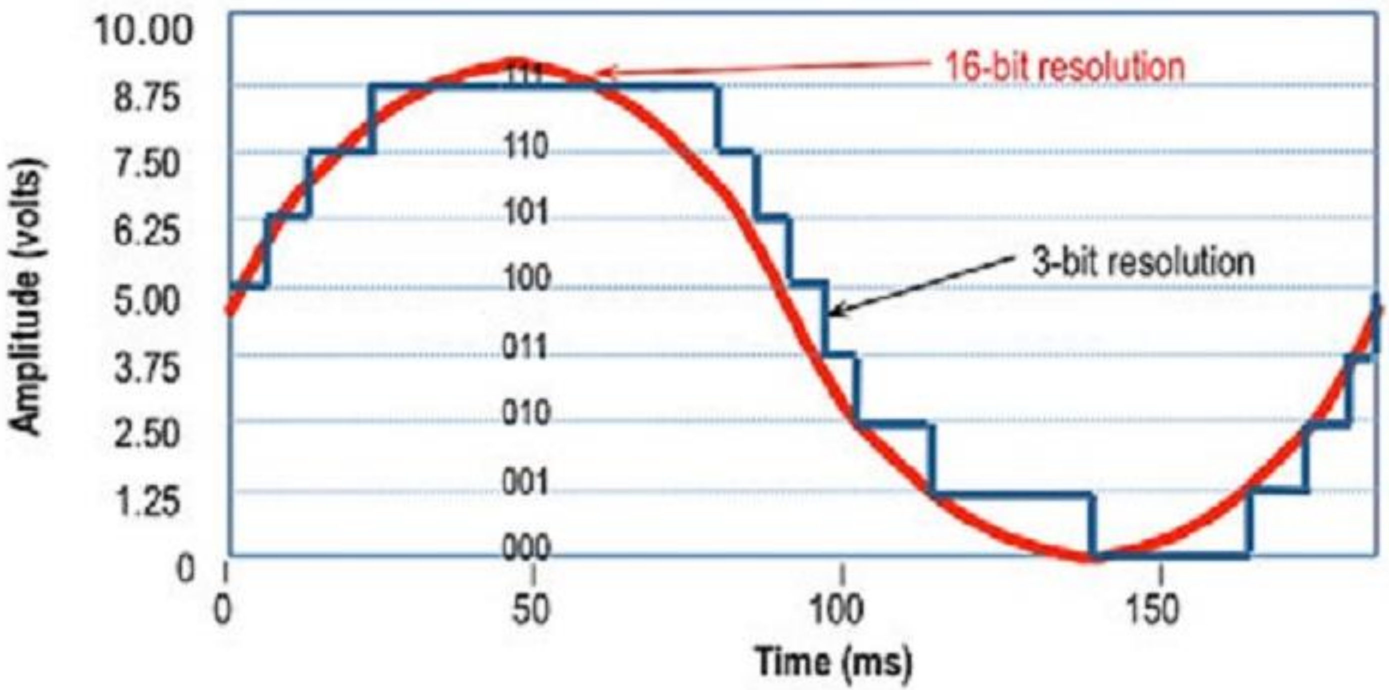
ALIASING

For example, consider a signal with a sample frequency of 100 Hz, and the input signal contains the following frequencies: 25 Hz, 70 Hz, 160 Hz, and 510 Hz. Frequencies below the Nyquist frequency of 50 Hz are sampled correctly; those over 50 Hz appear as alias.



Sampling theory

- Figure below compares a 3-bit ADC and a 16-bit ADC
- A 3-bit ADC can represent eight (23) discrete voltage levels.
- A 16-bit ADC can represent



Sampling theory

- Oversampling, or sampling at a rate beyond twice the Nyquist frequency, is recommended to help prevent aliasing and preserve the shape of the original signal.
- Because real-world signals are not perfectly fitered, they often contain frequency components greater than twice the critical frequency of interest.
- You can use oversampling to increase the Nyquist frequency (one half the sample rate) and reduce the possibility of aliasing in these higher frequency
components.
- Oversampling is also necessary when you want to capture fast edges,
transients, and one-time events.

Sampling theory

Sampling theory

Sampling theory

Sampling theory

MEASUREMENT AND DAQ
LECTURE #4

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Faculty of Engineering and Information Technology

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SIGNAL ACQUSITION OF ELECTRICAL SIGNALS

DAQ Card (Built in)

DAQ Card (Built in)

Low-Cost E Series Multifunction DAQ
12-Bit, 200 kS/s, 16 Analog Inputs

NI 6023E, NI 6024E, NI 6025E

- 16 analog inputs at 200 kS/s, 12-bit resolution
- Up to 2 analog outputs, 12-bit resolution
- 8 digital I/O lines (5 V/TTL/CMOS); two 24-bit counter/timers
- Digital triggering
- 4 analog input signal ranges
- NI-DAQ driver simplifies configuration and measurements

Models
- NI PCI-6023E
- NI PCI-6024E
- NI DAQCard-6024E for PCMCIA
- NI PCI-6025E
- NI PXI-6025E

*See ordering information

Operating Systems
- Windows 2000/NT/XP/Me/9x
- Mac OS 9*
- Real-time performance with LabVIEW (page 134)
- Others such as Linux (page 187)

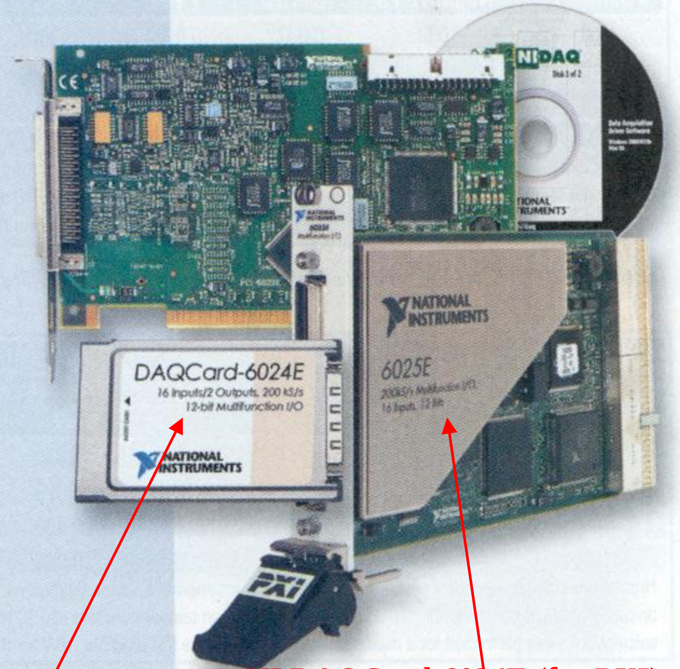
Recommended Software
- LabVIEW
- LabWindows/CVI
- Measurement Studio for Visual Basic
- VI Logger

Other Compatible Software
- Visual Basic
- C/C++

Driver Software (included)
- NI-DAQ

Calibration Certificate Included

See page 21



NI DAQCard-6024E (for PXI)

NI DAQCard-6024E (for PCMCIA)

Low-Cost E Series 12-Bit Multifunction DAQ

f_s=200 kHz

DAQ Card (Built in)

NI PCI-6120

16-Bit, 1 MS/s/ch, Simultaneous Sampling Multifunction DAQ

S Series Multifunction DAQ 12 or 16-Bit, 1 to 10 MS/s, 4 Analog Inputs

NI 6120, NI 6115, NI 6110, NI 6111

- 2 or 4 analog inputs; dedicated A/D converter per channel
- 1 to 10 MS/s per channel maximum sample rate
- Analog and digital triggering
- AC or DC coupling
- 8 input ranges from ±200 mV to ±42 V
- 2 analog outputs at 4 MS/s single channel or 2.5 MS/s dual channel
- 8 digital I/O lines (5 V TTL/CMOS)
- Two 24-bit counter/timers
- Measurement services that simplify configuration and measurements

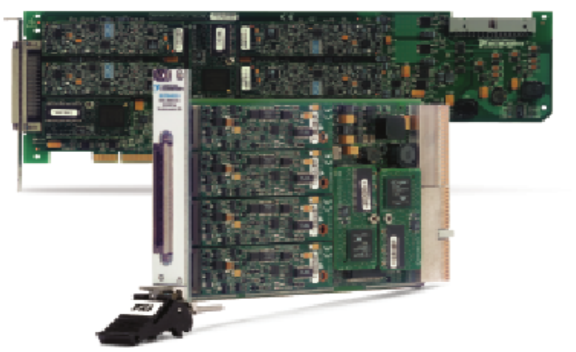
Operating Systems
- Windows 2000/NT/XP
- Mac OS X
- Linux

Recommended Software
- LabVIEW 7.x or higher
- LabWindows/CVI 7.x or higher
- Measurement Studio 7.x or higher
- Digital Waveform Editor
- SignalExpress 1.x or higher

Other Compatible Software
- VI Logger 2.x or higher
- Visual Studio .NET
- Visual Basic, C/C++, and C#

Measurement Services Software (included)[1]
- NI-DAQmx driver software
- Measurement & Automation Explorer configuration utility
- VI Logger Lite data-logging software

[1]Mac OS X and Linux applications must use NI-DAQmx Base driver software.



Calibration Certificate Available

Family	Bus	Analog Inputs	Input Resolution (bits)	Sampling Rate (MS/s)	Input Range (V)	Analog Outputs	Max Output Rate (MS/s)	Output Range (V)	Digital I/O	Counter/ Timers	Triggers
NI 6120	PCI, PXI	4	16	1[3]	±0.2 to ±42	2	4[1]	±10	8[2]	2, 24-bit	Analog, digital
NI 6115	PCI, PXI	4	12	10	±0.2 to ±42	2	4[1]	±10	8[2]	2, 24-bit	Analog, digital
NI 6110	PCI	4	12	5	±0.2 to ±42	2	4[1]	±10	8	2, 24-bit	Analog, digital
NI 6111	PCI	2	12	5	±0.2 to ±42	2	4[1]	±10	8	2, 24-bit	Analog, digital

[1]4 MS/s single channel; 2.5 MS/s on two channels [2]Hardware-timed up to 10 MB/s [3]800 kS/s with NI-DAQmx, 1 MS/s with additional download. Special conditions apply.

DAQ Card (Built in)

NI PCIe-6363

X Series Data Acquisition

32 analog inputs, 2 MS/s 1-channel, 1 MS/s multichannel; 16-bit resolution, ±10 V

Four analog outputs, 2.86 MS/s, 16-bit resolution, ±10 V

48 digital I/O lines (32 hardware-timed up to 10 MHz)

Four 32-bit counter/timers for PWM, encoder, frequency, event counting, and more

Analog and digital triggering and advanced timing with NI-STC3 technology

Support for Windows 7/Vista/XP/2000

Specifications (NI PCIe-6363)

General	
Product Name	NI PCIe-6363
Product Family	Multifunction Data Acquisition
Form Factor	PCI Express
Part Number	781051-01
Operating System/Target	Real-Time , Windows
LabVIEW RT Support	Yes
DAQ Product Family	X Series
Measurement Type	Digital , Frequency , Voltage , Quadrature encoder
RoHS Compliant	Yes

Specifications (NI PCIe-6363)

Analog Input

Channels 16 , 32

Single-Ended Channels 32

Differential Channels 16

Resolution 16 bits

Sample Rate 2 MS/s

Throughput (All Channels) 1 MS/s

Max Voltage 10 V

Maximum Voltage Range -10 V , 10 V

Maximum Voltage Range Accuracy 1.74 mV

Minimum Voltage Range -0.1 V , 0.1 V

Minimum Voltage Range Accuracy 38 µV

Number of Ranges 7

Simultaneous Sampling No

Specifications (NI PCIe-6363)

Analog Output

Channels	4
Resolution	16 bits
Max Voltage	10 V
Maximum Voltage Range	-10 V , 10 V
Maximum Voltage Range Accuracy	1.89 mV
Minimum Voltage Range	-5 V , 5 V
Minimum Voltage Range Accuracy	935 µV
Update Rate	2.86 MS/s

Specifications (NI PCIe-6363)

Digital I/O

Bidirectional Channels	48
Input-Only Channels	0
Output-Only Channels	0
Number of Channels	0 , 48
Timing	Software , Hardware
Clocked Lines	32
Max Clock Rate	10 MHz
Logic Levels	TTL
Input Current Flow	Sinking , Sourcing
Output Current Flow	Sinking , Sourcing
Programmable Input Filters	Yes
Supports Programmable Power-Up States?	Yes
Current Drive Single	24 mA
Current Drive All	1 A
Watchdog Timer	Yes
Supports Handshaking I/O?	No
Supports Pattern I/O?	Yes
Maximum Input Range	0 V , 5 V
Maximum Output Range	0 V , 5 V

Specifications (NI PCIe-6363)

Counter/Timers

Counters 4

Number of DMA Channels 8

Buffered Operations Yes

Debouncing/Glitch Removal Yes

GPS Synchronization No

Maximum Range 0 V , 5 V

Max Source Frequency 100 MHz

Pulse Generation Yes

Resolution 32 bits

Timebase Stability 50 ppm

Logic Levels TTL

Specifications (NI PCIe-6363)

Physical Specifications

Length 16.8 cm

Width 50 mm

Height 9.9 cm

I/O Connector 68-pin VHDCI female

Timing/Triggering/Synchronization

Triggering Digital , Analog

Synchronization Bus (RTSI) Yes

DAQ CARDS

NI PXIe-5665
High-Performance Vector Signal Analyzer up to 14 GHz

20 Hz to 3.6 GHz / 14 GHz frequency range
25/50 MHz instantaneous bandwidth
129 dBc/Hz typical phase noise at 10 kHz offset at 800 MHz
±0.35 dB typical flatness within 20 MHz bandwidth
±0.1 dB typical amplitude accuracy

DAQ CARDS

750 MB/s sustained read and write speeds for 80 percent of the storage capacity
Three storage capacities available: 6TB (12 x 500GB), 12TB (12 x 1TB) and 24TB (12 x 2TB)
Supports various RAID modes (RAID-0/1/10/5/6)
Programmatic control and monitoring of hard drives and RAID partitions
Supports hot swap of hard drives
Offers Endless record mode

DAQ CARDS

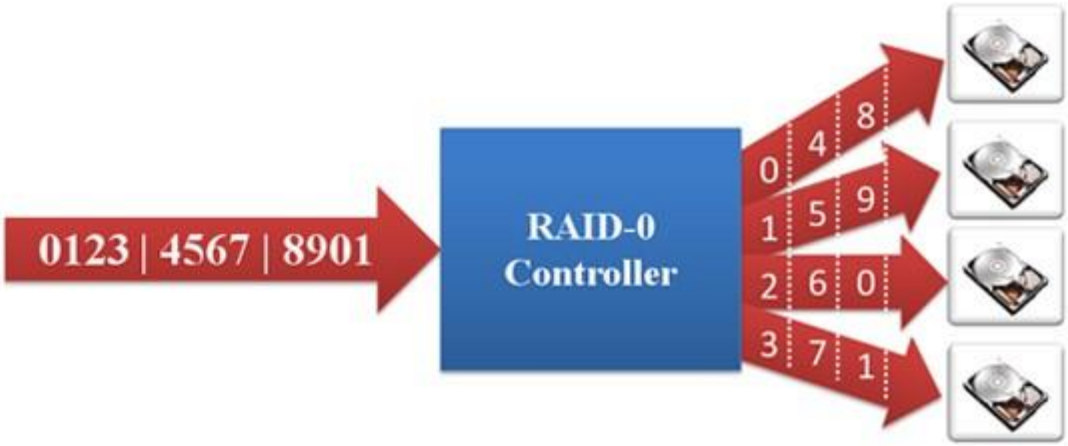
- PXIe
- 5 GB/s
- 4 TB
- SSD based
- approx. 8 400 EUR

RAID TECHNOLOGY

- Redundant Array of Inexpensive Disks (RAID), also known as Redundant Array of Independent Drives, is a general term for mass storage schemes that split or replicate data across multiple hard drives.
- Some RAID modes allow for very high-bandwidth applications to stream data to hard drives, and others allow redundancy where a hard drive failure will not cause data loss.

Different RAID Levels

- **RAID 0**: Striped Set without Parity (Requires Minimum 2 Disks)
- Data is equally divided into fragments across a number of disks.
- The maximum read and write rates of the RAID array is theoretically equal to the number of drives in the array and the read and write rate of an individual drive

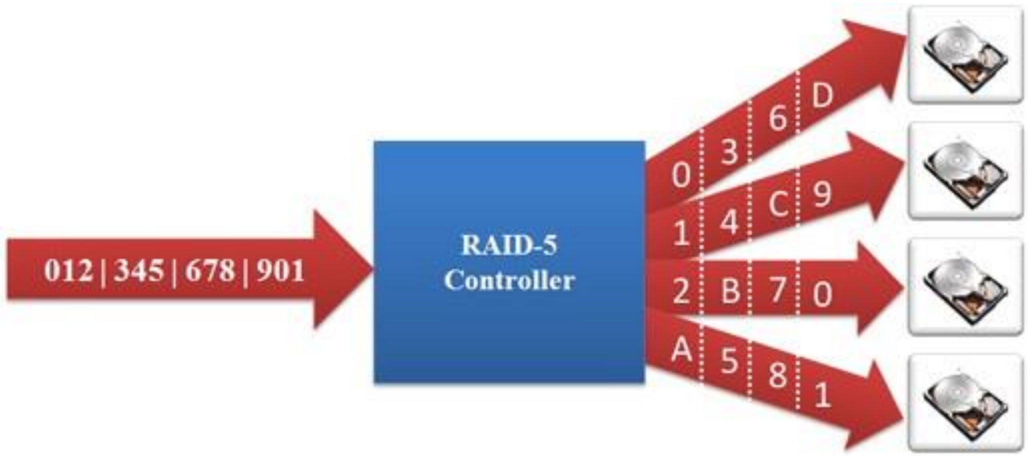


Different RAID Levels

- **<u>RAID 1:</u>** Mirrored Set (Requires Even Number, Minimum 2 Disks)
- Focuses only on redundancy.
- Data is mirrored across all the drives in the RAID array.
- The read and write performance of an array configured as RAID 1 is the same as the read or write performance an individual drive.
- The array however offers the highest reliability as it continues operates as long as one drive is functioning.

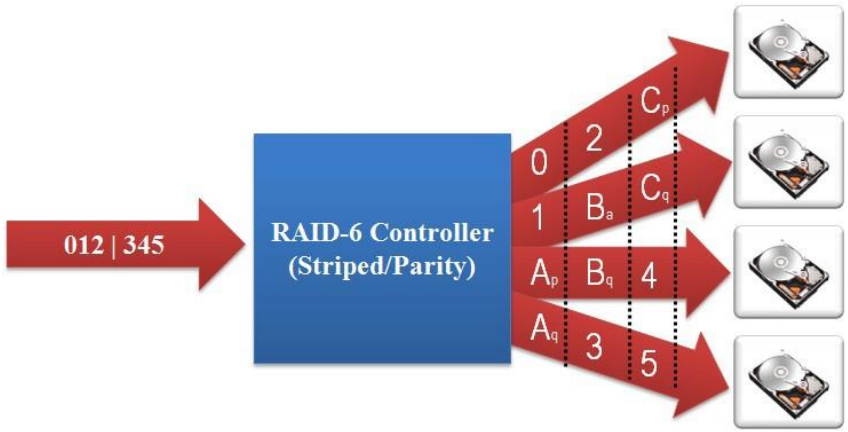
Different RAID Levels

- **RAID 5:** Striped Set (Requires Minimum 3 Disks) with Distributed Parity
- Parity information is stored on the drives allowing the reconstruction of the array if one disk fails.
- The parity information is rotated through all disks.
- Performance increase is just below RAID 0 but increased fault protection makes RAID 5 an ideal choice over RAID 0.



Different RAID Levels

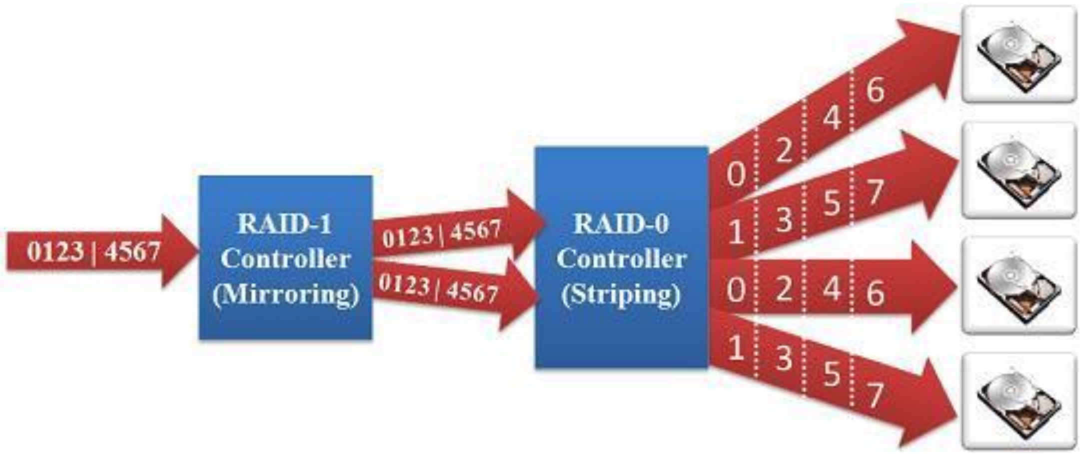
- **<u>RAID 6</u>**: Double distributed parity.
- Similar to RAID 5 it stripes blocks of data and parity across an array of drives like RAID 5, except that is calculates two set of parity information for each set of data.
- RAID 6 can withstand multiple drive failures.



Different RAID Levels

<u>RAID 1+0 (also called RAID 10)</u>:

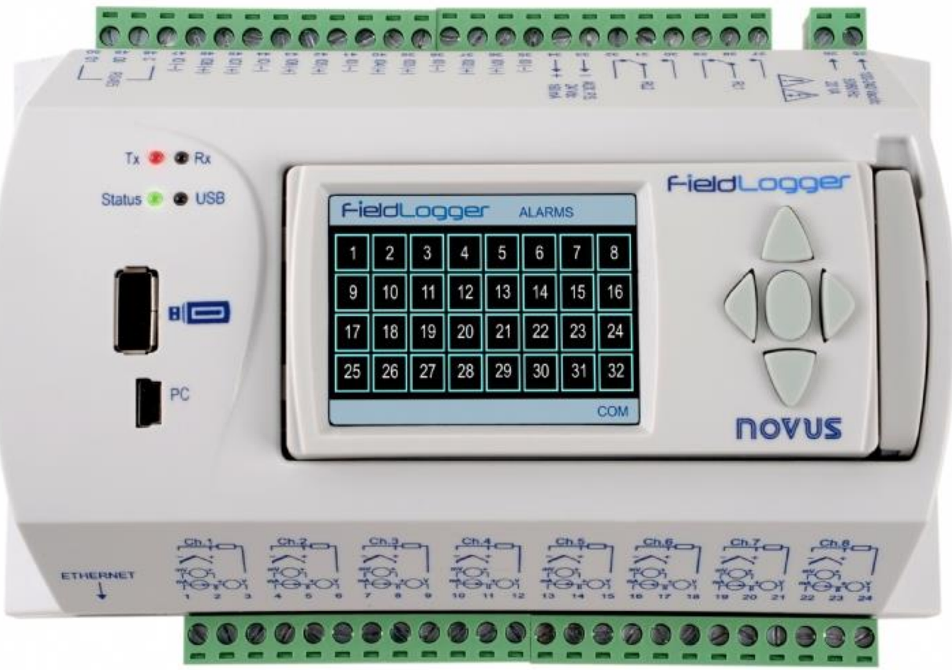
- RAID levels can be nested in order to increase performance while providing redundancy.
- RAID 1+0 mirrors the data first, and then stripes them. This allows for a performance increase, with the added feature of fault tolerance.



SAMPLE BENCHMARK

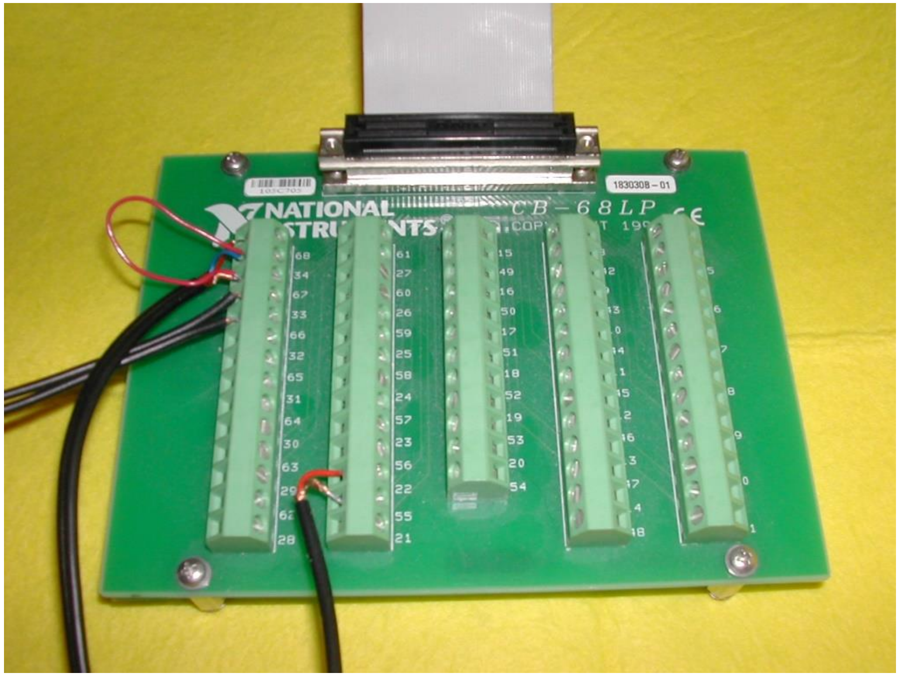
Drive(s)	Write/Read (MB/sec)	Rate Types
Laptop	30 (PXIe-8103 internal drive; 5400 RPM)	Peak
IDE	57 (Western Digital 160 GB; 7200 RPM)	Peak
SATA	62 (Western Digital 160 GB; 7200 RPM)	Peak
SATA	75 (Seagate Barracuda 7200 10;250GB)	Peak
2 RAID	114/127 (PXI 8351 1U Rack Mount Controller)	Peak
4 RAID	200+/200+ (NI HDD-8263, NI 8353)	Sustained
8 RAID	448/439 (PCIe x4 HighPoint 2320 RAID Controller)	Peak
8 RAID	370/374 (PCIe x4 Promise)	Peak
12 RAID	600+/600+ (NI 8264 RAID Controller)	Sustained
12 RAID	750+/750+ (NI 8265 RAID Controller)	Sustained

FieldLogger



- 8 universal analog channels per module
- Accepts t/c J, K, T, E, N, R, S, B; 4-20 mA, Pt100, 0-50 mV without hardware change
- Internal memory (optional) for 32,000 to 128,000 recordings and real time clock
- Input resolution: 12,000 levels
- Accuracy: 0.1 % of full scale (FS)
- Scanning: 8 channels in 0.5 seconds
- Reading rate: from 0.2s to 1 day
- Power: 100-240 Vac, optional 24 Vdc/ac
- Alarms: 2 relays 3 A for the 8 channels
- Digital input for remote START/STOP
- RS-485, MODBUS - RTU, 19200 bps
- 35 mm DIN rail mounting

Connector Panel(68LP)



ACH8	34	68	ACH0
ACH1	33	67	AIGND
AIGND	32	66	ACH9
ACH10	31	65	ACH2
ACH3	30	64	AIGND
AIGND	29	63	ACH11
ACH4	28	62	AISENSE
AIGND	27	61	ACH12
ACH13	26	60	ACH5
ACH6	25	59	AIGND
AIGND	24	58	ACH14
ACH15	23	57	ACH7
DAC0OUT[1]	22	56	AIGND
DAC1OUT[1]	21	55	AOGND
RESERVED	20	54	AOGND
DIO4	19	53	DGND
DGND	18	52	DIO0
DIO1	17	51	DIO5
DIO6	16	50	DGND
DGND	15	49	DIO2
+5 V	14	48	DIO7
DGND	13	47	DIO3
DGND	12	46	SCANCLK
PFI0/TRIG1	11	45	EXTSTROBE*
PFI1/TRIG2	10	44	DGND
DGND	9	43	PFI2/CONVERT*
+5 V	8	42	PFI3/GPCTR1_SOURCE
DGND	7	41	PFI4/GPCTR1_GATE
PFI5/UPDATE*	6	40	GPCTR1_OUT
PFI6/WFTRIG	5	39	DGND
DGND	4	38	PFI7/STARTSCAN
PFI9/GPCTR0_GATE	3	37	PFI8/GPCTR0_SOURCE
GPCTR0_OUT	2	36	DGND
FREQ_OUT	1	35	DGND

[1] Not available on the 6023E

Figure 4-1. I/O Connector Pin Assignment for the 6023E/6024E

Other connector panels (BNC, examples)

NI BNC-2110

(standard, differencial)

NI BNC-2111

(standard, single ended)

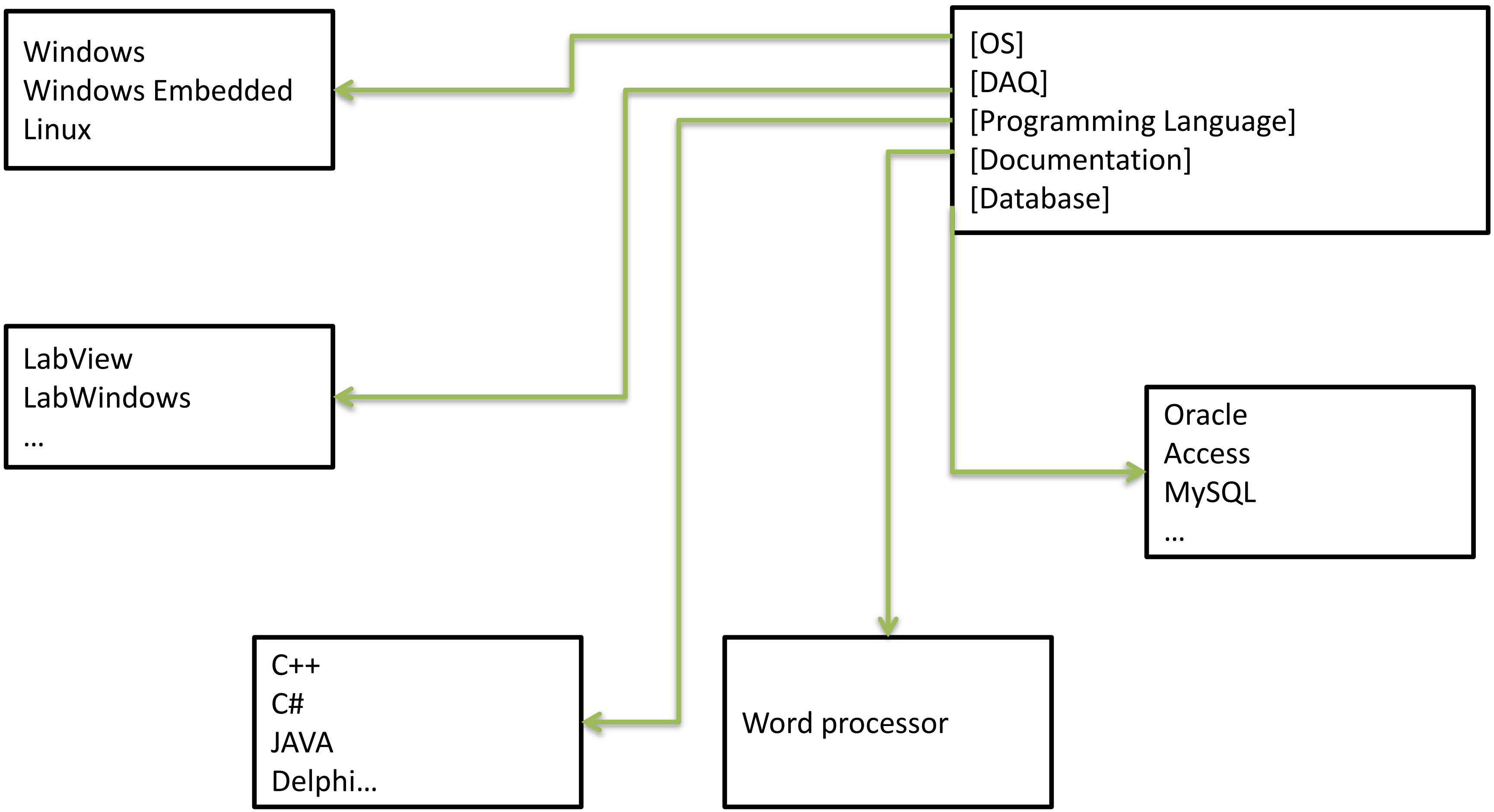
NI BNC-2090A

DIN-Rail Mount Terminal Block for 37-Pin D-SUB Modules

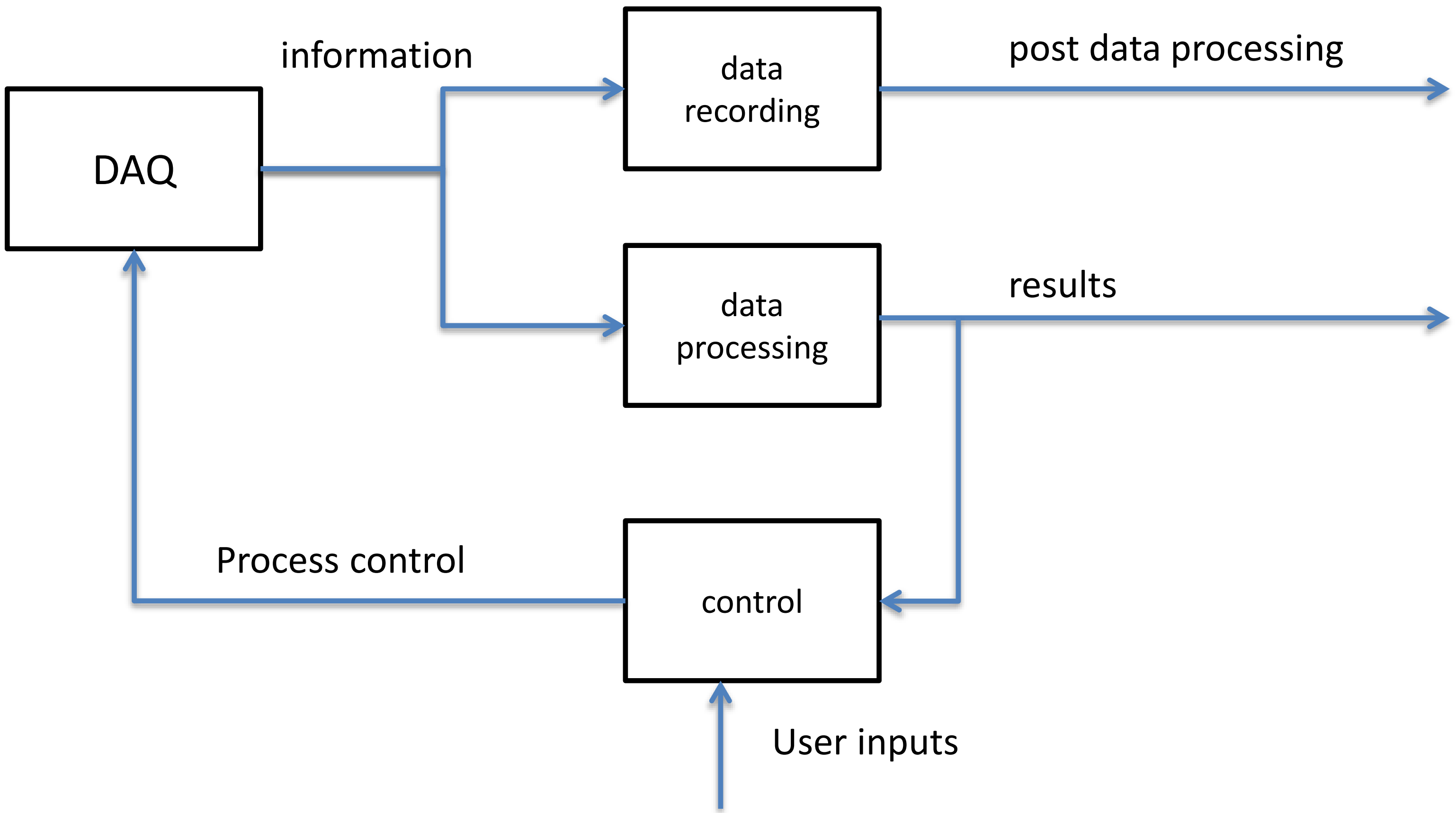
Tasks of the computer based measurement

- Data acquisition: collection, archiving, simplifying, data processing, data storage,
- Devices, other peripherals, process control,
-Measurement process development,
-Documentation.

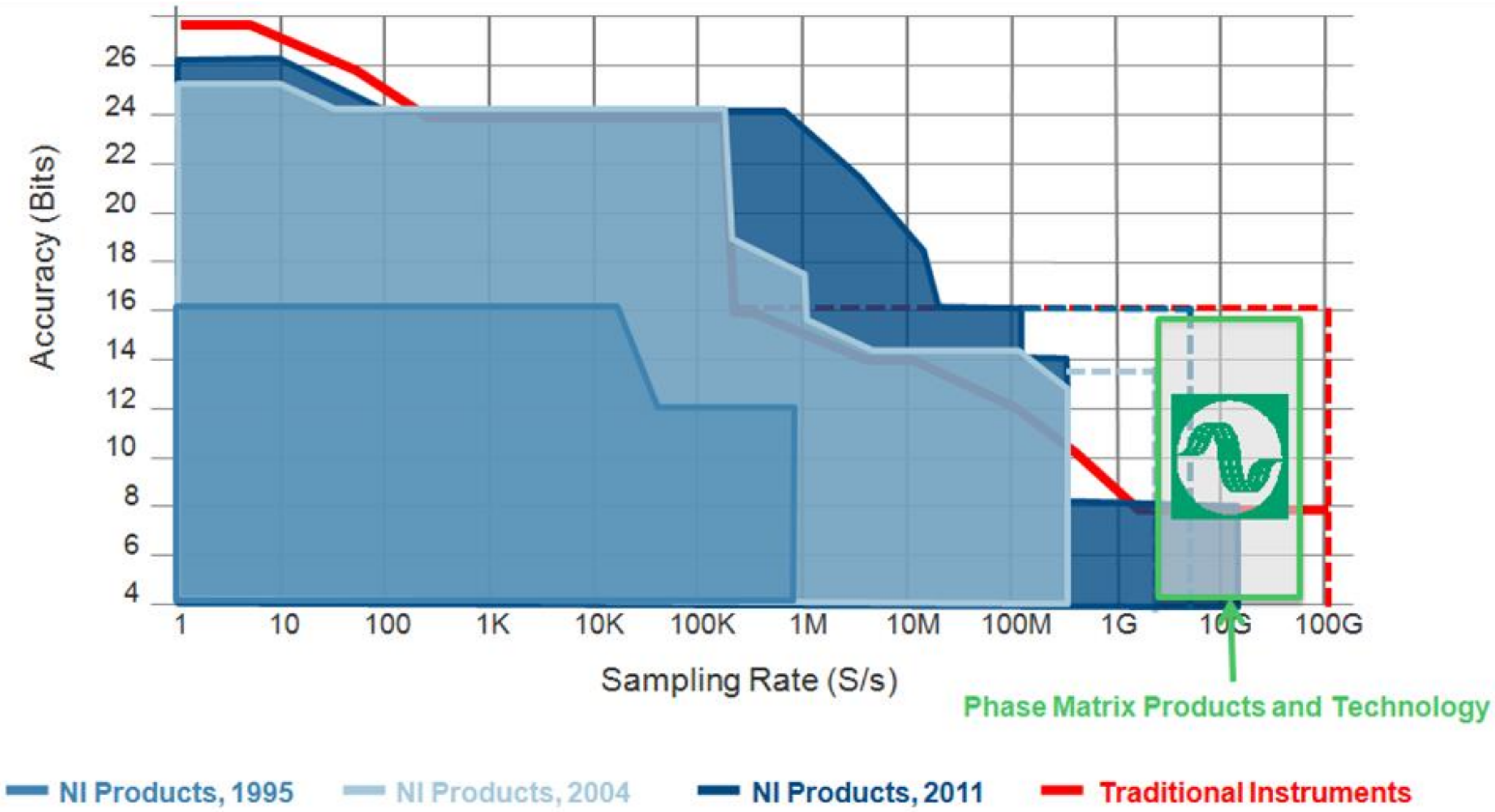
Computer (PC) based measurement system's software background



Data processing in the PC based measurement systems



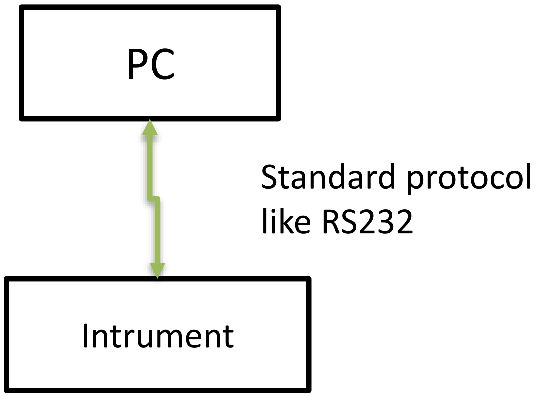
TRENDS



Accuracy (Bits)
26
24
22
20
18
16
14
12
10
8
6
4
1
10
100
1K
10K
100K
1M
10M
100M
1G
10G
100G
Sampling Rate (S/s)
Phase Matrix Products and Technology
NI Products, 1995
NI Products, 2004
NI Products, 2011
Traditional Instruments

Structure of the PC based measurement systems

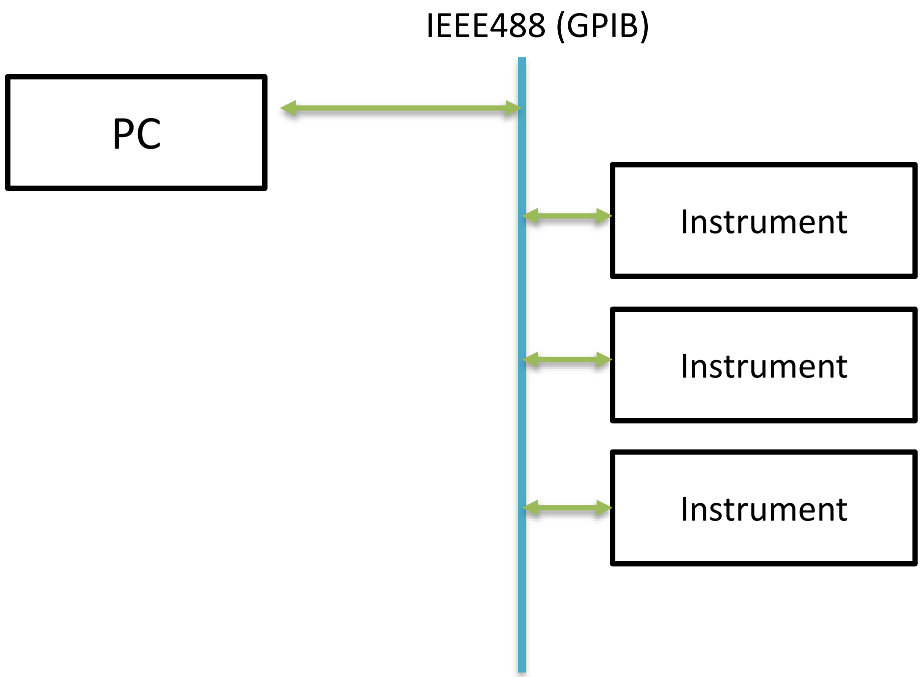
The functional organization of the measuring devices and the PC, the measurement system's layout is determined by the measurement task.
The simplest measurement structure is one PC and one instrument in a system. According to a standard protocol, for example RS232 is made of the transfer.
Such an arrangement meter park, especially for serial communication is very limited form suitable for real-time tasks. (Communication between the PC and the instrument has a low bandwidth)



1 PC more instruments

•The communication between the PC and the instruments is based on a strandard protocoll as IEEE488 (GPIB)

•This type of arrangement is felxible, new instruments can be connected a defined easily.



Huge number of instruments

•Huge numbers of instruments slow down the system's operating speed. There is a demand level that is no longer able to fulfill your PC. In this case more PCs are required.

•With this the instrument number per PC is reduced, the controller has more time.

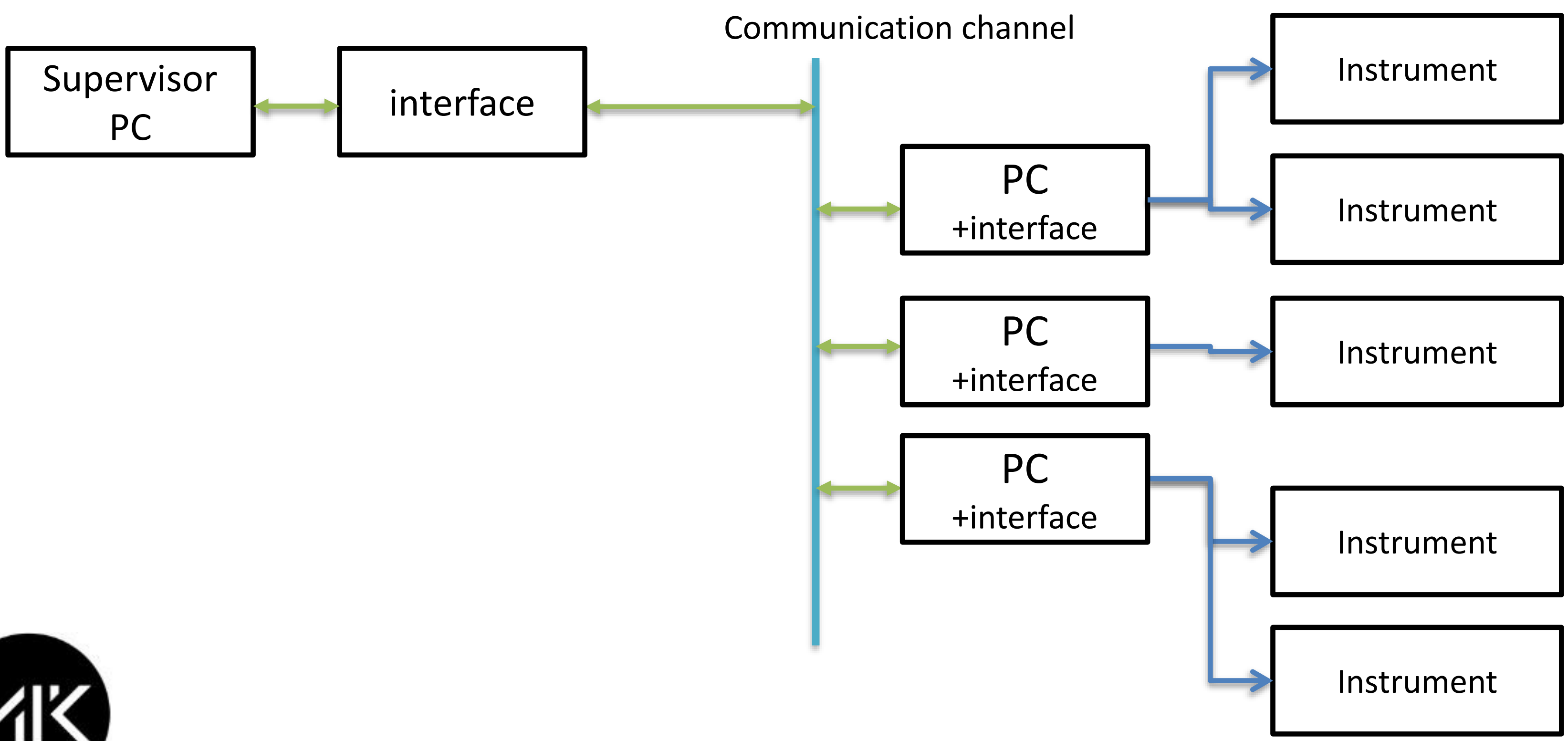
•The PC-based communication is made by a channel (shared communication channel)

•done The communication channel can be another form of this arrangement, the so-called. LAN (Local Area Network).

•Through the LAN the communication between the processors are generally slower because the system needs to fit into a standard LAN to communicate well,

Supervisor PC

- For the coordination tasks between the PCs.
- Instruments are not connected to the Supervisor PC. The task of the work of the management of PCs
- This is called as „master-slave” hierarchy



Supervisor PC

•The PC supervisor constantly monitors the system activity
•The flexibility of the system grows, easily reconfigurable measuring equipments, development and installation of new measurement processes can be performed
• In case of failure of the supervisor PC you can take over the task of faulty PC
•Multi-user system can be developed, which means that each slave has spare capacity PCs from the process of independent "outside" may perform tasks (time-sharing)

Data transfer methods in measurement systems

The PC-based measurement system can be done in three different ways to move data:
- program-controlled
- Interrupt controlled
-DMA controlled (Direct Memory Access)

Method	relative speed	control
program-controlled	slow	high
Interrupt controlled	middle	middle
DMA controlled	fast	low

The „relative speed” is related to the system’s data transfer speed.

The „control” is related to the CPU’s utilization

Data transfer methods in measurement systems

- The high level of controllability shows that the process of the CPU control over each step has the sequence of control commands executed strictly defined.
- The low controllability means that the CPU gives the control for other units, such as less or not at all involved in the transmission of data management.
- The table shows that the speed is increased, the system controllability decreases, and vice versa. Therefore it is always decided by the respective measurement task to use in each case which method provides a more efficient operation.

Program controlled data transfer

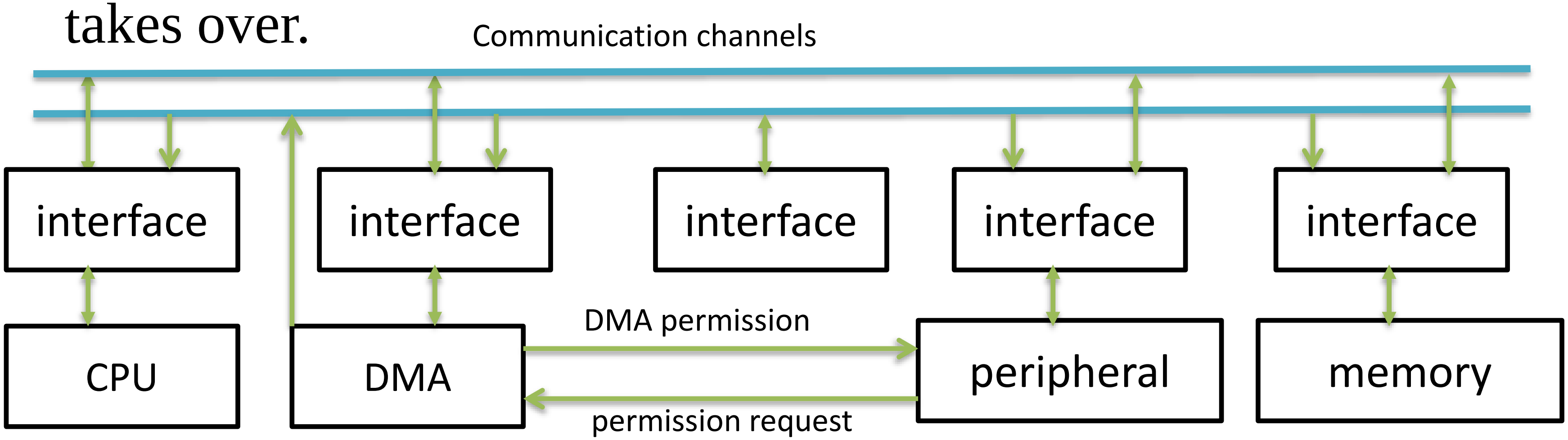
- The processor in this case, is always keep the process control.
- Following the instructions it handles the peripherals, it controls the data collection, data movement, storage, and processing.
- For example, the program is controlled to wait for the processor until the sampling is in progress

Interrupt controlled data transfer

•Each peripheral has a user-defined level interrupt (interrupt - IRQ -level).
•When a peripheral wants to „speak", an interrupt request is forwarded to the encoding priority. The processor then suspends the currently running process and enables the respective periphery of the disclosure of information.
•When the transmission is complete, the CPU continues the work where it left off before the break.
•If there are multiple interrupt the periphery of the first to get the opportunity to present information in which the IRQ level is higher. Thus, the higher priority peripheral interrupt a lower priority peripheral operation of which is running well.

DMA controlled data transfer

This is the fastest data transfer method, but this method of control is almost entirely out of the CPU’s control.
The control (management of I / O operations) in this case the processor is a separate circuit board, called a direct memory access controller (DMA - Direct Memory Access - controller) takes over.



MEASUREMENT AND DAQ
LECTURE #5

Adam Schiffer, PhD

University of Pecs

Faculty of Engineering and Information Technology

The presentation was supported by EFOP-3.4.3.-16-2016-00005 számú "Korszerű egyetem a modern városban: Értékközpontúság, nyitottság és befogadó szemlélet egy 21. századi felsőoktatási modellben „ programme.

RS-232, RS-422, RS-485 Serial Communication General Concepts

Serial Communication

- The concept of serial communication is simple. The serial port sends and receives bytes of information one bit at a time.
- Typically, serial is used to transmit ASCII data. Communication is completed using 3 transmission lines: (1) Ground, (2) Transmit, and (3) Receive.
- Since serial is asynchronous, the port is able to transmit data on one line while receiving data on another. This is referred to as Full-Duplex transmission
- The important serial characteristics are baud rate, data bits, stop bits, and parity.

Serial Communication

Baud rate is a speed measurement for communication. It indicates the number of bit transfers per second

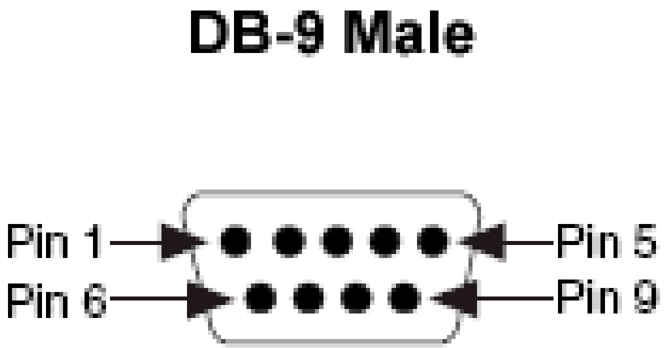
Data bits are a measurement of the actual data bits in a transmission

Stop bits are used to signal the end of communication for a single packet. Typical values are 1, 1.5, and 2 bits

Parity is a simple form of error checking that is used in serial communication. There are four types of parity: even, odd, marked, and spaced.

RS232

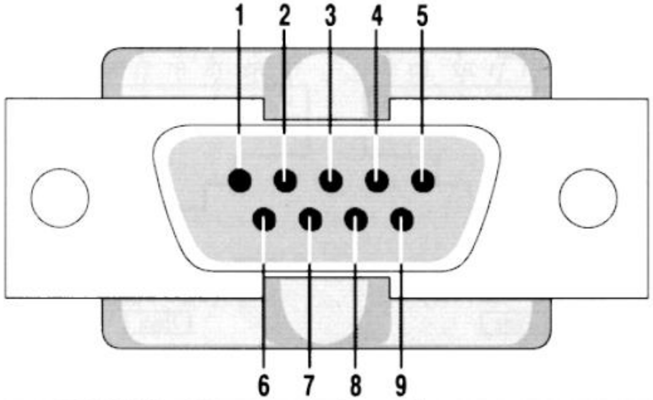
- RS-232 (ANSI/EIA-232 Standard) is the serial connection historically found on IBM-compatible PCs.
- RS-232 is limited to point-to-point connections between PC serial ports and devices.
- RS-232 hardware can be used for serial communication up to distances of 50 feet.
- RS-232 is a popular communications interface for connecting
- modems and data acquisition devices (i.e. GPS receivers,
- electronic balances, data loggers, ...) to computers.



RS232

- Two independent channels are established for two-way (fullduplex) communications.
- RS-232 can also carry
- additional signals used for flow
- control (RTS, CTS) and
- modem control (DCD, DTR,
- DSR, RI).

(serial port - PC side)



Pin	Signal	Pin	Signal
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2	Received Data	7	Request to Send
3	Transmitted Data	8	Clear to Send
4	Data Terminal Ready	9	Ring Indicator
5	Signal Ground		

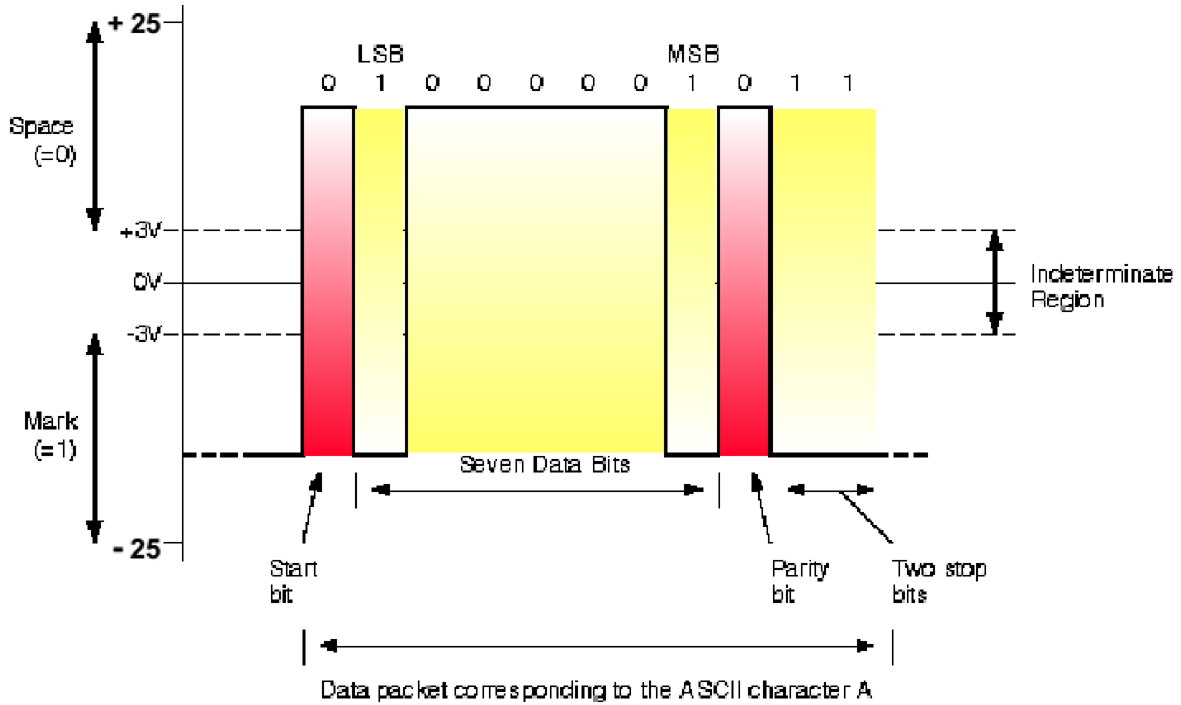
RS232 SPEED

- The maximum speed, according to the standard, is 20kbit/s.
- However, modern equipment can operate much faster than this. (i.e. Lynx can reach 115200 baud.)
- The length of the cable also plays a part in maximum speed.
- The longer the cable and the slower the speed at which you can obtain accurate results.
- 50 feet (15m) @ max baudrate is commonly quoted as the maximum distance.
- It is not specified in EIA standard but it’s recommended respect these values

RS232 SW SETTINGS

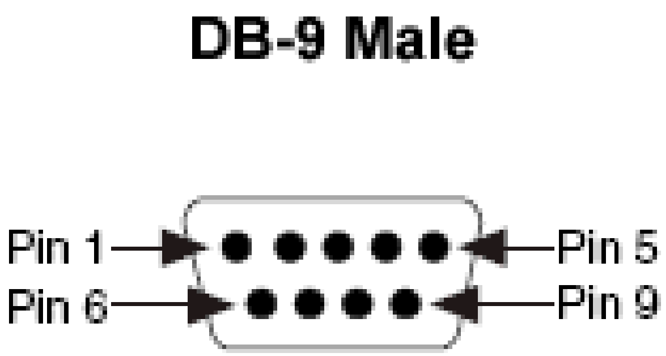
- One byte of async data has:

- Start Bit = 1 (always)
- Data Bits = 8 (or 7)
- Stop bits = 1 (or 2)
- Parity = NONE (or EVEN or ODD)



RS422

- RS-422 (EIA RS-422-A Standard) is the serial connection historically used on Apple Macintosh computers
- Differential transmission uses two lines each for transmit and receive signals which results in greater noise immunity and longer distances as compared to the RS-232



RS485

- RS-485 is a EIA standard interface which is very common in the data acquisition world
- RS-485 (EIA-485 Standard) is an improvement over RS-422, because it increases the number of devices from 10 to 32
- can create networks of devices connected to a single RS-485 serial port
- The noise immunity and multi-drop capability make RS-485 the serial connection of choice in industrial applications requiring many distributed devices networked to a PC or other controller for data collection, HMI, or other operations.
- all RS-422 devices may be controlled by RS-485. RS-485 hardware may be used for serial communication with up to 4000 feet of cable.

RS232 vs RS485

	RS-232	RS-485
Mode of Operation	SINGLE-ENDED	DIFFERENTIAL
Total Number of Drivers and Receivers on One Line	1 DRIVER 1 RECEIVER	32 DRIVER 32 RECEIVER
Maximum Cable Length	50 FEET	4000 FEET
Maximum Data Rate @Max length	20kb/s	100kb/s
Driver Output Signal Level (Loaded Min.) Loaded	+/-5V to +/-15V	+/-1.5V
Driver Output Signal Level (Unloaded Max) Unloaded	+/-25V	+/-6V
Driver Load Impedance	3kΩ to 7kΩ	54Ω
Max. Driver Current in High Z State Power On	N/A	N/A
Max. Driver Current in High Z State Power Off	+/-6mA @ +/-2v	+/-100uA
Slew Rate (Max.)	30V/µS	N/A
Receiver Input Voltage Range	+/-15V	-7V to +12V
Receiver Input Sensitivity	+/-3V	+/-200mV
Receiver Input Resistance	3kΩ to 7kΩ	≥ 12kΩ

Data Format and Protocols

Information content passing through peer-to-peer connection is packed in a very simple structure:
<Header-string> <Code identifier ><INFO-FIELD><Terminatorstring>
<Header-string> and <Terminator-string> are both configurable via software (device configuration parameters)

Most common generic *H a nd s ha ke* are available/selectable with RS232 interface:
Hardware (RTS-CTS)
Software XON/XOFF

MEASUREMENT AND DAQ LECTURE #6

Adam Schiffer, PhD

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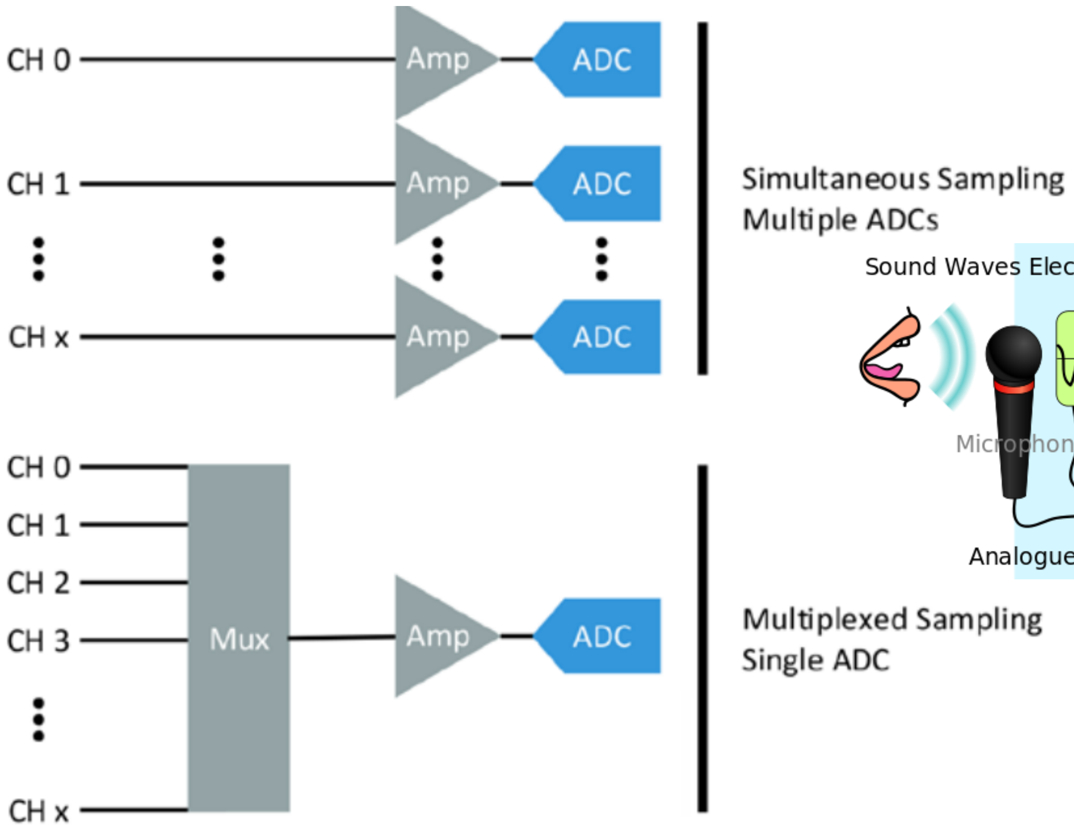
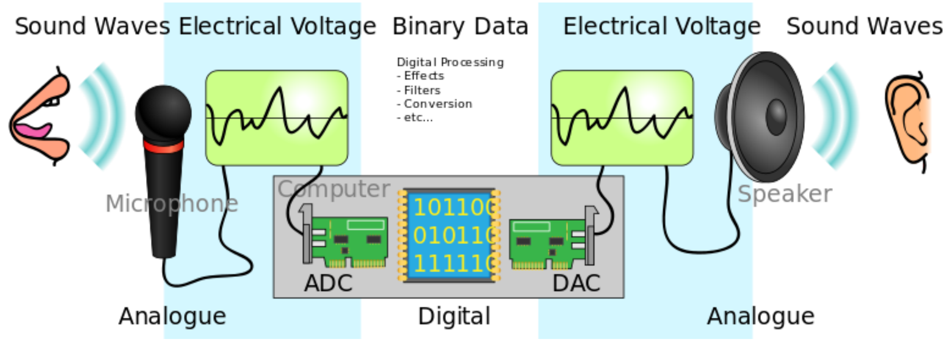
Digitization Timing

Digitization Timing

- The two most common architectures are simultaneous and multiplexed DAQ devices





Digitization Timing

Simultaneous architectures use one ADC per input channel. This has several implications:

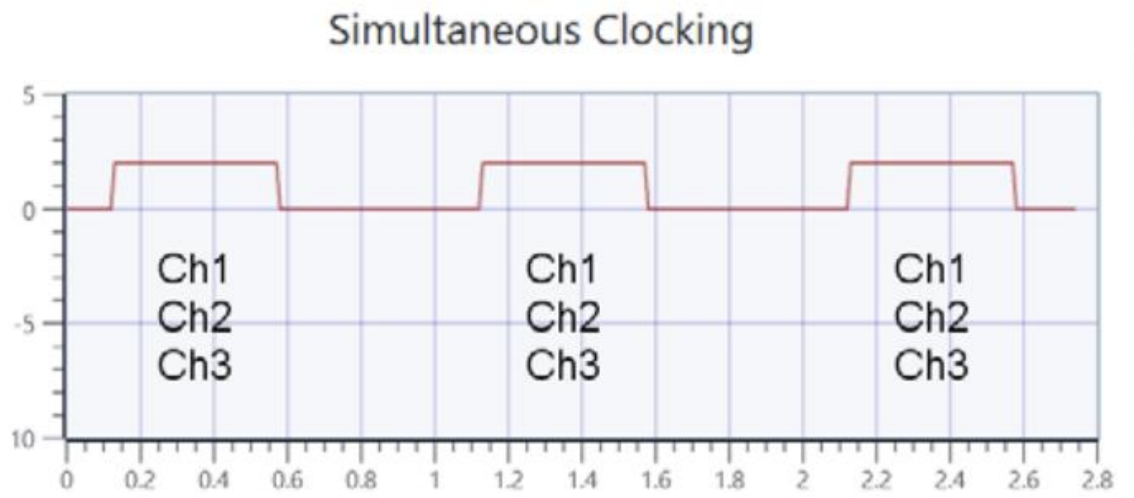
1. You can achieve the full sample rate on all channels regardless of how many channels you are using
2. You can acquire samples in parallel at precisely the same moment in time
3. Space limitations curb the number of channels that can fi on a DAQ device
4. Device cost tends to be greater due to the extra ADC and analog front-end components

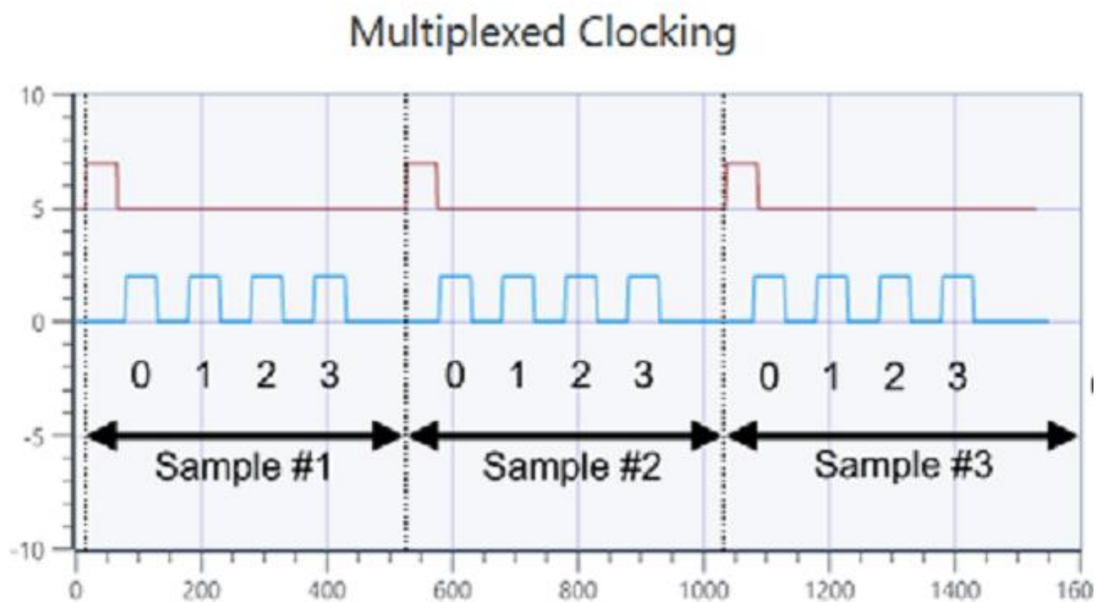
Digitization Timing

Multiplexed architectures use one ADC and analog front end for all channels and a multiplexer —or switch—to scan the input channels. This also has several implications:

1. The full sample rate is shared among all channels, meaning the maximum rate per channel decreases as more channels are added to the acquisition
2. Samples are acquired in series with a precise delay between channel
3. You can achieve greater channel densities on a single DAQ device
4. Cost per channel tends to be less

Digitization Timing





Bus systems and buffering

- All PC buses have a limit to the amount of data that can be transferred in a certain period of time. Known as the bus bandwidth, this limit is often specifid in megabytes per second (MB/s). If dynamic waveform measurements are important in your application, be sure to consider a bus with enough bandwidth
- The PCI bus, for example, has a theoretical bandwidth of 132 MB/s that is shared among all PCI boards in the computer.
- Gigabit Ethernet offers 125 MB/s shared across devices on a subnet or network.

Digitization Timing

● = Best | ◐ = Better | ○ = Good

Bus	Waveform Streaming	Latency	Portability	Distributed Measurements
PCI	132 MB/s (shared)	●	○	○
PCI Express	250 MB/s (per lane)	●	○	○
PXI	132 MB/s (shared)	●	◐	◐
PXI Express	250 MB/s (per lane)	●	◐	◐
USB	60 MB/s	◐	●	◐
Ethernet	125 MB/s (shared)	○	●	●
Wireless	6.75 MB/s (per 802.11g channel)	○	●	●

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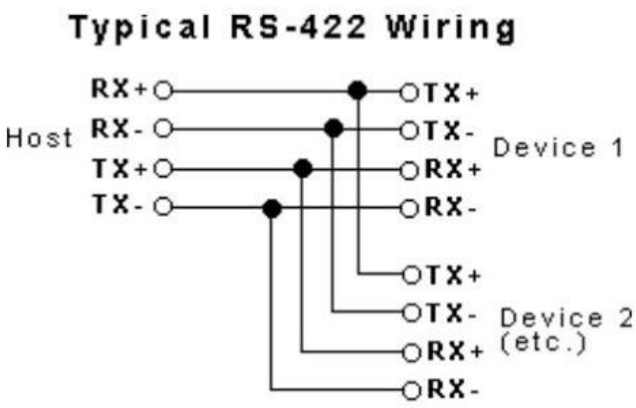

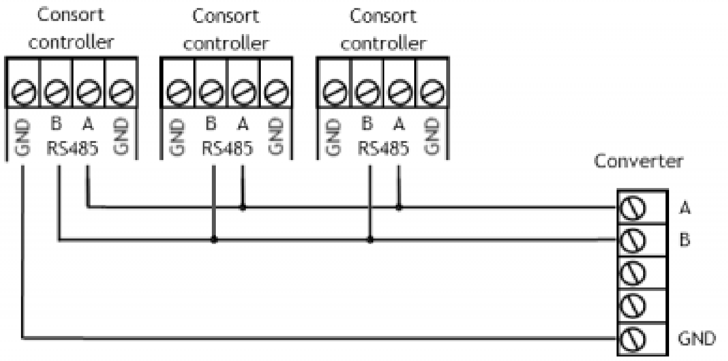

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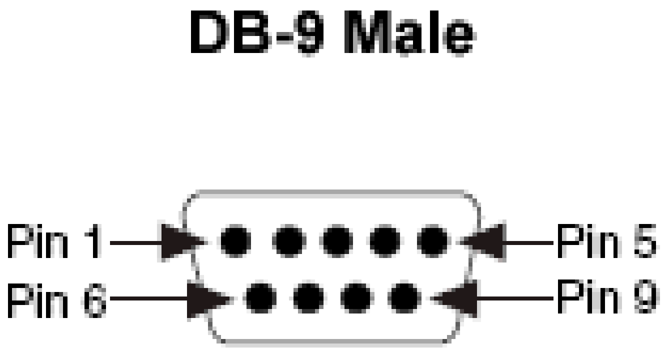

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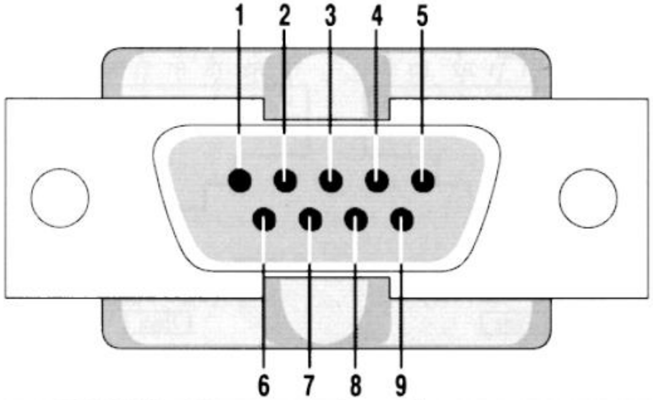

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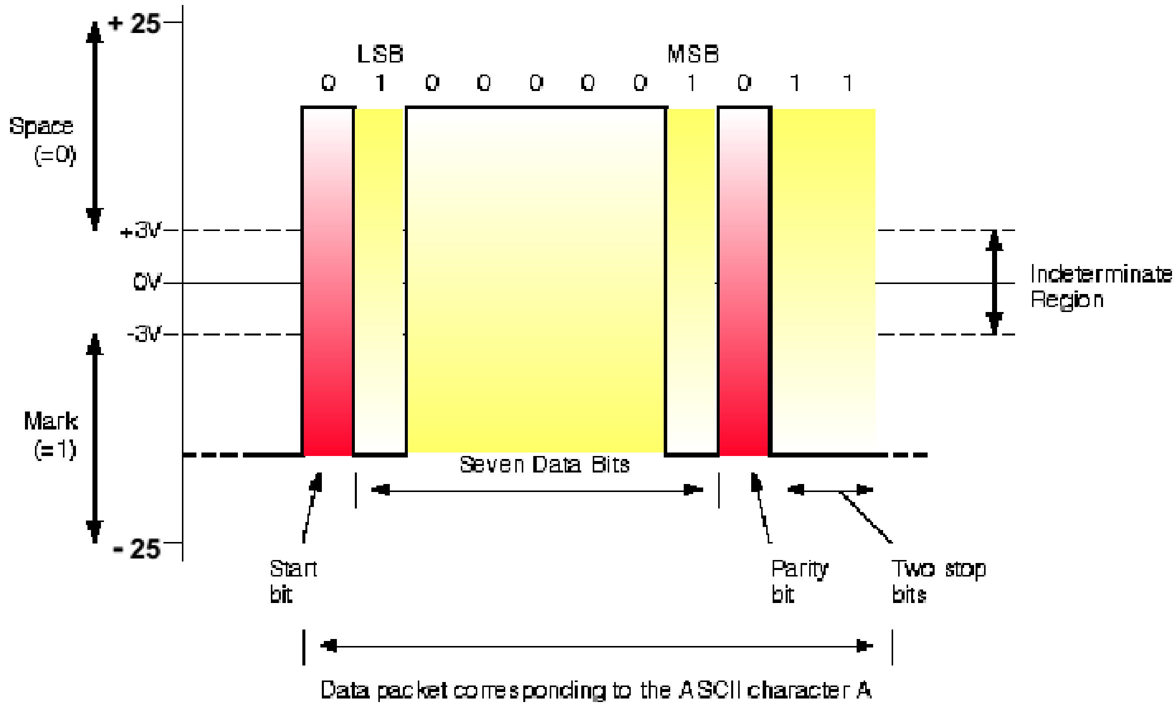

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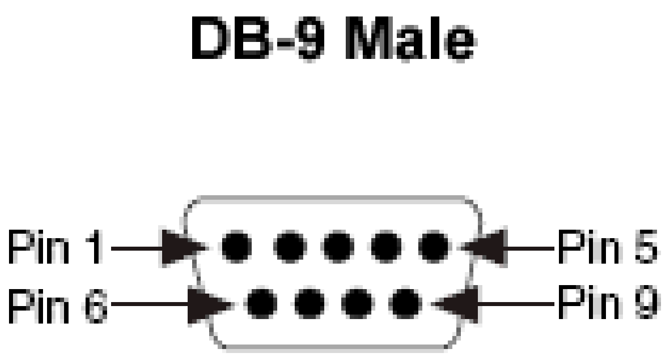

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Driver Load Impedance	3kΩ to 7kΩ	54Ω
Max. Driver Current in High Z State Power On	N/A	N/A
Max. Driver Current in High Z State Power Off	+/-6mA @ +/-2v	+/-100uA
Slew Rate (Max.)	30V/µS	N/A
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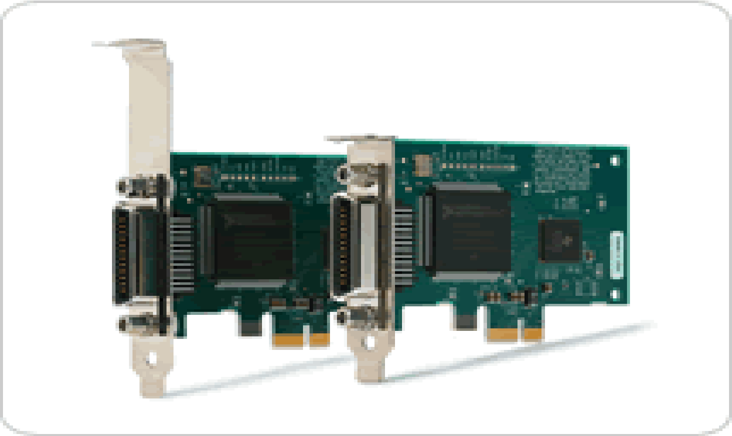
Most common generic *H a nd s ha ke* are available/selectable with RS232 interface:
Hardware (RTS-CTS)
Software XON/XOFF

GPIB

•The original GPIB was developed in the late 1960s by Hewlett-Packard (where it is called the HP-IB) to connect and control programmable instruments that Hewlett-Packard manufactured.

• With the introduction of digital controllers and programmable test equipment, the need arose for a standard, high-speed interface for communication between instruments and controllers from various vendors.



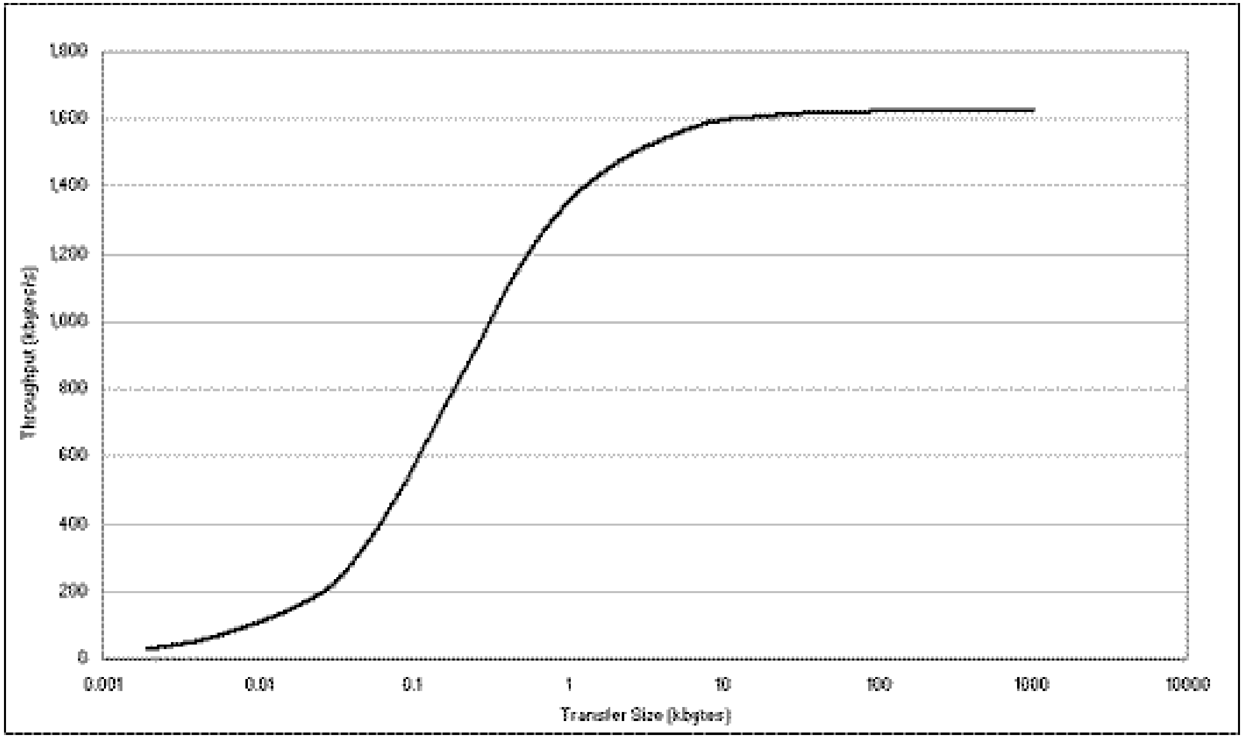
GPIB

GPIB controllers (PXI and External)

GPIB connector

GPIB

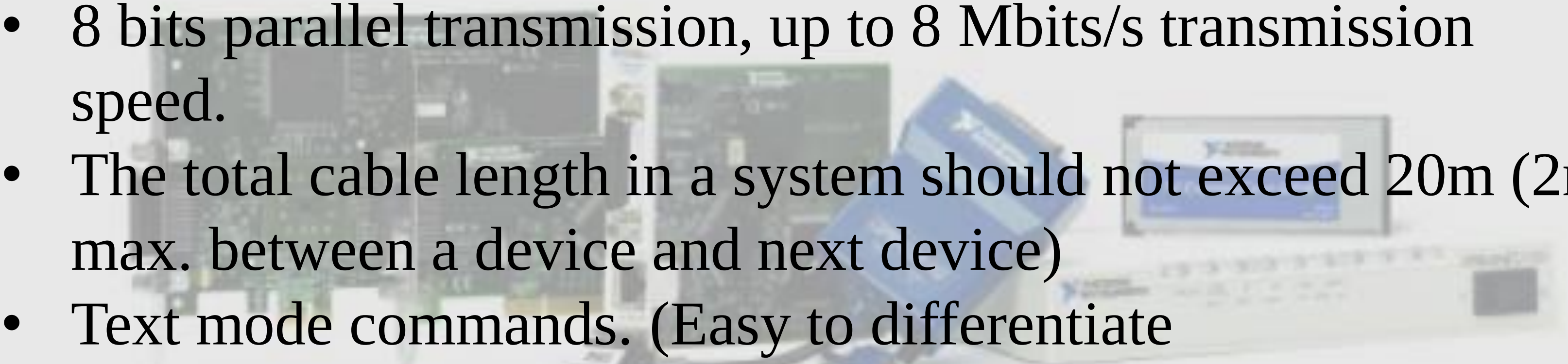
Performance of a PCI-GPIB Board



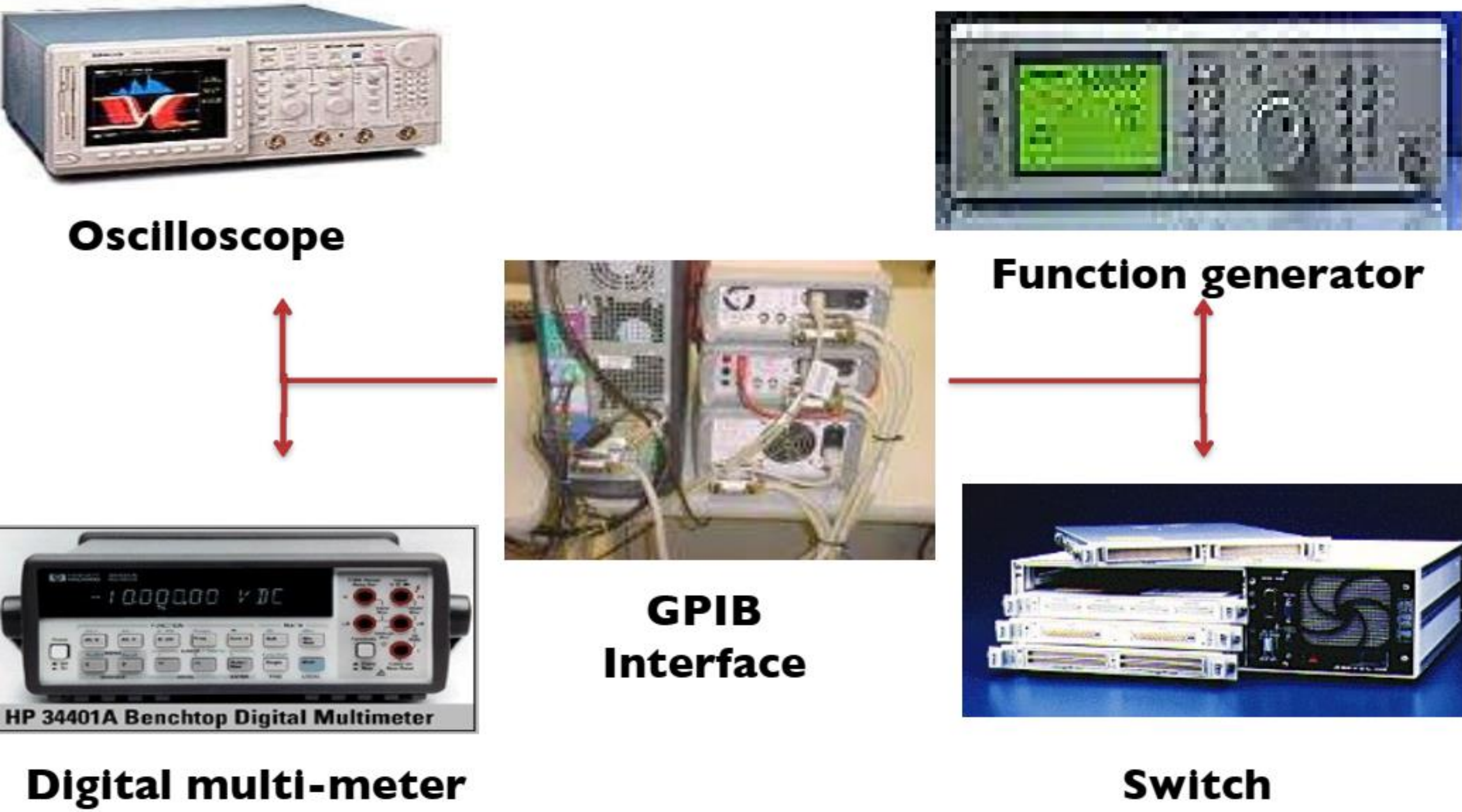
As you can see from the chart, the maximum NI PCI-GPIB transfer rate is more than 1.5 MB/s and reaches a transfer rate of greater than 1 MB/s for a transfer block size of 500 B, a fairly common transfer size. In addition, even at transfer block sizes of less than 500 B, the board still performs very well.

GPIB

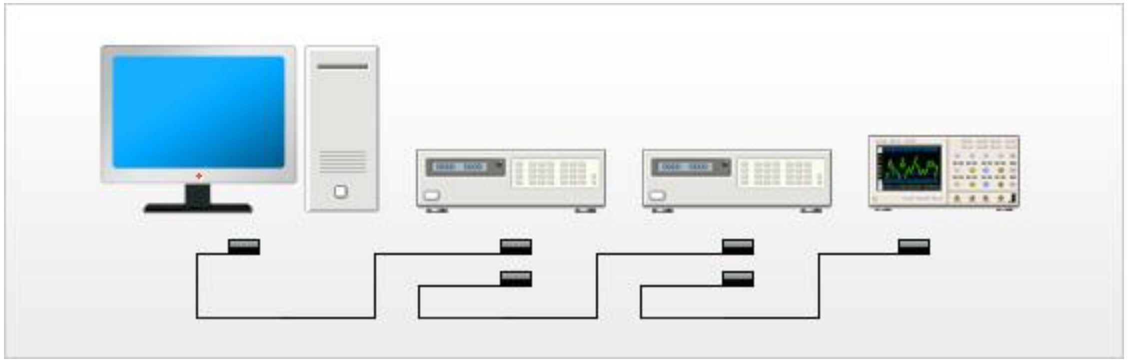
- GPIB can connect 15 instruments (0~31 address can be assigned) to a PC (controller). The PC handles the transmission
  on the bus
- 8 bits parallel transmission, up to 8 Mbits/s transmission speed.
- The total cable length in a system should not exceed 20m (2m max. between a device and next device)
- Text mode commands. (Easy to differentiate
- Using three handshake line for handshaking to ensure data transmission accuracy.



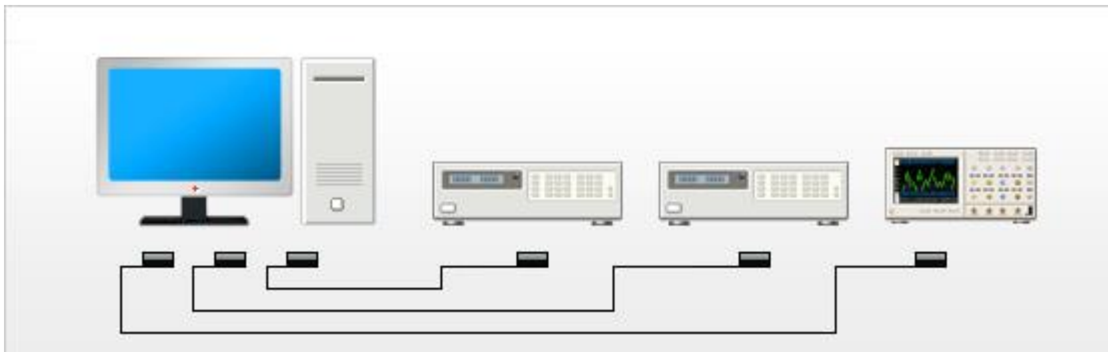
GPIB

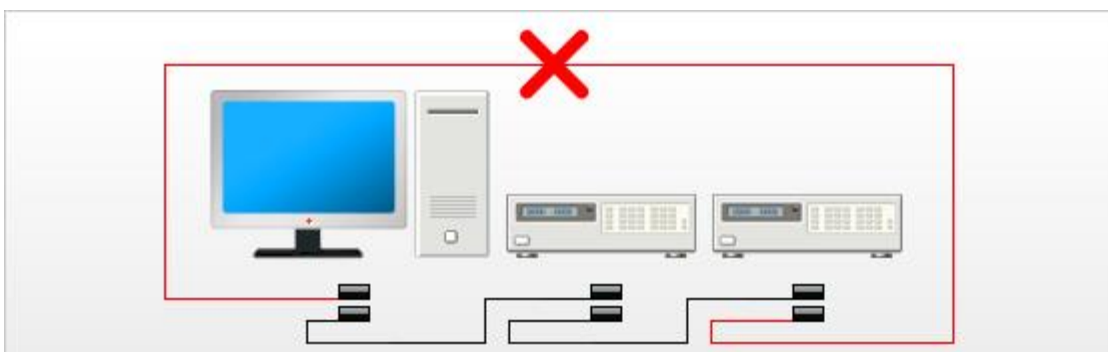

Oscilloscope
Function generator
GPIB
Interface
HP 34401A Benchtop Digital Multimeter
Digital multi-meter
Switch

GPIB LINEAR CONNECTION

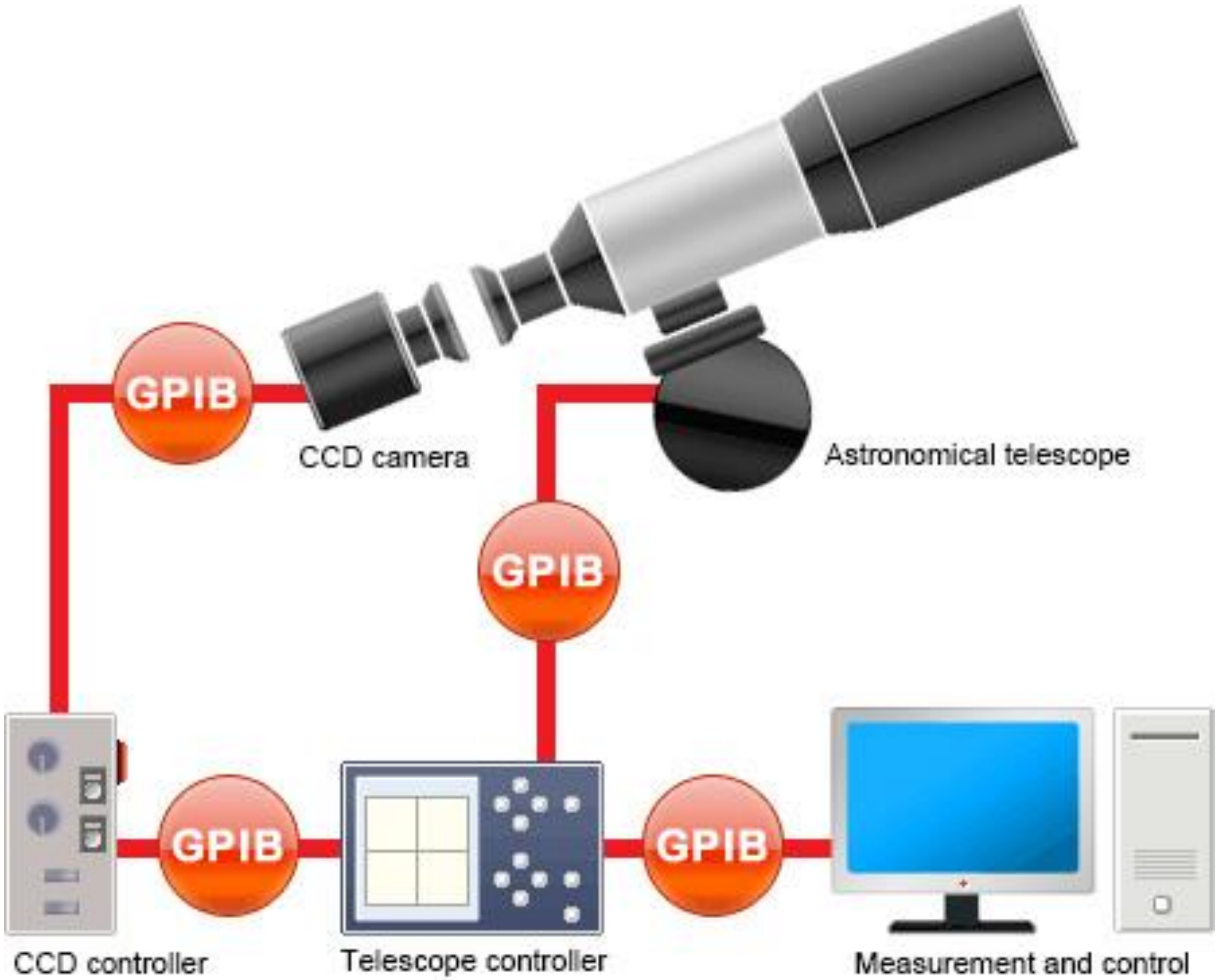


GPIB STAR CONNECTION





GPIB


GPIB
CCD camera
Astronomical telescope
GPIB
GPIB
GPIB
CCD controller
Telescope controller
Measurement and control

GPIB

MEASUREMENT AND DAQ LECTURE #7

Adam Schiffer, PhD

University of Pecs
Faculty of Engineering and Information Technology

The presentation was supported by EFOP-3.4.3.-16-2016-00005 számú "Korszerű egyetem a modern városban: Értékközpontúság, nyitottság és befogadó szemlélet egy 21. századi felsőoktatási modellben „ programme.

CONTROL BUSES

ATE System Design (Automated Test Eq)

- Common instrument considerations
  - Measurement functionality
  - Instrument performance
- Evaluate bus technologies of the instruments available
  - Meets performance needs
  - Suitable for application
- Various bus technologies are available
  - GPIB,LAN,USB , PCI,PXI ,And so on

Overview

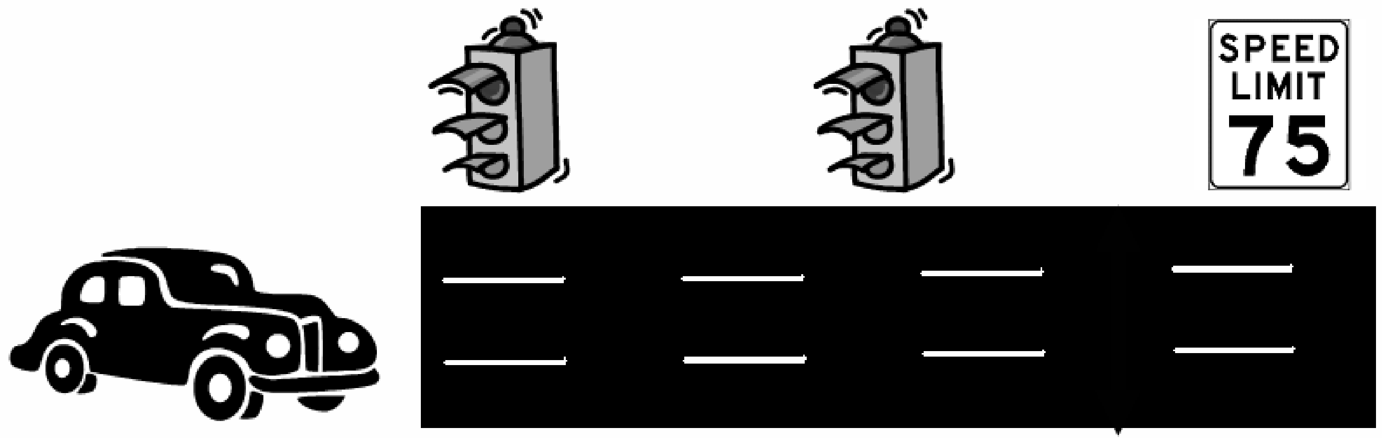
- In 1997 Hewlett-Packard (now Keysight) strongly claimed that IEEE 1394 (Firewire) was ideally situated to be the new leading bus technology in instrument control.
- HP advocated abandoning the then-leading technology, GPIB, in light of IEEE 1394 potential
- While other bus technologies have certainly proved more successful than IEEE 1394 in fulfilling a broad range of application needs, even GPIB, the most adopted instrument control standard in the past 40 years, cannot claim to be categorically superior to all other buses.

Bus Technology Considerations

- Key bus factors that affect instrument performance
  - Latency
  - Bandwidth
- Other considerations
  - Timing and synchronization
  - Distributed networks and remote monitoring (Some systems require either remote control of systems or distributed networks)
  - Standard software frameworks (does the bus specification implement a software framework?)

Latency and Bandwidth

- Latency measures the delay of transmission of data across a bus. The latency measures the delay of transmission of data, so you can think of it as corresponding to the number of stoplights in the road
- Bandwidth measures the rate at which data is sent across the bus (typically MBytes/s) (width of the road and speed of travel)



Impact on Application

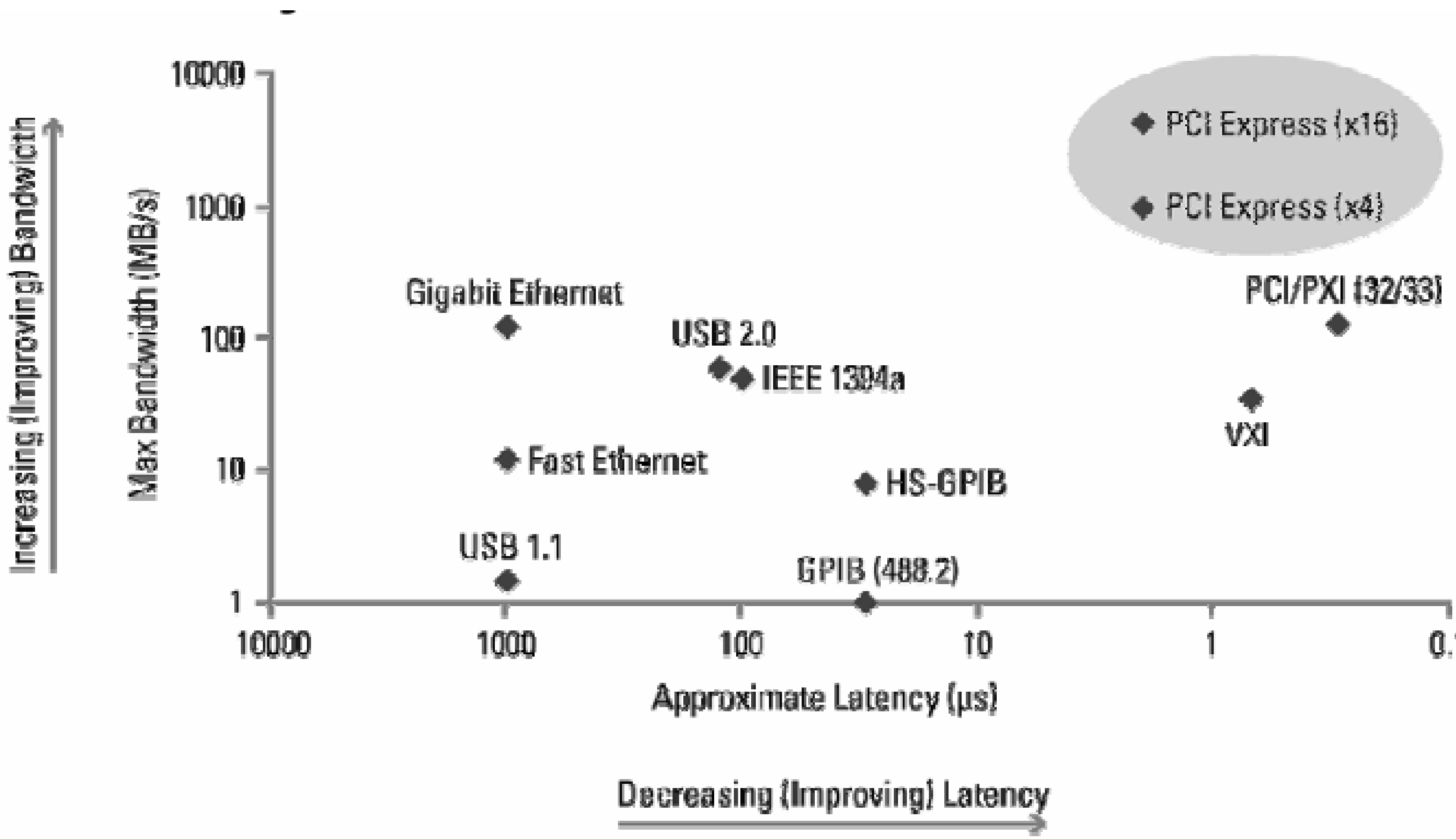
Latency

- Important for applications that include
- Digital multimeter (DMM) measurements
- Switching
- Instrument configuration
- Serial buses tend to have higher or worse latency

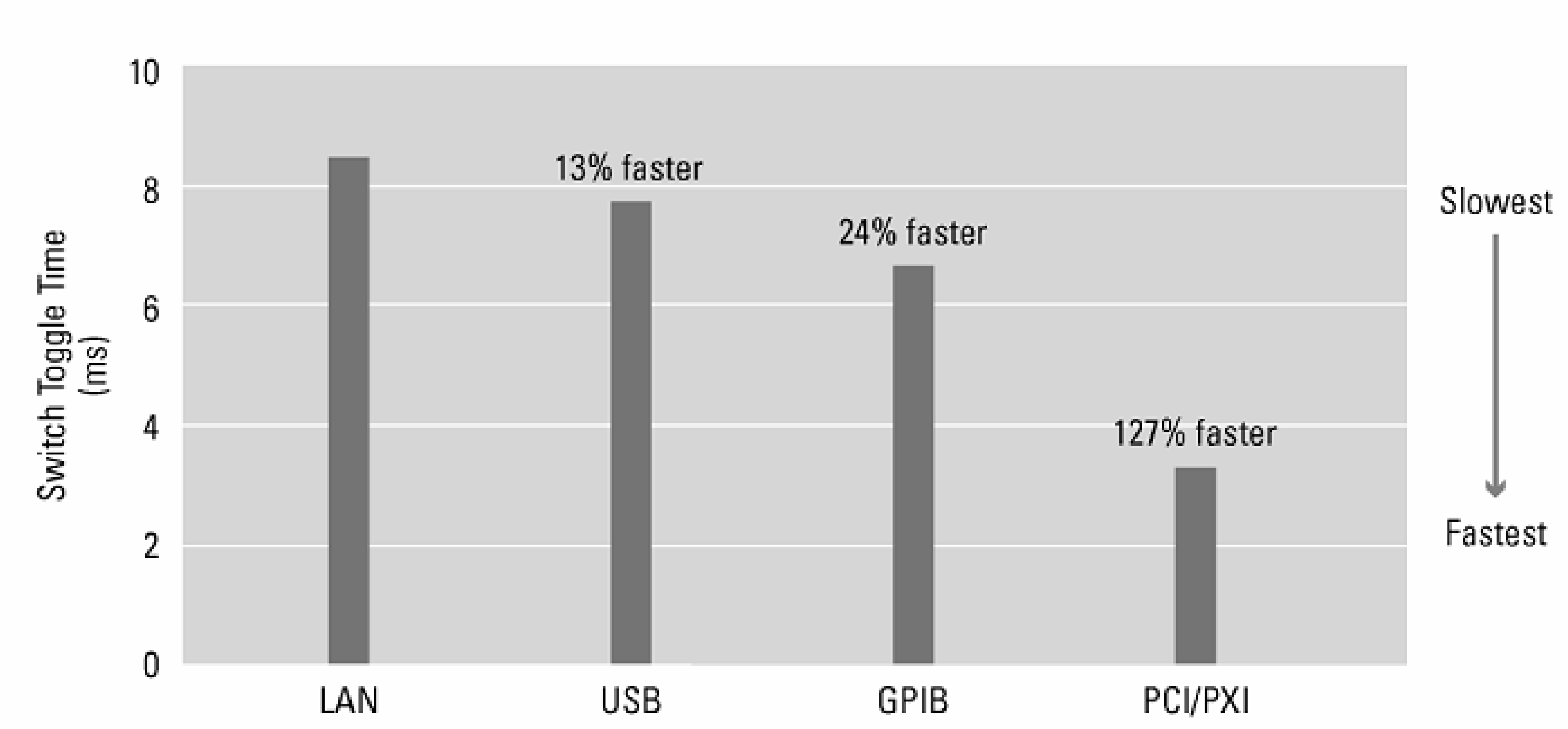
Bandwidth

- Important for applications that send large sets of data
  or require data streaming
  - RF applications
  - Waveform acquisition or generation
- High-speed or high-channel
  systems often require 10 to
  100 MBytes/s or more

Industry Bus Performance



Single Command Performance
Latency in an application



Timing and Synchronization

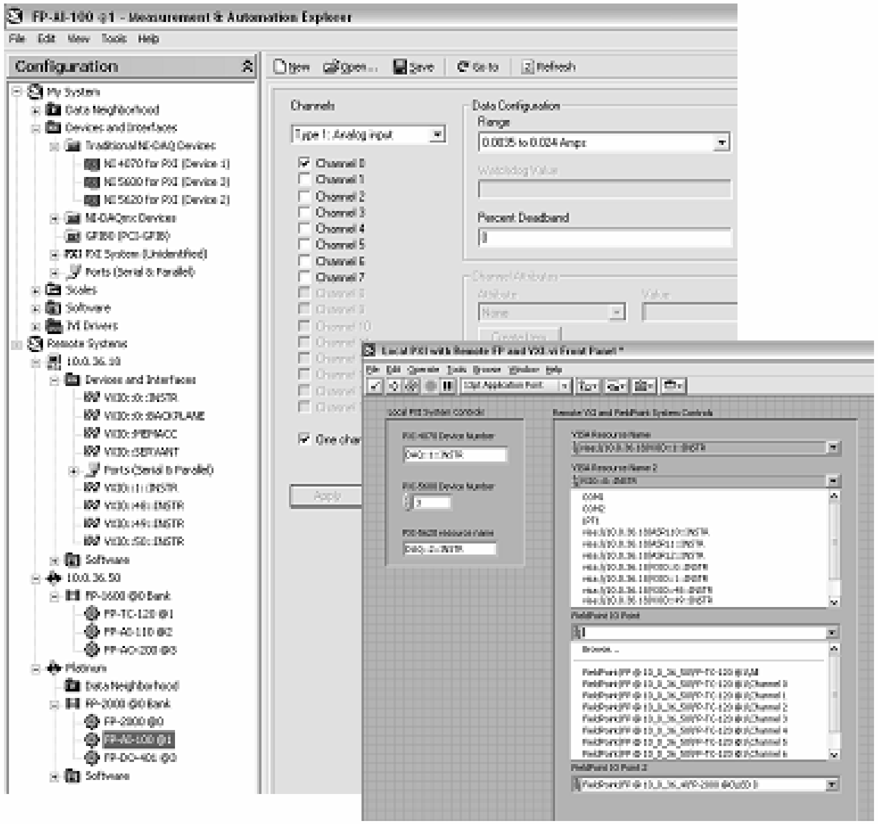
- Used for handling synchronous events.
  For example, Starting signal generator and digitizer at same time
- Used for performing asynchronous events.
  For example, Handshaking with switch and DMM
- Backplane buses provide most direct and accurate method of synchronization (PXI and VXI)
- IEEE 1588 protocol provides external synchronization (LAN)
- Input and output triggers available for GPIB, USB, and 1394

Distributed Networks or Remote Monitoring

Design Considerations

- Locality: Requirements to place certain measurement components close to other components. Timing and synchronization. (RF application)
- Distribution: Needs including physical requirements, remote locations, and connectivity. Distance support with and without repeaters. Programming connectivity protocols (software)

Software is Key



With proper software tools you can:

- Abstract system complexity
- Use instruments of various buses
- Integrate instruments into one system

Software Standard Frameworks

- Impacts development and integration of the system:
  - Ease system integration tasks
  - Driver software eases programming
    - VISA
    - Plug and Play drivers
- PXI and VXI specify a standard driver framework
- Virtual Instrumentation Software Architecture (VISA) available for PXI,VXI, LAN, GPIB, USB, and 1394

Bus Comparison

	GPIB	VXI	1394a	USB	TCP/IP Ethernet	Standard PCs	PXI
Latency (us)	◒	●	○	○	○	●	●
Bandwidth (Mbytes/s)	○	◒	○	○	◒	●	●
Timing and Synchronization	○	●	○	○	◒	○	●
Standard Software Frameworks	◒	●	◒	◒	◒	○	●
Measurement Availability	●	◒	○	○	○	◒	◒
High Channel Count	○	◒	○	○	◒	●	●
Data Streaming	◒	●	○	○	○	●	●
Distributed and Remote Systems	○	◒ / ● [1]	○	○	●	◒ / ● [1]	◒ / ● [1]

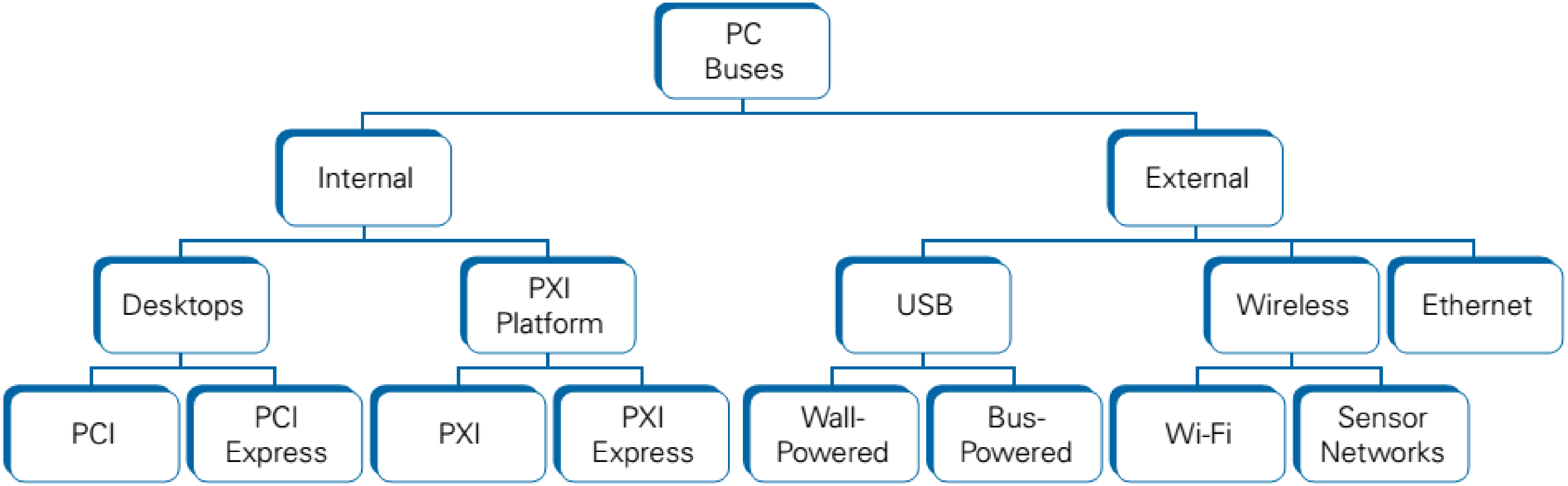
[1] Achieved with Ethernet connection to controller

- ● Best
- ◒ Better
- ○ Good

bus-selection guide based on application requirements

Bus	Waveform[1] Streaming	Single-Point I/O	Multidevice	Portability	Distributed Measurements
PCI	132 MB/s (shared)	Best	Better	Good	Good
PCI Express	250 MB/s (per lane)	Best	Better	Good	Good
PXI	132 MB/s (shared)	Best	Best	Better	Better
PXI Express	250 MB/s (per lane)	Best	Best	Better	Better
USB	60 MB/s	Better	Good	Best	Better
Ethernet	125 MB/s (shared)	Good	Good	Best	Best
Wireless	6.75 MB/s (per 802.11g channel)	Good	Good	Best	Best

You can choose from many buses to meet your DAQ requirements



PCI

- The Peripheral Component Interconnect (PCI) bus is one of the most commonly used internal computer buses today.
- With a shared bandwidth of 132 MB/s, PCI offers high-speed data streaming and deterministic data transfer for single-point control applications.
- There are many different DAQ hardware options for PCI, with multifunction I/O boards up to 10 MS/s and up to 18-bit resolution.

PCI Express

- PCI Express, an evolution of PCI, offers a new level of innovation in the PC industry.
- The single biggest benefi of PCI Express architecture is
- the dedicated bus bandwidth provided by independent data transfer lines.
- Unlike PCI, in which 132 MB/s of bandwidth is shared among all
- devices, PCI Express uses independent data lanes that are each
- capable of data transfer up to 250 MB/s
- 6 data lanes for a maximum throughput of 4 GB/s

USB

- The Universal Serial Bus (USB) was originally designed to connect peripheral devices, such as keyboards and mice, with PCs
- It is useful for many other applications, including measurement and automation.
- inexpensive and easy-to-use connection between DAQ devices and PCs.
- SB devices are inherently latent and nondeterministic. This means that single-point data transfers may not happen exactly when expected, and therefore USB is not recommend for closed-loop control applications, such as PID.

GPIB/IEEE 488 Bus

- The GPIB or General Purpose Interface Bus or IEEE 488 bus is still one of the more popular and versatile interface standards available today.
- GPIB is widely used for enabling electronics test equipment to be controlled remotely
- The standard has defined in 1978 by HP
- The GPIB or IEEE 488 bus is a very flexible system, allowing data to flow between any of the instruments on the bus, at a speed suitable for the slowest active instrument, max length 20m
- here must also be no more than 2 m between two adjacent instruments on the bus.

GPIB/IEEE 488 Bus

Within IEEE 488, the equipment on the bus falls into three categories, although items can fulfil more than one function:

Controller: As the name suggests, the controller is the entity that controls the operation of the bus. It is usually a computer and it signals that instruments are to perform the various functions. The GPIB controller also ensures that no conflicts occur on the bus. If two talkers tried to talk at the same time then data would become corrupted and the operation of the whole system would be seriously impaired. It is possible for multiple controllers to share the same bus; but only one can act as a controller at any particular time.

Listener: A listener is an entity connected to the bus that accepts instructions from the bus. An example of a listener is an item such as a printer that only accepts data from the bus

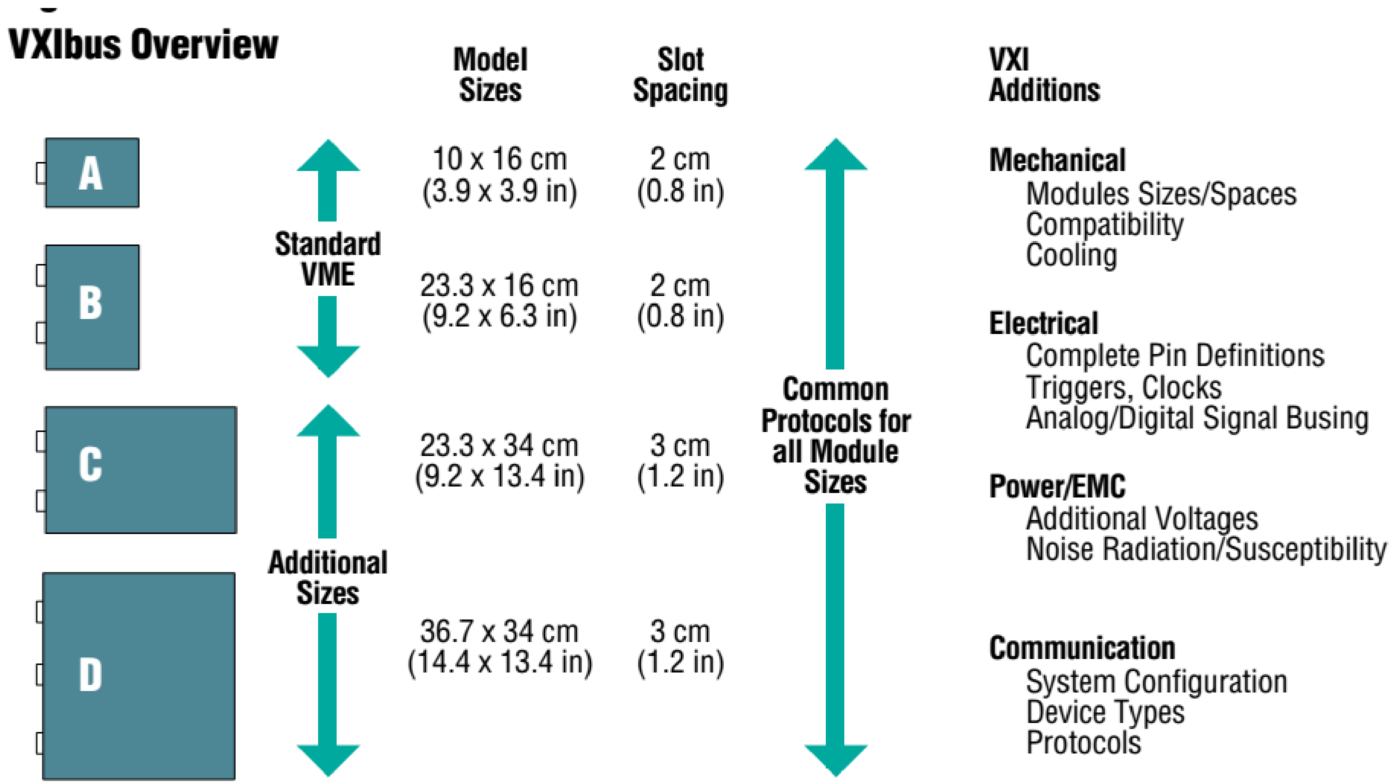
Talker: This is an entity on the bus that issues instructions / data onto the bus.

VXI

- VXIbus is an exciting, fast-growing platform for instrumentation systems.
- VXI standard was designed as an open specification to take advantage of the latest computer technologies to decrease test costs, increase throughput, and reduce development time
- Open, multivendor standards maximize flexibility and minimize obsolescence
- Smaller size and higher density reduce floor space, enhance mobility or portability, and give close proximity to device(s) under test or control
- More precise timing and synchronization improve measurement capability
- In essence, VXI combines the best technology from GPIB instruments, modular plug-in DAQ boards, and modern computers.

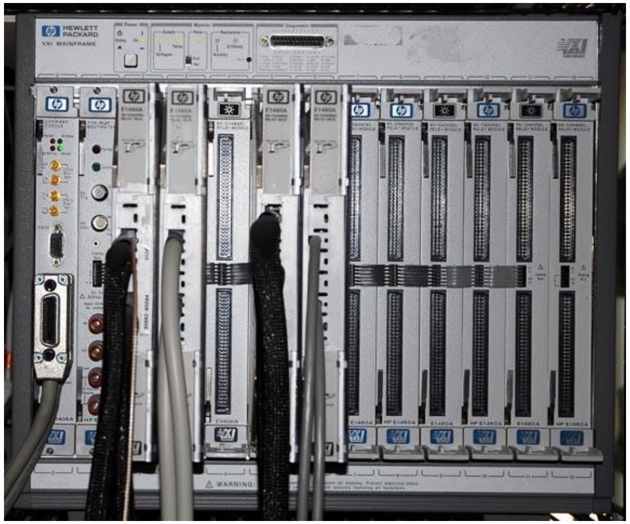
VXI

- VXI instruments have the ability to communicate at very high speeds
- Competitive pressures demand faster time to market, lower unit costs, and an increasing emphasis on quality



VXI

- Today, you can use VXI to build a variety of test systems, from portable testers for field use and remote data acquisition applications to high performance data acquisition and functional test systems.

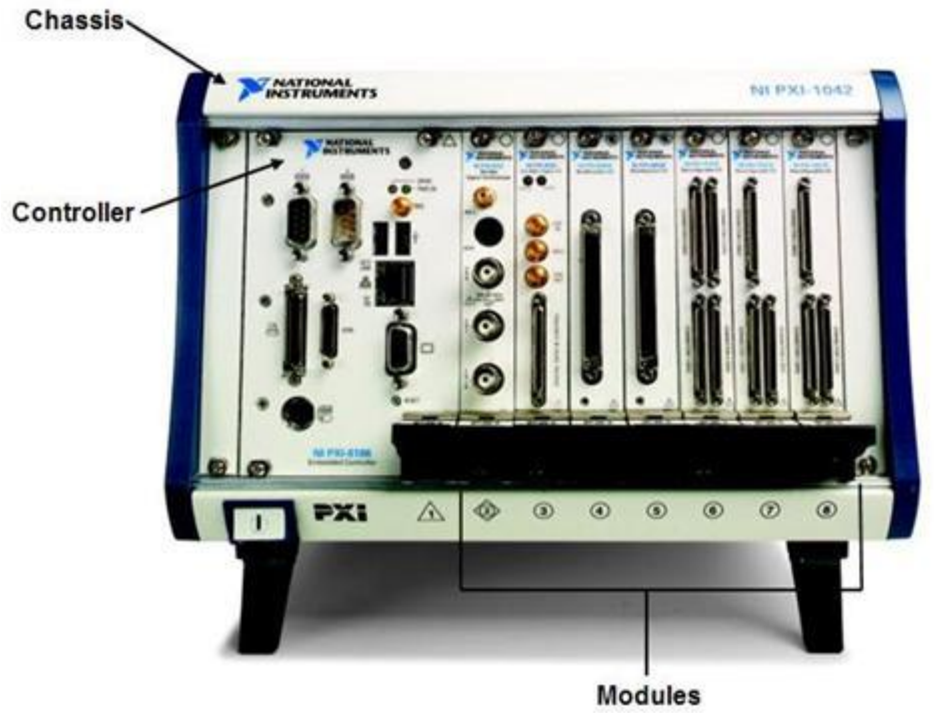


PXI Platform

- PCI eXtensions for Instrumentation (PXI) were developed to bridge the gap between desktop PC systems and high-end VXI and GPIB systems
- Open standard
- Rugged packing
- Modular architecture (hot swap, plug&play)
- integrated timing and triggering features

NI PXIe-8880 controller
XEON 8 Core, 24 GB/s

2.170.000 HUF



Ethernet

- Ethernet is the backbone of almost every corporate network in the world and, therefore, is widely available
- As a bus for DAQ, Ethernet is ideal for taking portable or distributed measurements at distances beyond the 5 m length of a USB cable (extend 100 m before needing a hub)
- Ethernet an ideal choice for distributing measurements to remote locations
- 100BASE-T (100 Mbit/s) Ethernet can accommodate multiple Ethernet DAQ devices running at full speed

Wireless

- A vezeték nélküli technológia kiterjeszti a PC-alapú adatgyűjtés rugalmasságát és hordozhatóságát olyan mérési alkalmazásokra, ahol a kábelek alkalmazása kényelmetlen vagy nem praktikus, például a szélerőművek vagy a civil építmények.
- A vezeték nélküli technológia a többi DAQ buszhoz képest a legnagyobb késleltetési idővel rendelkezik, így a nagysebességű vezérlést vagy determinizmust igénylő alkalmazások nem ajánlottak
- A legnépszerűbb az IEEE 802.11 (Wi-Fi)
- A Wi-Fi „hotspot” -hoz történő csatlakozás a legtöbb ember számára ugyanolyan ismerős, mint az USB-kábel csatlakoztatása
- Biztonságos

MEASUREMENT AND DAQ LECTURE #8

Adam Schiffer, PhD

University of Pecs

Faculty of Engineering and Information Technology

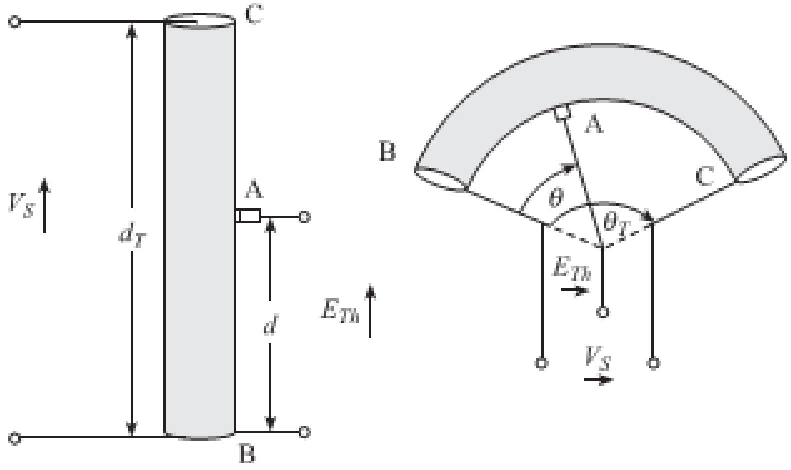
The presentation was supported by EFOP-3.4.3.-16-2016-00005 számú "Korszerű egyetem a modern városban: Értékközpontúság, nyitottság és befogadó szemlélet egy 21. századi felsőoktatási modellben „ programme.

SENSING ELEMENTS

Adam Schiffer, PhD

	Input measured variable / Physical principle	Temperature	Heat/light flux	Pressure	Force	Torque	Level	Density	Flow rate	Flow velocity	Displacement/strain	Velocity	Acceleration	Gas composition	Ionic concentration	Humidity	Magnetic field
Electrical output passive	Resistive	8.1		8.6	8.6	8.6					5.1		8.6	8.1		8.1	
		15.5	15.5							14.3	8.1		4.4	14.4			
	Capacitive			8.2			8.2				8.2					8.2	
	Inductive										8.3						
	Piezoresistive			8.8													
	Photovoltaic		15.5														
	Photoconductive		15.5														
	FET													8.9	8.9		
	Hall effect																8.10
Electrical output active	Electromagnetic								12.4			8.4					
	Thermoelectric	8.5															
		15.5	15.5														
	Piezoelectric			16.2	8.7								8.7				
	Electrochemical													8.9	8.9		
	Pyroelectric	15.5	15.5														
Mechanical output	Elastic			8.6	4.1												
				9.4	8.6	8.6	9.4										
				9.5	9.5			9.5					8.6				
	Differential pressure								12.3	12.2							
	Turbine								12.3								
	Vortex								12.3								
	Pneumatic			13.1	13.1		13.1				13.1						
	Coriolis								12.4								
Thermal output	Heat transfer		15.5							14.3				14.4			
Optical output	Various		15.6	15.6	15.6		15.6				15.6	15.6		15.6			

Potentiometers for linear and angular displacement measurement



(a) Linear (rectilinear) displacement

(b) Angular (rotary) displacement

$$\frac{E_{Th}}{V_S} = \frac{\text{voltage across AB}}{\text{voltage across CB}} = \frac{\text{resistance across AB}}{\text{resistance across CB}}$$

where:

resistance of CB = total resistance of potentiometer $= R_P$

resistance of AB = fractional resistance $= R_P d/d_T = R_P x$

x = fractional displacement $= d/d_T$.

$$E_{Th} = V_S x = V_S d/d_T \qquad E_{Th} = V_S \theta/\theta_T = V_S x$$

Resistive metal and semiconductor sensors for temperature measurement

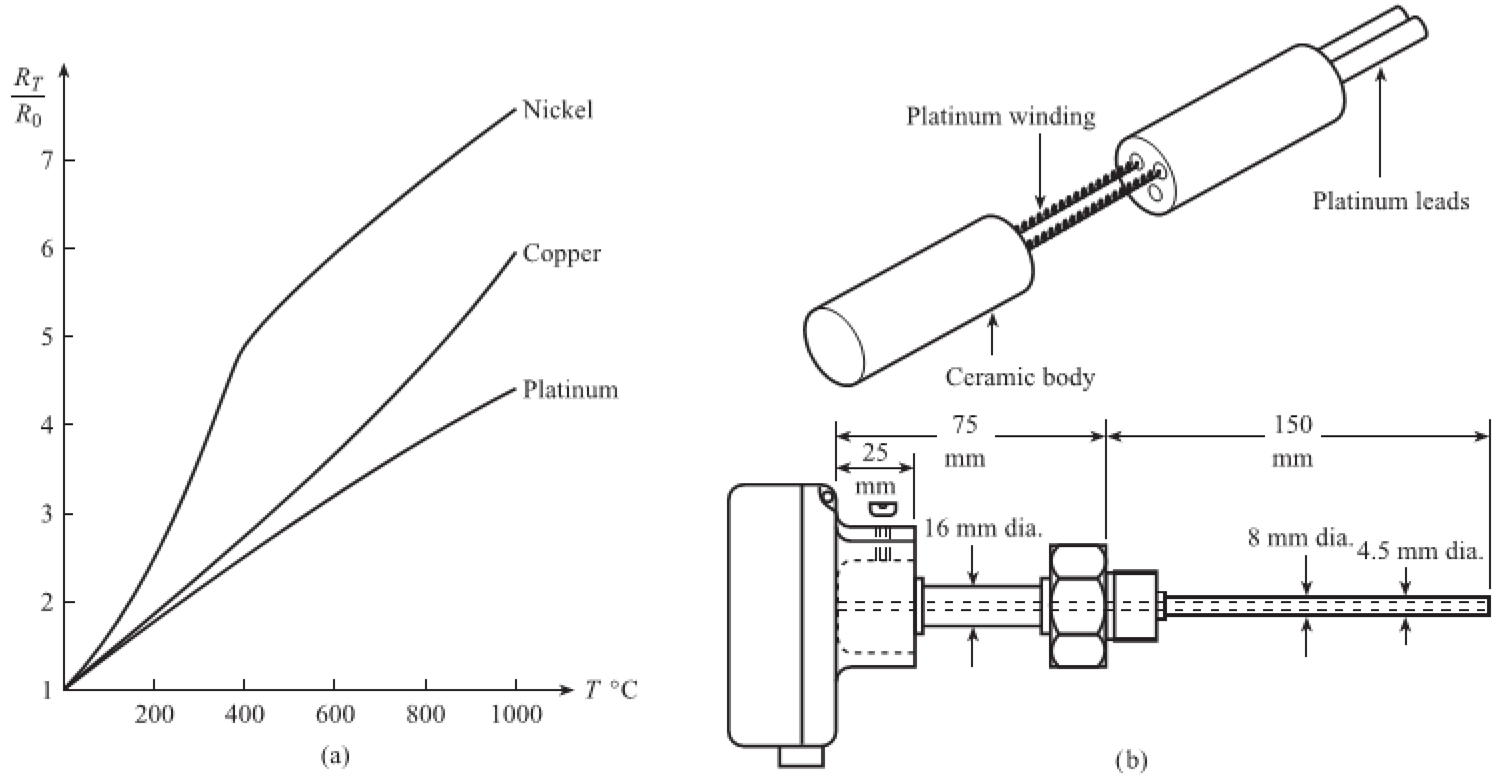
- The resistance of most **metals** increases reasonably linearly with temperature in the range −100 to +800 °C.
- Although relatively expensive, platinum is usually chosen for industrial resistance thermometers; cheaper metals, notably nickel and copper, are used for less demanding applications.
- The general relationship between the resistance *RT* Ω of a metal element and temperature *T* °C is a power series of the form:

$$RT = R0(1 + \alpha T + \beta T2 + \gamma T3 + . . .),$$

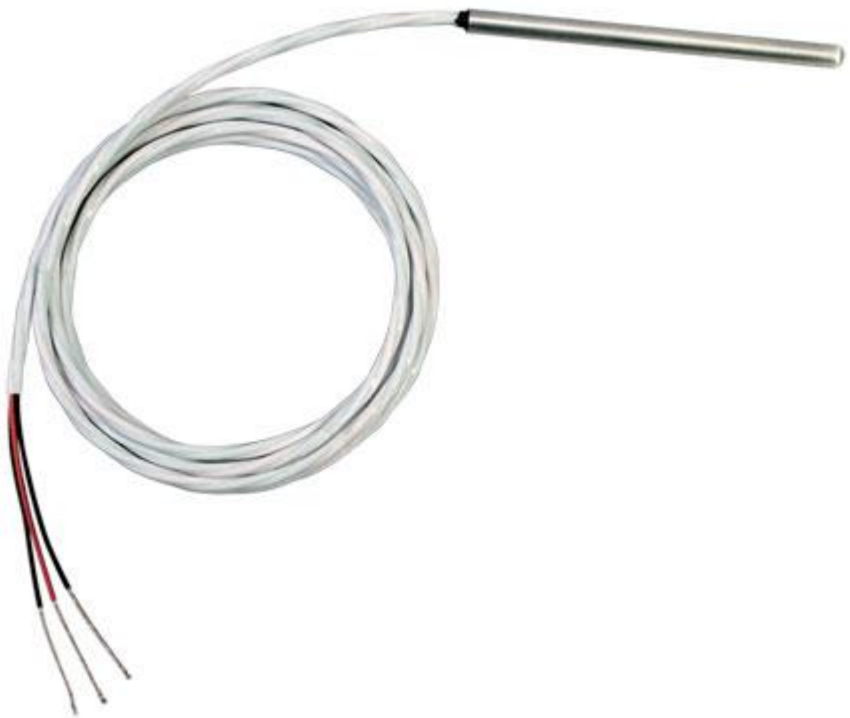
where *R*0 Ω is the resistance at 0 °C and α, β, γ are temperature coefficients of resistance.

- A typical platinum element has *R* 0 = 100.0 Ω, *R*100 = 138.50 Ω, *R*200 = 175.83 Ω, $\alpha = 3.91 \times 10-3\ °C^{-1}$ and $\beta = -5.85 \times 10^{-7}\ °C^{-2}$.

Resistive metal and semiconductor sensors for temperature measurement



Resistive sensing elements



RTD

Advantages:

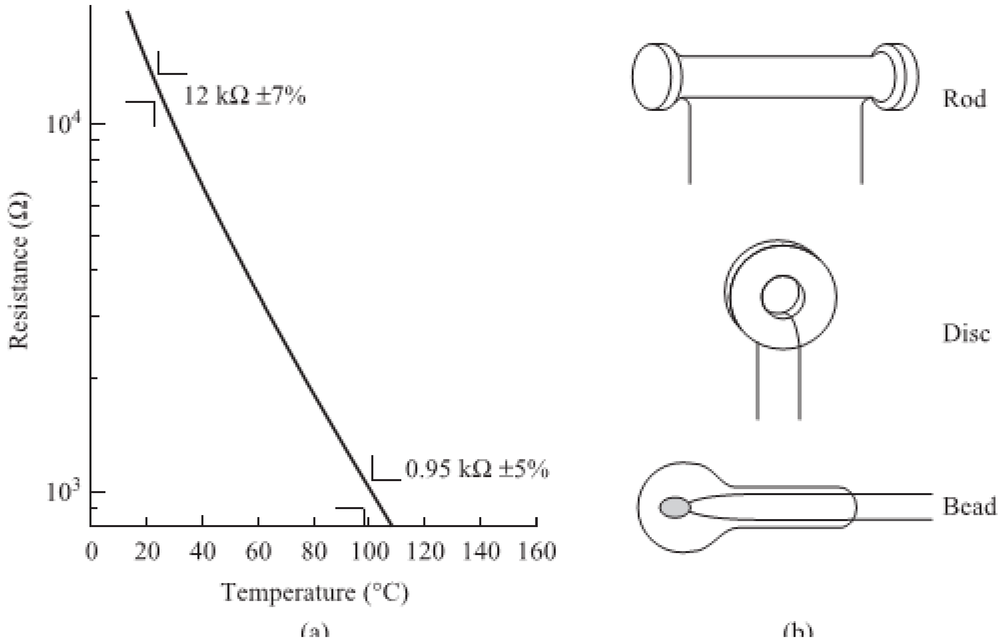
- Stabe
- Very accurate
- Linear

Disadvantages

- Expensive
- Current source required
- Small change in resistance
- Self heating

Semiconductors (Thermistors)

The resistance of these elements decreases with temperature – in other words there is a negative temperature coefficient (NTC) – in a highly non-linear way.



Resistive sensing elements

Semiconductors (Thermistors)

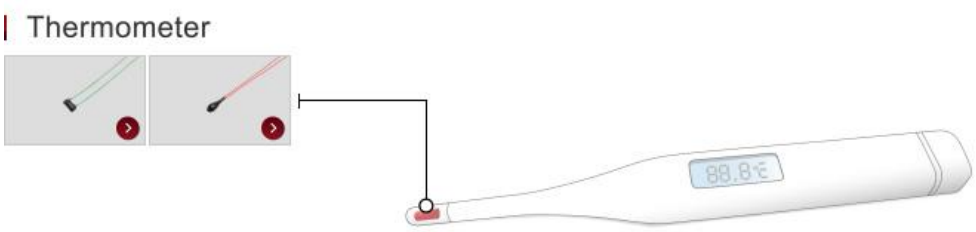
Thermistor

Advantages:

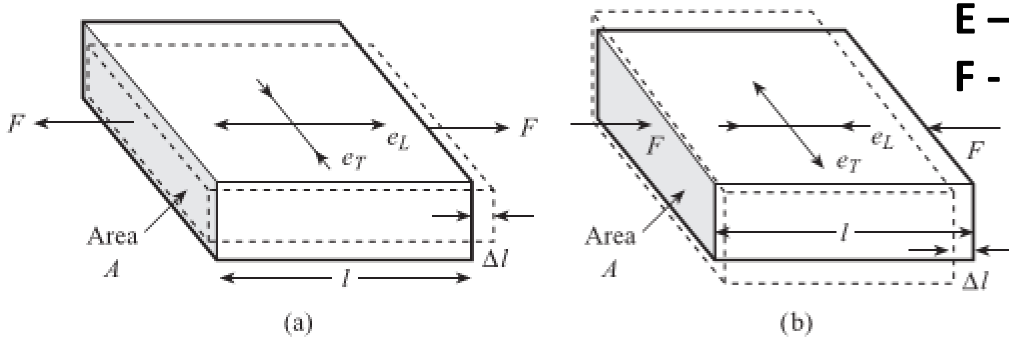
- Very sensitive
- Quick response
- Best accuracy

Disadvantages

- Non-linear
- Small temperature range
- Current source required
- Self heating



Metal and semiconductor resistive strain gauges



E – strain
F - stress

Effect of tensile stress

Effect of compressive stress

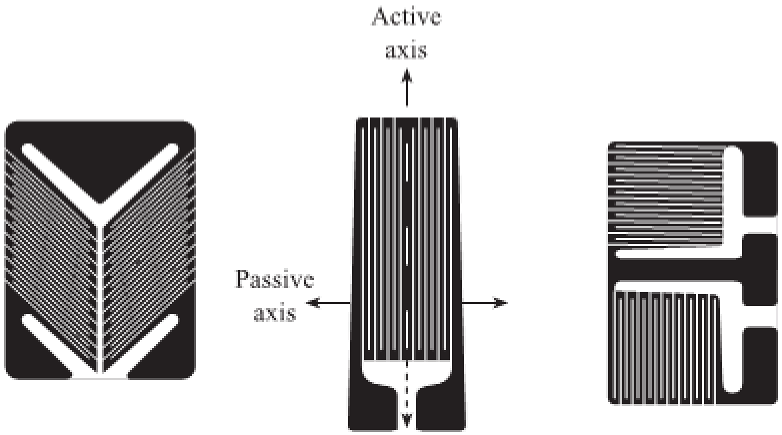
$$\text{Elastic modulus} = \frac{\text{stress}}{\text{strain}}$$

A **strain gauge** is a metal or semiconductor element whose resistance changes when under strain.
We can derive the relationship between changes in resistance and strain by considering the factors which influence the resistance of the element. The resistance of an element of length *l*, cross-sectional area *A* and resistivity ρ is given by:

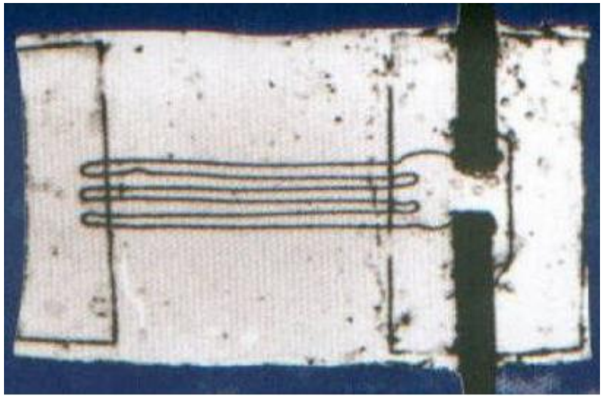
$$R = \frac{\rho l}{A}$$

$$\Delta R = \left(\frac{\partial R}{\partial l}\right)\Delta l + \left(\frac{\partial R}{\partial A}\right)\Delta A + \left(\frac{\partial R}{\partial \rho}\right)\Delta \rho$$

Metal and semiconductor resistive strain gauges



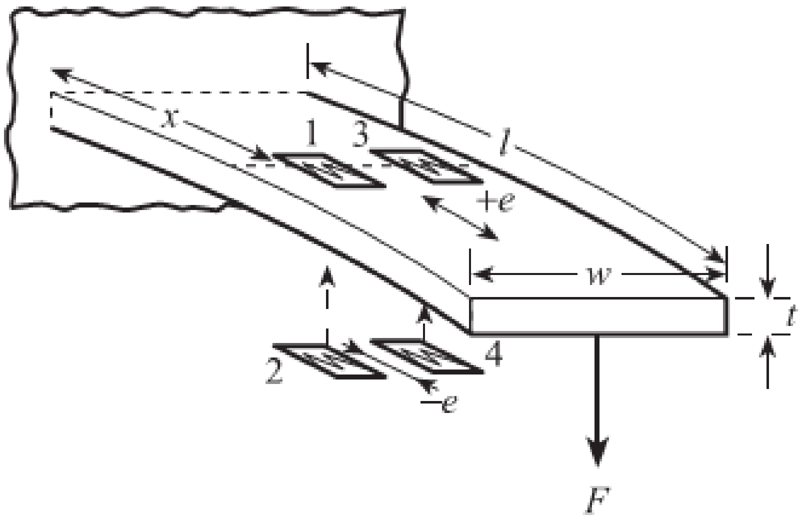
First Strain Gauge, Ruge, 1938

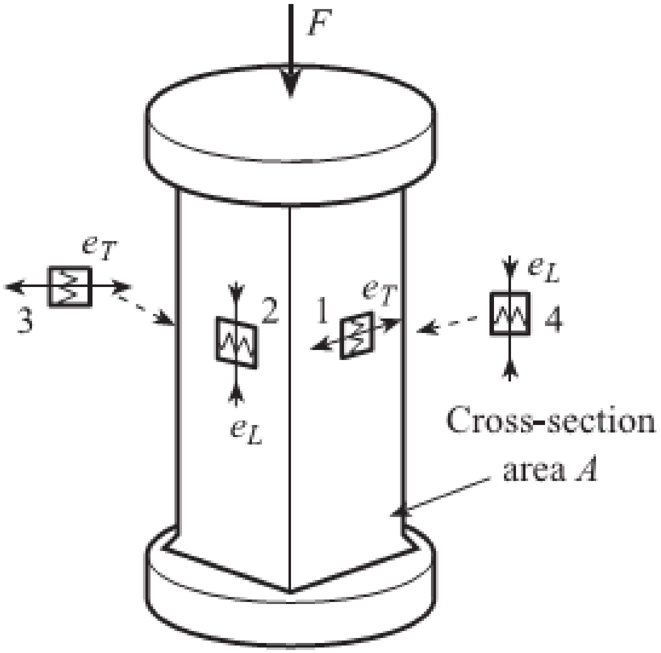


We now define the **gauge factor** *G* of a strain gauge, hence

$$\frac{\Delta R}{R_0} = Ge$$

Metal and semiconductor resistive strain gauges





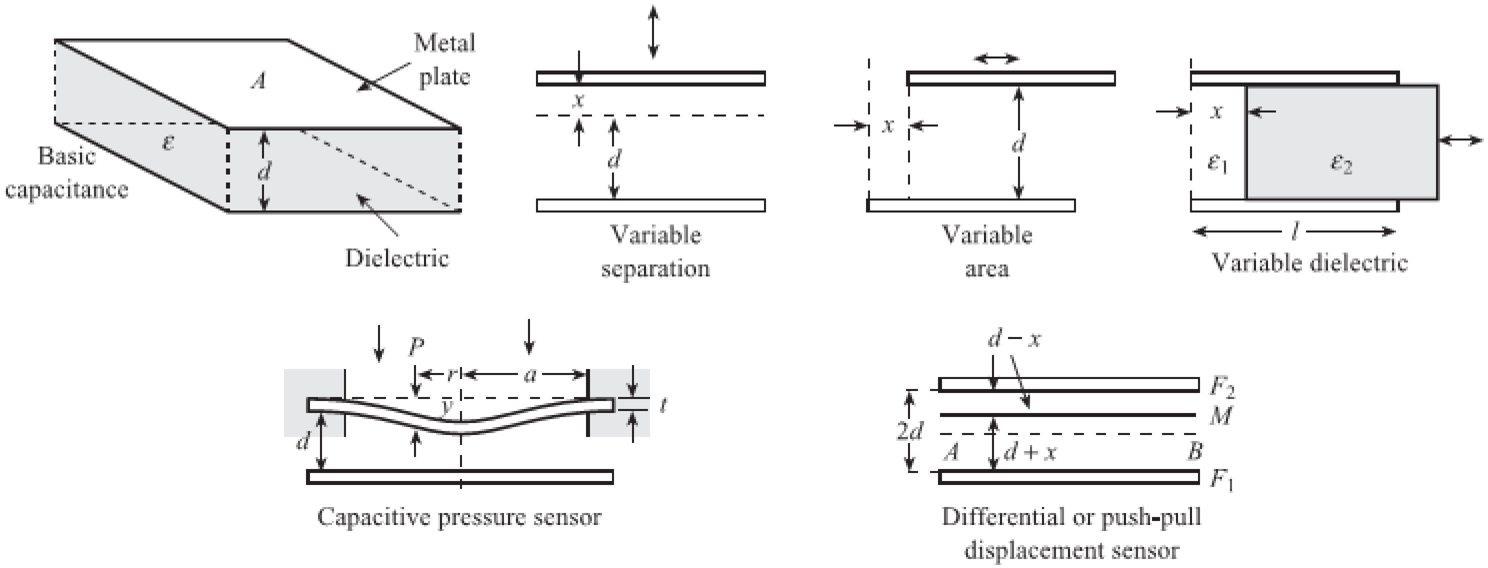
Most alloys have a low **temperature coefficient of resistance** (2×10^{-5} °C $^{-1}$) and a low **temperature coefficient of linear expansion**.

A typical gauge has:

- Gauge factor 2.0 to 2.2
- Unstrained resistance 120 ± 1 Ω
- Linearity within ±0.3%
- Maximum tensile strain +2 × 10−2
- Maximum compressive strain −1 × 10−2
- Maximum operating temperature 150 °C.

Capacitive sensing elements

The simplest capacitor or condenser consists of two parallel metal plates separated by a dielectric or insulating material

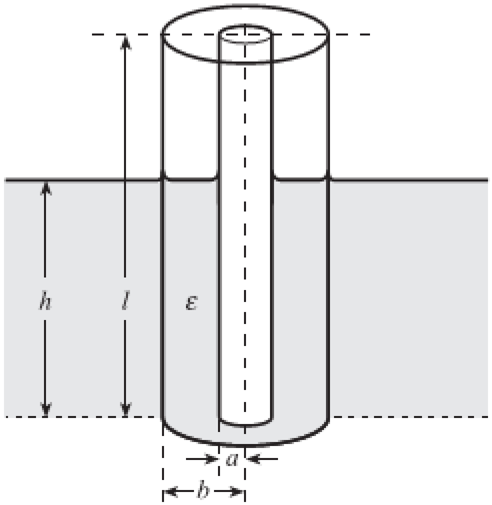


The capacitance of this parallel plate capacitor is given by:

$$C = \frac{\varepsilon_0 \varepsilon A}{d}$$

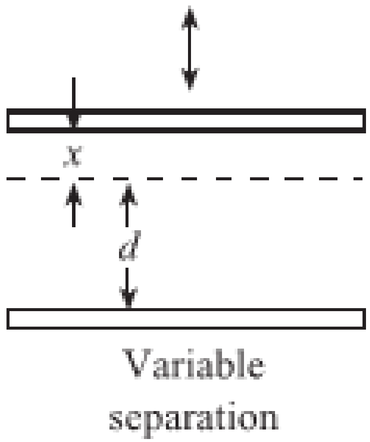
where ε0 is the permittivity of free space (vacuum) of magnitude 8.85 pF m^{-1}, ε is the relative permittivity or dielectric constant of the insulating material, *A* m^2 is the area of overlap of the plates, and *d* m is their separation

Capacitive sensing elements



Capacitive level sensor

Capacitive humidity sensor



EXAMPLE:

capacitive displacement sensors using each of these methods. If the displacement *x* causes the plate
separation to increase to $d + x$ the capacitance of the sensor is:

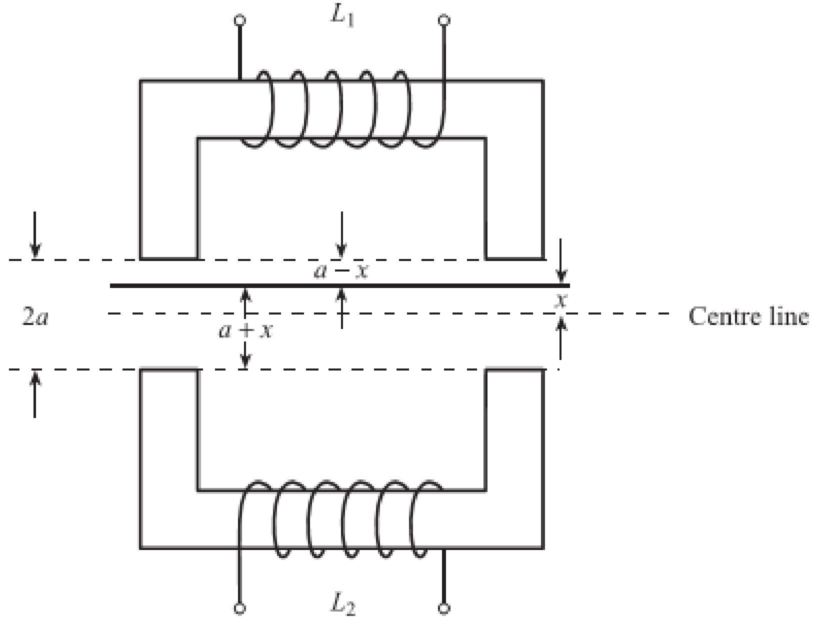
$$C = \frac{\varepsilon_0 \varepsilon A}{d + x}$$

Inductive sensing elements

In order to discuss the principles of these elements we must first introduce the concept of a **magnetic circuit**. In an electrical circuit an electromotive force (e.m.f.) drives a current through an electrical resistance and the magnitude of the current is given by

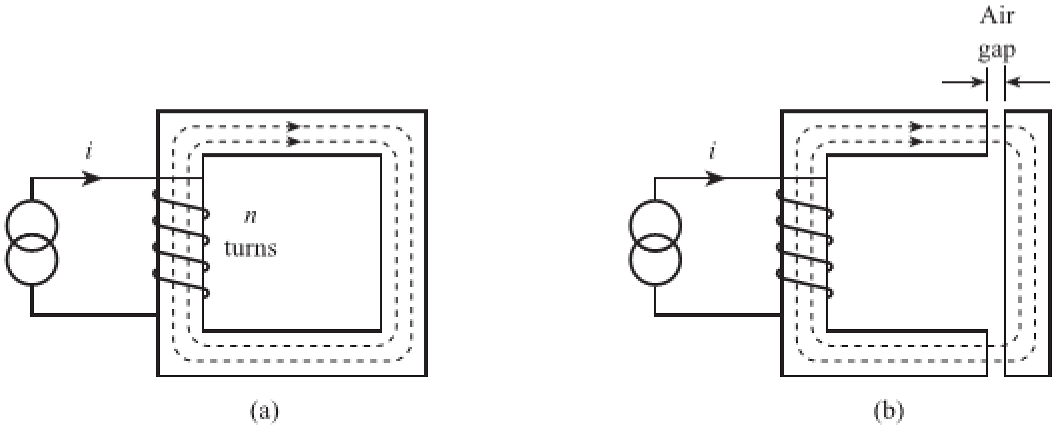
e.m.f. = current × resistance

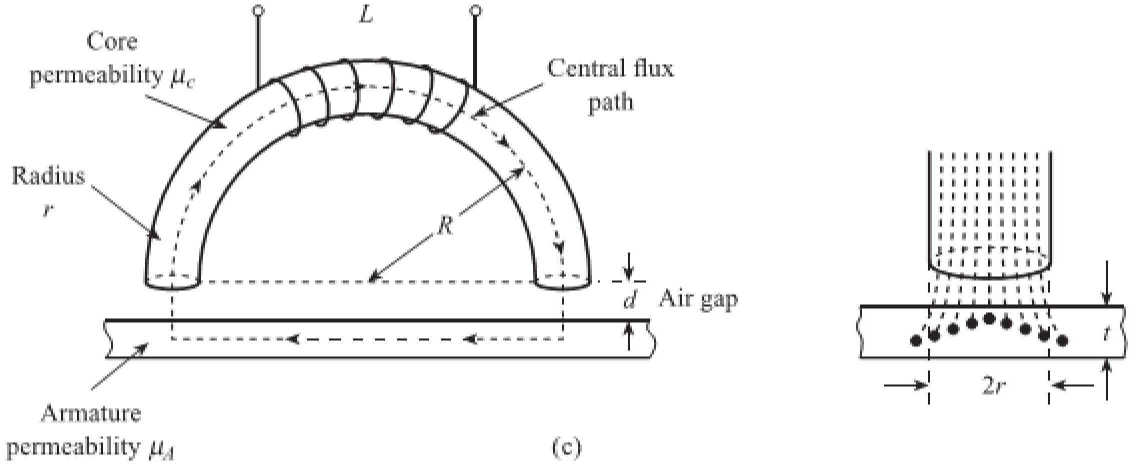
Since the relative permeability of air is close to unity and that of the core material many thousands, the presence of the air gap causes a large increase in circuit reluctance and a corresponding decrease in flux and inductance. Thus a small variation in air gap causes a measurable change in inductance so that we have the basis of an **inductive displacement sensor**.



Inductive sensing elements

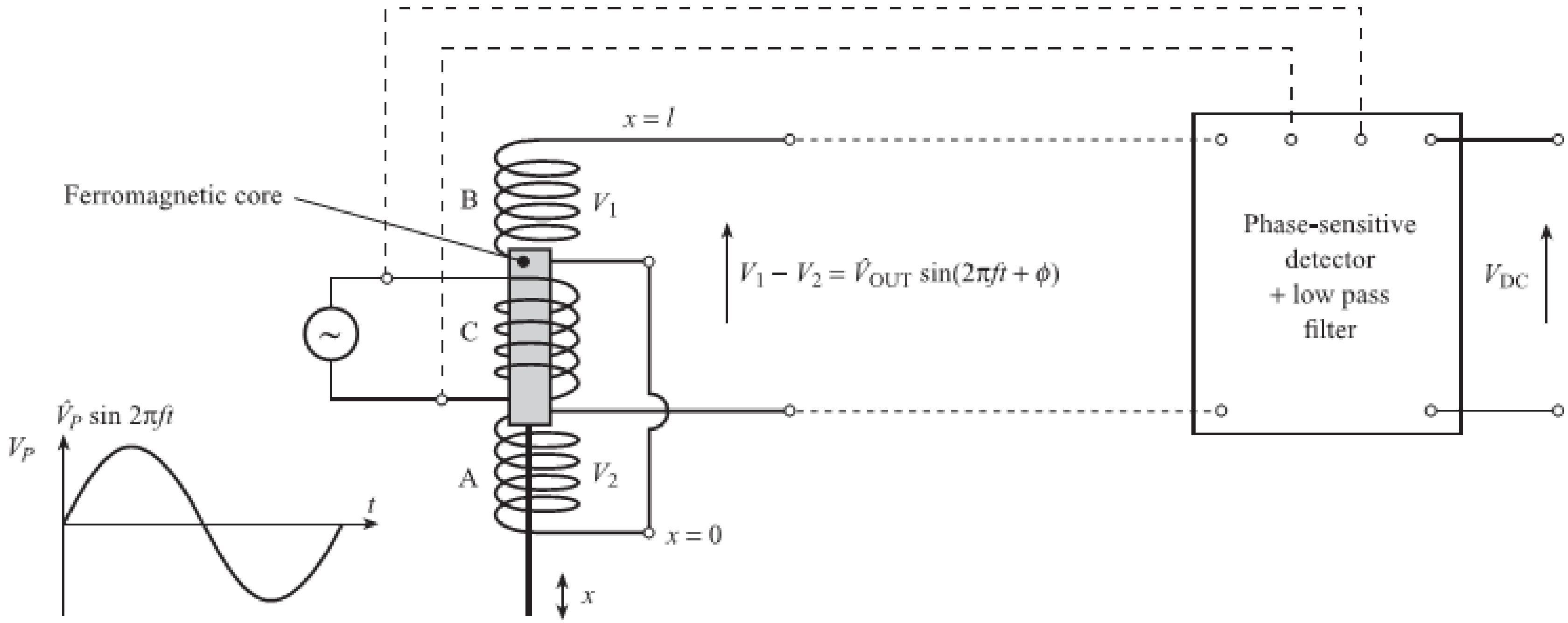
(a)(b) Basic principle of reluctance sensing elements
(c) Reluctance calculation for typical element



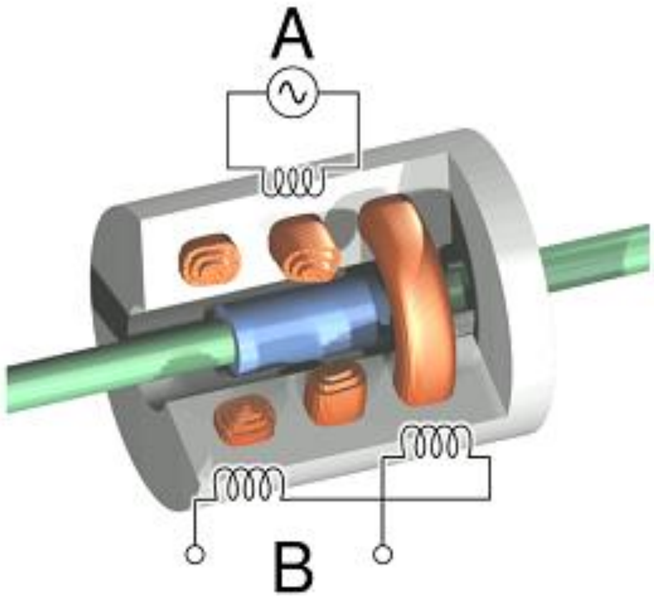


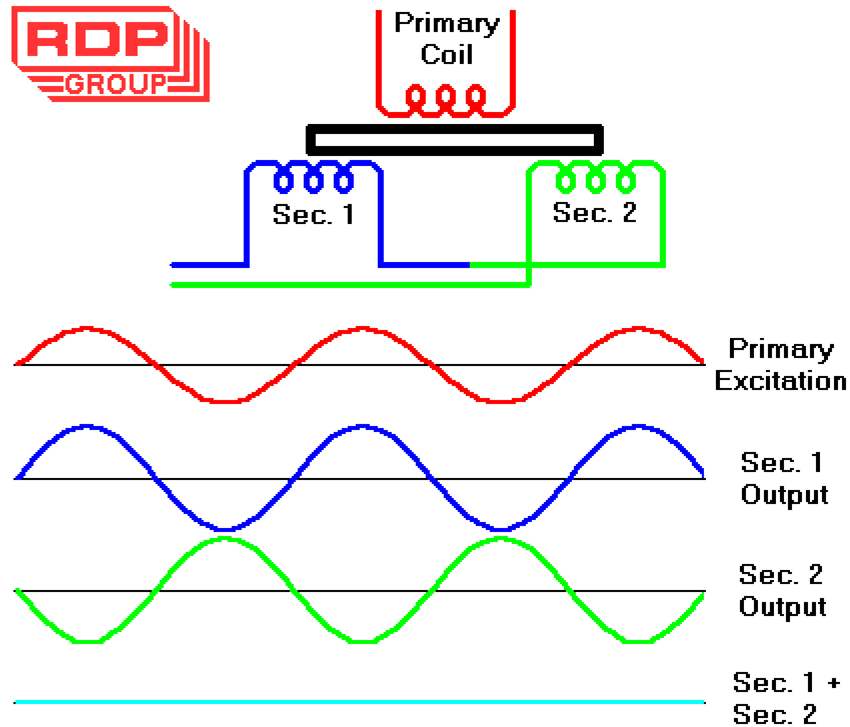
Linear Variable Differential Transformer (LVDT) displacement sensor

This sensor is a transformer with a single primary winding and two identical secondary windings wound on a tubular ferromagnetic former



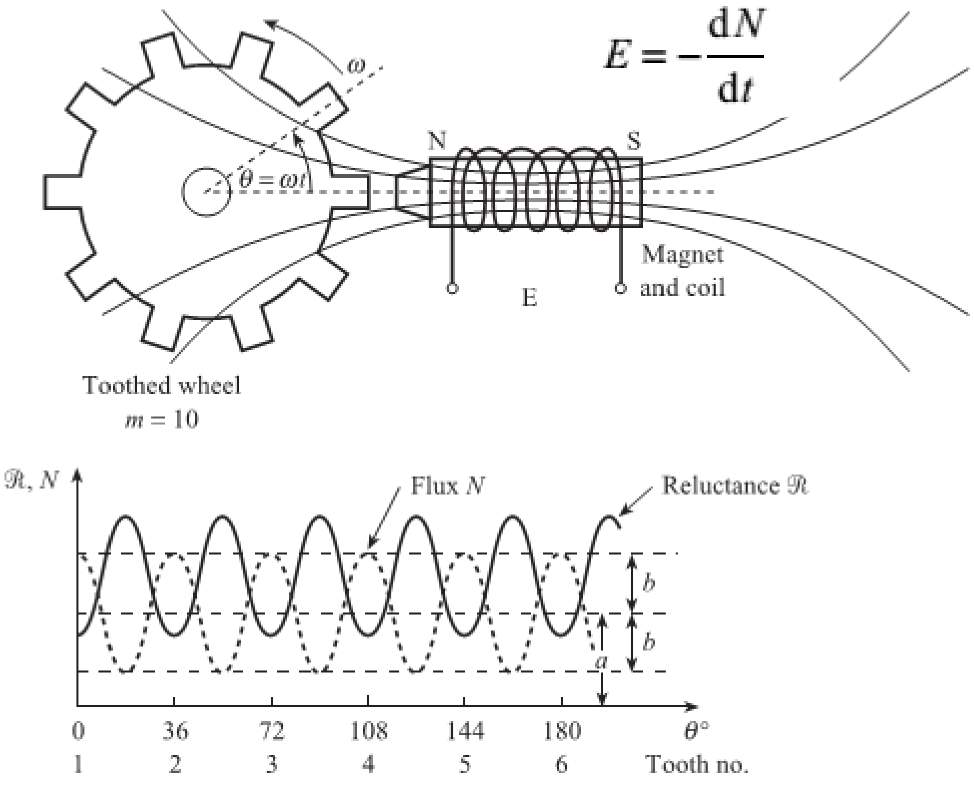
Linear Variable Differential Transformer (LVDT) displacement sensor





Electromagnetic sensing elements

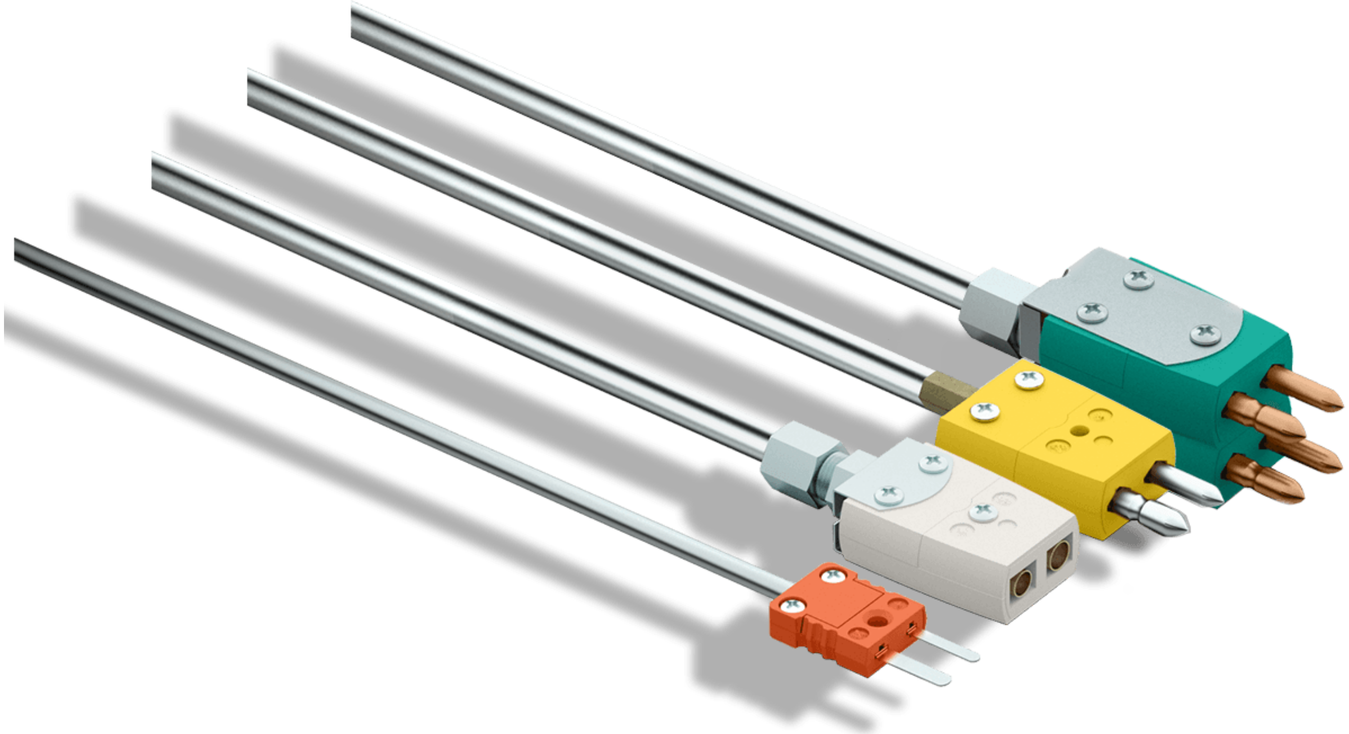
These elements are used for the measurement of linear and angular velocity and are based on Faraday's law of electromagnetic induction. This states that if the flux *N* linked by a conductor is changing with time, then a back e.m.f. is induced in the conductor with magnitude equal to the rate of change of flux, i.e.



Variable reluctance tachogenerator, angular variations in reluctance and flux.

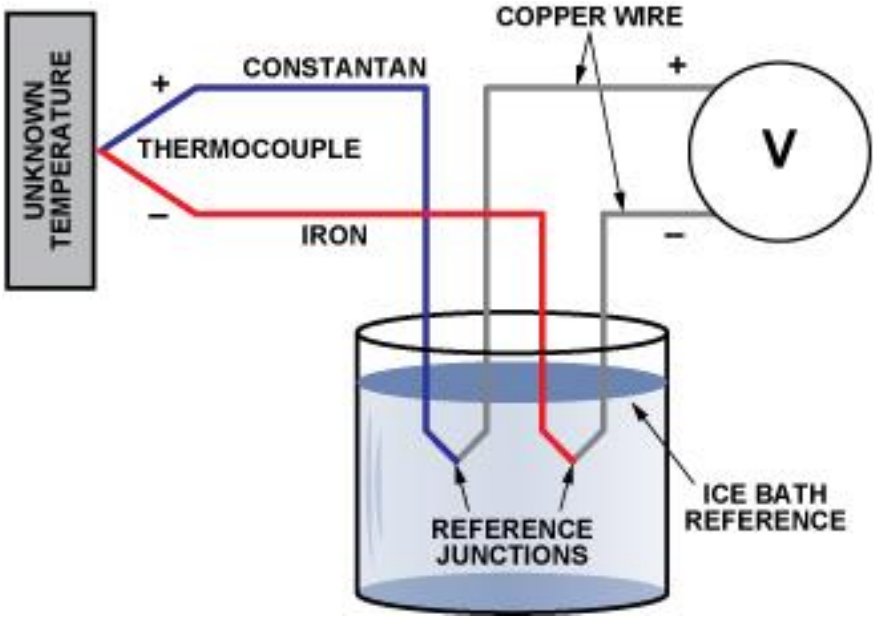
Thermoelectric sensing elements

Thermoelectric or thermocouple (TC) sensing elements are commonly used for measuring
temperature. If two different metals *A* and *B* are joined together, there is a difference in electrical potential across the junction called the **junction potential**



Thermoelectric sensing elements

the **junction potential**



TC

Advantages:

- Self powered
- rugged
- Inexpensive
- simple

Disadvantages

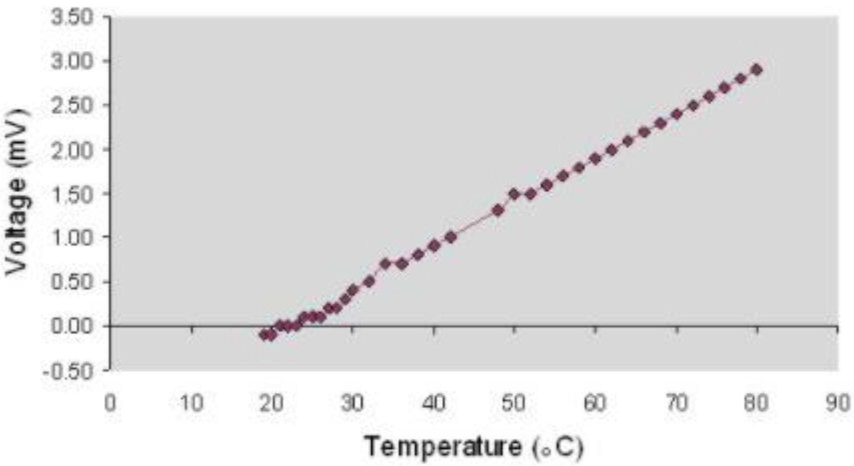
- Extremly low voltage output
- Not very stable
- Needs a reference point

Temperature sensing elements

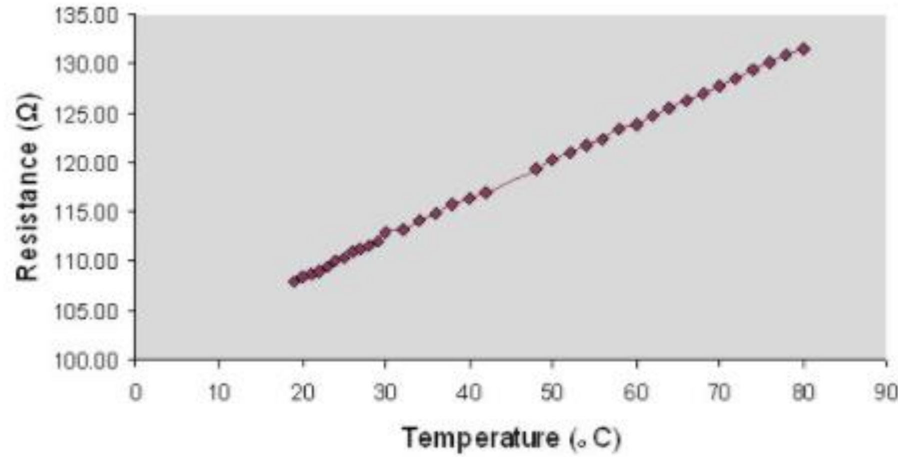
Temperature (degrees Celsius)	Thermocouple (mille-Volts)	RTD (ohms)	Thermistor (kilo-ohms)
19	-0.10	108.00	105.60
20	-0.10	108.40	99.80
21	0.00	108.70	94.20
22	0.00	109.00	88.20
23	0.00	109.50	83.80
24	0.10	110.00	79.70
25	0.10	110.40	75.90
26	0.10	110.90	73.30
27	0.20	111.30	70.00
28	0.20	111.50	68.40
29	0.30	112.00	63.40
30	0.40	112.90	60.50
32	0.50	113.20	54.80
34	0.70	114.10	49.20
36	0.70	114.80	45.50

Temperature sensing elements

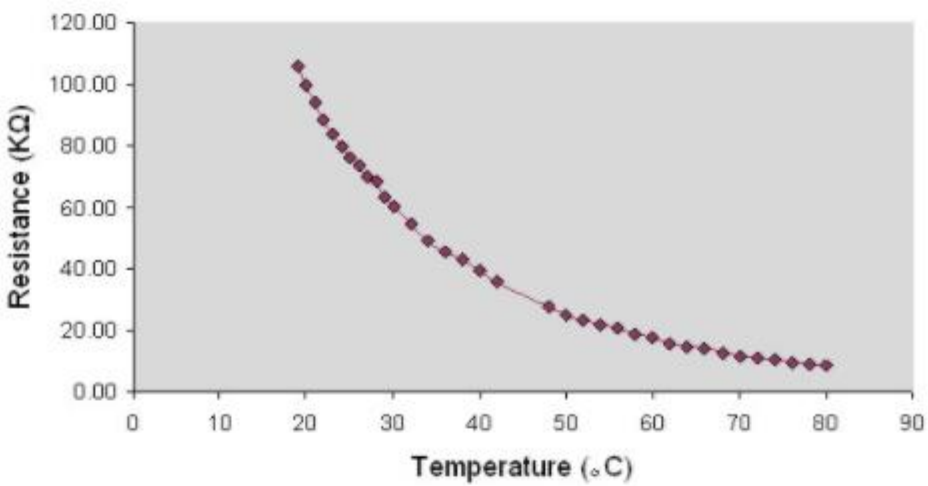
Thermocouple



RTD

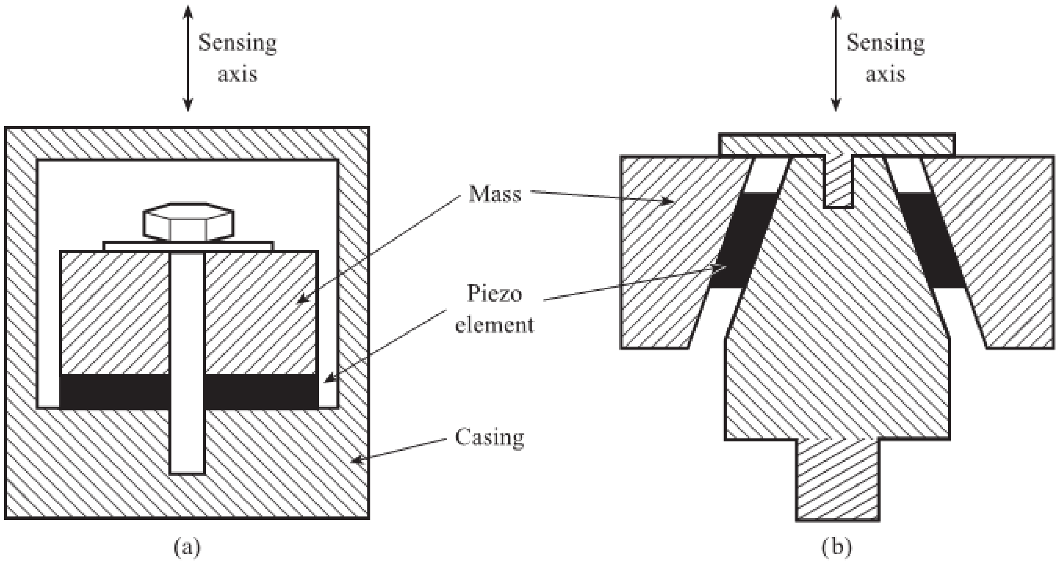


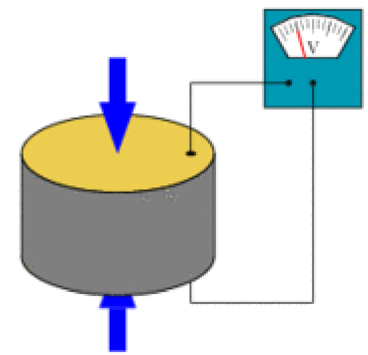
Thermistor



Piezoelectric sensing elements

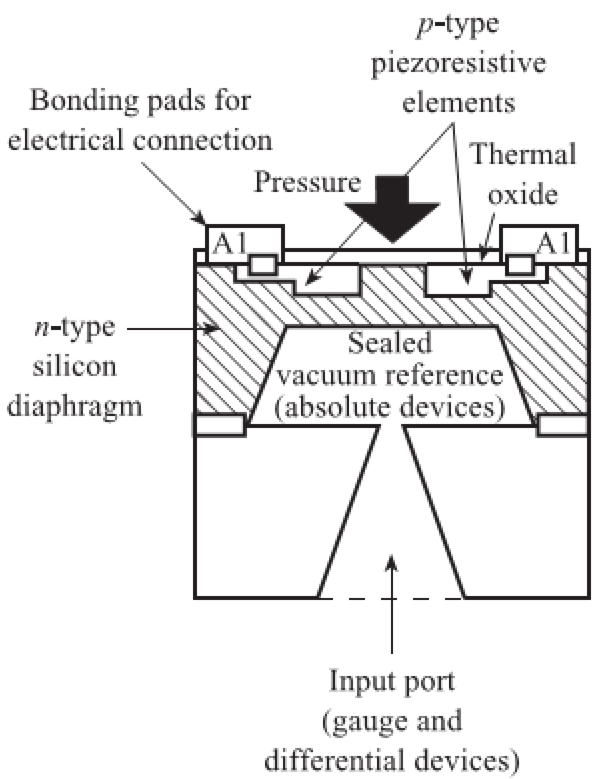
If a force is applied to any crystal, then the crystal atoms are displaced slightly from their normal positions in the lattice. This displacement *x* is proportional to the applied force *F*: i.e., in the steady state,



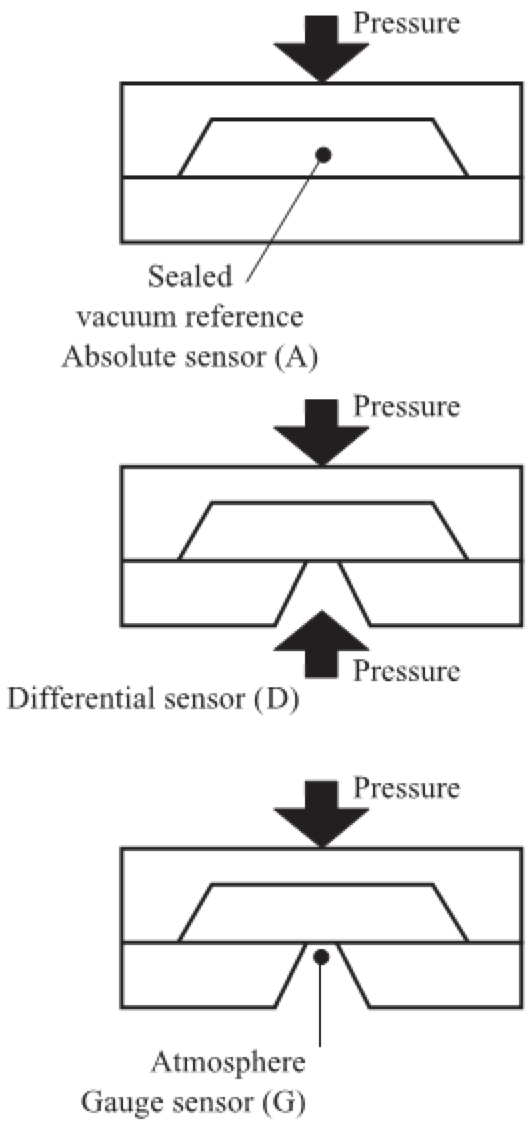


Piezoelectric accelerometers:
(a) Compression mode
(b) Shear mode

Piezoelectric sensing elements



(a)



(b)