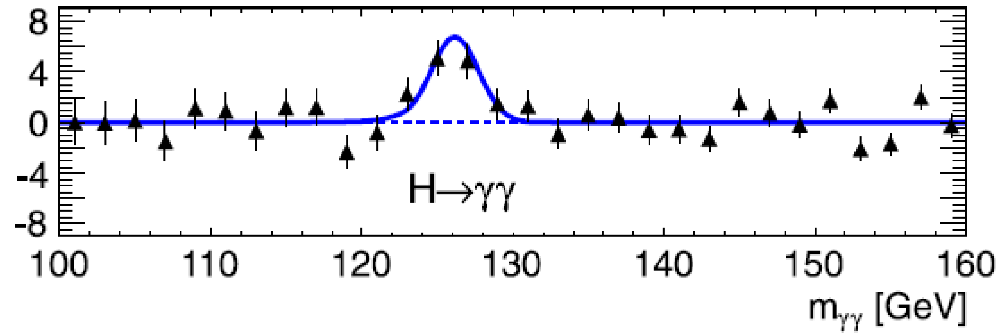
EP122
Measurement Techniques and Calibration

Topic 5

Measurement Systems



http://www.gantep.edu.tr/~bingul/ep122

Department of Engineering Physics

University of Gaziantep

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Content

PART I

THE GENERAL MEASUREMENT SYSTEM

PART II

THE STATIC CHARACTERISTICS OF MEASUREMENT SYSTEM

PART I

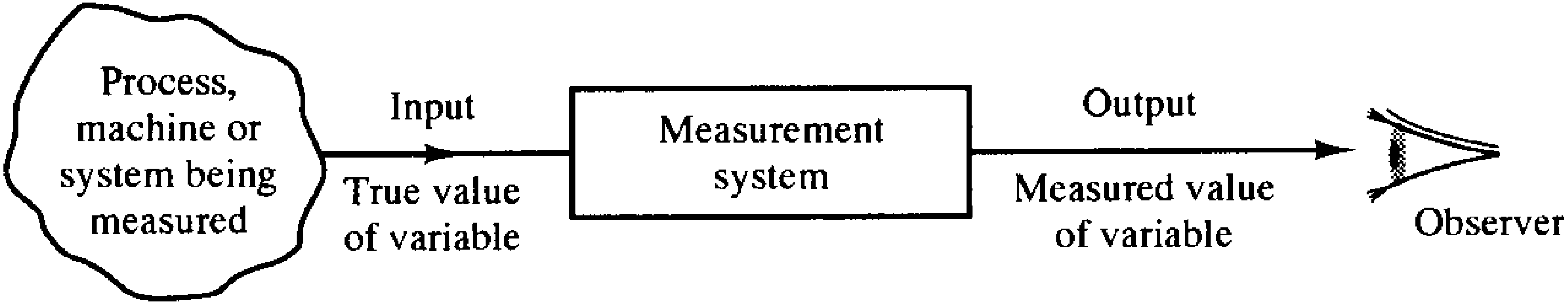
THE GENERAL MEASUREMENT SYSTEM

The General Measurement System

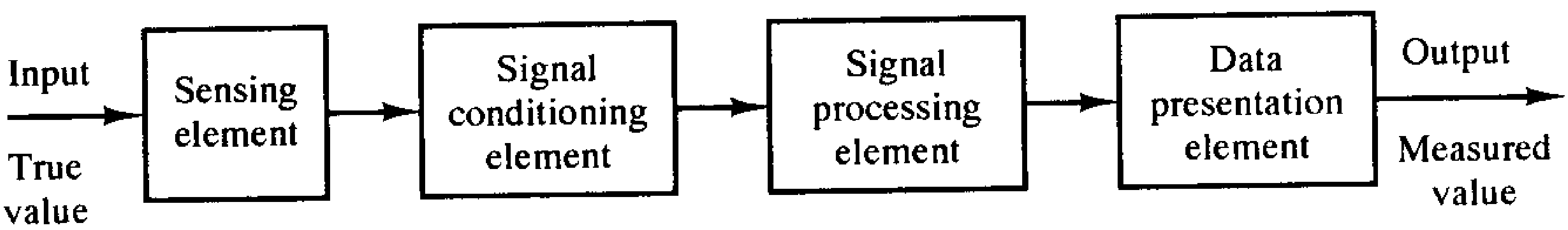
The purpose of a measurement system is to present an observer with numerical value corresponding to the variable being measured [1].

In general

"measured value does NOT equal to true value"



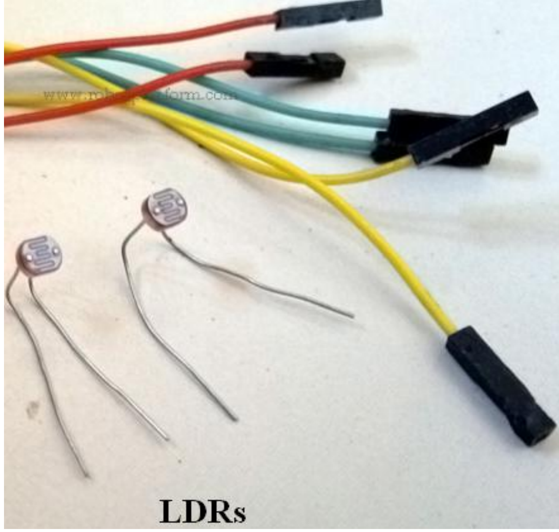
The measurement system consists of several elements or blocks.



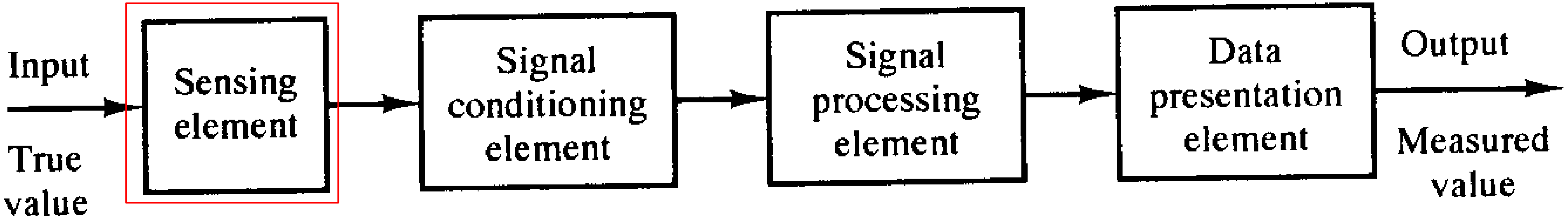
Sensing Element

Gives an output depending on input (measured) variable.

Examples are:

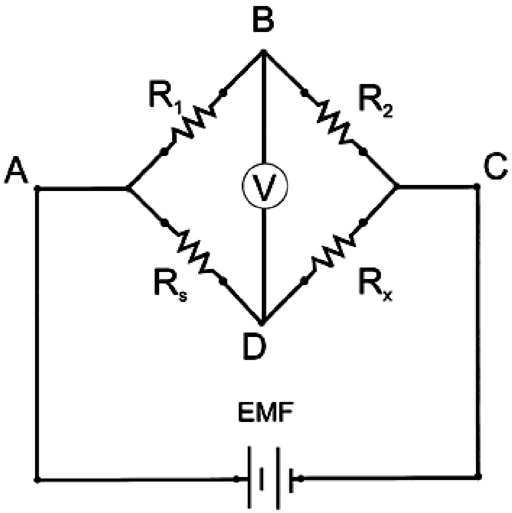


Input	Sensor	output
Temperature	Thermocouple	emf (in mV)
Mechanical strain	Strain gauge	resistance
Light	LDR	resistance



Signal Conditioning Element

Converts output of the sensor into a more suitable form for processing. Examples are:

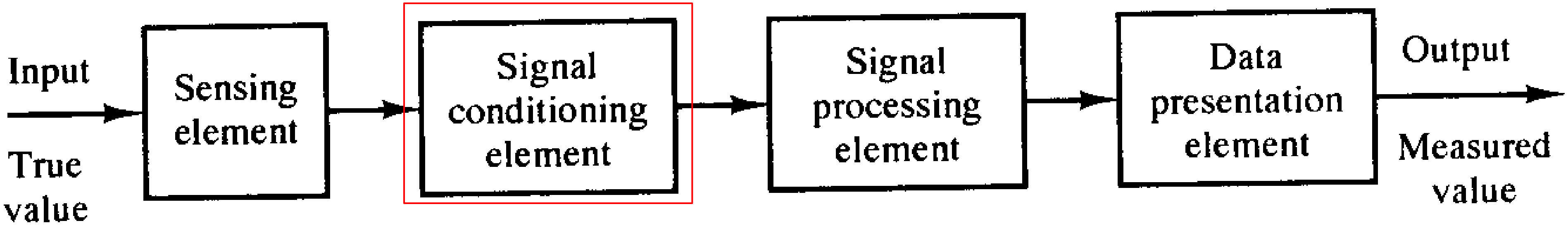


Amplifier:

Amplifies millivolts to Volt

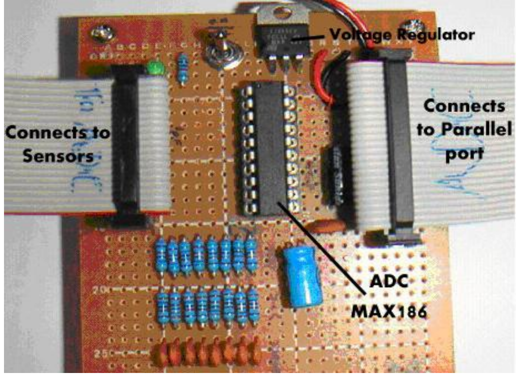
Deflection Bridge:

Converts an impedance chance to a voltage change.



Signal Processing Element

Converts output of the signal conditioning element into a more suitable form for presentation.

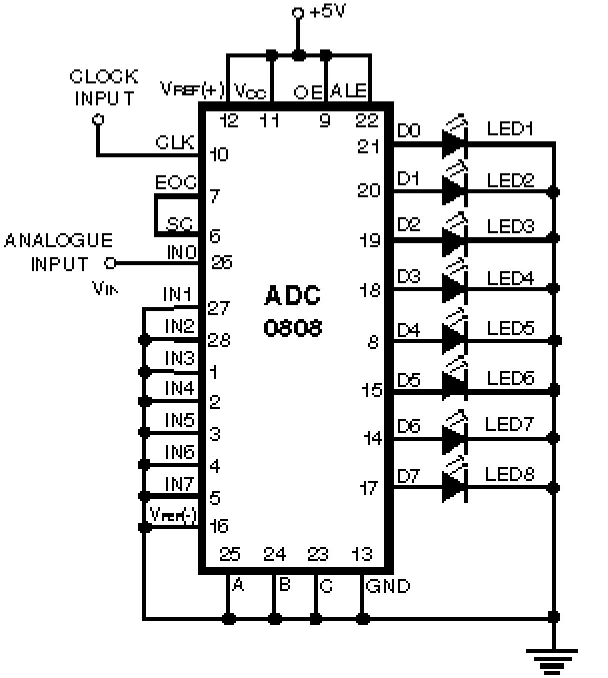


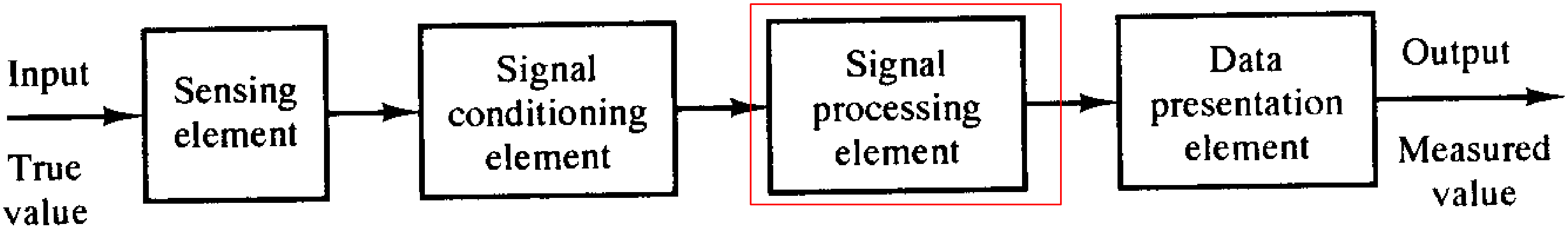
An Example is:

ADC:

Analog-to-Digital Converter

Converts a voltage into a digital form for input to a computer.





Data Presentation Element

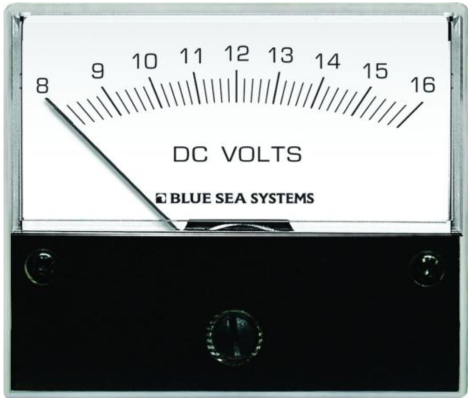
Presents the measured value in a form understandable by the observer.

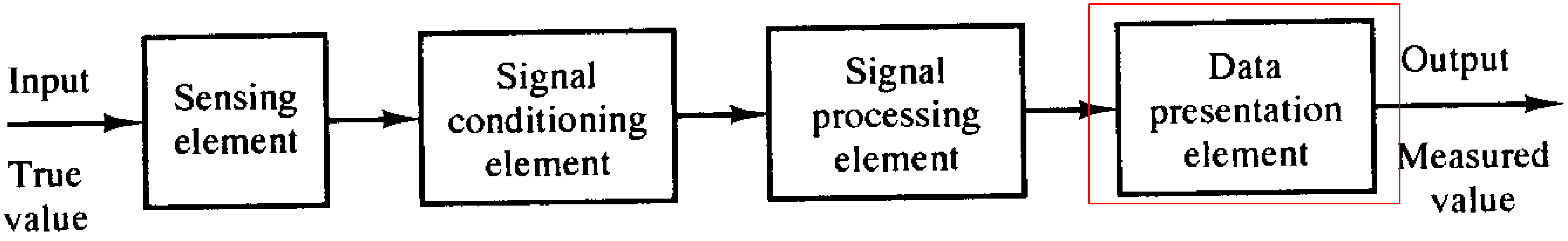
Examples are:

Analog pointer

7-segment display

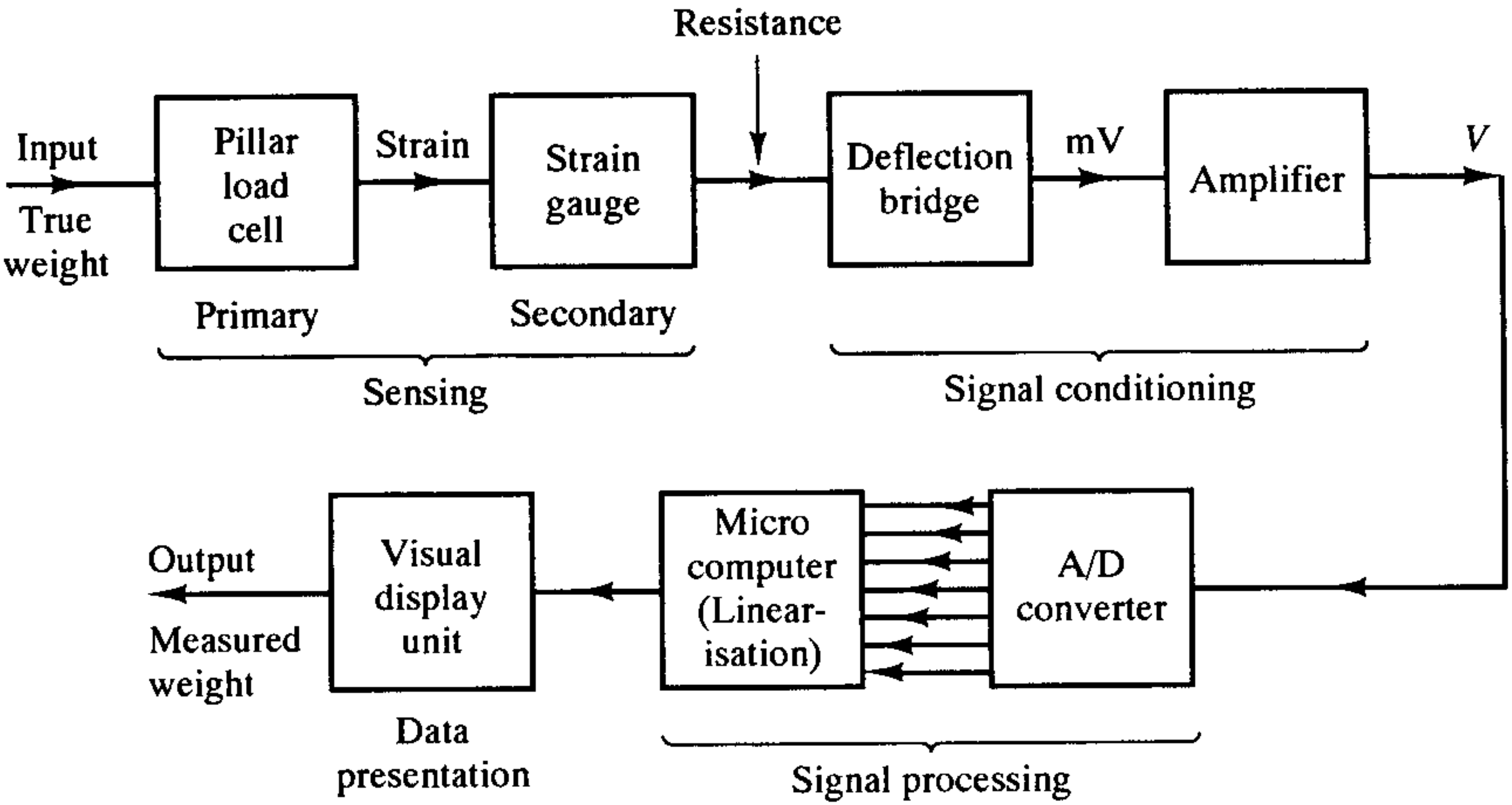
Computer Monitor

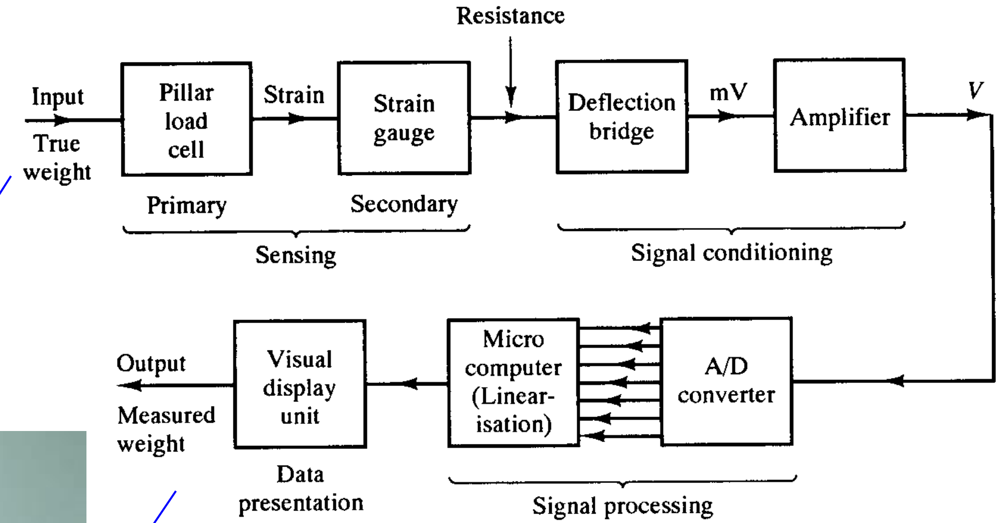




Example: Weight Measurement

A weight measurement system can be illustrated as incorporating one or more of each of these types of elements.




Resistance
Input
True weight
Pillar load cell
Strain
Strain gauge
Deflection bridge
mV
Amplifier
V
Primary
Secondary
Sensing
Signal conditioning
Output
Measured weight
Visual display unit
Micro computer (Linear-isation)
A/D converter
Data presentation
Signal processing


Precisa
32.51 g
ON/OFF
MODE
T
REF
PRINT

Data Acquisition Cards

Data acquisition (DAQ) is the process of sampling signals that measure real world physical conditions.

DAQ electronic cards typically convert analog waveforms into digital values for processing.

See Also: http://www.ni.com/data-acquisition

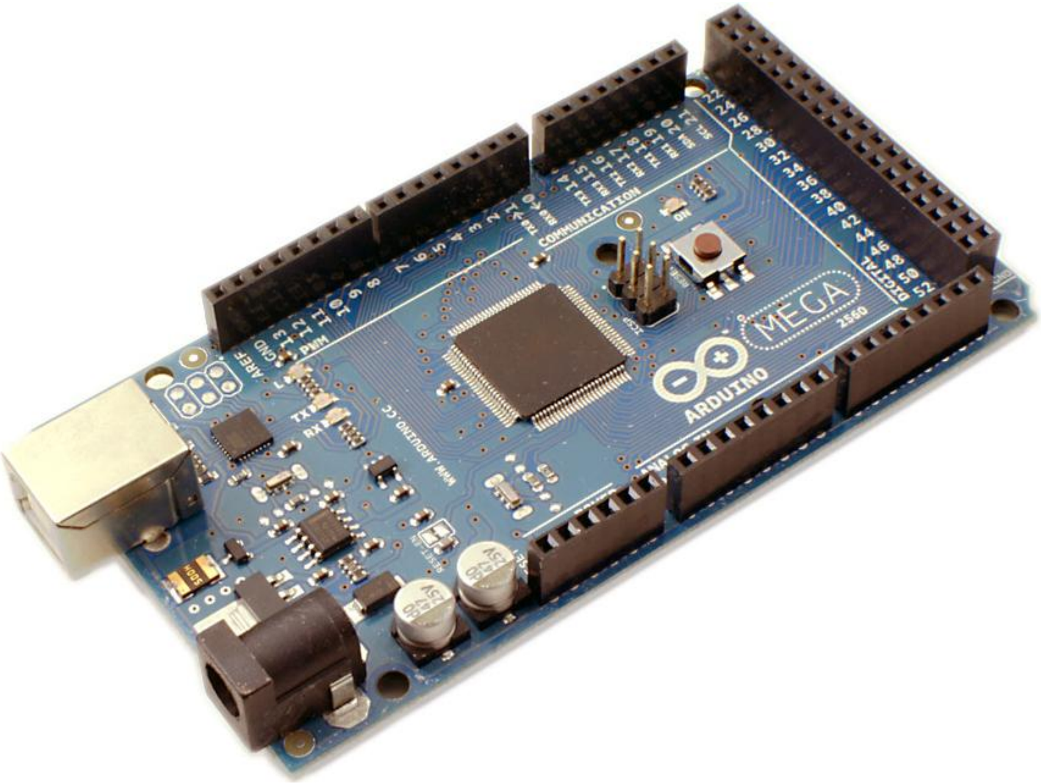
Example DAQ card: Arduino Mega

10-Bit resolution

16 MHz

50-bit digital input

15-bit analog input



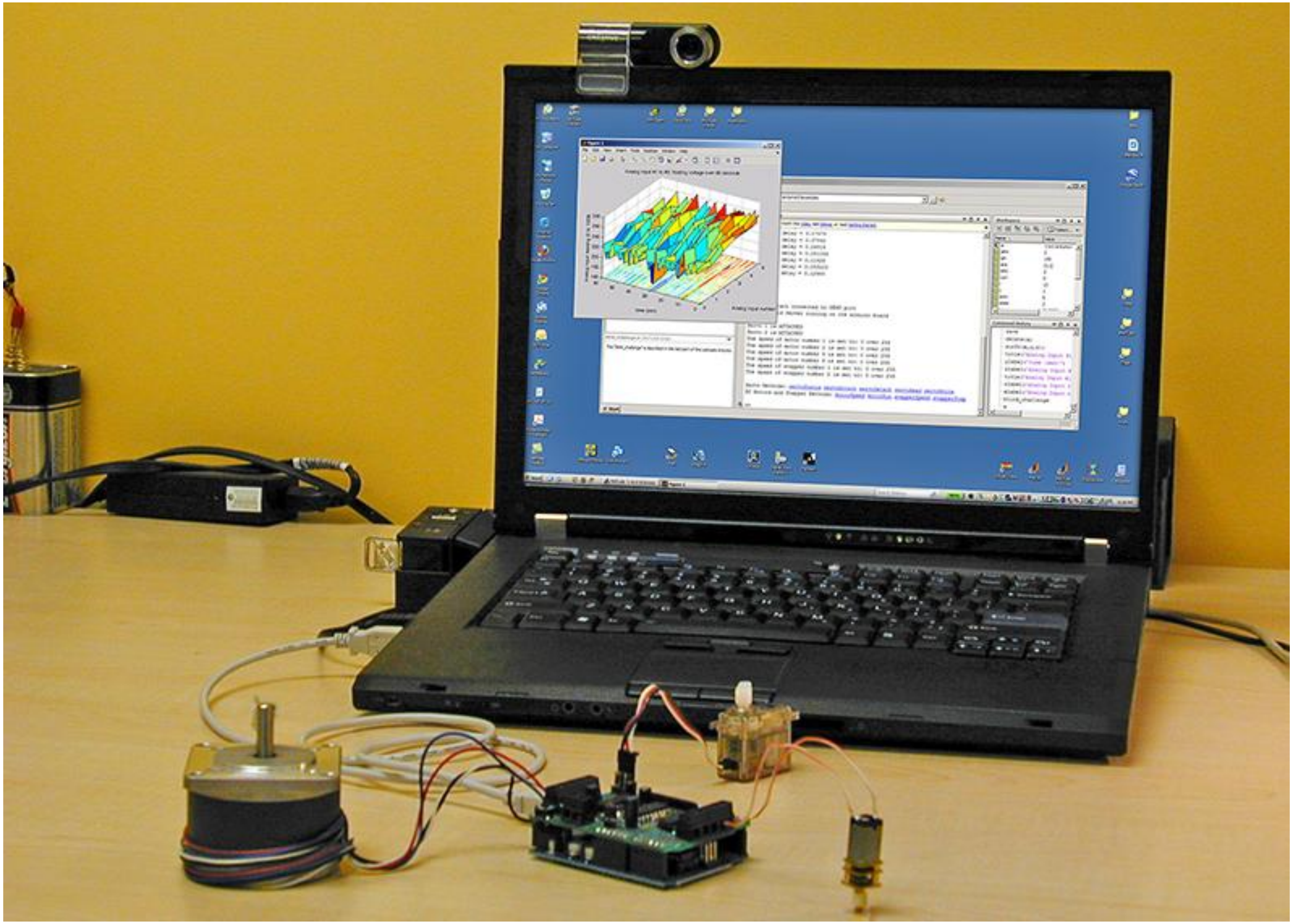
Example DAQ card: USB-1608FS-Plus

16-Bit resolution,

400 kS/s,

Multifunction USB Data Acquisition Device

Software



PART II

THE STATIC CAHARCTERISTICS
OF
MEASUREMENT SYSTEMS

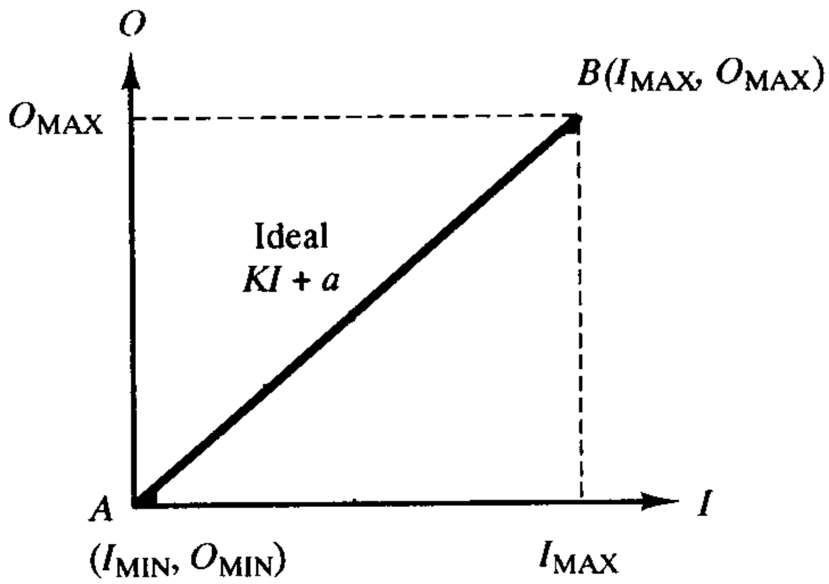
Systematic Characteristics

This is realated to relationships between
the output ***O*** and the input ***I***.

Linearty:

An elemen is said to be linear if corresponding values of ***I*** and ***O*** lie on a straight line.

The ideal straight line connects
the minimum point A(Imin, Omin)
To
the maximum point B(Imax,Omax).

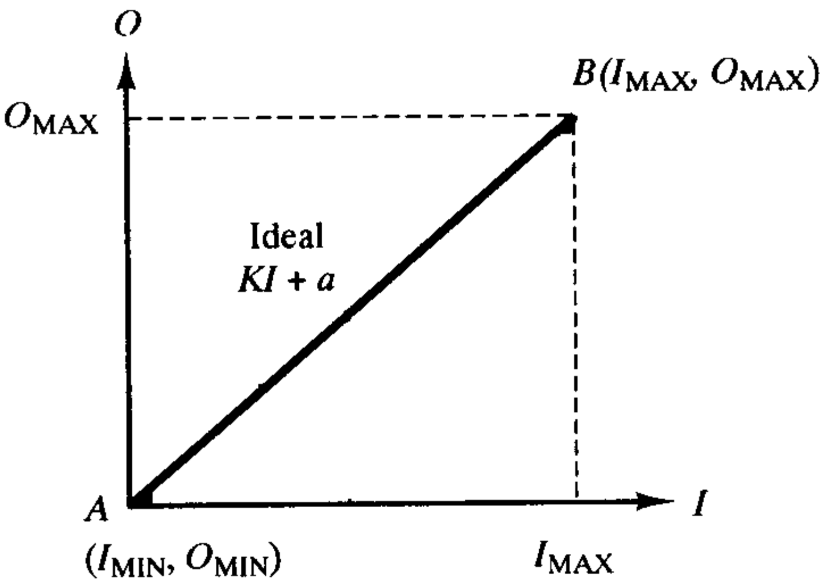


The ideal line equation:

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

or

$$O = KI + a$$



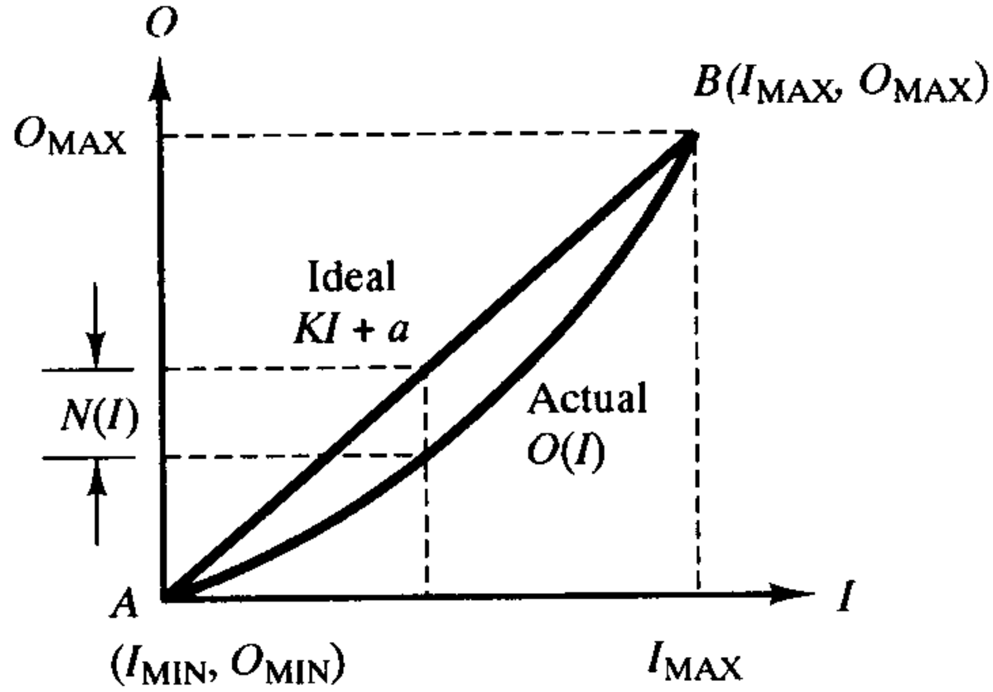
Non-Linearity:

In many cases the ideal line relationship is not obeyed and the element is said to be **non-linear**.

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

or

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



Sensitivity (S):

This is the rate of change of *O* with respect to *I*.

$$S = \frac{dO}{dI}$$

For example: A pressure sensor produces an output as follows

$$O = 0.16I + 4.0$$

where

I is the input pressure in Pa

O is the output in mV.

So

$$S = \frac{dO}{dI} = 0.16 \text{ mV/Pa}$$

Example

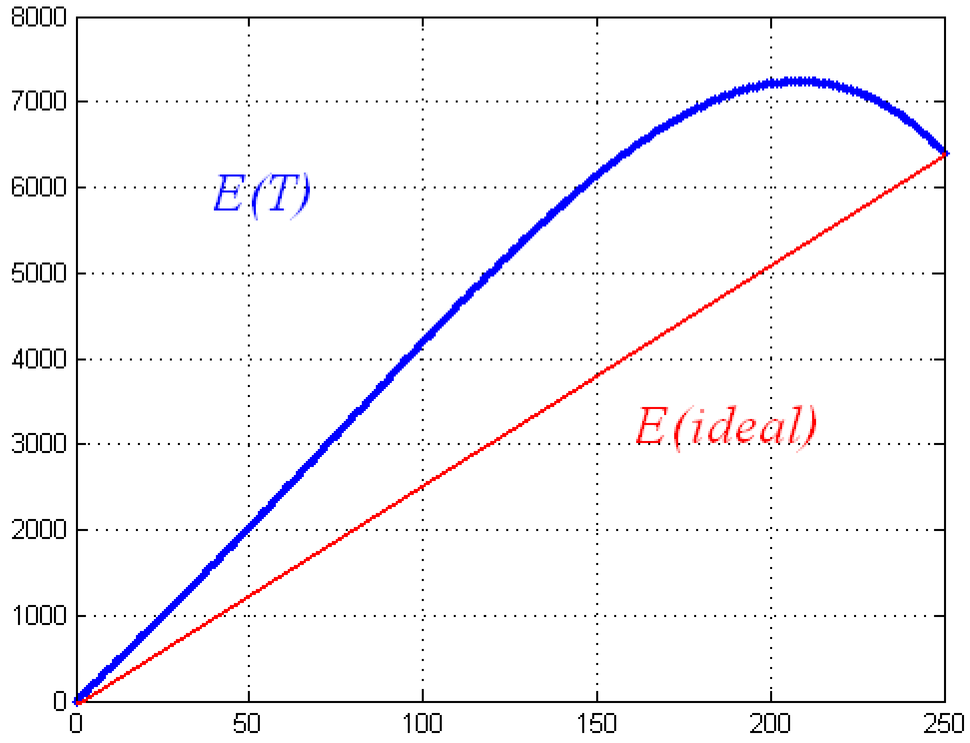
Consider a thermocouple generates the following output (μV) for the input temperature T (oC).

$$E(T) = (38.74)T + (3.32\text{x}10^{-2})T^{2} + (2.07\text{x}10^{-4})T^{3} - (2.20\text{x}10^{-4})T^{4}$$

$E = 0$ at T=0 and E = 6400 μV at T=250 oC.

```
octave:> T = 0:250;
octave:> E = (38.74)*T+(3.32e-2)*T.^2+(2.07e-4)*T.^3-(2.20e-6)*T.^4;
octave:> plot(T,E,'.')
octave:> grid on
```

$$E(T) = (38.74)T + (3.32\text{x}10^{-2})T^2 + (2.07\text{x}10^{-4})T^3 - (2.20\text{x}10^{-4})T^4$$



(a) Find the equation of E(Ideal)

(b) Find the equation of $N(T)$ (non-linearity function)

(c) Find the sensitivity at T = 200 oC.

Example

A temperature measurement element has an input range of 26 to 110 Celcius. The output of the element (micro-volts) is measured under standard conditions and a third-order polynomial fit to the data yields the following calibration function:

$$O(T) = 0.90010800 + 0.09152215T + 0.00009274T^2 + 0.00000103T^3$$

a) write down the input span for this data

b) write down the output span for this data

c) write down the ideal linear response equation

d) write down the non-linearity function

e) write down the maximum non-linearity

Answers:

c) $O_{ideal} = 0.23424280 + 0.12023987T$

d) $N(T) = 0.66586520 - 0.02871772T + 0.00009274T^2 + 0.00000103T^3$

e) A Maximum non-linearity of -0.536942 micro-volts occurs at 71 Celcius

In general, the output O depends not only on the input signal I but also on environmental inputs such as

- temperature,
- atmospheric pressure,
- relative humidity,
- supply voltage
- etc.

Hence the equation

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

represents the behavior under standard conditions (e.g. 20 oC, 1000 mbar, 50% RH, 10 V, etc)

Once you perform your experiment,
you should include the effects of environmental conditions.

That is you need to add a modifying input function such that:

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

Where Im is the modifying input.

References

1. “Principles of Measurement Systems”, J.P.Bentley, Longman Scientific & Techical (3rd Ed)
2. “Probability and Statistics” - M. Spiegel et. al., Shaum
3. “Probability” - S. Lipshutz, Shaum
4. “Radiation Detection and Measurement”, G.F.Knoll, Wiley