INTRODUCTION TO INSTRUMENTATION

INTRODUCTION

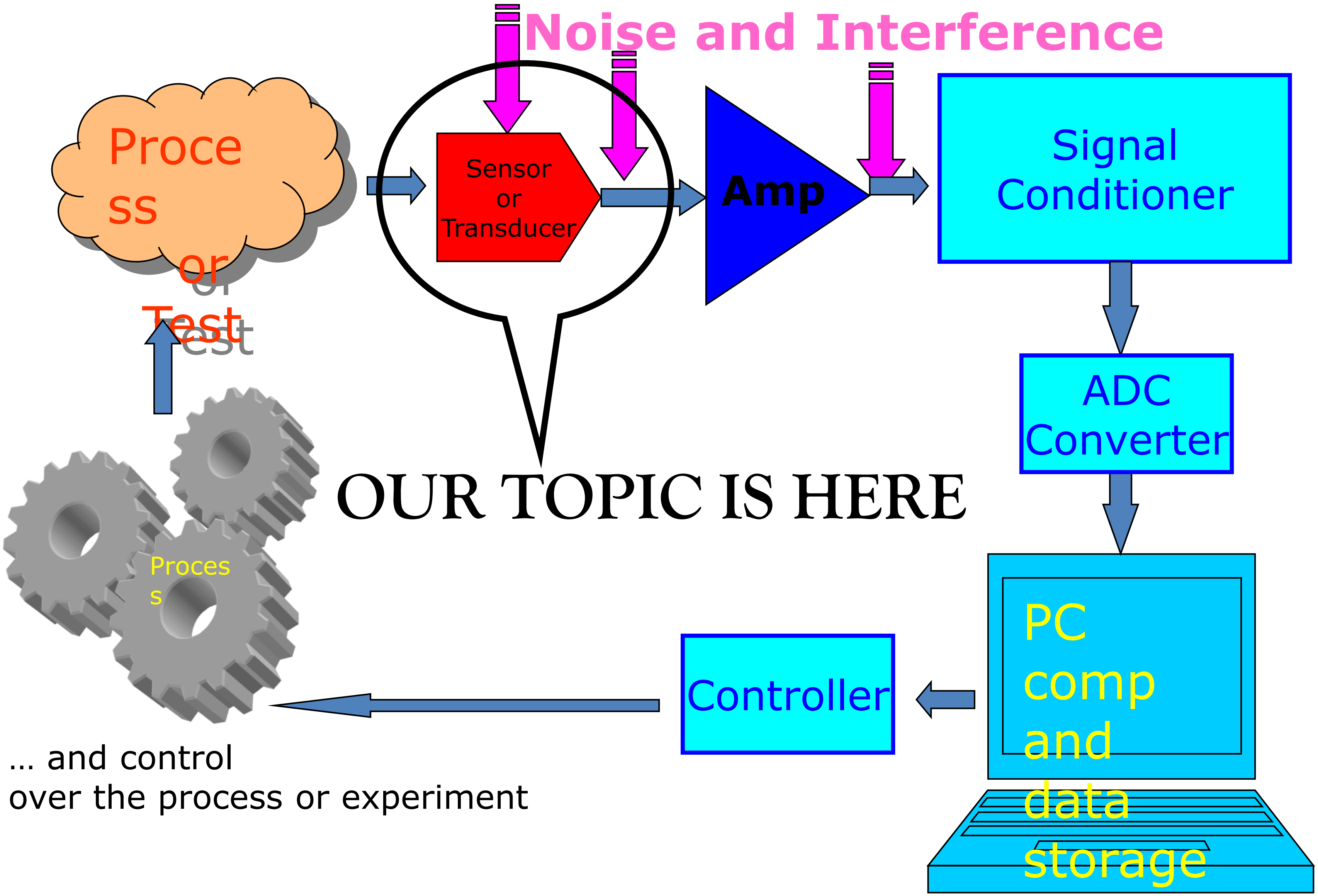
- Instrumentation is a technology of measurement which serves sciences, engineering, medicine and etc.
- Measurement is the process of determining the amount, degree or capacity by comparison with the accepted standards of the system units being used.
- Instrument is a device for determining the value or magnitude of a quantity or variable.
- Electronic instrument is based on electrical or electronic principles for its measurement functions.

FUNCTION AND ADVANTAGES

- The 3 basic functions of instrumentation :-
  - **Indicating** – visualize the process/operation
  - **Recording** – observe and save the measurement reading
  - **Controlling** – to control measurement and process

- Advantages of electronic measurement
  - Results high sensitivity rating – the use of amplifier
  - Increase the input impedance – thus lower loading effects
  - Ability to monitor remote signal

Typical Measurement System Architecture



Examples of Electronic Sensor applications

Uses infrared optical sensor

New Solar Power Faucet by Sloan Valve
•0.5 gpm aerator regulates water flow
•Electronic sensor automatically turns water on/off
•Integral temperature control

PERFORMANCE CHARACTERISTICS

- Performance Characteristics - characteristics that show the performance of an instrument.
  - Eg: accuracy, precision, resolution, sensitivity.
- Allows users to select the most suitable instrument for a specific measuring jobs.
- Two basic characteristics :
  - Static – measuring a constant process condition.
  - Dynamic - measuring a varying process condition.

PERFORMANCE CHARACTERISTICS

- Accuracy – the degree of exactness (closeness) of measurement compared to the expected (desired) value.
- Resolution – the smallest change in a measurement variable to which an instrument will respond.
- Precision – a measure of consistency or repeatability of measurement, i.e successive reading do not differ.
- Sensitivity – ratio of change in the output (response) of instrument to a change of input or measured variable.
- Expected value – the design value or the most probable value that expect to obtain.
- Error – the deviation of the true value from the desired value.

ERROR IN MEASUREMENT

- Measurement always introduce error
- Error may be expressed either as absolute or percentage of error

Absolute error, e = $Y_n - X_n$

where Y_n – expected value

X_n – measured value

% error = $\left|\frac{Y_n - X_n}{Y_n}\right| \times 100$

ERROR IN MEASUREMENT

Relative accuracy, $A = 1 - \left| \frac{Y_n - X_n}{Y_n} \right|$

% Accuracy, a = 100% - % error

= $A \times 100$

Precision, P = $1 - \left| \frac{X_n - \overline{X_n}}{\overline{X_n}} \right|$

where X_n - value of the n[th] measurement

$\overline{X_n}$ - average set of measurement

LIMITING ERROR

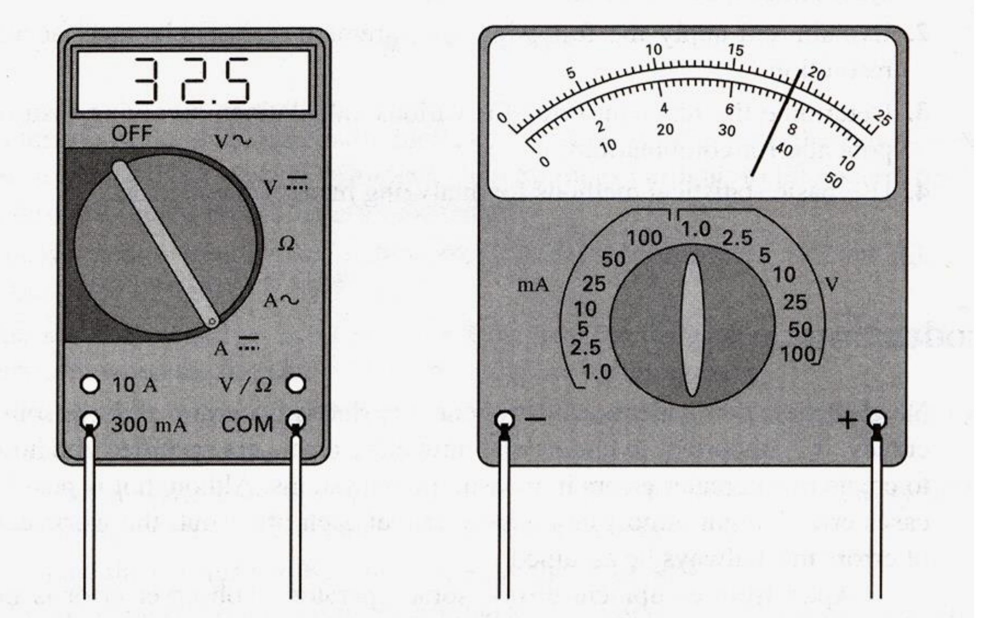
- The accuracy of measuring instrument is guaranteed within a certain percentage (%) of full scale reading
- E.g manufacturer may specify the instrument to be accurate at ±2 % with full scale deflection
- For reading less than full scale, the limiting error increases

TYPES OF STATIC ERROR

- Types of static error

    1) Gross error/human error
    2) Systematic Error
    3) Random Error

1. **Gross Errors or Human Errors**
   - Resulting from carelessness, e.g. misreading, incorrectly recording

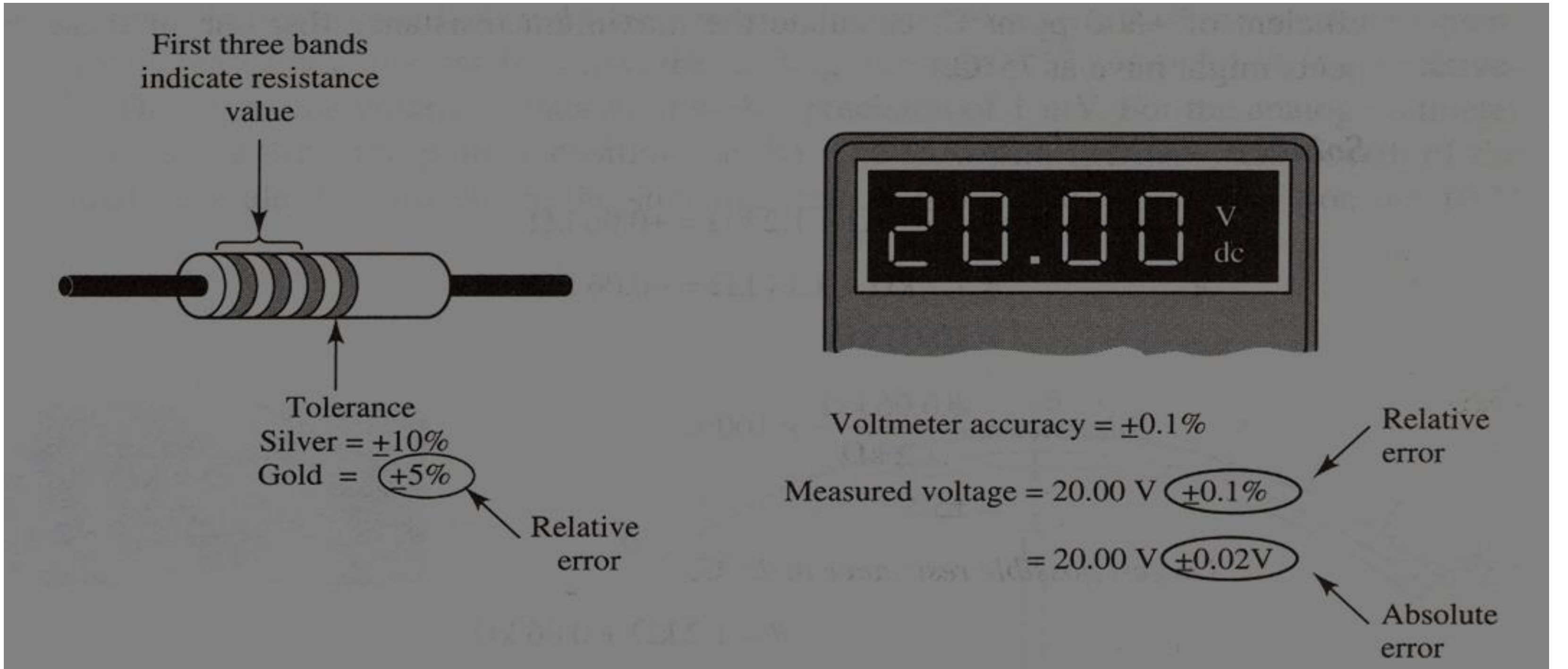


(a) Digital instrument indicating 32.5 mA

(b) Analog instrument indicating 0.76 V

Serious measurement errors can occur if an instrument is not read correctly. The digital instrument is on a 300 mA range, so its reading is in milliamperes. For the analog meter, the range selection must be noted, and the pointer position must be read from the correct scale

Absolute Errors and Relative Errors

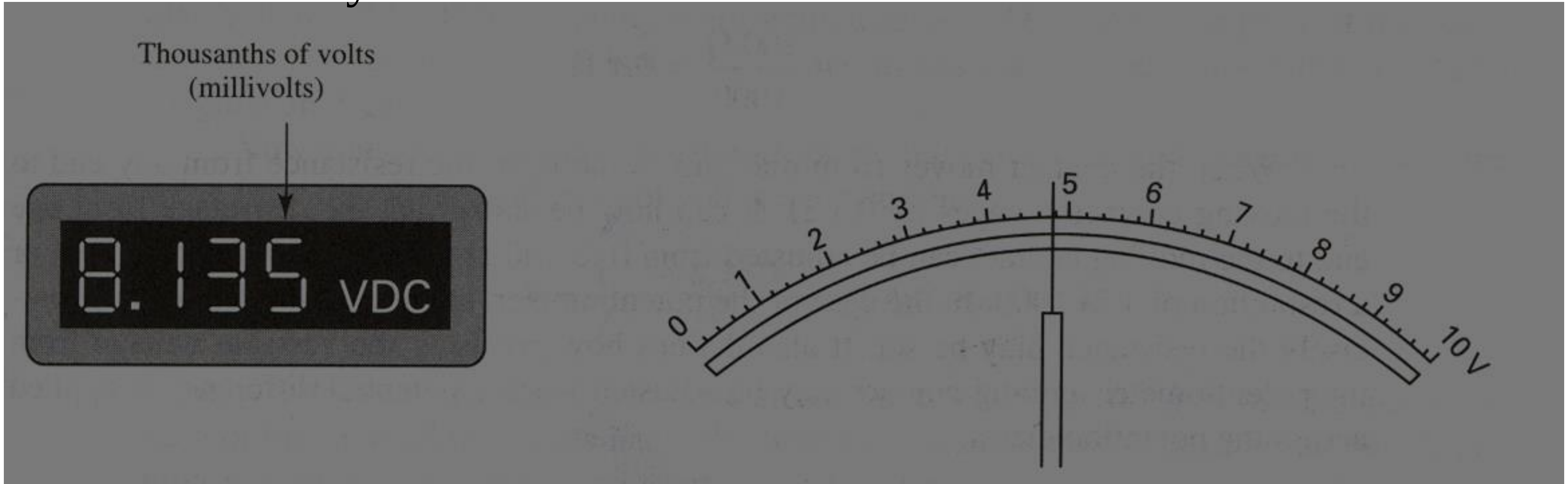


(a) Resistor tolerance is identified by a colored band

(b) Voltmeter accuracy defines the upper and lower limits of measured quantity

Percentage accuracy gives the relative error in a measured, or specified quantity. The absolute error can be determined by converting the percentage error into an absolute quantity

- Accuracy, Precision, Resolution, and Significant Figures
  - Accuracy (A) and Precision
    - The measurement accuracy of ±1% defines how close the measurement is to the actual measured quality.
    - The precision is not the same as the accuracy of measurement, but they are related



(a) Digital voltmeter display with a precision of 1 mV

(b) Analog instrument display with a precision of 50 mV

Measurement precision depends on the smallest change that can be observed in the measured quantity. A 1mV change will be indicated on the digital voltmeter display above. For the analog instrument, 50 mV is the smallest change that can be noted

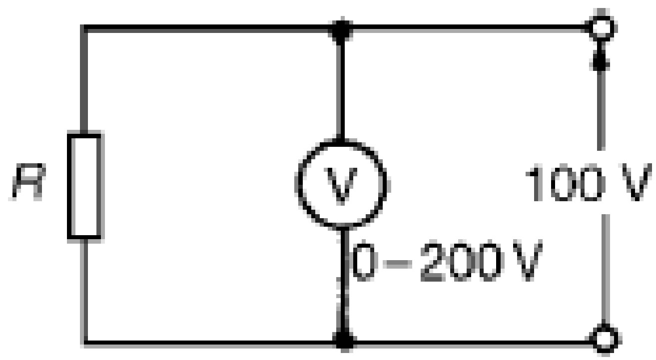
Instrument ‘loading’ effect : Some measuring instruments depend for their operation on power taken from the circuit in which measurements are being made. Depending on the ‘loading’ effect of the instrument (i.e. the current taken to enable it to operate), the prevailing circuit conditions may change.

The resistance of voltmeters may be calculated since each have a stated sensitivity (or ‘figure of merit’), often stated in ‘k per volt’ of f.s.d. A voltmeter should have as high a resistance as possible (ideally infinite).

In a.c. circuits the impedance of the instrument varies with frequency and thus the loading effect of the instrument can change.

Example:

Calculate the power dissipated by the voltmeter and by resistor R in Figure 10.9 when (a) R=250 Ω, (b) R=2 MΩ. Assume that the voltmeter sensitivity (sometimes called figure of merit) is 10 kΩ/V



(a) Resistance of voltmeter, R_v = sensitivity × f.s.d.

Hence, $R_v = (10\ \text{k}\Omega/\text{V}) \times (200\ \text{V}) = 2000\ \text{k}\Omega = 2\ \text{M}\Omega$

Current flowing in voltmeter, $I_v = \dfrac{V}{R_v} = \dfrac{100}{2 \times 10^6} = 50 \times 10^{-6}\text{A}$

Power dissipated by voltmeter $= VI_v = (100)(50 \times 10^{-6}) = \mathbf{5\ mW}$

When $R = 250\ \Omega$, current in resistor, $I_R = \dfrac{V}{R} = \dfrac{100}{250} = \mathbf{0.4\ A}$

Power dissipated in load resistor $R = VI_R = (100)(0.4) = \mathbf{40\ W}$

Thus the power dissipated in the voltmeter is insignificant in comparison with the power dissipated in the load.

(b) When $R = 2\ \text{M}\Omega$, current in resistor, $I_R = \dfrac{V}{R} = \dfrac{100}{2 \times 10^6}$

$$= 50 \times 10^{-6}\text{A}$$

Power dissipated in load resistor $R = VI_R = 100 \times 50 \times 10^{-6}$

$$= \mathbf{5\ mW}$$

In this case the higher load resistance reduced the power dissipated such that the voltmeter is using as much power as the load.

2. Systematic Error: due to shortcomings of the instrument (such as defective or worn parts, ageing or effects of the environment on the instrument)

- In general, systematic errors can be subdivided into static and dynamic errors.
  - Static – caused by limitations of the measuring device or the physical laws governing its behavior.
  - Dynamic – caused by the instrument not responding very fast enough to follow the changes in a measured variable.

\- 3 types of systematic error :-

(i) Instrumental error

(ii) Environmental error

(iii) Observational error

Types of static error

(i) Instrumental error

- inherent while measuring instrument because of their mechanical structure **(eg: in a D'Arsonval meter, friction in the bearings of various moving component**, irregular spring tension, stretching of spring, etc)

- error can be avoid by:

(a) selecting a suitable instrument for the particular measurement application

(b) apply correction factor by determining instrumental error

(c) calibrate the instrument against standard

(ii) Environmental error

- due to external condition effecting the measurement including surrounding area condition such as change in temperature, humidity, barometer pressure, etc
- to avoid the error :-
  (a) use air conditioner
  (b) sealing certain component in the instruments
  (c) use magnetic shields

(iii) Observational error

- introduce by the observer
- most common : parallax error and estimation error (while reading the scale)
- Eg: an observer who tend to hold his head too far to the left while reading the position of the needle on the scale.

3) Random error

- due to unknown causes, occur when all systematic error has accounted
- accumulation of small effect, require at high degree of accuracy
- can be avoid by
  (a) increasing number of reading
  (b) use statistical means to obtain best approximation of true value

2- Systematic Errors versus Random errors

- Systematic Errors
  - Instrumental Errors
    - Friction
    - Zero positioning
  - Environment Errors
    - Temperature
    - Humidity
    - Pressure
  - Observational Error
- Random Errors

Dynamic Characteristics

- Dynamic – measuring a varying process condition.
- Instruments rarely respond instantaneously to changes in the measured variables due to such things as mass, thermal capacitance, fluid capacitance or electrical capacitance.
- Pure delay in time is often encountered where the instrument waits for some reaction to take place.
- Such industrial instruments are nearly always used for measuring quantities that fluctuate with time.
- Therefore, the dynamic and transient behavior of the instrument is important.

Dynamic Characteristics

- The dynamic behavior of an instrument is determined by subjecting its primary element (sensing element) to some unknown and predetermined variations in the measured quantity.
- The three most common variations in the measured quantity:
  - Step change
  - Linear change
  - Sinusoidal change

Dynamic Characteristics

- **Step change-**in which the primary element is subjected to an instantaneous and finite change in measured variable.
- **Linear change-**in which the primary element is following the measured variable, changing linearly with time.
- **Sinusoidal change-**in which the primary element follows a measured variable, the magnitude of which changes in accordance with a sinusoidal function of constant amplitude.

Dynamic Characteristics

- The dynamic performance characteristics of an instrument are:
  - Speed of response- The rapidity with which an instrument responds changes in measured quantity.
  - Dynamic error-The difference between the true and measured value with no static error.
  - Lag – delay in the response of an instrument to changes in the measured variable.
  - Fidelity – the degree to which an instrument indicates the changes in the measured variable without dynamic error (faithful reproduction).

Standard

- A standard is a known accurate measure of physical quantity.
- Standards are used to determine the values of other physical quantities by the comparison method.
- All standards are preserved at the International Bureau of Weight and Measures (BIMP), Paris.
- Four categories of standard:
  - International Standard
  - Primary Standard
  - Secondary Standard
  - Working Standard

Standard

- International Std
  - Defined by International Agreement
  - Represent the closest possible accuracy attainable by the current science and technology

- Primary Std
  - Maintained at the National Std Lab (different for every country)
  - Function: the calibration and verification of secondary std
  - Each lab has its own secondary std which are periodically checked and certified by the National Std Lab.
  - For example, in Malaysia, this function is carried out by SIRIM.

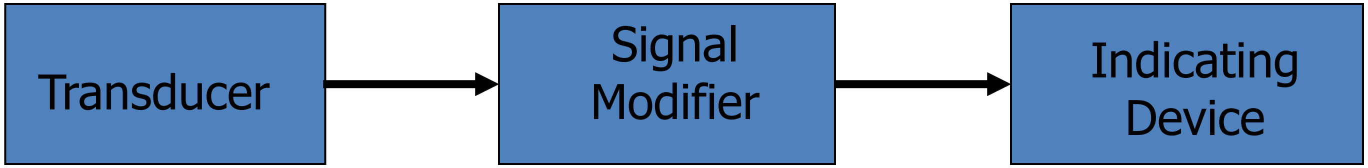
Standard

- Secondary Standard
  - Secondary standards are basic reference standards used by measurement and calibration laboratories in industries.
  - Each industry has its own secondary standard.
  - Each laboratory periodically sends its secondary standard to the National standards laboratory for calibration and comparison against the primary standard.
  - After comparison and calibration, the National Standards Laboratory returns the secondary standards to particular industrial laboratory with a certification of measuring accuracy in terms of a primary standard.

- Working Std
  - Used to check and calibrate lab instrument for accuracy and performance.
  - For example, manufacturers of electronic components such as capacitors, resistors and many more use a standard called a working standard for checking the component values being manufactured.

ELECTRONIC INSTRUMENT

- Basic elements of an electronics instrument



1) Transducer
   - convert a non electrical signal into an electrical signal
   - e.g: a pressure sensor detect pressure and convert it to electricity for display at a remote gauge.
2) Signal modifier
   - convert input signal into a suitable signal for the indicating device
3) Indicating device
   - indicates the value of quantity being measure