MEASUREMENT AND INSTRUMENTATION (EEE326.2)

BY

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DEPARMENT OF ELECTRICAL ENGINEERING

LECTURE 1

INTRODUCTION

MEASUREMENT

- Measurement is the process of determining the amount, degree or capacity by comparison with the accepted standards of the system units being used.
- Measurement is the act, or the result of a quantitative comparison between a given quantity and a quantity of the same kind chosen as a unit.
- Measurements are carried to conform compliance of a system to a pre-determined or pre-established or pre-conceived information or data.

MEASUREMENT ….contd

- The result of the measurement is expressed by a pointer deflection over a predefined scale or a number representing the ratio between the unknown quantity and the standard.
- A standard is defined as a physical personification of the unit of measurement and its submultiple or multiple values.
- The device or instrument used for comparing the unknown quantity with the unit of measurement or a standard quantity is called *measuring instrument*

INSTRUMENTATION

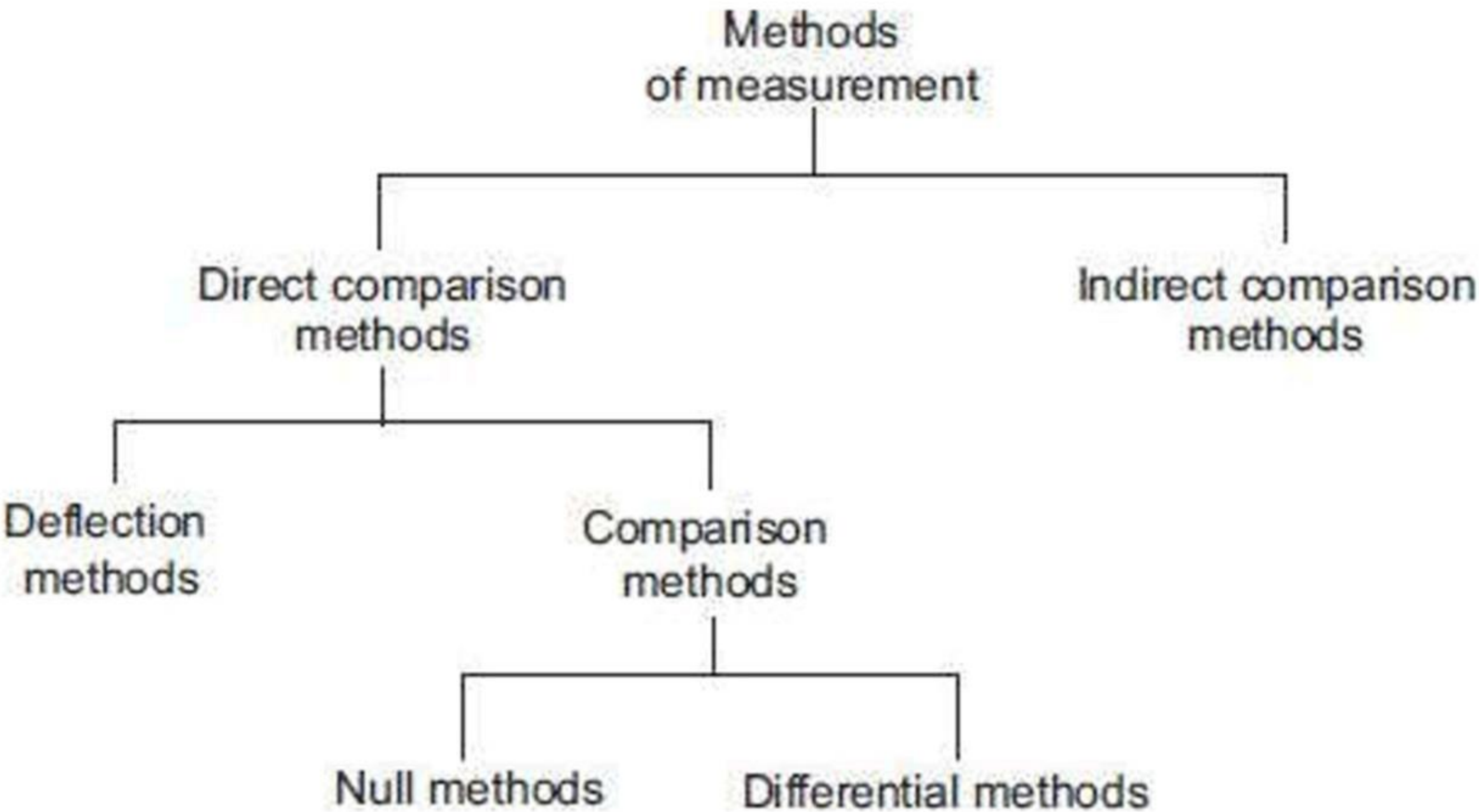
- Instruments are tools designed and adapted for effective measurement in control processes. They are devices for determining the value or magnitude of a quantity or variable. Electronic instruments are based on electrical or electronic principles for its measurement functions.

INSTRUMENTATION..contd

Instruments are tools but tools are not necessarily instruments

- Instrumentation; a technology of measurement which serves sciences, engineering, medicine etc is an arrangement of instruments and the necessary accessories for effective measurement or control processes.

METHODS OF MEASUREMENT



METHODS OF MEASUREMENT

In direct measurement methods, the unknown quantity is measured directly. Direct methods of measurement are of two types, namely, *deflection methods* and *comparison methods*.

In deflection methods, the value of the unknown quantity is measured by the help of a measuring instrument having a calibrated scale indicating the quantity under measurement directly, such as measurement of current by an ammeter.

In comparison methods, the value of the unknown quantity is determined by direct comparison with a standard of the given quantity, such as measurement of emf by comparison with the emf of a standard cell. Comparison methods can be classified as null methods, differential methods, etc. In null methods of measurement, the action of the unknown quantity upon the instrument is reduced to zero by the counter action of a known quantity of the same kind, such as measurement of weight by a balance, measurement of resistance, capacitance, and inductance by bridge circuits.

In indirect measurement methods, the comparison is done with a standard through the use of a calibrated system. These methods for measurement are used in those cases where the desired parameter to be measured is difficult to be measured directly, but the parameter has got some relation with some other related parameter which can be easily measured.

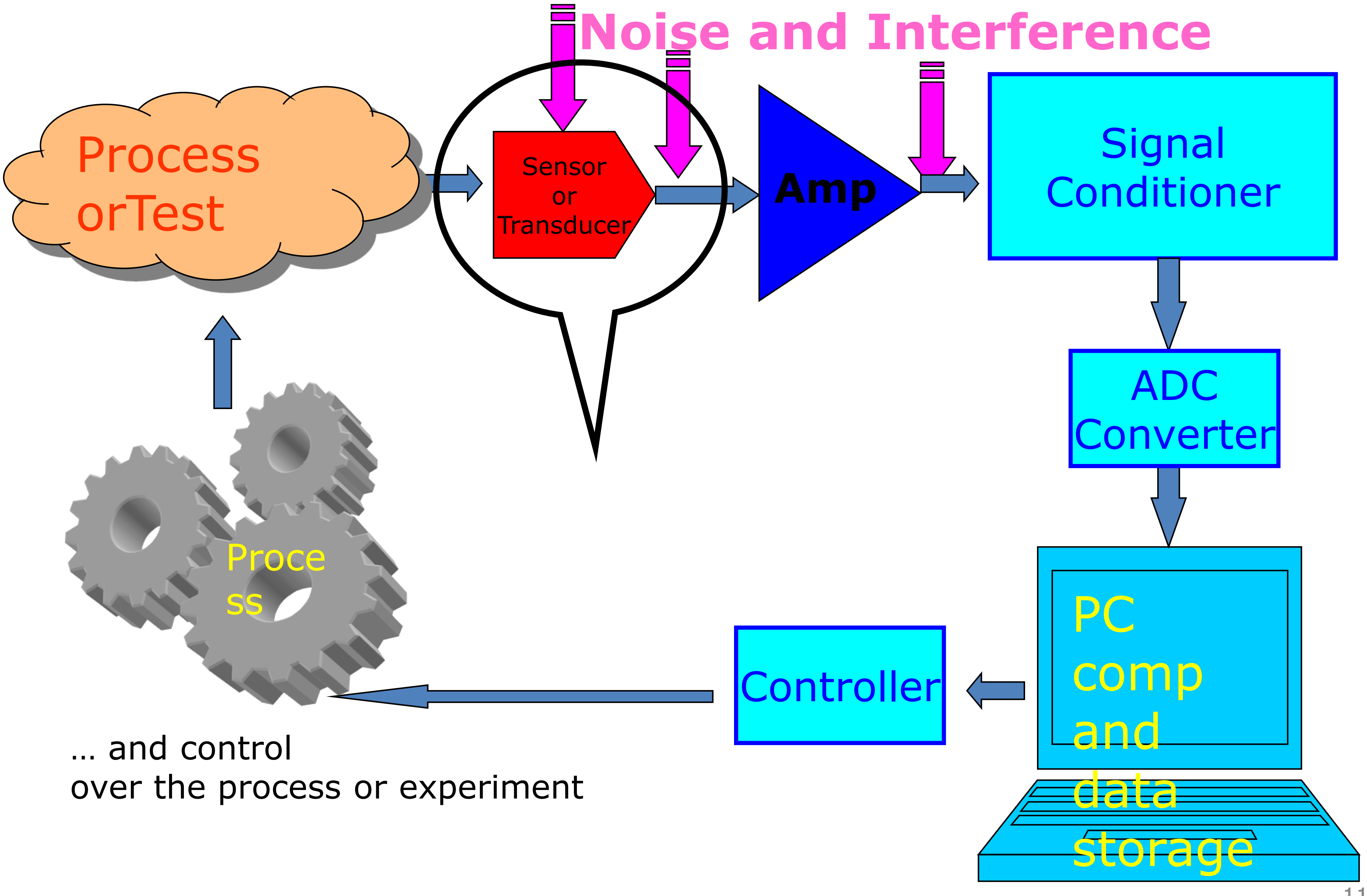
For instance, the elimination of bacteria from some fluid is directly dependent upon its temperature. Thus, the bacteria elimination can be measured indirectly by measuring the temperature of the fluid.

In indirect methods of measurement, it is general practice to establish an empirical relation between the actual measured quantity and the desired parameter.

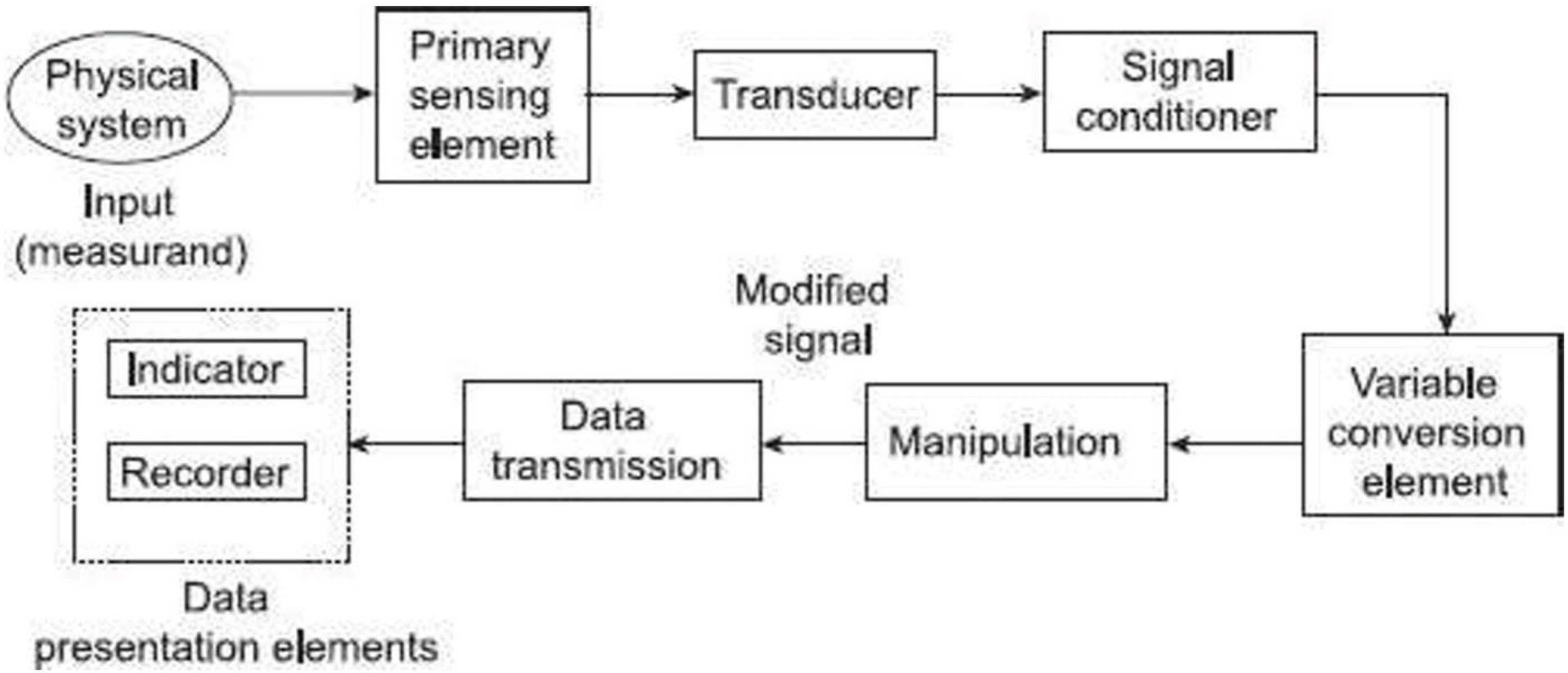
MEASUREMENT SYSTEM AND ELEMENTS

- A measurement system may be defined as a systematic arrangement for the measurement or determination of an unknown quantity and analysis of instrumentation.
- The operation of a measurement system can be explained in terms of functional elements of the system. Every instrument and measurement system is composed of one or more of these functional elements and each of these functional elements is made up of distinct components or group of components which perform defined or required steps in measurement.

Typical Measurement System Architecture



… and control
over the process or experiment


Physical system
Input (measurand)
Primary sensing element
Transducer
Signal conditioner
Variable conversion element
Manipulation
Modified signal
Data transmission
Indicator
Recorder
Data presentation elements

Primary Sensing Elements

It is an element that is sensitive to the measured variable. The physical quantity under measurement, called the *measurand*, makes its first contact with the primary sensing element of a measurement system. The measurand is always disturbed by the act of the measurement, but good instruments are designed to minimise this effect. Primary sensing elements may have a non-electrical input and output such as a spring, manometer or may have an electrical input and output such as a rectifier. In case the primary sensing element has a non-electrical input and output, then it is converted into an electrical signal by means of a transducer. The transducer is defined as a device, which when actuated by one form of energy, is capable of converting it into another form of energy.

Many a times, certain operations are to be performed on the signal before its further transmission so that interfering sources are removed in order that the signal may not get distorted. The process may be linear such as amplification, attenuation, integration, differentiation, addition and subtraction or nonlinear such as modulation, detection, sampling, filtering, chopping and clipping, etc. The process is called signal conditioning. So a signal conditioner follows the primary sensing element or transducer, as the case may be. The sensing element senses the condition, state or value of the process variable by extracting a small part of energy from the measurand, and then produces an output which reflects this condition, state or value of the measurand.

Variable Conversion Elements

After passing through the primary sensing element, the output is in the form of an electrical signal, may be voltage, current, frequency, which may or may not be accepted to the system. For performing the desired operation, it may be necessary to convert this output to some other suitable form while retaining the information content of the original signal. For example, if the output is in analog form and the next step of the system accepts only in digital form then an analog-to-digital converter will be employed. Many instruments do not require any variable conversion unit, while some others require more than one element.

Manipulation Elements

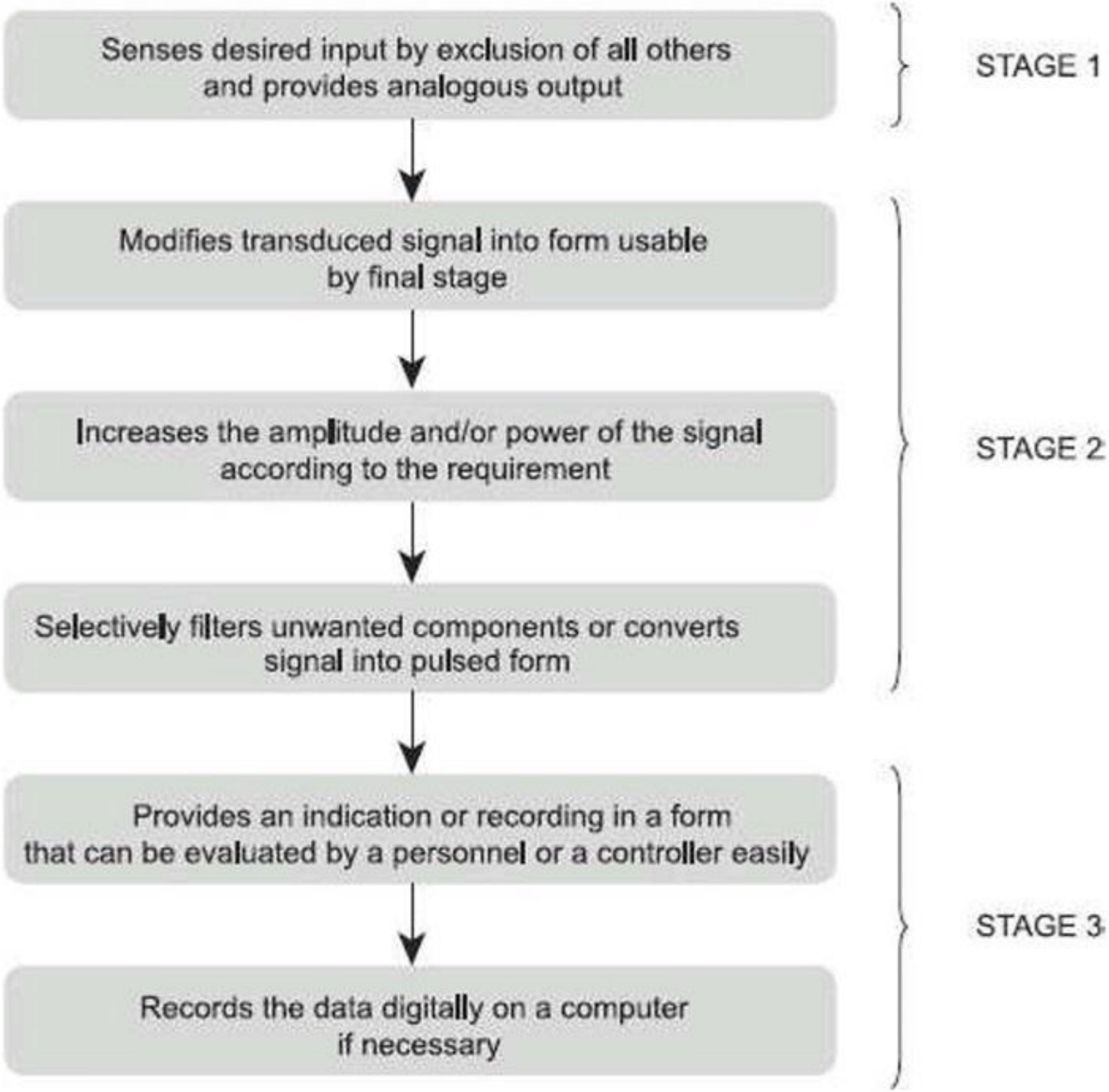
Sometimes it is necessary to change the signal level without changing the information contained in it for the acceptance of the instrument. The function of the variable manipulation unit is to manipulate the signal presented to it while preserving the original nature of the signal. For example, an electronic amplifier converts a small low voltage input signal into a high voltage output signal. Thus, the voltage amplifier acts as a variable manipulation unit. Some of the instruments may require this function or some of the instruments may not.

Data Transmission Elements

- The data transmission elements are required to transmit the data containing the information of the signal from one system to another. For instance ,satellites are physically separated from the earth where the control stations guiding their movement are located.

Data Presentation Elements

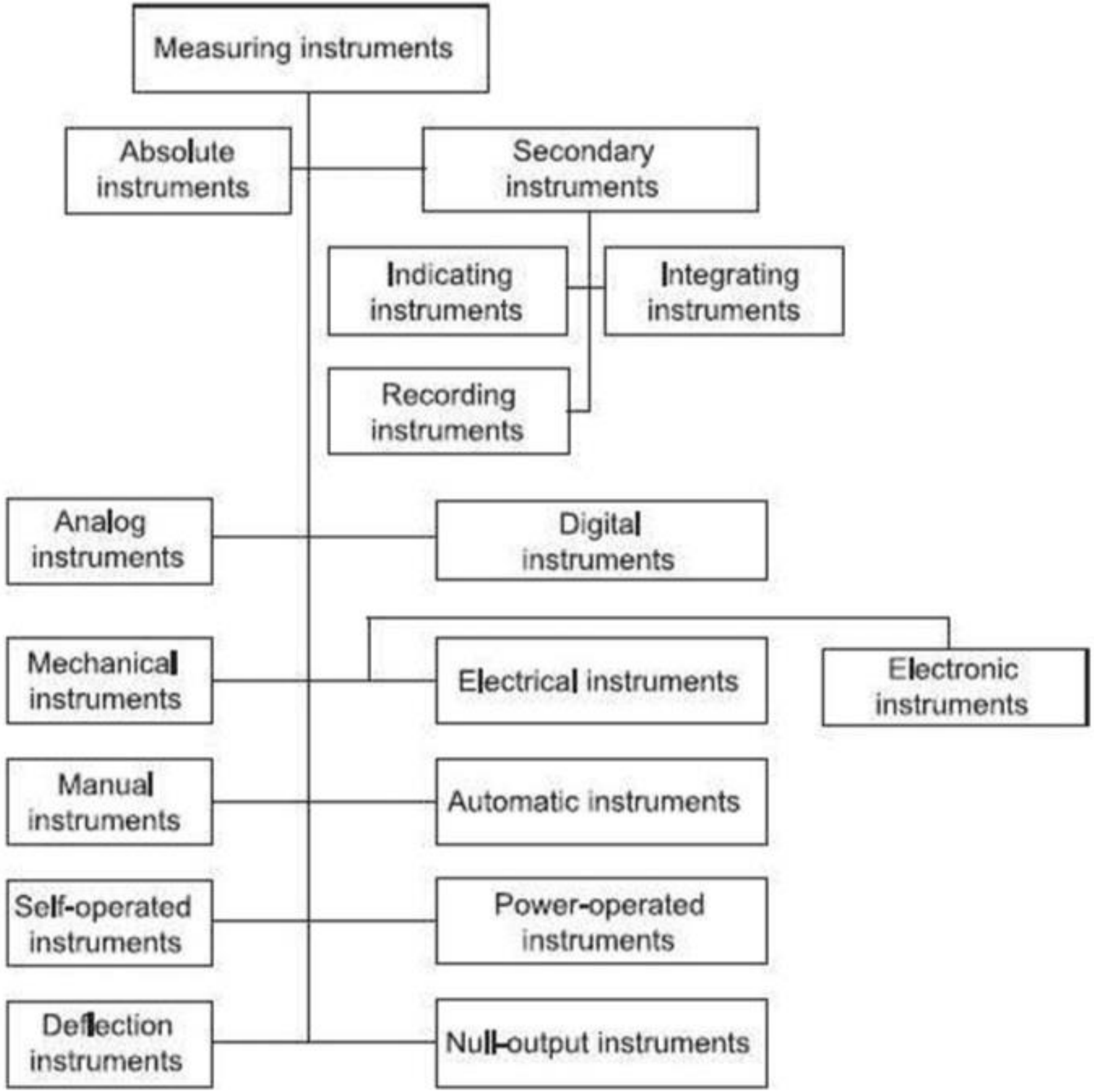
The function of the data presentation elements is to provide an indication or recording in a form that can be evaluated by an unaided human sense or by a controller. The information regarding measurand (quantity to be measured) is to be conveyed to the personnel handling the instrument or the system for monitoring, controlling or analysis purpose. Such a device may be in the form of analog or digital format. The simplest form of a display device is the common panel meter with some kind of calibrated scale and pointer. In case the data is to be recorded, recorders like magnetic tapes or magnetic discs may be used. For control and analysis purpose, computers may be used.



Steps of a measurement system

CLASSIFICATION OF INSTRUMENTS

- Measuring instruments are classified into two:
- ABSOLUTE INSTRUMENTS
- SECONDARY INSTRUMENTS


Measuring instruments
Absolute instruments
Secondary instruments
Indicating instruments
Integrating instruments
Recording instruments
Analog instruments
Digital instruments
Mechanical instruments
Electrical instruments
Electronic instruments
Manual instruments
Automatic instruments
Self-operated instruments
Power-operated instruments
Deflection instruments
Null-output instruments

1. Absolute Instruments

The instruments of this type give the value of the measurand in terms of instrument constant and its deflection. Such instruments do not require comparison with any other standard. The example of this type of instrument is tangent galvanometer, which gives the value of the current to be measured in terms of tangent of the angle of deflection produced, the horizontal component of the earth's magnetic field, the radius and the number of turns of the wire used. Rayleigh current balance and absolute electrometer are other examples of absolute instruments. Absolute instruments are mostly used in standard laboratories and in similar institutions as standardising.

2. Secondary Instruments

These instruments are so constructed that the deflection of such instruments gives the magnitude of the electrical quantity to be measured directly. These instruments are required to be calibrated by comparison with either an absolute instrument or with another secondary instrument, which has already been calibrated before the use. These instruments are generally used in practice.

Secondary instruments are further classified as

- Indicating instruments
- Integrating instruments
- **Recording instruments**

(i) Indicating Instruments

Indicating instruments are those which indicate the magnitude of an electrical quantity at the time when it is being measured. The indications are given by a pointer moving over a calibrated (pregraduated) scale. Ordinary ammeters, voltmeters, wattmeters, frequency meters, power factor meters, etc., fall into this category.

(ii) Integrating Instruments

Integrating instruments are those which measure the total amount of either quantity of electricity (ampere-hours) or electrical energy supplied over a period of time. The summation, given by such an instrument, is the product of time and an electrical quantity under measurement. The ampere-hour meters and energy meters fall in this class.

(iii) Recording Instruments

Recording instruments are those which keep a continuous record of the variation of the magnitude of an electrical quantity to be observed over a definite period of time. In such instruments, the moving system carries an inked pen which touches lightly a sheet of paper wrapped over a drum moving with uniform slow motion in a direction perpendicular to that of the direction of the pointer. Thus, a curve is traced which shows the variations in the magnitude of the electrical quantity under observation over a definite period of time. Such instruments are generally used in powerhouses where the current, voltage, power, etc., are to be maintained within certain acceptable limit.

Analog and Digital Instruments

1. Analog Instruments

The signals of an analog unit vary in a continuous fashion and can take on infinite number of values in a given range. Fuel gauge, ammeter and voltmeters, wrist watch, speedometer fall in this category.

2. Digital Instruments

Signals varying in discrete steps and taking on a finite number of different values in a given range are digital signals and the corresponding instruments are of digital type. Digital instruments have some advantages over analog meters, in that they have high accuracy and high speed of operation. It eliminates the human operational errors. Digital instruments can store the result for future purposes. A digital multimeter is the example of a digital instrument.

Mechanical, Electrical and Electronics Instruments

1. Mechanical Instruments

Mechanical instruments are very reliable for static and stable conditions. They are unable to respond rapidly to the measurement of dynamic and transient conditions due to the fact that they have moving parts that are rigid, heavy and bulky and consequently have a large mass. Mass presents inertia problems and hence these instruments cannot faithfully follow the rapid changes which are involved in dynamic instruments. Also, most of the mechanical instruments causes noise pollution.

Advantages of Mechanical Instruments

- Relatively cheaper in cost
- More durable due to rugged construction
- Simple in design and easy to use
- No external power supply required for operation
- Reliable and accurate for measurement of stable and time invariant quantity

Disadvantages of Mechanical Instruments

- Poor frequency response to transient and dynamic measurements
- Large force required to overcome mechanical friction
- Incompatible when remote indication and control needed
- Cause noise pollution

Electrical Instruments

When the instrument pointer deflection is caused by the action of some electrical methods then it is called an electrical instrument. The time of operation of an electrical instrument is more rapid than that of a mechanical instrument. Unfortunately, an electrical system normally depends upon a mechanical measurement as an indicating device. This mechanical movement has some inertia due to which the frequency response of these instruments is poor.

Electronic Instruments

Electronic instruments use semiconductor devices. Most of the scientific and industrial instrumentations require very fast responses. Such requirements cannot be met with by mechanical and electrical instruments. In electronic devices, since the only movement involved is that of electrons, the response time is extremely small owing to very small inertia of the electrons. With the use of electronic devices, a very weak signal can be detected by using pre-amplifiers and amplifiers.

Advantages of Electrical/Electronic Instruments

- Non-contact measurements are possible
- These instruments consume less power
- Compact in size and more reliable in operation
- Greater flexibility
- Good frequency and transient response
- Remote indication and recording possible

Manual and Automatic Instruments

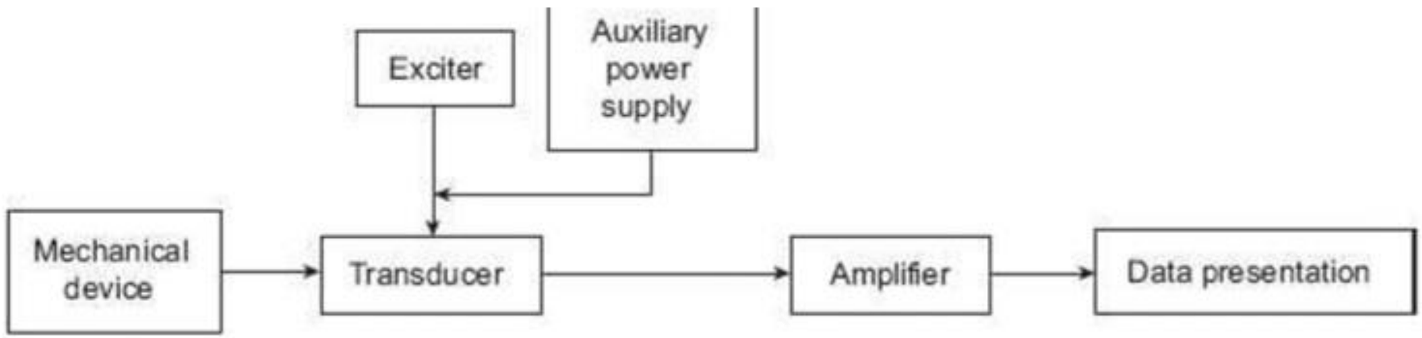
In case of manual instruments, the service of an operator is required. For example, measurement of temperature by a resistance thermometer incorporating a Wheatstone bridge in its circuit, an operator is required to indicate the temperature being measured.

In an automatic type of instrument, no operator is required all the time. For example, measurement of temperature by mercury-in-glass thermometer.

Self-operated and Power-operated Instruments

Self-operated instruments are those in which no outside power is required for operation. The output energy is supplied wholly or almost wholly by the input measurand. Dial-indicating type instruments belong to this category.

The power-operated instruments are those in which some external power such as electricity, compressed air, hydraulic supply is required for operation. In such cases, the input signal supplies only an insignificant portion of the output power.



Electromechanical measurement system

Deflection and Null Output Instruments

In a deflection-type instrument, the deflection of the instrument indicates the measurement of the unknown quantity. The measurand quantity produces some physical effect which deflects or produces a mechanical displacement in the moving system of the instrument. An opposite effect is built in the instrument which opposes the deflection or the mechanical displacement of the moving system. The balance is achieved when opposing effect equals the actuating cause producing the deflection or the mechanical displacement. The deflection or the mechanical displacement at this point gives the value of the unknown input quantity. These type of instruments are suited for measurement under dynamic condition. Permanent Magnet Moving Coil (PMMC), Moving Iron (MI), etc., type instruments are examples of this category.

In null-type instruments, a zero or null indication leads to determination of the magnitude of the measurand quantity. The null condition depends upon some other known conditions. These are more accurate and highly sensitive as compared to deflection-type instruments. A dc potentiometer is a null- type instrument.

FUNCTION AND ADVANTAGES

- The 3 basic functions of measurement and 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

Examples of Electronic Sensor applications

Uses infrared optical sensor

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 nth measurement

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

The precision of a measurement is a quantitative or numerical indication of the closeness with which a repeated set of measurement of the same variable agree with the average set of measurements.

Example 1.1

Given expected voltage value across a resistor is 80V. The measurement is 79V. Calculate,

i. The absolute error
ii. The % of error
iii. The relative accuracy
iv. The % of accuracy

Solution (Example 1.1)

Given that , expected value = 80V
measurement value = 79V

i. Absolute error, e = $Y_n - X_n$ = 80V – 79V = 1V

ii. % error = $\left|\dfrac{Y_n - X_n}{Y_n}\right| \times 100 = \dfrac{80-79}{80} \times 100$ = 1.25%

iii. Relative accuracy, $A = 1 - \left|\dfrac{Y_n - X_n}{Y_n}\right|$ = 0.9875

iv. % accuracy, a = A x 100% = 0.9875 x 100%=98.75%

Example 1.2

From the value in table 1.1 calculate the precision of 6th measurement?

Solution

the average of measurement value

$$\overline{X}_n = \frac{98 + 101 + ... + 99}{10} = \frac{1005}{10} = 100.5$$

the 6th reading

Precision = $1 - \left| \frac{100 - 100.5}{100.5} \right| = 1 - \frac{0.5}{100.5} = 0.995$

Table 1.1

No	X_n
1	98
2	101
3	102
4	97
5	101
6	100
7	103
8	98
9	106
10	99

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

LIMITING ERROR (cont)

Example 1.6

Given a 600 V voltmeter with accuracy ±2% full scale.

Calculate limiting error when the instrument is used to measure a voltage of 250V?

Solution

The magnitude of limiting error, 0.02 x 600 = 12V

Therefore, the limiting error for 250V = 12/250 x 100 = 4.8%

LIMITING ERROR (cont)

Example 1.7

Given for certain measurement, a limiting error for voltmeter at 70V is 2.143% and a limiting error for ammeter at 80mA is 2.813%. Determine the limiting error of the power.

Solution

The limiting error for the power = 2.143% + 2.813%

= <u>4.956%</u>

Exercise

- A voltmeter is accurate 98% of its full scale reading.
  i. If the voltmeter reads 200V on 500V range, what is the absolute error?
  ii. What is the percentage error of the reading in (i).

Significant Figures

- Significant figures convey actual information regarding the magnitude and precision of quantity
- More significant figure represent greater precision of measurement

Example 1.3

Find the precision value of X_1 and X_2?

$$X_n = 101$$

$$X_1 = 98 \quad ====>> \mathit{2\ s.f}$$

$$X_2 = 98.5 \quad ====>> \mathit{3\ s.f}$$

Solution (Example 1.3)

$$\overline{X_n} = 101$$

$$X_1 = 98 ====>> \mathit{2\ s.f}$$

$$X_2 = 98.5 ====>> \mathit{3\ s.f}$$

$$X_1 = \text{Precision} = 1 - \left|\frac{98-101}{101}\right| = 0.97$$

$$X_2 = \text{Precision} = 1 - \left|\frac{98.5-101}{101}\right| = 0.975 \textit{ ===>more precise}$$

Significant Figures (cont)

Rules regarding significant figures in calculation

1) For adding and subtraction, all figures in columns to the right of the last column in which all figures are significant should be dropped

Example 1.4

$$\begin{aligned} & V_1 = 6.31\ \text{V} \\ + \quad & V_2 = 8.736\ \text{V} \end{aligned}$$

Therefore $V_T = 15.046\ \text{V}$

$$\cong \underline{15.05\ \text{V}}$$

Significant Figures (cont)

2) For multiplication and division, retain only as many significant figures as the least precise quantity contains

Example 1.5

From the value given below, calculate the value for R_1, R_2 and power for R_1?

$I = 0.0148$ A ===> 4 s.f

$V_1 = 6.31$ V ===> 2 s.f

$V_2 = 8.736$ V ===> 3 s.f

Solution (Example 1.5)

$$R_1 = \frac{V_1}{I} = \frac{6.31V}{0.0148A} = 426.35 = 426\Omega \text{ ===> 3 s.f}$$

$$R_2 = \frac{V_2}{I} = \frac{8.736V}{0.0148A} = 590.27 = 590\Omega \text{ ===> 3 s.f}$$

$$P_1 = V_1 \times I = (6.31V) \times (0.0148A)$$

$$= 0.09339$$

$$= 0.0934 \text{ ===> 3 s.f}$$

Significant Figures (cont)

3) When dropping non-significant figures

0.0148 ==> 0.015 (2 s.f)

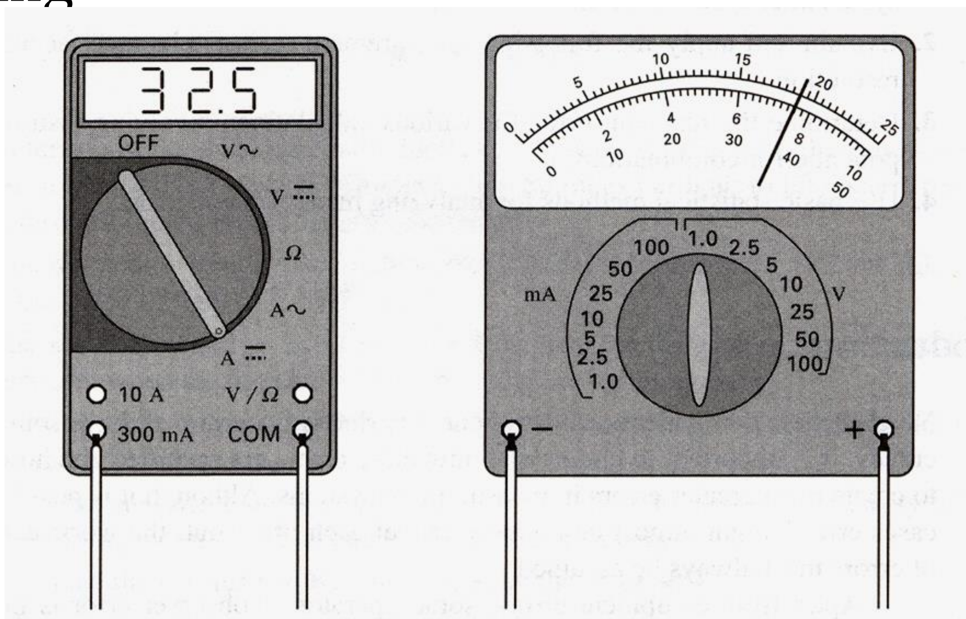
==> 0.01 (1 s.f)

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

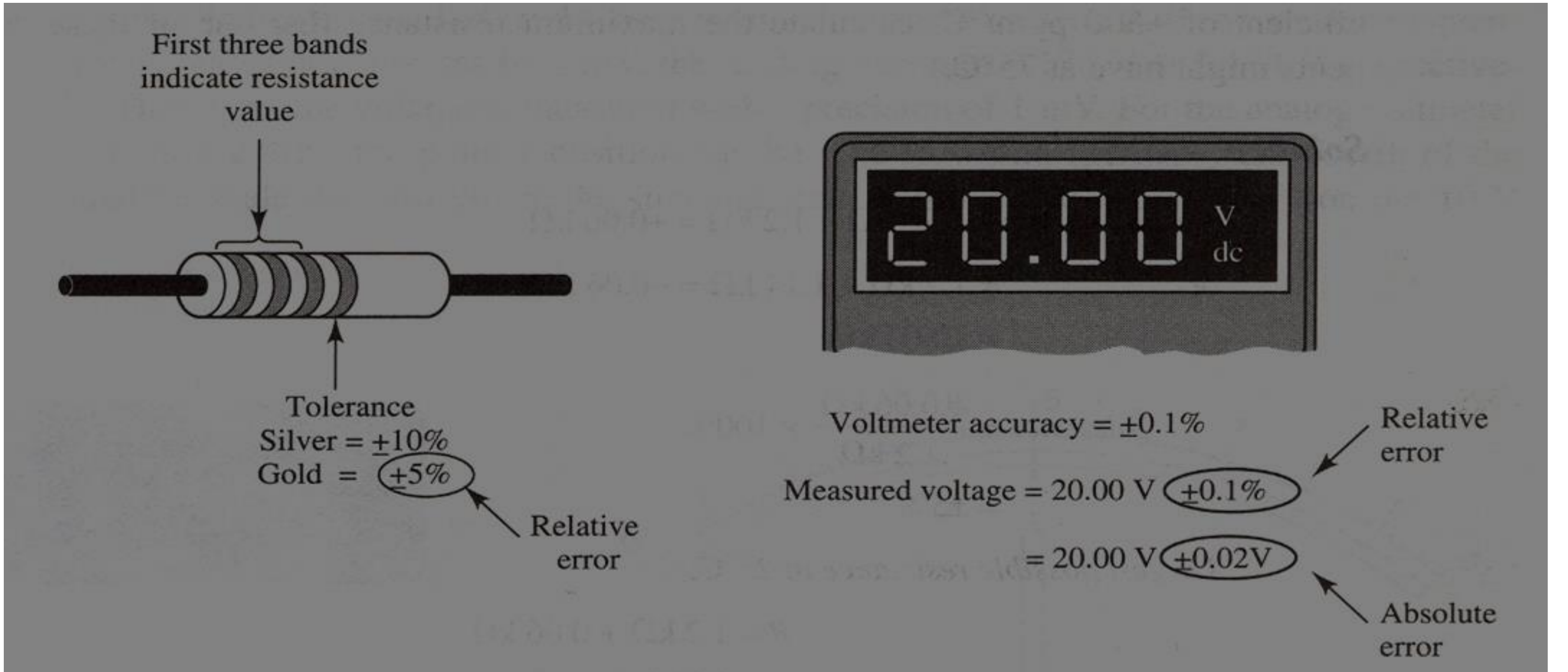


(a) Digital instrument indicating 32.5 mA

(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

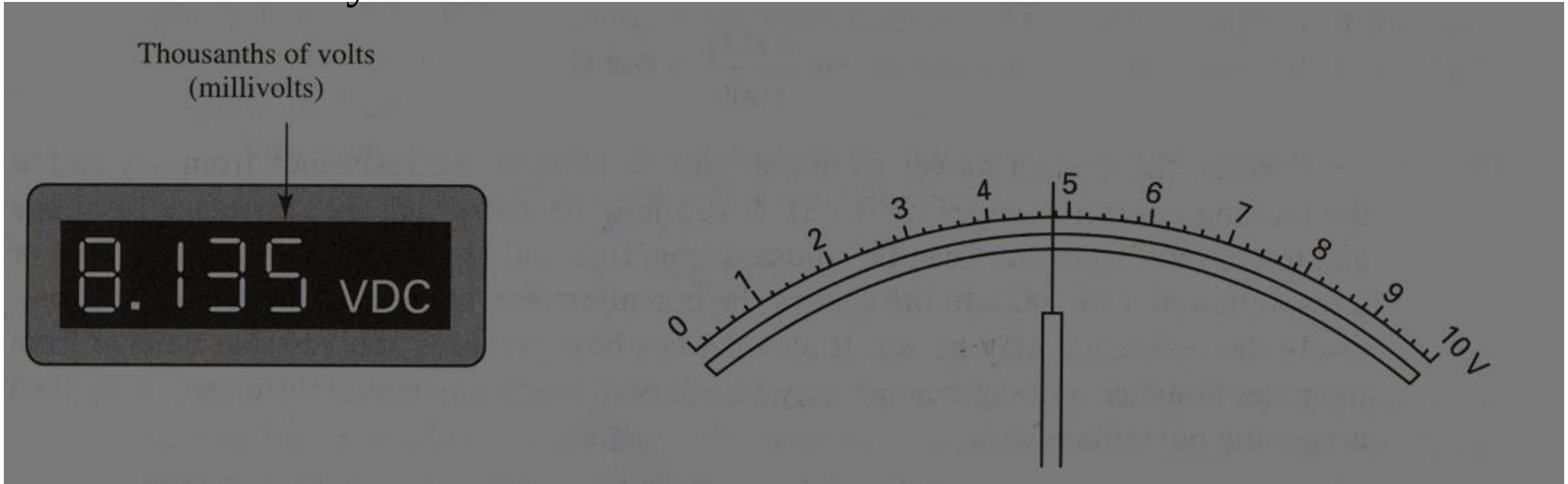


(a) Resistor tolerance is identified by a colored band

(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

a) If the measured quantity increases or decreases by 1 mV, the reading becomes 8.936 V or 8.934 V respectively. Therefore, the voltage is measured with a precision of 1 mV.

b) The pointer position can be read to within one-fourth of the smallest scale division. Since the smallest scale division represents 0.2 V, one-fourth of the scale division is 50 mV.

- Resolution

  The measurement precision of an instrument defines the smallest change in measured quantity that can be observed. This smallest observable change is the resolution of the instrument.

- Significant Figures

  The number of significant figures indicate the precision of measurement.

Example 2.1: An analog voltmeter is used to measure voltage of 50V across a resistor. The reading value is 49 V. Find

a) Absolute Error
b) Relative Error
c) Accuracy
d) Percent Accuracy

<u>Solution</u>

a) $e = X_t - X_m = 50V - 49V = 1V$

b) $\%Error = \left|\dfrac{X_t - X_m}{X_t}\right| \times 100\%$

$$= \left|\frac{50V - 49V}{50V}\right| \times 100\% = 2\%$$

c) $A = 1 - \%Error = 1 - 2\% = 0.98$

d) $\%Acc = 100\% - 2\% = 98\%$

Measurement Error Combinations

- When a quantity is calculated from measurements made on two (or more) instruments, it must be assumed that the errors due to instrument inaccuracy combine is the worst possible way.
- Sum of Quantities

  Where a quantity is determined as the sum of two measurements, the total error is the sum of the absolute errors in each measurement.

$$E = (V_1 \pm \Delta V_1) + (V_2 \pm \Delta V_2)$$

giving $E = (V_1 + V_2) \pm (\Delta V_1 + \Delta V_2)$

➢Difference of Quantities

The error of the difference of two measurements are again additive

$$
\begin{aligned}
E &= \left(V_1 \pm \Delta V_1\right) - \left(V_2 \pm \Delta V_2\right) \\
&= \left(V_1 - V_2\right) \pm \left(\Delta V_1 + \Delta V_2\right)
\end{aligned}
$$

➢Product of Quantities

When a calculated quantity is the product of two or more quantities, the percentage error is the sum of the percentage errors in each quantity

$$
\begin{aligned}
P &= EI \\
&= \left(E \pm \Delta E\right)\left(I \pm \Delta I\right) \\
&= EI \pm E\Delta I \pm I\Delta E \pm \Delta E\Delta I
\end{aligned}
$$

since $\Delta E\Delta I$ is very small,

$$
P \approx EI \pm \left(E\Delta I \pm I\Delta E\right)
$$

Example: An 820Ω resistance with an accuracy of $\pm 10\%$ carries a current of 10 mA. The current was measured by an analog ammeter on a 25mA range with an accuracy of $\pm 2\%$ of full scale. Calculate the power dissipated in the resistor, and determine the accuracy of the result.

Solution

$$P = I^2 R = (10\,mA)^2 \times 820\Omega$$
$$= 82\,mW$$

$$error in\, R = \pm 10\%$$
$$error in\, I = \pm 2\%\, of\ 25\,mA$$
$$= \pm 0.5\,mA$$
$$= \frac{\pm 0.5\,mA}{10\,mA} \times 100\% = \pm 5\%$$

$$\%error in\, I^2 = 2(\pm 5\%) = \pm 10\%$$
$$\%error in\, P = (\%error in\, I^2) + (\%error in\, R)$$
$$= \pm(10\% + 10\%) = \pm 20\%$$

➢Deviation

- Difference between any one measured value and the arithmetic mean of a series of measurements
- May be positive or negative, and the algebraic sum of the deviations is always zero

$$\mathrm{d_n = x_n - \overline{x}}$$

- The average deviation (D) may be calculated as the average of the absolute values of the deviations.

$$D = \frac{|d_1| + |d_2| + |d_3| + \ldots + |d_n|}{n}$$

- Standard Deviation and Probable of Error
  - ✓ Variance: the mean-squared value of the deviations

$$\sigma^2 = \frac{d_1^2 + d_2^2 + \ldots + d_n^2}{n}$$

  - ✓ Standard deviation or root mean squared (rms)

$$\text{SD or } \sigma = \sqrt{\frac{d_1^2 + d_2^2 + \ldots + d_n^2}{n}}$$

  - ✓ For the case of a large number of measurements in which only random errors are present, it can be shown that the probable error in any one measurement is 0.6745 times the standard deviation:

$$\text{Probable Error} = 0.6745\sigma$$

Example: The accuracy of five digital voltmeters are checked by using each of them to measure a standard 1.0000V from a calibration instrument. The voltmeter readings are as follows: V_1 = 1.001 V, V_2 = 1.002, V_3 = 0.999, V_4 = 0.998, and V_5 = 1.000. Calculate the average measured voltage and the average deviation.

Solution

$$V_{av} = \frac{V_1 + V_2 + V_3 + V_4 + V_5}{5}$$

$$= \frac{1.001 + 1.002 + 0.999 + 0.998 + 1.000}{5} = 1.000V$$

$$d_1 = V_1 - V_{av} = 1.001 - 1.000 = 0.001V$$

$$d_2 = V_2 - V_{av} = 1.002 - 1.000 = 0.002V$$

$$d_3 = 0.999 - 1.000 = -0.001V$$

$$d_4 = 0.998 - 1.000 = -0.002V$$

$$d_5 = 1.000 - 1.000 = 0V$$

$$D = \frac{|d_1| + |d_2| + \dots + |d_5|}{5}$$

$$= \frac{0.001 + 0.002 + 0.001 + 0.002 + 0}{5} = 0.0012V$$

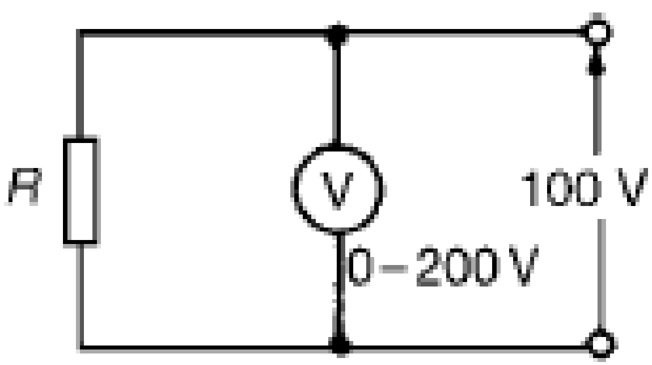
Instrument 'loading' effect : Some measuring instruments depend for their operation on power taken from the circuit in which measurements are being made. Depending on the 'loading' effect of the instrument (i.e. the current taken to enable it to operate), the prevailing circuit conditions may change.

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 avoided 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.
- 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 Nigeria, this function is carried out by SON.

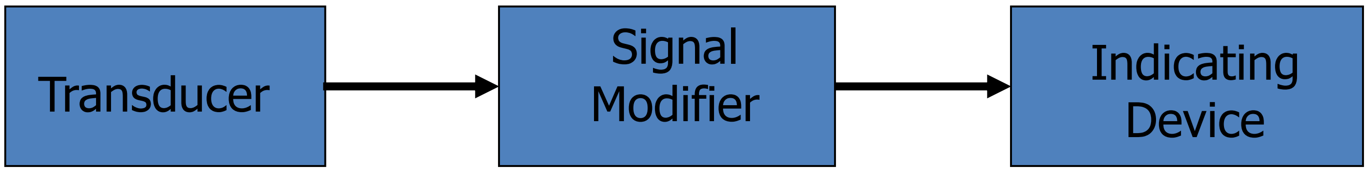
Standard

- 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

INSTRUMENT APPLICATION GUIDE

- Selection, care and use of the instrument :-
  - ✓ Before using an instrument, students should be thoroughly familiar with its operation ** read the manual carefully
  - ✓ Select an instrument to provide the degree of accuracy required (accuracy + resolution + cost)
  - ✓ Before used any selected instrument, do the inspection for any physical problem
  - ✓ Before connecting the instrument to the circuit, make sure the ‘function switch’ and the ‘range selector switch’ has been set-up at the proper function or range

INSTRUMENT APPLICATION GUIDE

Analog Multimeter

INSTRUMENT APPLICATION GUIDE

Digital Multimeter

THE END