Electronic Instrumentation

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Syllabus

UNIT I

- **Basics:**

Parameters, Units of measurements, Accuracy, Resolution, Precision

Sensors and Transducers:

Various types of sensors, Signal Conditioners, Data Acquisition systems

Syllabus

UNIT II

- **Analog measurements**

Voltage, Current and Power, Impedance, Resistance, Capacitance, Inductance, Time and Phase, Gain and loss, Frequency, Frequency response, Noise power, Noise figure, Non-linearity, Group Delay, Distortion, Video Measurements

- **Digital measurements**

Jitter, BER, Eye diagram

Syllabus

UNIT III

Signal Sources

Audio and RF Oscillators, Data Generators, Pattern Generators, Video Signal Generator.

Measuring Instruments

DMM, Oscilloscopes, DSO, Spectrum Analyzer, Logic Analyzer, Distortion Analyzer, Network Analyzer, TDR, RF Power Meters

Syllabus

UNIT IV

- **Interfaces**

  GPIB, HPIB, USB, PCI

- **Virtual Instruments**

Software based instrumentation,
PC based instrumentation

Books

1. David A. Bell, "Electronic Instrumentation and Measurements", 3rd Ed, Oxford University Press, 2013. (Text Book)
2. Oliver and Cage, "Electronic Measurements and Instrumentation", McGraw Hill
3. H.Kalsi, "Electronic Instrumentation", McGraw Hill India, 2004
4. Banerjee, Gopal Krishna, " Electrical and Electronic Measurements", PHI Learning, 2012

Introduction

- Instrumentation is the branch of engineering that deals with *measurement* and *control*.
- **Instrumentation** is defined as the art and science of measurement and control.
- It serves not only sciences but all branches of engineering, medicine, and almost every human endeavor.
- Electronics Instrumentation is the application of measurement technology in electronic-related field.

Basics

- **What is measurement?**

It is the art of obtaining a numerical value of physical quantity or the charecteristic condition by quantitative comparison between a accepted standards of the system units being used and an unknown magnitude.

- **What is Instrumentation?**

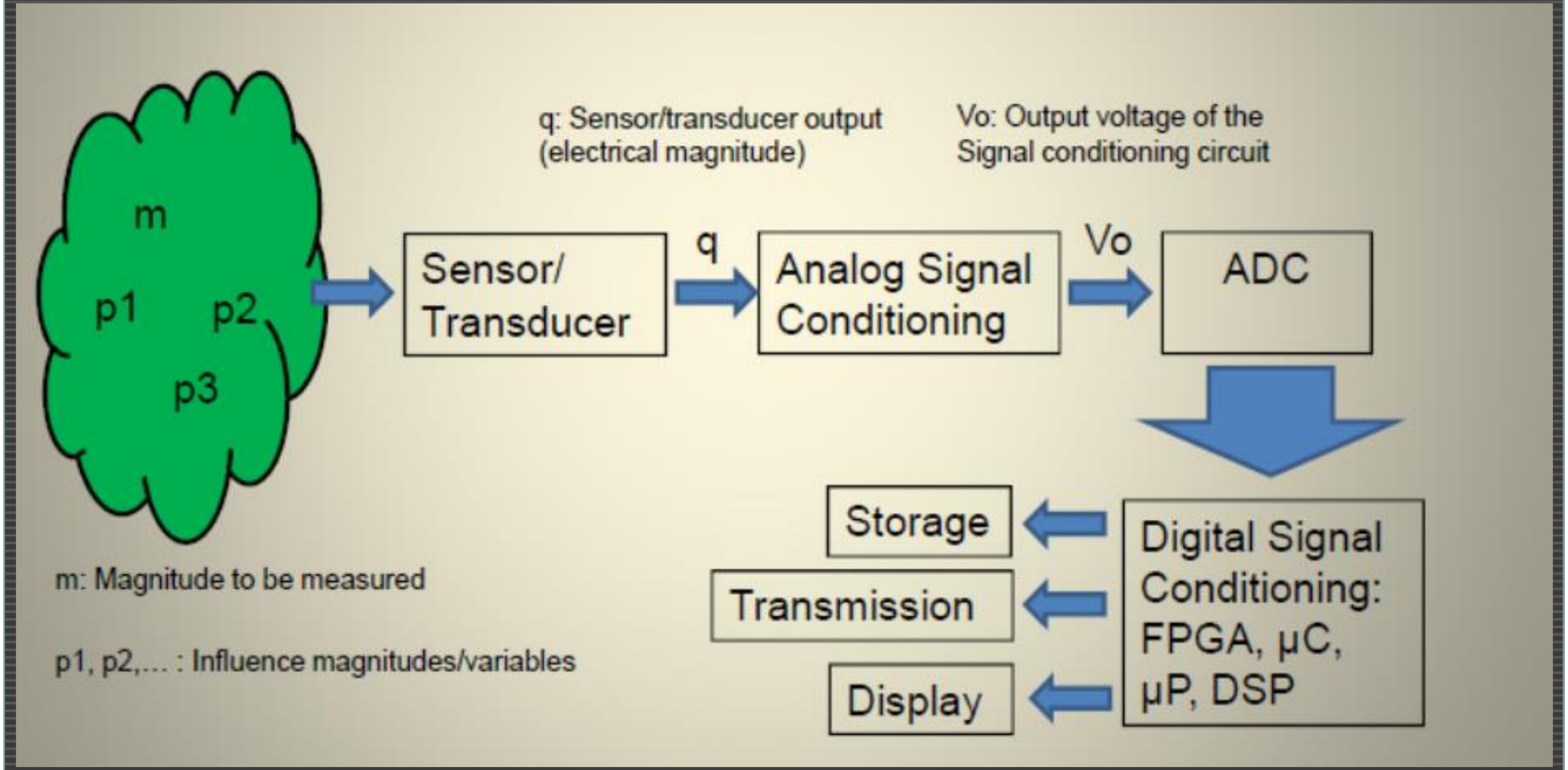
It collective term for measuring instruments that are used for measuring, indicating and recording physical quantities.

e.g. direct reading thermometers, smoke detectors

What is Electronic Instrumentation?

- It is the system for measurement of electrical and non electrical (physical) quantities.
- Most physical quantities can be converted into electrical signals using transducers.
- Once in the common format, they can be amplified, filtered, sampled, multiplexed, measured and displayed.
- Measurements can be automated.

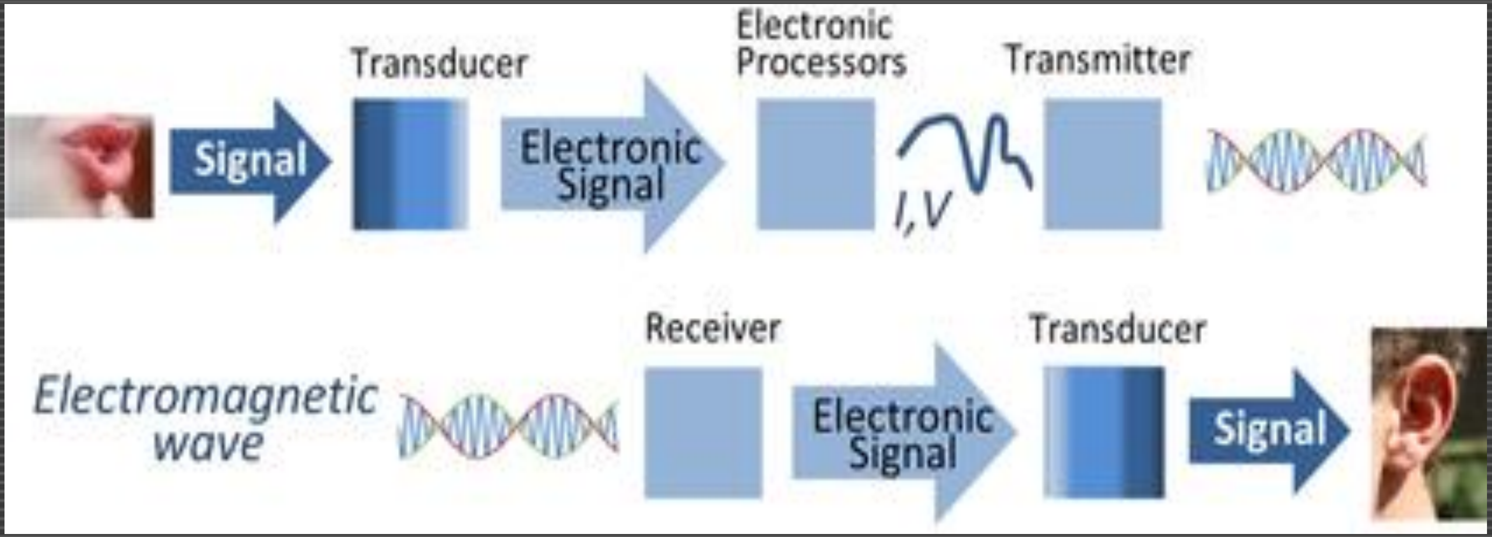
Basic Architecture for an Electronic Instrumentation Measurement System



Function of the components of EI & M system

- **Transducer** converts one form of energy into another form.
- **Signal conditioning** can include amplification, filtering, converting and any other processes required to make sensor output suitable for processing after conditioning.
- **ADC** is Analog to Digital converter which conerts the anlog signals in to form of digital signals which can be stored, transmitted and displayed with more accuracy.

Example of Transducer



In the above figure the first transducer could be a microphone, and the second transducer could be a speaker.

UNIT I

Technical Definition: Measurement

- ***Science is experimental and all experiments involve measurements.***
- ***Measurements convert all parameters into numbers.***
- **Measurement** is the process of experimentally obtaining a numerical value of physical quantity or the charecteristic condition.

Parts of Measurement

- A measurement consists of two parts:
  - numerical value: describes how big the measurement is
  - unit: tells us what the measurement is in; e.g., meters, kilograms, cubic centimeters, etc.
    - the unit also shows the type of measurement we are making; e.g., length, mass, volume, etc.

- Magnitude of a phsical quantity= (numerical value) Uniit

Physical System of Measurements

- **MKS Unit System**

  It uses meter, kilogram, second as base units of length, mass and time.

- **SI Unit System**

  It uses units of Electricity and magnetism along with meter, kilogram, second units.

Fundamental (Base) and Derived Properties

- **Fundamental (base) property**
  - defined by itself, independent of other properties
  - Fundamental (base) properties are:
    - length, mass, time, temperature, electric current

- **Derived property**
  - defined in terms of fundamental properties (depends on fundamental properties)
  - Examples: surface area, volume, speed etc.

The Seven Base SI Units

Quantity	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Temperature	kelvin	K
Time	second	s
Amount of Substance	mole	mol
Luminous Intensity	candela	cd
Electric Current	ampere	A

Derived SI Units (examples)

Quantity	Unit	Symbol
Volume	cubic meter	m^3
Density	kilograms per cubic meter	kg/m^3
Speed	meter per second	m/s
Newton	kg m/ s^2	N
Energy	Joule (kg m^2/s^2)	J
Pressure	Pascal (kg/(ms^2)	Pa

SI Unit Prefixes - Part I

Name	Symbol	Factor
tera-	T	10^{12}
giga-	G	10^{9}
mega-	M	10^{6}
kilo-	k	10^{3}
hecto-	h	10^{2}
deka-	da	10^{1}

SI Unit Prefixes- Part II

Name	Symbol	Factor
deci-	d	10^{-1}
centi-	c	10^{-2}
milli-	m	10^{-3}
micro-	µ	10^{-6}
nano-	n	10^{-9}
pico-	p	10^{-12}
femto-	f	10^{-15}

Points to be cosidered while measuring parameters

- A suitable instrument should be chosen.
- Measuring instrument should not affect the quantity should be measured.
- Knowledge of the instrument.
- Careful planning , execution and evaluation of the experiment.

Definitions

- **Accuracy**: Closeness of the measured value to the actual value of the variable being measured.
- **Precision:** A measure of the reproducibility of measurement. It is necessary but not sufficient.
- Given a fixed value of the variable, precision is the measure of the degree to which successive measurements differ from each other.
- **Sensitivity:** Ratio of the output response of instrument to the input changes.
- **Resolution:** Smallest change in the input to which the instrument responds.
- **Error:** Deviation from the true (expected) value of measured parameter.

Accuracy

- Accuracy = the extent to which a measured value agrees with a standard value.
  - Accuracy of a device must be checked.
  - Does it read a proper accepted value?

Example: Accuracy

- Who is more accurate when measuring a book that has a true length of 17.0 cm?

Susan:

17.0 cm, 16.0 cm, 18.0 cm, 15.0 cm

Amy:

15.5 cm, 15.0 cm, 15.2 cm, 15.3 cm

Precision

- Precision = the degree of exactness of a measurement that is repeatedly recorded.

- Which set is more precise?

★ 18.2 , 18.4 , 18.35

17.9 , 18.3 , 18.85

16.8 , 17.2 , 19.44

Example: Precision

Who is more precise when measuring the same 17.0 cm book?

Susan:

17.0 cm, 16.0 cm, 18.0 cm, 15.0 cm

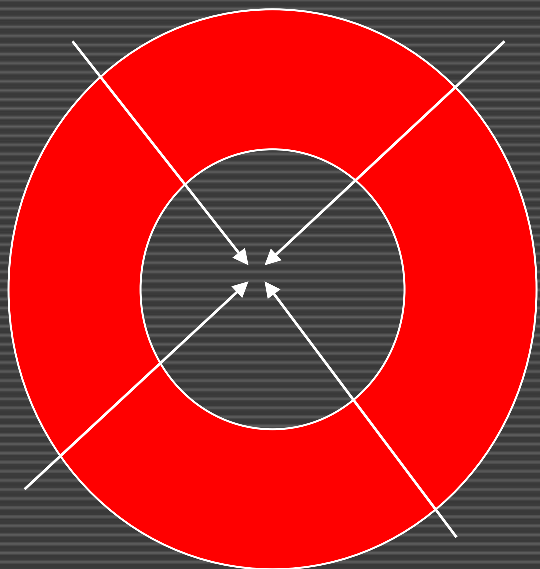
★Amy:

15.5 cm, 15.0 cm, 15.2 cm, 15.3 cm

Accuracy vs. Precision

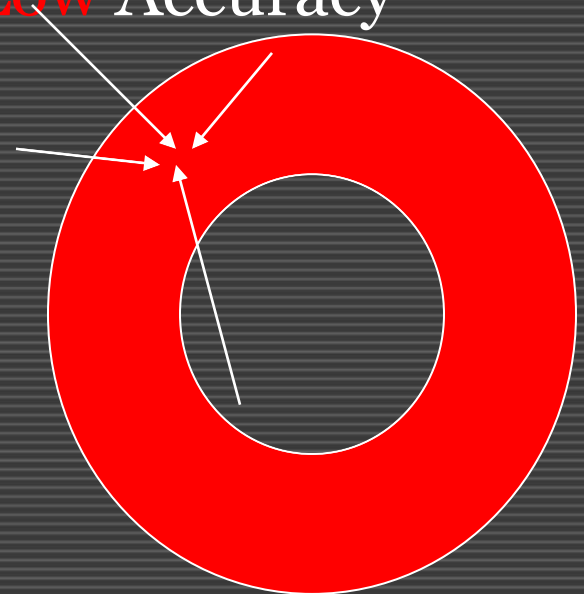
High Accuracy

High Precision



High Precision

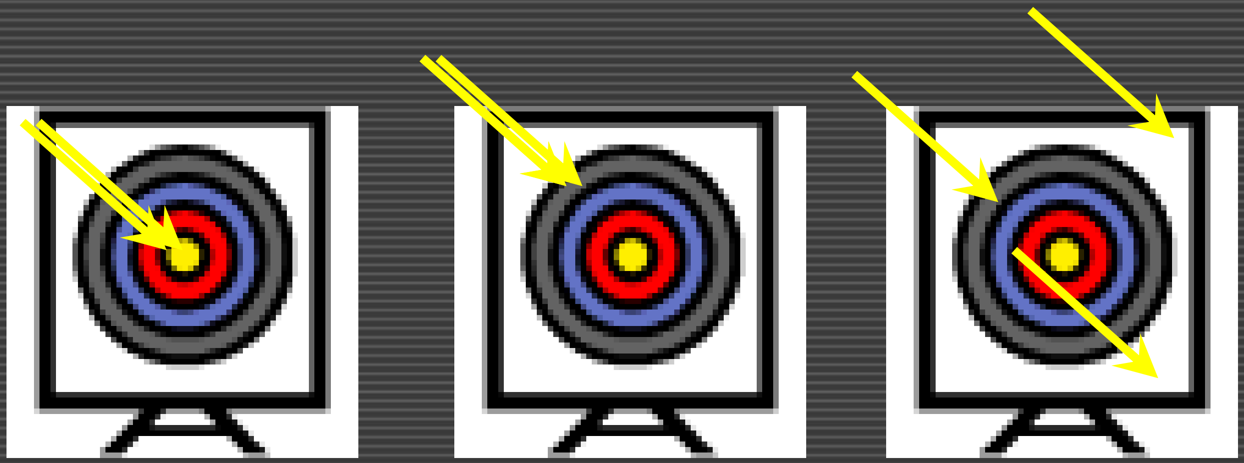
Low Accuracy



Can you hit the bull's-eye?

Three targets with three arrows each to shoot.

How do they compare?



Both accurate and precise

Precise but not accurate

Neither accurate nor precise

Can you define accuracy vs. precision?

Error

- It can be expressed as the absolute or percentage of error.

- **Absolute error :** Difference between expected value (true value) of variable and measured value of the variable.

Absolute error (e) =X-Y

X = Expected value (True vale)

Y= Measured Value

- **Relative error:** It can also be expressed as percentage or as fraction of true value.

$$\% \text{ Error} = \frac{\text{Absolute error}}{\text{True Value}} \times 100$$

Numerical on Error

$$\%e = [\frac{X-Y}{X}] * 100$$

Then Accuracy is given by

$$A = 1 - [\frac{X-Y}{X}]$$

Relative Accuracy is expressed in term of percentange

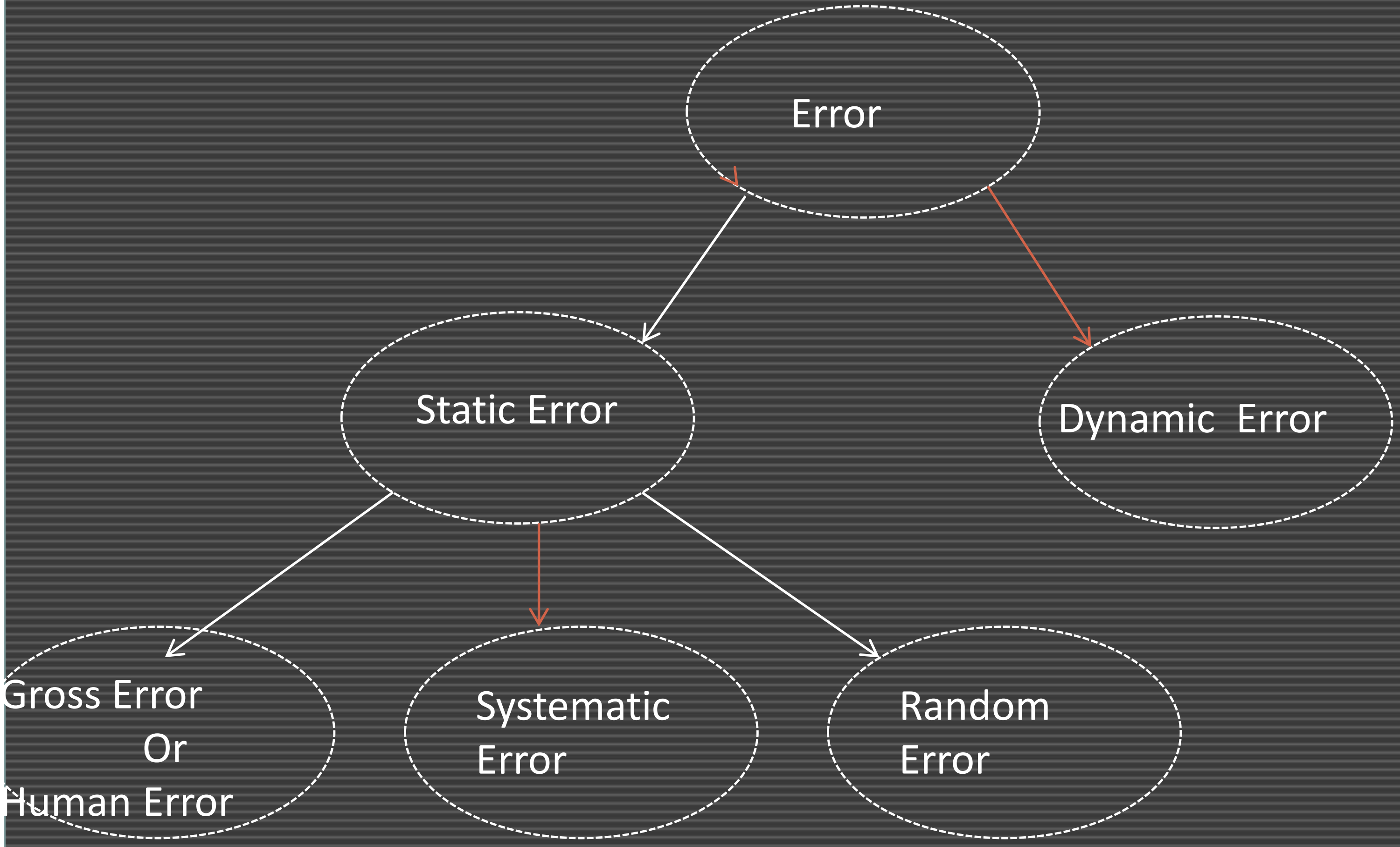
$$a = 100\% - e\%$$

$$a = A * 100\%$$

Que.

A volatge has a true value of 1.5 V. An analog indicating instrument with a scale range of 0-2.5 V shows a volatge of 1.46 V. What are the values of absolute error and % error?

Types of Error



Types of Static Error

Gross error

- Numerical difference between true value and measured value.
- Repeated measurement of same quantity give different values of Gross error.

- This class of errors mainly cover followings:
- Human mistake in reading (32.5 mA instead of 3.25 mA)
- Error in recording observations (Wrong Scale)
- Incorrect adjustment of instrument
- Computational mistake
- Improper use of an instrument

Gross error can't be eliminated but it can be minimized by

- Proper use of instrument
- Proper care in reading

Types of Static Error

Systematic error

- Defective of the instrument
- Ageing or effect of the environment on the instrument
- These errors are consistent with the repetition of the experimentt

Systematic error can be classified as

1. Instrumental error
2. Environmental error
3. Observational error

Types of Systematic Errors

1. Instrumental errors

- These errors are inherent in measuring instruments, because of their mechanical structure. For example, in the D' Arsonval movement, friction in the bearings of various moving components, irregular spring tensions, stretching of the spring, or reduction in tension due to improper handling or overloading of the instrument.

- Instrumental errors can be avoided by

(a) selecting a suitable instrument for the particular measurement applications.

(b) applying correction factors after determining the amount of instrumental error.

(c) calibrating the instrument against a standard.

2. Environmental error

- Environmental errors are due to conditions external to the measuring device, including conditions in the area surrounding the instrument, such as the effects of change in temperature, humidity, barometric pressure or of magnetic or electrostatic fields.
- These errors can also be avoided by (i) air conditioning, (ii) hermetically sealing certain components in the instruments, and (iii) using magnetic shields.

3. Observational error

- Observational errors are errors introduced by the observer. The most common error is the parallax error (different line of sight) introduced in reading a meter scale, and the error of estimation when obtaining a reading from a meter scale.
- wrong scale reading or wrong recording of the data

Types of Error

Static errors are caused by limitations of the measuring device or the physical laws governing its behaviour.

Dynamic errors are caused by the instrument not responding fast enough to follow the changes in a measured variable.

Random error

- Error remains after static and dynamic error
- Error due to unknown causes
- Errors are small , accidential & independant.
- Uncontrolled and unobserved external influences on the measurement. For e.g. consider the effect of wind on a rain gage measurement.
- Such errors are normally small and follow the laws of probability. Random errors can thus be treated mathematically.

Transducers

- It transform energy from one form to another.
- The input may be physical quantity or mechanical quantity and the output is electrical signal in the form of analog, digital or frequency modulated signal.
- It is also called pick up.

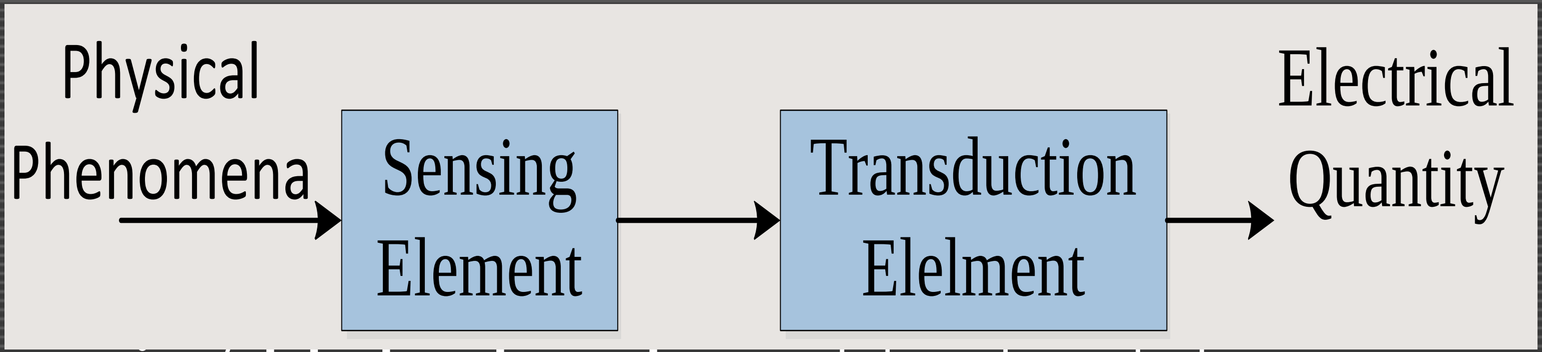
- Basically transducers can be categorized as

1) Electrical Transducers
2) Mechanical Transducers

- **<u>Electrical Transducers</u>**

Physical, Mechanical or optical quantity to be measured is directly converted into electrical signal voltage or current proportional to the input measured.

A transducer which converts non-electrical quantity into an electrical signal consists of 2 parts:



The sensing/ detector element responds to a physical phenomenon or cahnge in physical phenomenon.

The trsnduction element converts output of sensing element to an electric output.

Mechanical transducers

- They sre simple and rugged in construction, cheaper in cost, accurate and operate without external power supplies.
- They are not advantageous for many of the modern scientific experiments and process control instrumentation owing to their poor frequency response, requirement of large forces to overcome mechanical friction, in compatibility when remote control or indication is required, and a lot of other limitations.
- All these drawbacks have been overcome with the introduction of electrical transducers.

Electrical Transducers

- Mostly quantities to be measured are non-electrical such as temperature, pressure, displacement, humidity, fluid flow, speed etc., but these quantities cannot be measured directly. Hence such quantities are required to be sensed and changed into some other form for easy measurement.

- Electrical quantities such as current, voltage, resistance. inductance and capacitance etc. can be conveniently measured, transferred and stored, and therefore, for measurement of non-electrical quantities these are to be converted into electrical quantities first and then measured.

Electrical Transducers

- The function of converting non-electrical quantity into electrical one is accomplished by a device called the electrical transducer.
- Basically an electrical transducer is a sensing device by which a physical, mechanical or optical quantity to be measured is transformed directly, with a suitable mechanism, into an electrical signal (current, voltage or frequency).
- The production of these signals is based upon electrical effects which may be resistive, inductive, capacitive etc in nature.

Advantages of Electrical transducers

- Electrical signal can be easily transmitted and processed.
- Mass- inertia effects are minimized.
- Effect of friction are minimized.
- Electronic system can be controlled with a very small power level.
- electrical amplification & attenuation can easily be done.
- The output can be indicated & recorded remotely at a distance from sensing element.

Basic Requiremnets of a Transducer

- The main function of a transducer is to respond only for the measurement under specified limits for which it is designed.

- It is, therefore, necessary to know the relationship between the input and output quantities and it should be fixed. Transducers should meet the following basic requirements.

1. Linearity
2. Sensitivity
3. Dynamic Rabge
4. Repeatability
5. Physical Size

Basic Requirements Of a Transducer

- Ruggedness. It should be capable of withstanding overload and some safety arrangement should be provided for overload protection.
- Linearity. Its input-output characteristics should be linear and it should produce these characteristics in symmetrical way.
- Repeatability. It should reproduce same output signal when the same input signal is applied again and again under fixed environmental conditions e.g. temperature, pressure, humidity etc.

Basic Requirements Of a Transducer

- High Output Signal Quality. The quality of output signal should be good i.e. the ratio of the signal to the noise should be high and the amplitude of the output signal should be enough.

- High Reliability and Stability. It should give minimum error in measurement for temperature variations, vibrations and other various changes in surroundings.

- Good Dynamic Response. Its output should be faithful to input when taken as a function of time. The effect is analyzed as the frequency response.

Classification Of Transducers

- The transducers may be classified in various ways such as on the basis of electrical principles involved, methods of application, methods of energy conversion used, nature of output signal etc.

1. Active transducer- Passive transducer
2. Primary transducer - Secondary transducer
3. Analog transducer - Digital transducer
4. Transducer- Inverse Transducer

It can also be classified on the principle of transduction element

Resistive	Thermo-electric
Inductive	Frequency generating
Capacitive	Photo-resistive
Electro-magnetic	Photo-emissive
Piezo-electric	Potentiometric

Classification Of Transducers

- ***Primary and Secondary Transducers:*** Transducers, on the basis of methods of applications, may be classified into primary and secondary transducers.

- When the input signal is directly sensed by the transducer and physical phenomenon is converted into the electrical form directly then such a transducer is called the **primary transducer**.

- For example a thermistor used for the measurement of temperature fall in this category. The thermistor senses the temperature directly and causes the change in resistance with the change in temperature.

1-Primary and Secondary Transducers

- When the input signal is sensed first by some detector or sensor and then its output being of some form other than input signals is given as an input to a transducer for conversion into electrical form, then such a transducer falls in the category of **secondary transducers**.

- For example, in case of pressure measurement, bourdon tube is a primary sensor which converts pressure first into displacement, and then the displacement is converted into an output voltage by an LVDT (Linear Variable Differential Transducer). In this case LVDT is secondary transducer.

2-Active and Passive Transducers.

- Transducers, on the basis of methods of energy conversion used, may be classified into active and passive *transducers*.

- An **Active Transducer** generates an electrical signal directly in response to the physical parameter and does not require an external power source for its operation. They are self-generating devices, which operate under energy conservation principle and generate an equivalent output signal.

- Normal such transducers give very small output and, therefore, use of amplifier becomes essential.

- For eg. photo-voltaic cells which generate voltage in response to illumination.
- piezo-electric sensors, which generate charge corresponding to pressure.

Active and Passive Transducers

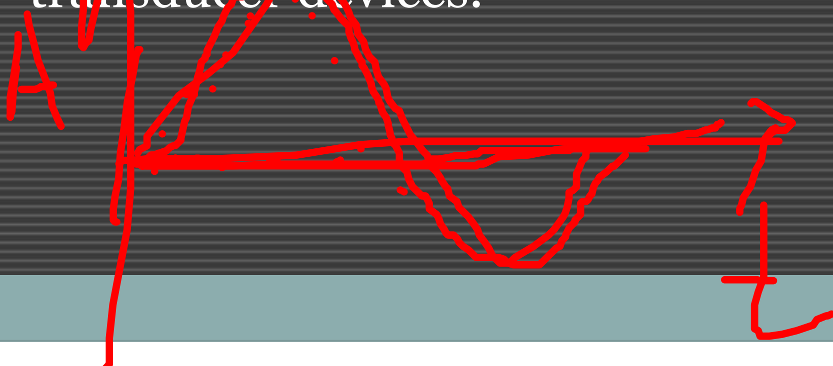
- **Passive transducer** operate under the energy controlling principles, which makes it necessary to use an external electrical source with them.
- They depend upon change in Resistance, Inductance and Capacitance (electrical parameters) with change in input siganl.
- Resistance, inductance or capacitance causes a change in voltages current or frequency of the external power source and hence giving an electrical signal output corresponding to input changes.
- Eg. Straing gauges in which resistance changes in response to pressure, Thermistors in which resistance changes corresponding to tenperature changes.

3-*Analog and Digital Transducers*

- Transducers, on the basis of nature of output signal, may be classified into analog and digital transducers.

- **Analog transducer** converts input signal into output signal, which is a continuous function of time such as thermistor, strain gauge, LVDT, thermo-couple etc.

- **Digital transducer** converts input signal into the output signal of the form of digital signal or pulse e.g. it gives discrete output. The digital techometer, the digital pedometers watch are examples of digital transducer devices.



Analog and Digital Transducers

- Digital transducers are becoming more and more popular now-a-days because of advantages associated with digital measuring instruments and also due to the effect that digital signals can be transmitted over a long distance without causing much distortion due to amplitude variation and phase shift.

- Sometimes an analog transducer combined with an ADC (analog-digital convector) is called a digital *transducer*.

4-Transducers and Inverse Transducers

- Transducer, as already defined, is a device that converts a non-electrical quantity into an electrical quantity.

- Normally a transducer and associated circuit has a non-electrical input and an electrical output, for example a thermo-couple, photoconductive cell, pressure gauge, strain gauge etc.

- An inverse transducer is a device that converts an electrical quantity into a non-electrical quantity. It is a precision actuator having an electrical input and a low-power non-electrical output.

Transducers and Inverse Transducers

- For examples a piezoelectric crystal and transnational and angular moving-coil elements can be employed as inverse transducers.

- Many data-indicating and recording devices are basically inverse transducers.

- An ammeter or voltmeter converts electric current into mechanical movement and the characteristics of such an instrument placed at the output of a measuring system are important.

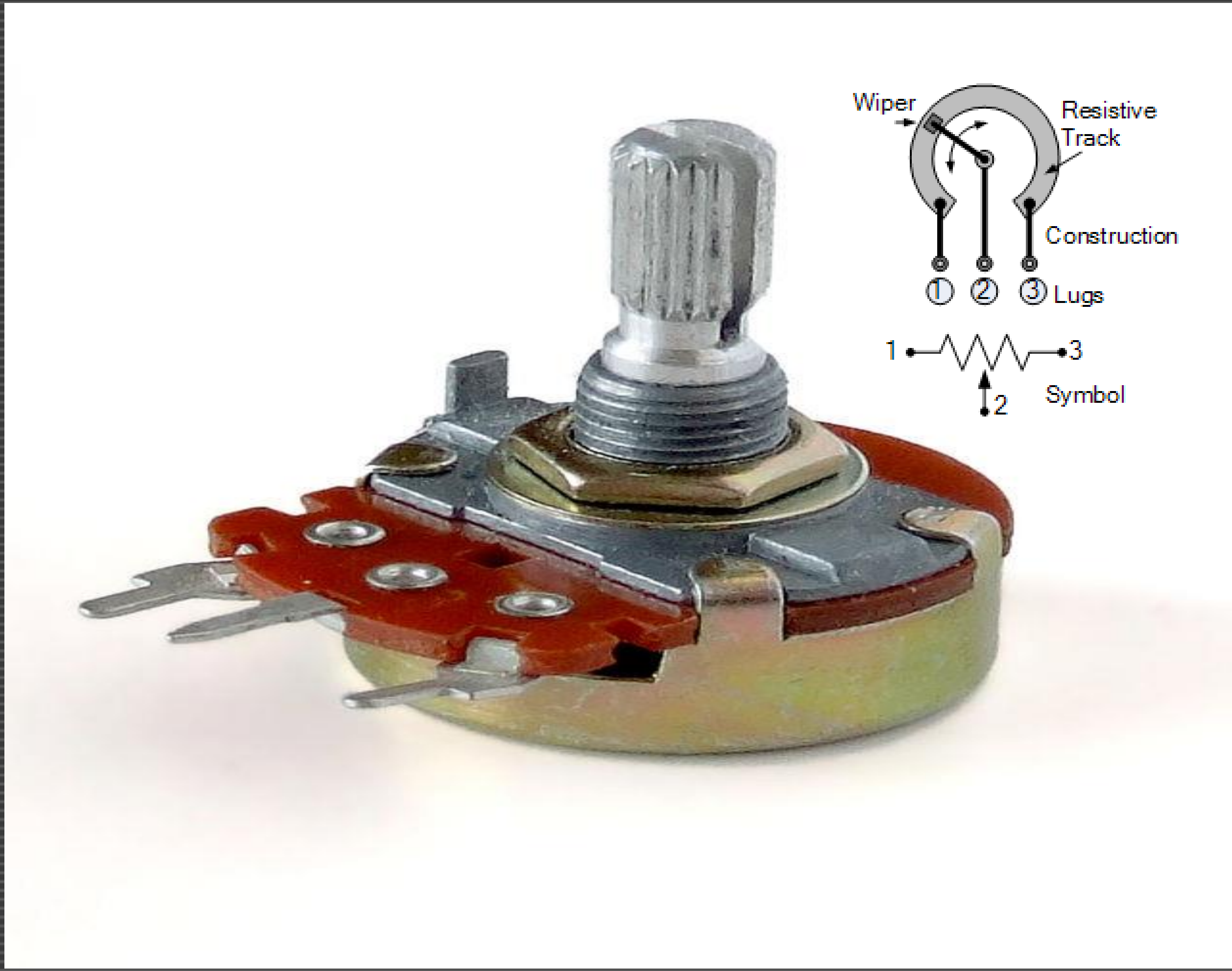
- The most useful application of inverse transducers is in feedback measuring systems.

One Typical Example-Resistive Transducer

- In Resistive transducer, change in the value of resistance occurs due to some physical phenomenon.
- Used for measurement of displacement ,temperature ,force and pressure.

1. Potentiometer (POT)

- Use to measure displacement in term of change in resistance.
- Passive transducer
- Can be used as variable resistance



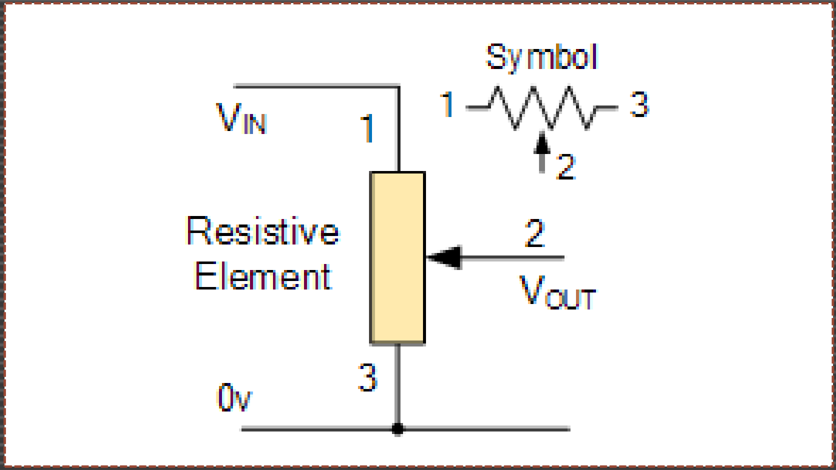
https://www.electronics-tutorials.ws/resistor/potentiometer.html

Potentiometers and Rheostats create a change in their resistive value when a connected shaft is physically rotated.

Potentiometer

- When used as a potentiometer, connections are made to both ends as well as with the wiper, as shown. The position of the wiper then provides an appropriate output signal at pin 2 which will vary between the voltage level applied between pin 1 and pin 3.

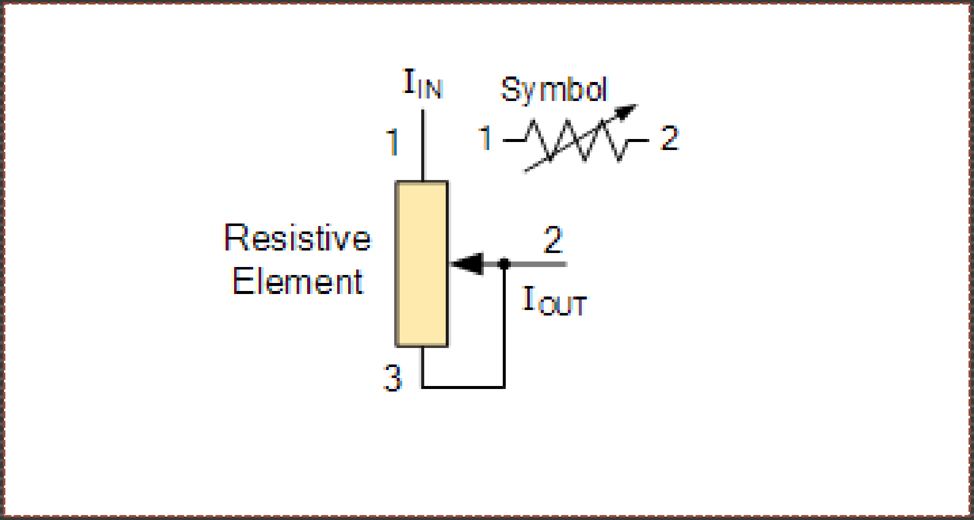
- The potentiometer is a three-wire resistive device that acts as a voltage divider producing a continuously variable voltage output signal which is proportional to the physical position of the wiper along the track.



Variable Resistor

- When used as a variable resistor, connections are made to only one end of the resistive track (either pin 1 or pin 3) and the wiper (pin 2) as shown. The position of the wiper is used to vary the amount of effective resistance connected between the movable contact and the stationary fixed end.

- A variable resistor is a two-wire resistive device that provides an infinite number of resistance values controlling the current offered to the connected circuit in proportion to the physical position of the wiper along the track.



Selection Of Transducers

- In a measurement system the transducer (or a combination of transducers) is the input element with the critical function of transforming some physical quantity to a proportional electrical signal. So selection of an appropriate transducer is most important for having accurate results.

- The first step in the selection procedure is to clearly define the nature of quantity under measurement (measurand) and know the range of magnitudes and frequencies that the measurand is expected to exhibit.

- Next step will be to examine the available transducer principles for measurement of desired quantity.

- The type of transducer selected must be compatible with the type and range of the quantity to be measured and the output device.

Selection Of Transducers(cont'd)

- The points to be considered in determining a transducer suitable for a specific measurement are as follows:
- ***Range***. The range of the transducer should be large enough to encompass all the expected magnitudes of the measurand.
- ***Sensitivity***. The transducer should give a sufficient output signal per unit of measured input in order to yield meaningful data.
- ***Electrical Output Characteristics***. The electrical characteristics-the output impedance, the frequency response, and the response time of the transducer output signal should be compatible with the recording device and the rest of the measuring system equipment.
- ***Physical Environment***. The transducer selected should be able to withstand the environmental conditions to which it is likely to be subjected while carrying out measurements and tests.
- Such parameters are temperature, acceleration, shock and vibration, moisture, and corrosive chemicals might damage some transducers but not others.

Selection Of Transducers(cont'd)

- ***Errors***. The errors inherent in the operation of the transducer itself, or those errors caused by environmental conditions of the measurement, should be small enough or controllable enough that they allow meaningful data to be taken.

- However the total measurement error in a transducer-activated system may be reduced to fall within the required accuracy range by adopting the following techniques.
- Calibrating the transducer output against some known standards while in use under actual test conditions. This calibration should be performed regularly as the measurement proceeds.
- There should be continuous monitoring of variations in the environmental conditions of the transducer and correcting the data accordingly.
- Controlling the measurement environment artificially in order to reduce possible transducer errors.
- Artificial environmental control includes the enclosing of the transducer in a temperature-controlled housing and isolating the device from external shocks and vibrations.

Signal Conditioners

- In electronics, signal conditioning is the manipulation of an analog signal in such a way that it meets the requirements of the next stage for further processing.

- The function of the signal conditioning circuits may include the following items:

- Signal amplification (opamp)
- Filtering (opamp)
- Interfacing with micro processor (ADC)
- Protection (Zener & photo isolation)
- Linearization
- Converting a resistance to a voltage signal
- Converting a current signal to a voltage signal
- Converting a voltage signal to a current signal

1. Filtering

- Filtering is the most common signal conditioning function to filter the noise signal (unwanted data), as usually not all the signal frequency spectrum contains valid data. The common example is 50/60 Hz AC power lines, present in most environments, which cause noise if amplified.

2. Amplification

- Signal amplification performs two important functions: increases the resolution of the input signal, and increases its signal-to-noise ratio.

- For example, the output of an electronic temperature sensor, which is probably in the millivolts range is probably too low for an analog-to-digital converter (ADC) to process directly.In this case it is necessary to bring the voltage level up to that required by the ADC.

3. Attenuation

- Attenuation, the opposite of amplification, is necessary when voltages to be digitized are beyond the ADC range.
- This form of signal conditioning decreases the input signal amplitude so that the conditioned signal is within ADC range. Attenuation is typically necessary when measuring voltages that are more than 10 V.

4. Linearization

- Linearization is necessary when sensors produce voltage signals that are not linearly related to the physical measurement.

- Linearization is the process of interpreting the signal from the sensor and can be done either with signal conditioning or through software.

Data Acquisition System

- Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer.

- Data acquisition systems, abbreviated by the acronyms DAS or DAQ, typically convert analog waveforms into digital values for processing.

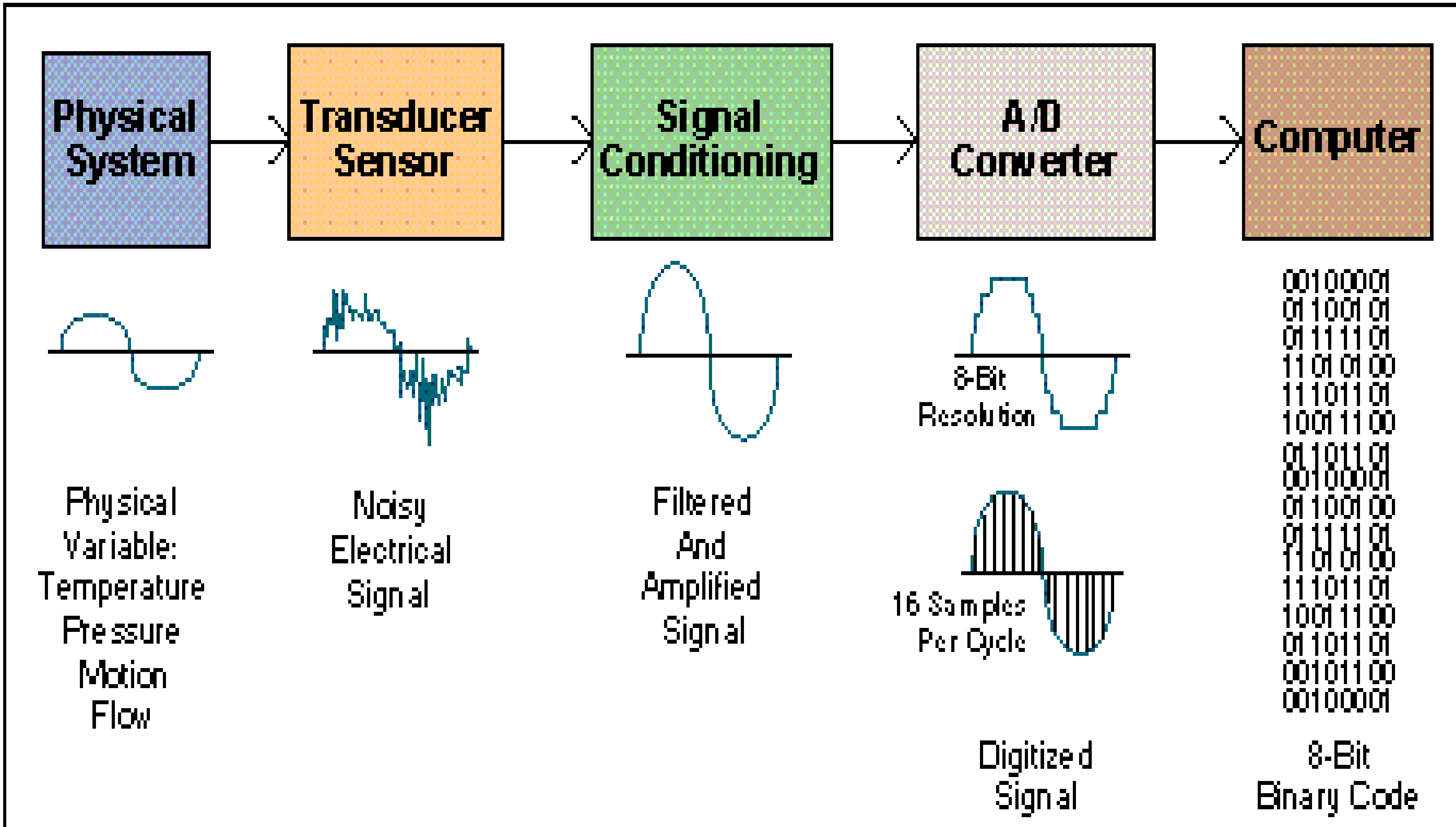
- The components of data acquisition systems include:

  - **Sensors**, to convert physical parameters to electrical signals.

  - **Signal conditioning circuitry**, to convert sensor signals into a form that can be converted to digital values.

  - **Analog-to-digital converters**, to convert conditioned sensor signals to digital values.

Data Acquisition System Block Diagram



Data Acquisition System (DAS)

A data acquisition system consists of many components that are integrated to:

- Sense physical variables (use of transducers)
- Condition the electrical signal to make it readable by an A/D board
- Convert the signal into a digital format acceptable by a computer
- Process, analyze, store, and display the acquired data with the help of software

Signal Conditioning

- The output signal from the sensor or transducer of a measurement system has generally to be processed to make it suitable for the next stage of operation.

- Signal conditioning refers to operation performed on signals to convert them to a suitable for interfacing with other elements.

- The signal may be
  - Too small - have to be amplified
  - Contain interference-has to be removed
  - Non linear--require linearization
  - Noise- Require filtering

- For example, thermocouple signals have very small voltage levels that must be amplified before they can be digitized. Other sensors, such as resistance temperature detectors (RTDs), thermistors, strain gages, and accelerometers, require excitation to operate. All of these preparation technologies are forms of signal conditioning.

Signal Conditioning

There are many possible functions of the signal-conditioning stage. The following are the most common:

- Amplification
- Attenuation
- Filtering (highpass, Iowpass, bandpass, or bandstop)
- Differentiation
- Integration
- Linearization
- Combining a measured signal with a reference signal
- Converting a resistance to a voltage signal.
- Converting a current signal to a voltage signal.
- Converting a voltage signal to a current signal

PROCESSES IN SIGNAL CONDITIONING

The following are some processes that can occur in signal conditioning

1) Protection to prevent damage to next element

A microprocessor, as a result of high current or voltage. Thus there can be series current-limiting resistors , fuses to break if the current is too high, polarity protection and voltage limitation circuits.

2) Getting the level of signal right

The signal from a thermocouple might be just a few volts. If the signal is to be fed into an analog to digital converter for inputting to microprocessor then it needs to be made larger ,volts rather than millivolts. Operational amplifiers are widely used for amplifications.

PROCESSES IN SIGNAL CONDITIONING

3) Eliminating or Reducing noise

Filter must be used to eliminate noise from a signal

4) Signal manipulation

Making it a linear function of some variable. The signal from some transducers are non linear and then signal conditioner might be used so that signal fed into the next stage element is linear.

Unit-1 Reference Books

Unit-1	Topics	Book
1.1	Measurements System ,Units and Standard	David A. BELL
1.1	Qualities of measurement	H S Kalsi
1.2	Transducers	H S Kalsi
1.3	Signal Conditioning	H S Kalsi
1.4	Data Acquistion and Conversion	H S Kalsi