Basics of Instrumentation Systems

Scope and necessity of instruments

-Instruments is a collective term for measuring instruments used for indicating, measuring and recording physical quantities, and has its origins in the art and science scientific instrument-making.

Nature of work of an instrumentation engineer ranges from designing, developing, installing, managing equipment's that are used to monitor and control machinery.

Instrument at home and elsewhere is only because of the science of instrumentation.

Instrumenting engineering is the branch of engineering that specializes on the principle and operation of measuring instruments that are used in Fields of design, gyration of automated systems in electrical, pneumatic domains, etc.

Job roles of an Instrumentation Engineer An instrumentation and Control engineer is required to:

1.Design and develop control systems Maintain the existing control Systems.

2.Manage the control systems Collaborate with design engineers,Purchasers and other staff members involved in the productionFocusses.

3.Manage projects within the given restraints including cost and time.

4. Ensure that the instruments comply with health and safetyregulation

Ensure that quality standards are maintained Provide consultancy support.

Measurement

Measurement is a technique in which properties of anobject are determined by comparing them to a standard.

Significance in Measurement

Measurements always involve a comparison.WhenWhen you say that a table is 6 feet long, you're really$eying that the table is six times longer than an objecthat is 1 foot long.

The foot is a unit; you measure the length of the table bycomparing it with an object like a yardstick or a tapemeasure that is a known number of feet long.

Types of measurement

There are two methods of measurement:

1) Direct Comparison with the Standard

In the diredtcomparison method of measurement, we compare thequantity directly with the primary or secondary standard. Say forinstance, if we have to measure the length of the bar, we willmeasure it with the help of the measuring tape or scale that acts asthe secondary standard. Here we are comparing the quantity to bemeasured directly with the standard.

2) **Indirect method**

There are number of quantities that cannot bemeasure directly by using some instrument.InIn the indirect method of measurements Sometransducing devise, called transducer, is used, which isCoupled to a chain of the connecting apparatus thatforms the part of the measuring system.

Block diagram of any instrumentation system

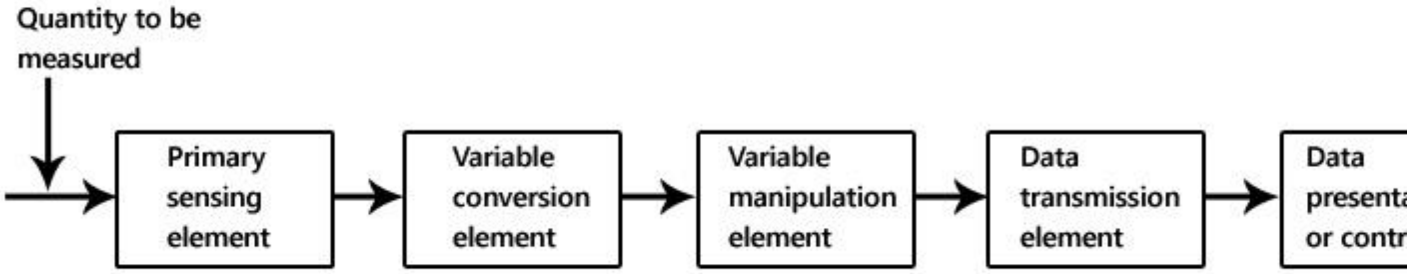
Instrumentation and control

Measurements through an instrument and it is a specific limit is called instruments and control.

Instrument

An instrument may be defined as a device or a system which is designed to maintain functional relationship between physical variable and means of communication to human observer.

The main building blocks of any measuring system are



Blocks diagram of instrumentation system

1. **Primary sensing element**

Primary sensing element is also known as sensor. Basically transducers are used as a primary stag element. Here, the physical quantity (such as temperature, pressure etc.) are sensed and then converted into analogues signal.

2. **Variable conversion element**

It converts the input of primary sensing element into suitable form without changing information. Basically these secondary transducers.

3. **Variable manipulation element**

The output of transducer may be electrical signal i.e. voltage, current or other electrical parameter Here manipulation means change in numerical value of signal. This element is used to convert the Signals into suitable range.

4. **Data transmission element**

Sometimes it is not possible to give direct read out of the quality at a particular place (Example-Measurement aperture in the furnace). in scan case, the data should transferfrom one place to another place channel which is known as data transmission element. Typically transmission path are punemetric pipe, electrical cable and radio links. When radio link is used, the electronic instrumentation system is called as telemetry system.

Sensing or control element

Either output is recorded or given to the controller to perform action. It performs different tons like indicating, recording or controlling.

Standard Test Signals

The standard test signals are impulse, step, ramp and parabolic. These signals are used to know the performance of the control systems using time response of the output.

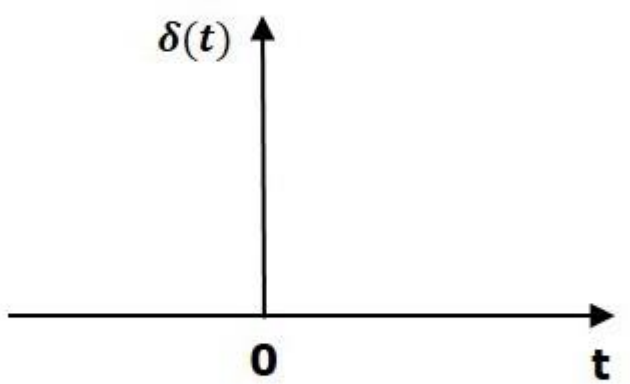
Unit Impulse Signal

A unit impulse signal, δ(t) is defined as

$\delta(t)=0$ $\delta(t)=0$ for $t\neq0$ $t\neq0$

and $\int_{0^-}^{0^+}\delta(t)dt=1$ $\int_{0^-}^{0^+}\delta(t)dt=1$

The following figure shows unit impulse signal.



So, the unit impulse signal exists only at ‘t’ is equal to zero. The area of this signal under small interval of time around ‘t’ is equal to zero is one. The value of unit impulse signal is zero for all other values of ‘t’.

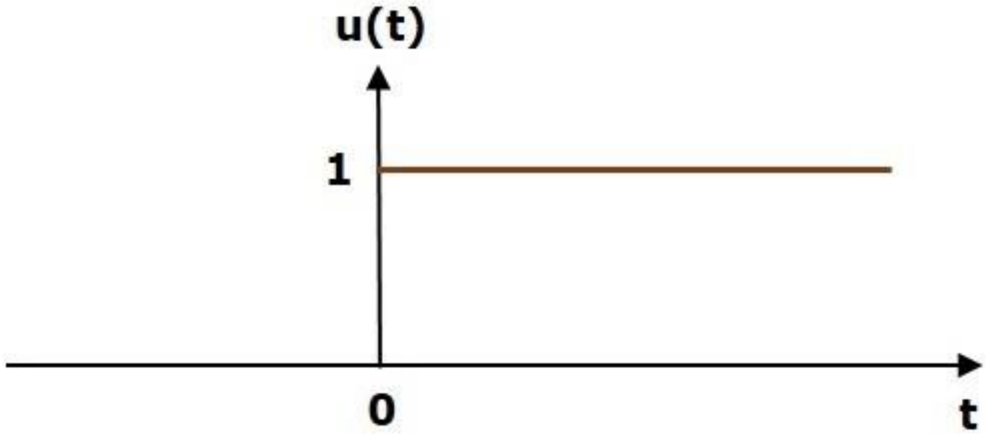
Unit Step Signal

A unit step signal, u(t) is defined as

$$u(t)=1;t\geq0 \quad u(t)=1;t\geq0$$

$=0;t<0$ $=0;t<0$

Following figure shows unit step signal.



So, the unit step signal exists for all positive values of ‘t’ including zero. And its value is one during this interval. The value of the unit step signal is zero for all negative values of ‘t’.

Unit Ramp Signal

A unit ramp signal, r(t) is defined as

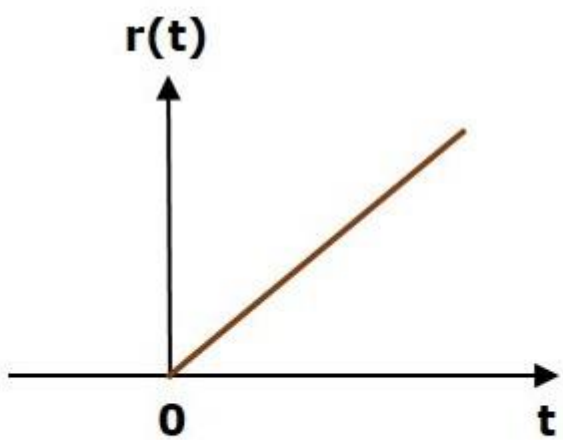
$$r(t)=t;t\geq 0$$ r(t)=t;t≥0

$=0;t<0$ =0;t<0

We can write unit ramp signal, $r(t)$ r(t) in terms of unit step signal, $u(t)$ u(t) as

$$r(t)=tu(t)$$ r(t)=tu(t)

Following figure shows unit ramp signal.



JiSo, the unit ramp signal exists for all positive values of ‘t’ including zero. And its value increases linearly with respect to ‘t’ during this interval. The value of unit ramp signal is zero for all negative values of ‘t’.

Unit Parabolic Signal

A unit parabolic signal, p(t) is defined as,

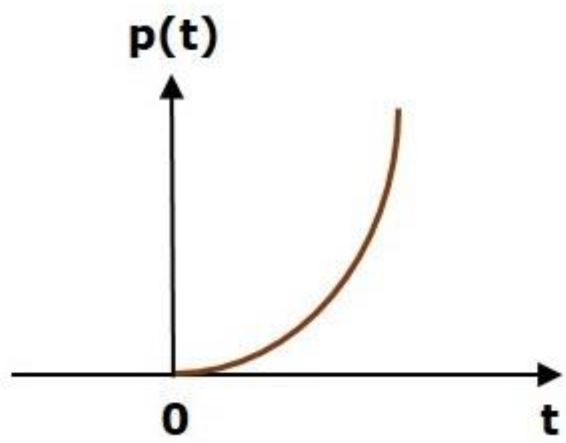
$$p(t)=t^{2}2;t\geq 0$$ p(t)=t22;t≥0

$=0;t<0$=0;t<0

We can write unit parabolic signal, $p(t)$p(t) in terms of the unit step signal, $u(t)$u(t) as,

$$p(t)=t^{2}2u(t)$$ p(t)=t22u(t)

The following figure shows the unit parabolic signal.



So, the unit parabolic signal exists for all the positive values of **‘t’** including zero. And its value increases non-linearly with respect to ‘t’ during this interval. The value of the unit parabolic signal is zero for all the negative values of ‘t’.

Important process variables and their units

The process Variables are:

- **Flow.**
- **Pressure.**
- **Temperature.**
- **Level.**

• Quality i.e. % O2, CO2, pH etc.

Flow:

Any fluids or liquids flowing from one place to another place is called flow and it is defined as volume per unit of time at specified temperature and pressure .Conditions, is generally measured by positive-displacement or rate meters.

Units: kg / hr, litter / min, gallon / min, m3 / hr, Nm3 / hr. (Gases)

Pressure

: It is defined as Force per unit Area. P = F/A

Units : bar, Pascal, kg / cm2, lb / in2.

Level

: The height of the water column, liquid and powder etc., at the desired measurement of height between minimum level points to maximum level point is called level. The measurement principle is, head pressure method.

Units: Meters, mm, cm, percentage.

Temperature

: It is the degree of hotness or coldness of a body is called temperature.

Units : Degree Centigrade, Degree Fahrenheit, Degree Kelvin, Degree Rankin.

Quality

: It deals with analysis.(pH, % CO2, % 02, Conductivity, Viscosity)

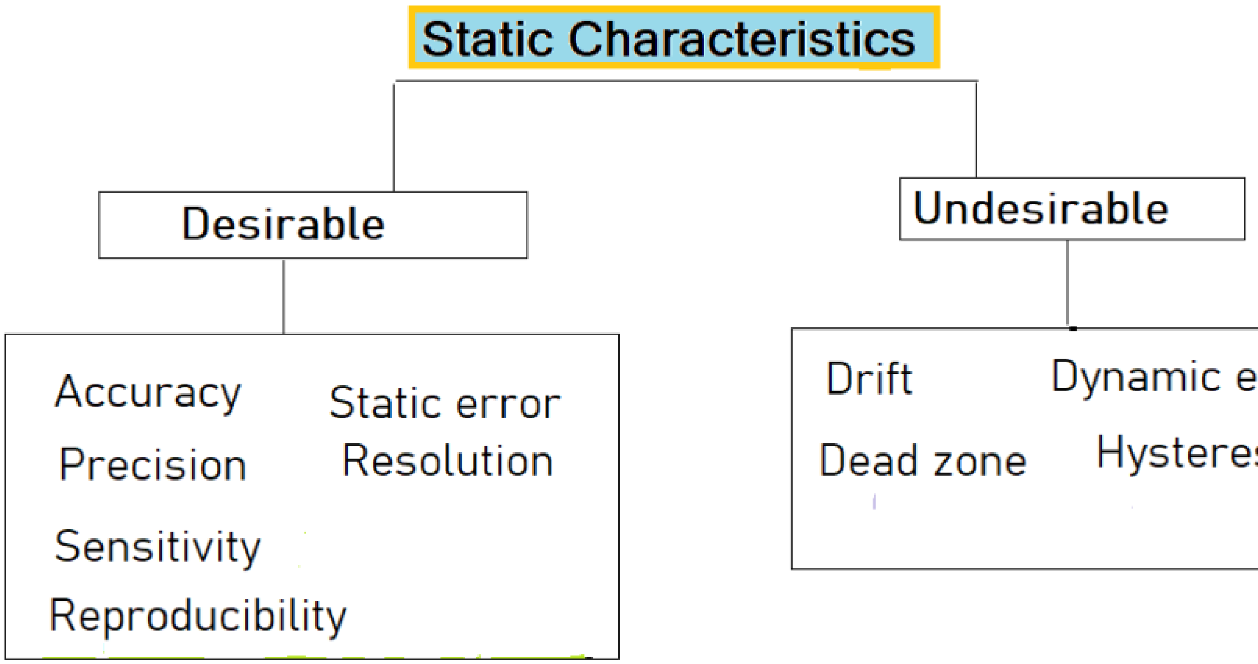
Static and Dynamic Characteristics of Instruments

The performance of any measuring instrument is affected by several factors. There are two basic performance characteristics of measuring instruments. Static Characteristics and Dynamic Characteristics.

Static Characteristics:

The following are the static characteristics.

Static Error
Accuracy
Precision
Sensitivity
Reproducibility
Hysteresis
Drift
Dead zone



Static Error: The difference between the true value of the measuring quantity to the value shown by the measuring instrument under not varying process conditions.

Static error = True value of a measured variable – Instrument reading.

+ Ve Static error means Instrument reads high,

– Ve Static error means Instrument reading low

Accuracy: may be defined as the degree of closeness with which the instrument reading approaching the true value of the quantity to be measured.

The measured quantity may be different from the true value due to the effects of temperature, humidity, etc.,

- Accuracy is expressed in the “ percentage of full-scale reading”.In the case of instruments having a uniform scale, the accuracy can be expressed as “ Percentage of Full-scale reading.
- The best way to develop the ideas of accuracy is to specify it in terms of the percentage of the true value of a quantity being measured.

Precision is the degree of exactness for which the instrument is designed.

It composed of two characteristics: **conformity** and **significant figures**.

More significant figures, estimated precision is more. For example two resistors for values of 1792 ohms and 174 ohms. A person even repeated measurement it indicates 1.7 M ohms. The reader can not read the true value from the scale.

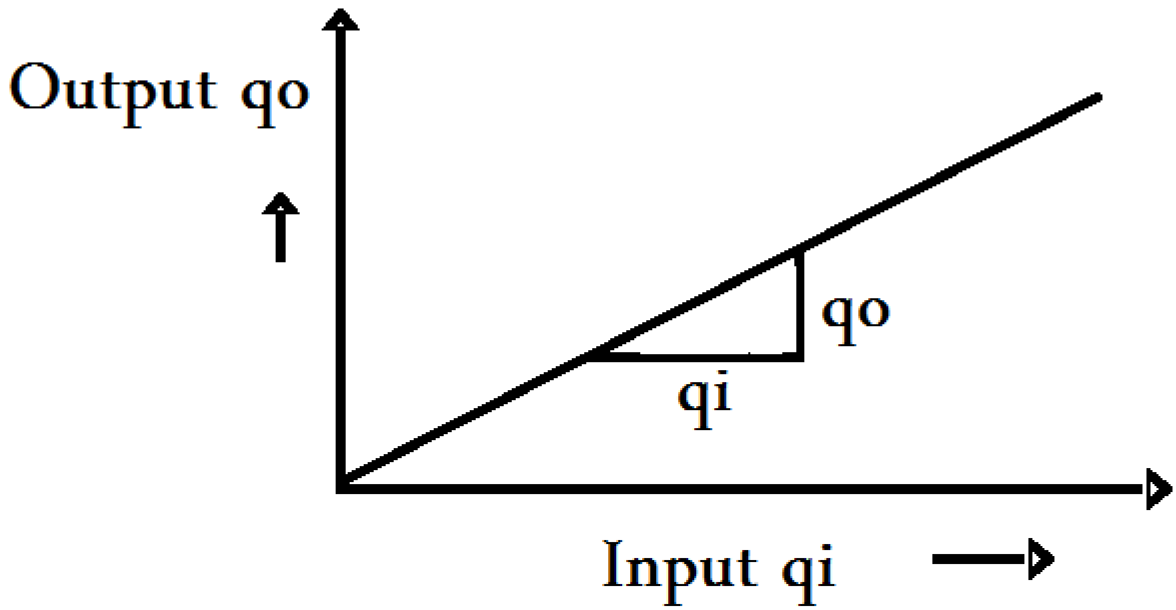
He estimates from the scale reading consistently yield a value of 1.5 M ohms. This is as close to the true scale as he can read the scale by estimation although there are no deviations from the observed value, the error created by the limitation of the error is called **precision error.**

This example indicates that the conformity is necessary but not enough condition, because of the lack of **significant figures** obtained.

Sensitivity: Sensitivity can also be derived as for the smallest changes in the measured variable for which the instrument responds.

Sensitivity can be defined as the ratio of a change in output to change in input which causes it, in steady-state conditions.

The usage of this term is generally limited to linear devices, where the plot of output to input magnitude is straight.



Sensitivity = Change in output **/** Change in input

Sensitivity can also be derived as for smallest changes in the measured variable instrument responds.

The term sensitivity is some times used to describe the maximum change in an input signal that will not initiate on the output.

Note: The sensitivity of the instrument should be high.

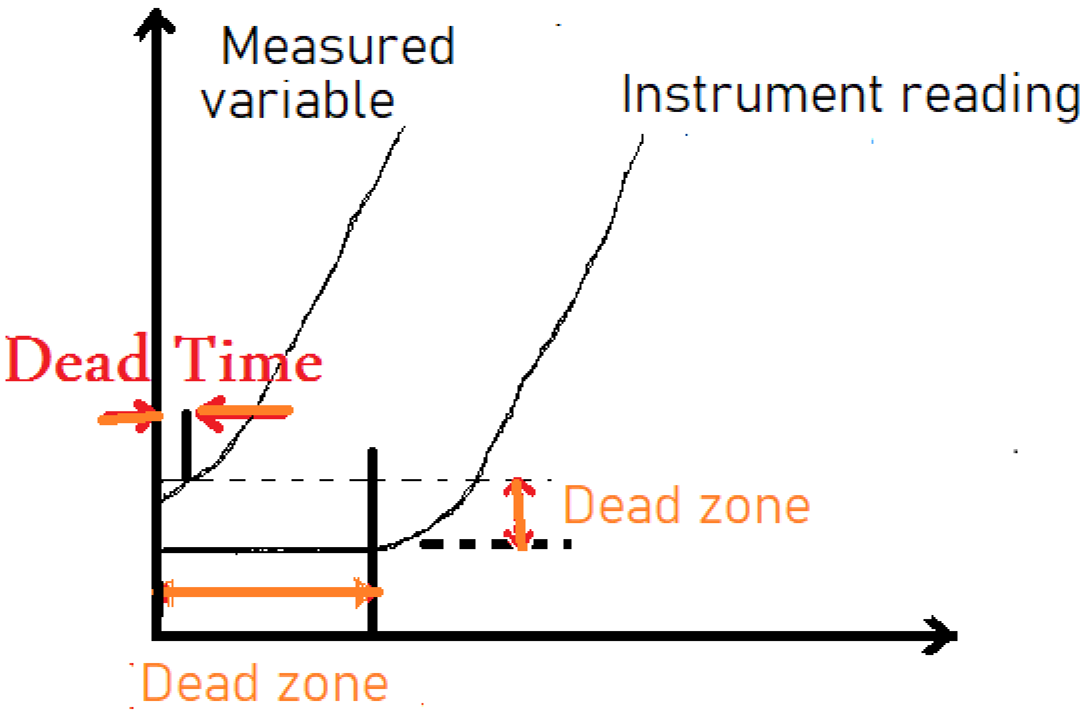
Reproducibility: Under the different measurement conditions, if the successive measurements of the same variable produce agreed results are called Reproducibility.

Resolution: It is the smallest quantity being measured which can be detected with certainty by an instrument.

If a non zero input quantity is slowly increased, the output reading won't increase until some minimum change in the input takes place. The minimum change which causes the change in output is termed resolution.

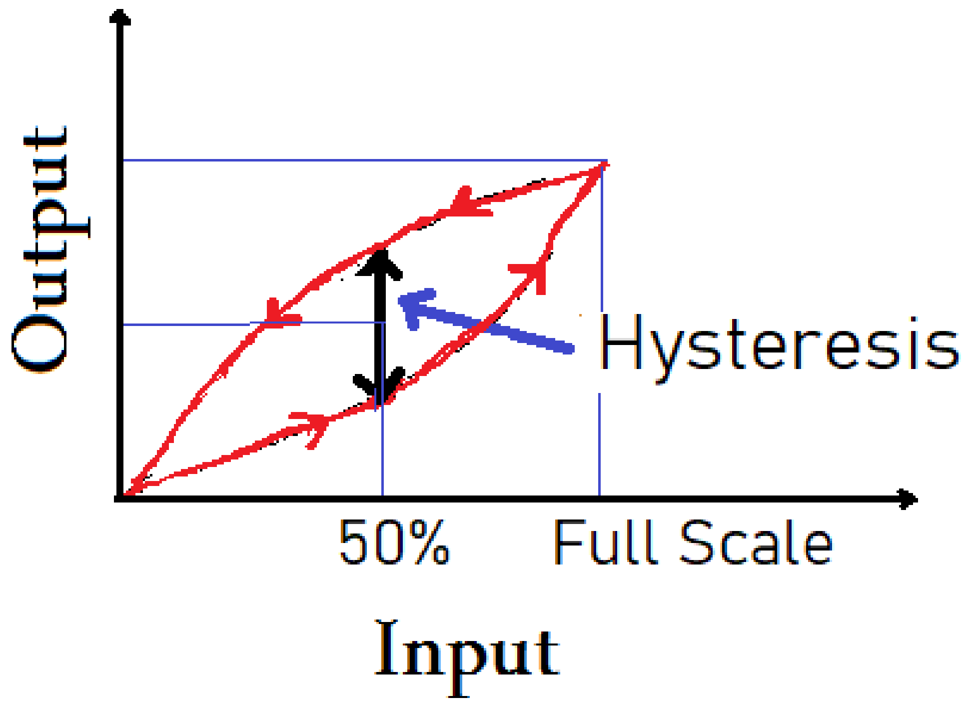
Dead Zone: for the largest range of values of a measured variable, to which instrument does not respond.

- The dead zone occurs more often due to static friction in indicating an instrument.
- **A practical example is:** Due to static friction, a Control valve does not open even for a large opening signals from the controller.



Hysteresis: Hysteresis: Hysteresis is a phenomenon that illustrates the different output effects when loading and unloading.

Many times, for the increasing values of input an instrument, may indicate one set of output values. For the decreasing values of the input, the same instrument may indicate its different set of output values. When output values are plotted against input the following kind of graph is obtained.



From the above figure, it can be seen that for increasing inputs and decreasing inputs the maximum variation is seen at 50% of the full scale.

Drift is an undesired change in the output of a measured variable over a period of time that is unrelated to the changes in output, operating conditions, load.

Drift may be caused by environmental factors mechanical vibrations, changes in temperatures, stray electric fields, stray magnetic fields, thermal EMFs.

A drift in the calibration of the instrument occurs due to the aging of component parts. Drift occurs in flow measurement due to wear and tear of primary sensing elements such as orifice plates.

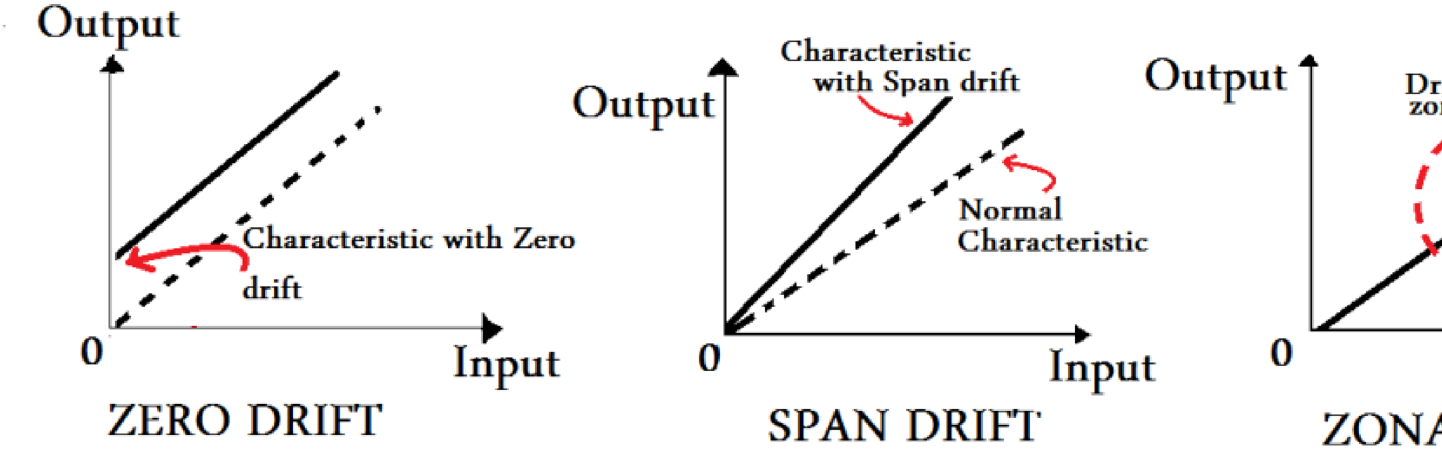
Drift occurs in temperature measurement due to scale formation on thermowell.

Drift occurs in Thermocouple or RTD elements due to the change of metallic properties.

Drift for a measuring device can be systematic or random or both some times. Due to wear and tear in the edge of an orifice plate the flow drift occurs systematic way.
Drift is further classified as :

- Zero Drift
- Span Drift

- Zonal Drift



Zero Drift: The zero drift is defined as the deviation in the measured variable starts right from zero in the output with time.

The whole instrument calibration may gradually shift by the same amount as shown in the above figure.

The mechanical **bathroom weighing scale** is a common example. It is quite casual to find that there is a reading perhaps 1kg with no one stood on the scale. If someone of known weight weighs 70 kgs were to get on the scale, the reading would be 71 kgs. If someone with a known weight of 100 kg the reading would be 101 kgs.

The Zero shift is normally removable by calibration.

Span Drift:: If there is a proportionate change in its indication right along the upward scale the drift is termed span drift or sensitivity drift.

Zonal Drift: In case if the drift occurs only a certain portion of the span of an instrument. It is called zonal drift.

Following are the dynamic characteristics

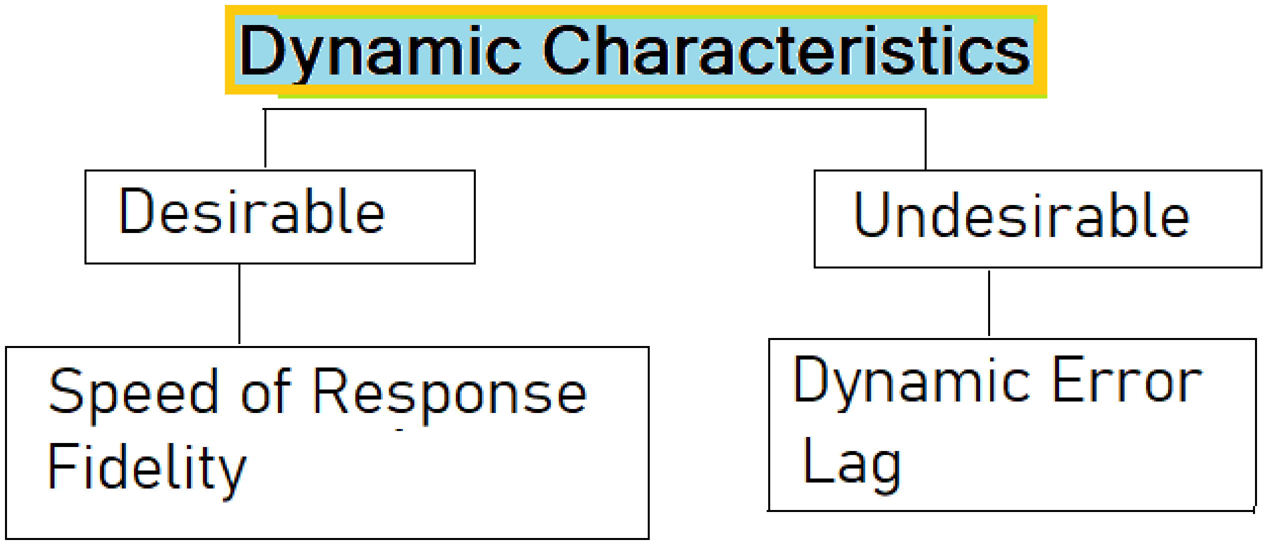
Dynamic Error

Speed of Response.

Fidelity

Lag.

Criteria



Dynamic Error: The difference between the true value of the measured quantity to the value shown by the measuring instrument under varying conditions.

Speed of response: It is defined as the rapidity of the measurement system that responds to the changes in the measuring variable.

It indicates how active and fast the system is.

Fidelity: It is defined as the degree to which a measuring instrument is capable of faithfully reproducing the changes in input, without any dynamic error.

Lag: Every system takes at least some time to respond, whatever time it may be to the changes in the measured variable.

For Example Lag occurs in temperature measurement by temperature sensors such as Thermocouple or RTD or dial thermometer due to scale formation on thermos

well due to process liquid.

Retardation lag: the response of the measurement begins immediately after the

change in measured quantity has occurred.

Time delay lag: in this case after the application of input, the response of the measurement system begins with some dead times.

Selection criteria of instruments

1. **accuracy,**
2. **robustness,**
3. **precision,**
4. **ruggedness,**
5. **sensitivity,**
6. **scale of operation,**
7. **Detection limit,**
8. **equipment,**
9. **selectivity,**
10. **Time**
11. **Linearity and Range**
12. **Cost.**

Accuracy

The accuracy of a measurement system is the degree of closeness of measurements of a quantity to the true value.

Precision

The precision of a measurement system, also called reproducibility or repeatability, is the degree to which repeated measurements under unchanged conditions show the same results.

Specificity

The specificity of a clinical test refers to the ability of the test to correctly identify those patients without the disease.

Therefore, a test with 100% specificity correctly identifies all patients without the disease.

A test with 80% specificity correctly reports 80% of patients without the disease as test negative (true negatives) but 20% patients without the disease are incorrectly identified as test positive (false positives).

Sensitivity and Specificity

$$\text{Sensitivity} = \frac{\text{True positives}}{\text{True positives} + \text{False negatives}}$$

$$\text{Specificity} = \frac{\text{True negatives}}{\text{True negatives} + \text{False positives}}$$

Detection Limit

Limit of Detection (LOD) or detection limit, is the lowest concentration level that can be determined to be statistically different from a blank (99% confidence).

The LOD is typically determined to be in the region where the signal to noise ratio is greater than 5.

Limits of detection are matrix, method, and analyse specific.

Instrument Detection Limit (IDL)
Instrument Detection Limit (IDL) is the concentration equivalent to a signal, due to the analyse of interest, which is the smallest signal that can be distinguished from background noise by particular instrument.

Method Detection Limit(**MDL**)

Method Detection Limit (MDL) is the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyse concentration is greater than zero.

Determined from analysis of a sample in a given matrix containing the analyse.

Selectivity

criterion of an analytical method is its capability to deliver signals that are free from interferences and give "true results".
Selectivity of a method refers to the extent to which it can determine particular analyse(s) in a complex mixture without interference from other components in the mixture

Specificity is the ultimate of Selectivity.

Robustness

Robustness is the capacity of a method to remain unaffected by small deliberate variations in method parameters.

Ruggedness

Ruggedness is defined as the degree of reproducibility of the test results obtained under a variety of normal test conditions, such as different laboratories, different analvsts, different instruments, different lots of reagents, different elapsed assay times, different assay temperatures, different days, etc.

Linearity and Range

Linearity is the ability of the method to elicit test results that are directly proportional to analyse concentration with in a given range.
Traditionally linearity was regarded as a desirable property of methods as only linear curves could be easily interpreted..

Range is the interval between lower and upper levels of analyse that is demonstrated to be determined with the stated precision and accuracy using the method as written.

Calibration
Introduction

Important part of all analytical procedures is the calibration and standardization process.

Calibration determines the relationship between the analyticalresponse and the analyse concentration.

This is determined by the use of chemical standards. Almost all analytical methods require some type of calibration with chemical standards.

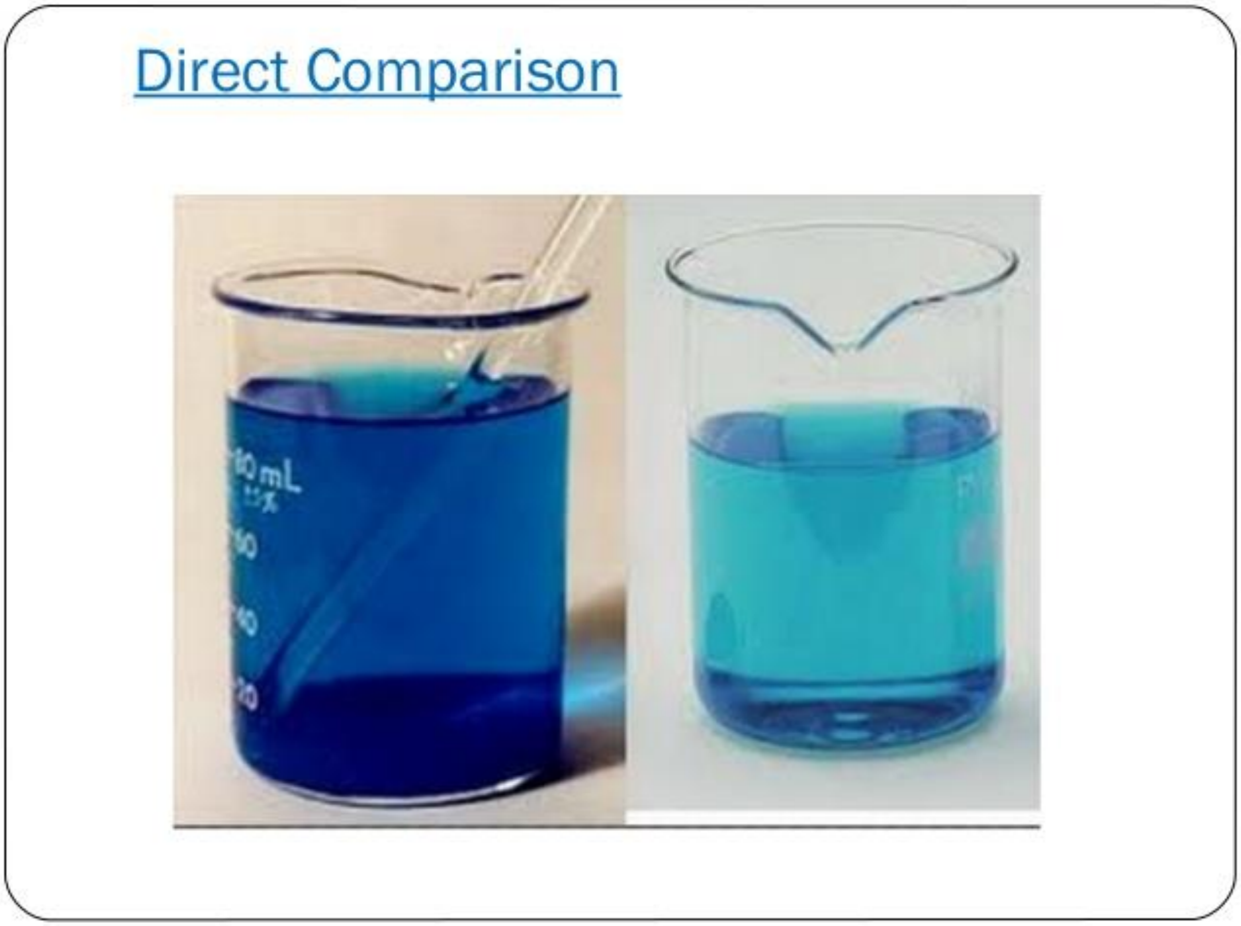
Exception Gravimetric methods and some gravimetric methods.

Comparison with Standards

Direct Comparison

Some analytical procedures involve comparing a property of the analytic (or the product of a reaction with the analytic) with standards such that the property being tested matches or nearly matches that of the standard.

Early colorimetric methods, the colour produced as the result of a chemical reaction of the analyse was compared with the colour produced by reaction of standards.



Direct Comparison

If the concentration of the standard is varied by dilution, it is possible to obtain a fairly exact colour match.

The concentration of the analyte will be equal to the concentration of the standard after dilution.Titrations

Titrations are among the most accurate of all analytical procedures.

The analyte reacts with a standardized reagent (the titrant) in a reaction of known stoichiometry.

Usually the amount of titrant is varied until chemical equivalence is reached, as indicated by the colour change of a chemical indicator or by the change in an instrument response.

The amount of the standardized reagent needed to achieve chemical equivalence can then be related to the amount of analyte present.

The titration is thus a type of "chemical comparison."

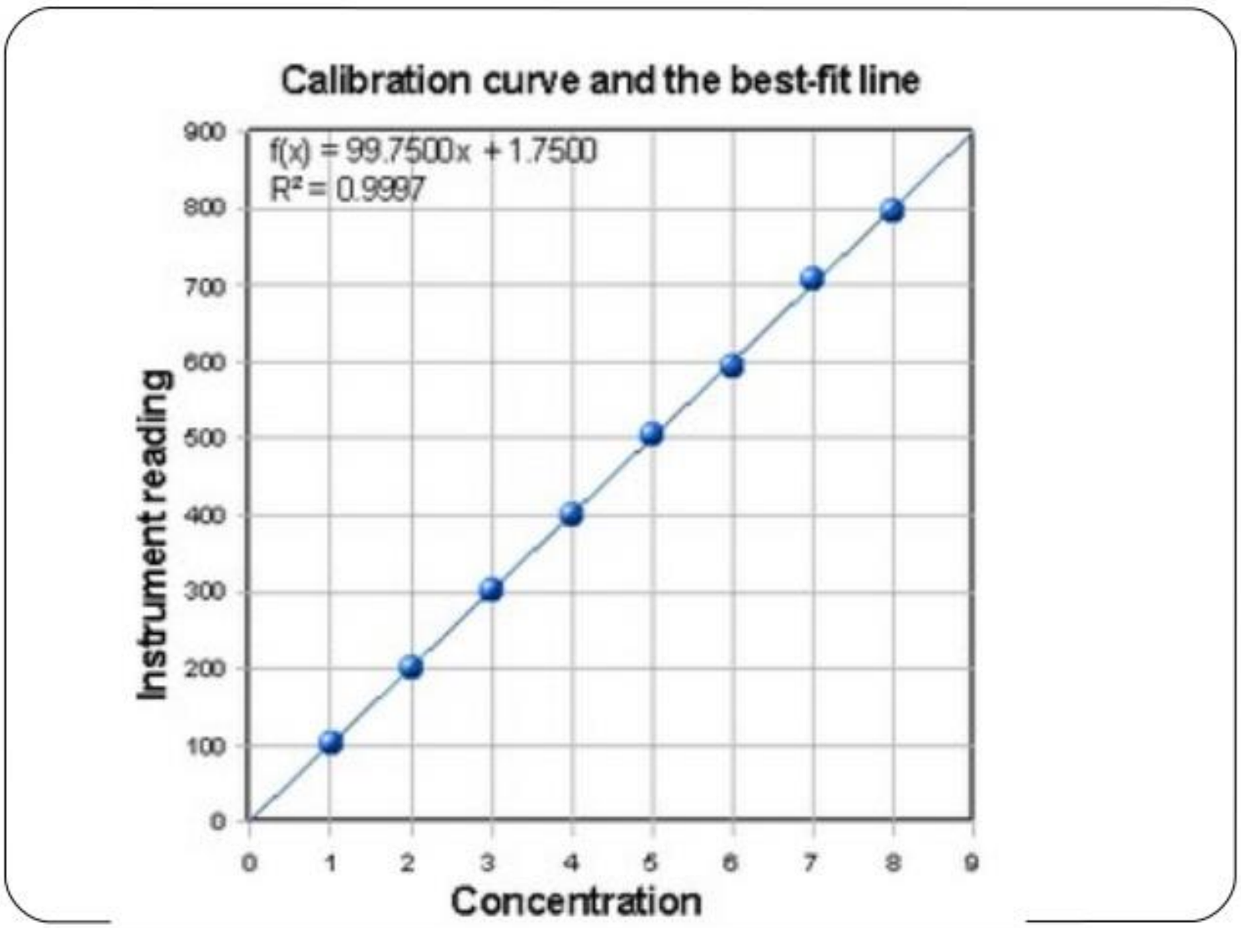
External Standard Calibration
An external standard is prepared separately from the sample.

External standards are used to calibrate instruments and procedures when there are no interference effects from matrix components in the analyte solution.

Series of such external standards containing the analyte in knownconcentrations is prepared.

Ideally, three or more such solutions are used in the calibrationprocess.

However, in some routine analyses, two-point calibrations can bereliable.



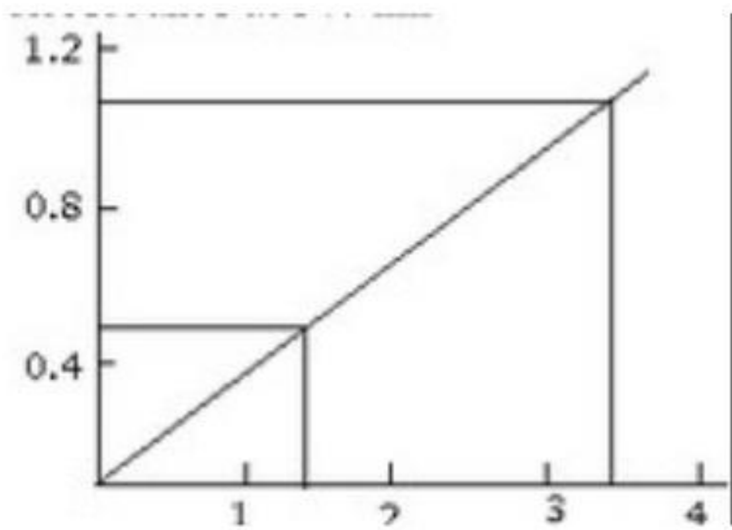
The Least-Squares Method

The method of least squares is based on two assumptions.

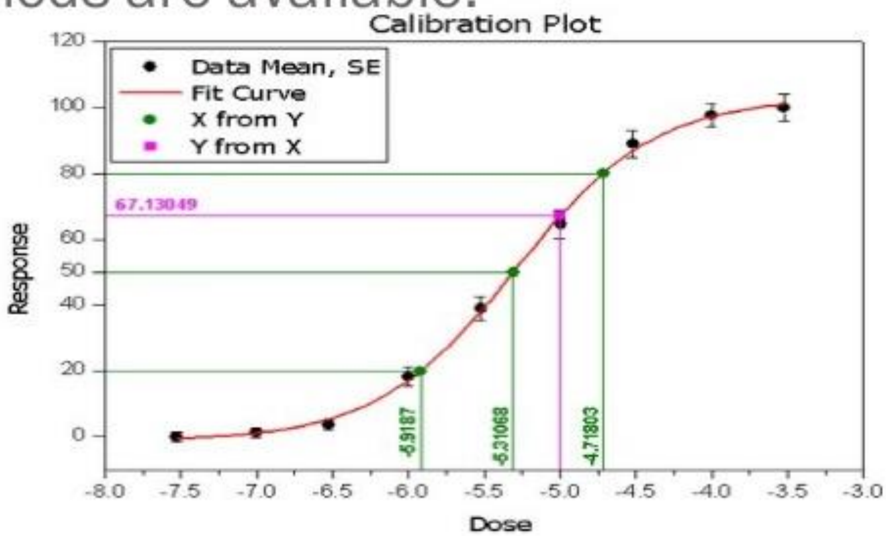
The first is that there is actually a linear relationship between the measured response and the standard analyte concentration x

Y= mx+b

where b is the y intercept (the value of y when x is zero) m is the slope of the line.



In cases where the data do not Fit a linear mode nonlinear regression methods are available.



In a determination, the raw response from the instrument is not used. Instead, the raw analytical response is corrected by measuring a blank.

An ideal blank is identical to the sample but without the analyte. In practice, with complex samples, it is too time-consuming or impossible to prepare an ideal blank and a compromise

must be made.

Most often a real blank is either a solvent blank, containing the same solvent in which the sample is dissolved, or a reagent blank, containing the solvent plus all the reagents used in sample preparation.

Errors in calibration
Systematic errors can occur during the calibration process.

For example, if the standards are prepared incorrectly ,an error will occur Concentration of the standards can change because of
decomposition, voltaic liquid or adsorption onto container walls.

Contamination of the standards can also result in higher analyte concentrations than expected.

Chapter 3 – display and recording device

Basic Strip chart recorder

 Figure 2.2 shows basic constructional features of a strip chart recorder.

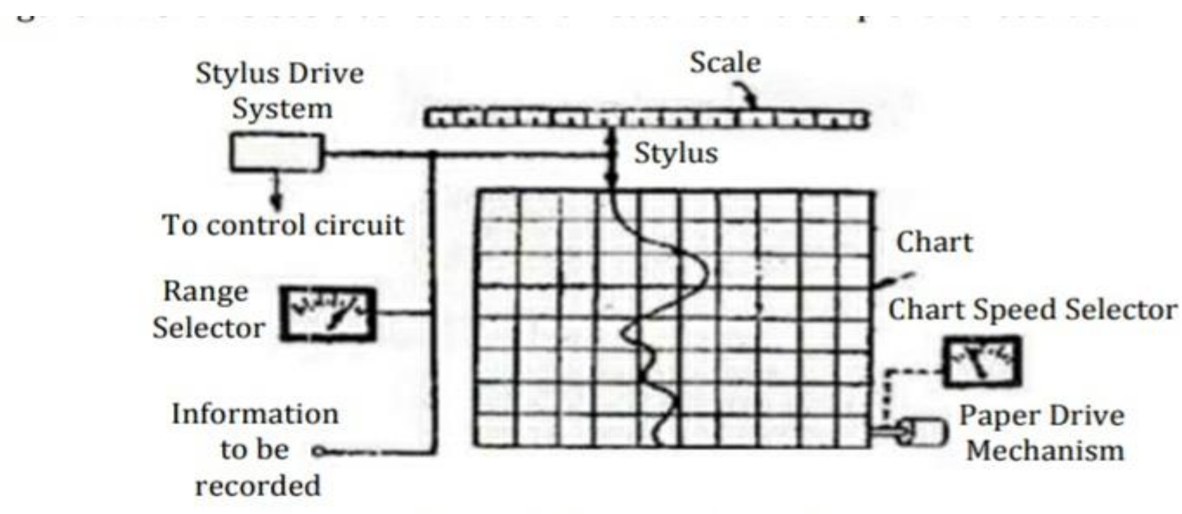


Figure 6. 2 Basic strip chart recorder

ıction

Construction

A strip chart recorder consists of:

(i) Paper drive systems

: It should move the paper at a uniform speed. A spring wound mechanism may be used but in most of the recorders and a synchronous motor is used for driving the paper.

(ii) Marking mechanism: The most commonly used marking mechanisms are as following:

a. Marking with ink filled stylus

b. Marking with heated stylus

c. Chopper bar

d. Electric stylus marking

e. Electrostatic stylus

f. Optical marking method

(iii) Tracing systems:

There are two types of tracing systems used for producing graphic representations.

a. Curvilinear system

b. Rectilinear system

Working

A strip chart recorder has:

(i) A long roll of graph paper moving vertically.

(ii) A system for driving the paper at some selected speed. A speed selector switch is generally provided. Chart speed of 1-100 mm/s are usually used.

(Iii)A stylus for making marks on the moving graph paper. The stylus moves horizontally in proportional to the quantity being recorded.

(iv) A stylus driving system which moves the stylus in a nearly exact replica or analog of the quantity being recorded.

(v) A range selector switch is used so that input to the recorder drive system is within the acceptable level.

(vi) Most recorder use a pointer attached to the stylus. This pointer moves over a calibrated scale thus showing the instantaneous value of the quantity being recorded. An external control circuit for the stylus may be used.

6.3. Types of Strip Chart Recorders

The different types of strip chart recorders are:

1. Galvanometer type 2. Null type

X-Y type recorders

- A strip chart recorder records the variations of a quantity w.r.t. time while a X-Y recorder is an instrument which gives a graphic record of the relationship between two variables.
- In X-Y recorders, an emf is plotted as a function of another emf. This is done by having one self-balancing potentiometer control the position of the rolls while another self- balancing potentiometer controls the position of the recording pen (stylus).
- In some X-Y recorders, one stylus moves in the X direction and second stylus moves in the Y direction at right angles to the X direction, while the paper remains stationary.
- With the help of X-Y recorders and appropriate transducers, a physical quantity may be plotted against another physical quantity.
- Hence, an X-Y recorder consists of a pair of servo-system, driving a recording pen and moving arm arrangement, with reference to a stationary paper chart. Attenuators are used to bring the input signals to the levels acceptable by the recorder.
- Figure 6.5 below shows a block diagram of a typical X-Y recorder.

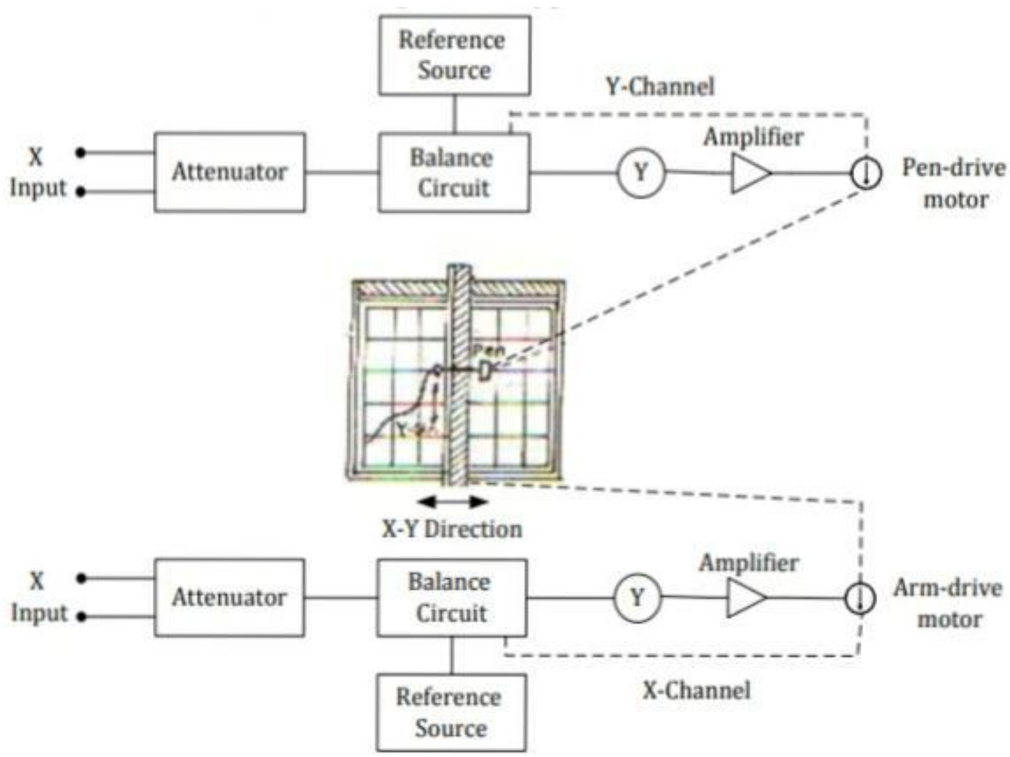
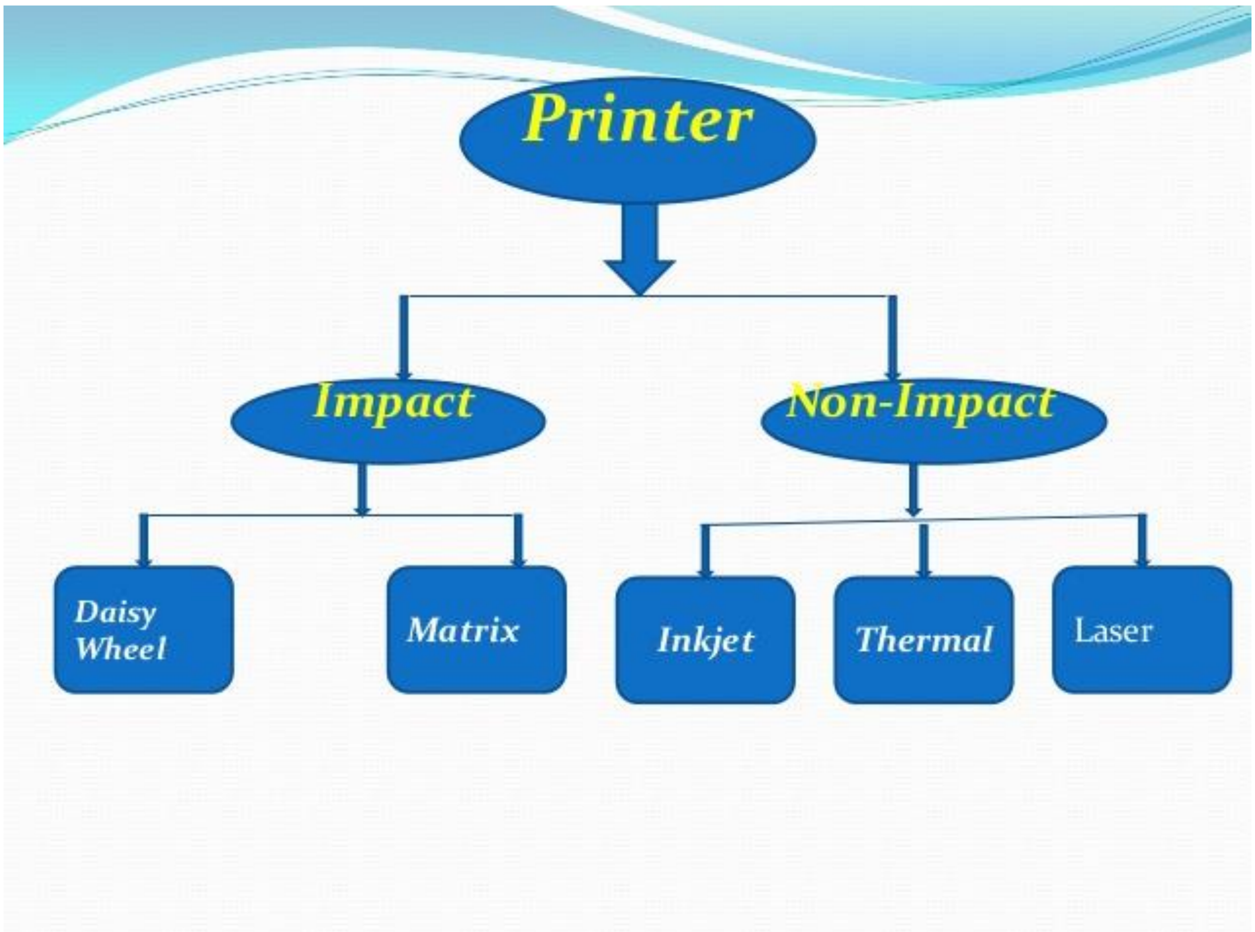


Figure 6. 5 Block diagram of a typical X-Y recorder

- A signal enters each block of the two channels. The signals are attenuated to the inherent full scale range of the recorder, the signal then passes to a balance circuit where it is compared with an internal reference voltage. The error signal and the reference voltage is fed to a chopper which converts d.c. signal to an a.c. signal. The signal is then amplified in order to actuate a servomotor which is used to balance the system and hold it in balance as the value of the quantity being recorded changes.
- The action described above takes place in both axes simultaneously. Thus we get a record of one variable w.r.t. another.
- The use of X-Y recorders in laboratories greatly simplifies and expedites many measurements and tests. A few examples are being given below:
- Speed torque characteristics of motors
- Lift drag wind tunnel tests
- Plotting of characteristics of vacuum tubes, Zener diodes rectifier and transistors etc.
- Regulation curves of power supplies
- Plotting stress-strain curves, hysteresis curves and vibrations amplitude against swept frequency.
- Electrical characteristics of materials such as resistance vs. temperature plotting the output from electronic calculators and computers.

- **Printer**
  What is Printer ?
  An external hardware device responsible for taking computer data and generating a hard copy of that data.
  Printers are one of the most commonly used peripherals and they print text and still images on the paper.



Impact Printer

These printers have a mechanism that touches the paper to create an image.

printers work by banging a print head containing a number of metal pins which strike an inked ribbon placed between the print head and the paper.

Non-Impact Printer

These printers create an image on the print medium without the use of force.
They don't touch the paper while creating an image.
Non-impact printers are much quieter than impact printers as they don't strike the paper.

A non-impact printer

Dot Matrix Printer

The term dot matrix refers to the process of placing dots to form an image.
Its speed is usually 30 to 550 characters per second (cps).
This is the cheapest and the mostnoisy printer and has a low print quality.
Dot Matrix were 1st introduced by Centronics in 1970

The dot matrix forms images one character at a time as the print head moves across the paper.

Uses tiny pins to hit an ink ribbon and the paper much as a typewriter does.

Daisy Wheel Printer

A daisy wheel printer is basically an impact printer consisting of a wheel and attached extensions on which molded metal characters are mounted.

A daisy wheel printer produces letter quality print and it can't produce graphics output.

In a daisy wheel printer, a hammer presses the wheel against a ribbon which in turn makes an ink stain on the paper in the form of a character mounted on the wheel extensions.

Its printing speed is also very slow ,i.e. less than gocps.

Ink-Jet Printer

- It is a non-impact printer producing a high quality print.

- A standard Inkjet printer has a resolution of 30odpi. Inkjet printers were introduced in the later half of 198os and are very popular owing to their extra-ordinary performance.

- Print head having four ink cartridges moves.
- Software instructs where to apply dots of ink, which color and what quantity to use.
- Electrical pulses are sent to the resistors behind each nozzle.

- Vapour bubbles of ink are formed by resistors and the ink is forced to the paper through nozzles.
- A matrix of dots forms characters and pictures.

Thermal Printer

Thermal printers are in-expensive printers mostly used in fax machines.

The Thermal printers are further classified into two types.

() Electro thermal printers
(2) Thermal Wax printers:

Thermal printers use heated pins and ribbons with different color bands.

These printers contain a stick of wax like ink. The ribbon passes infront of a print head that has a series of tiny heated pins.

The pins cause the wax to melt and adhere to the paper and when temperature reaches to a certain level, it is hardened.

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Plotter

A large scale printer which is very accurate in producing engineering drawings and architectural blueprints.

Two types of plotters are flatbed and drum.

Flatbed plotters are horizontally aligned while drum plotters are vertically positioned.

3D Printer

3D printing is a process of melting plastic filament and creating solid objects by building them up in very thin layers.

The technology is used in a wide range of industries from construction to aerospace, and is now starting to make its way into the mainstream.

Conclusion

In fact computer world is incomplete without printers in the modern age of technology.

A printer is one of the basic needs of every computer user and one can not utilize computer resources properly in the absence of a quality printer.

Scanning

- Laser scanners have the most flexibility of any non-contact scanning method. They can be mounted on a coordinate measuring machine, attached to portable measuring arms as well used with the Leica Tracker. Laser scanners regardless of where they are mounted have the ability to measure all sides of the component being inspected.

- White light scanning systems, or blue light as in some cases, are by far the fastest method of data accumulation. They are ideal for smaller components or large batch inspection of the same component. Once programmed, they operate automatically, even in conjunction with a rotary table or a loading robot.

- Analog scanning devices maintain constant contact with the component. They are generally mounted on a direct computer controlled coordinate measuring machine – their advantage is precision. Analog scanning devices can also function as a tactile measuring system and blend tactile measurements with scanning measurements.

Data logger

INTRODUCTION

The term Data Logging' refers to collecting or gathering dataover a period of time.

A data logger is a device that can be used to store and retrievethe data.

Data loggers capture, measure,and analyse physicalphenomena from the real world.

Light, temperature and pressure are examples of the differenttypes of signals that a Data logger can measure.A data logger is often a hand-held battery operated devicewhich has a large amount of memory.

How Data is Collected?

The objective of this work is to use data logging for temperature measurement. In order to meet the above requirements, a low cost, portable data logger is designed.

A microcontroller based data logger has been developed for measuring temperature at different input channels of ADC.

Sensors are used to take readings or measurements at regular intervals of their environment.

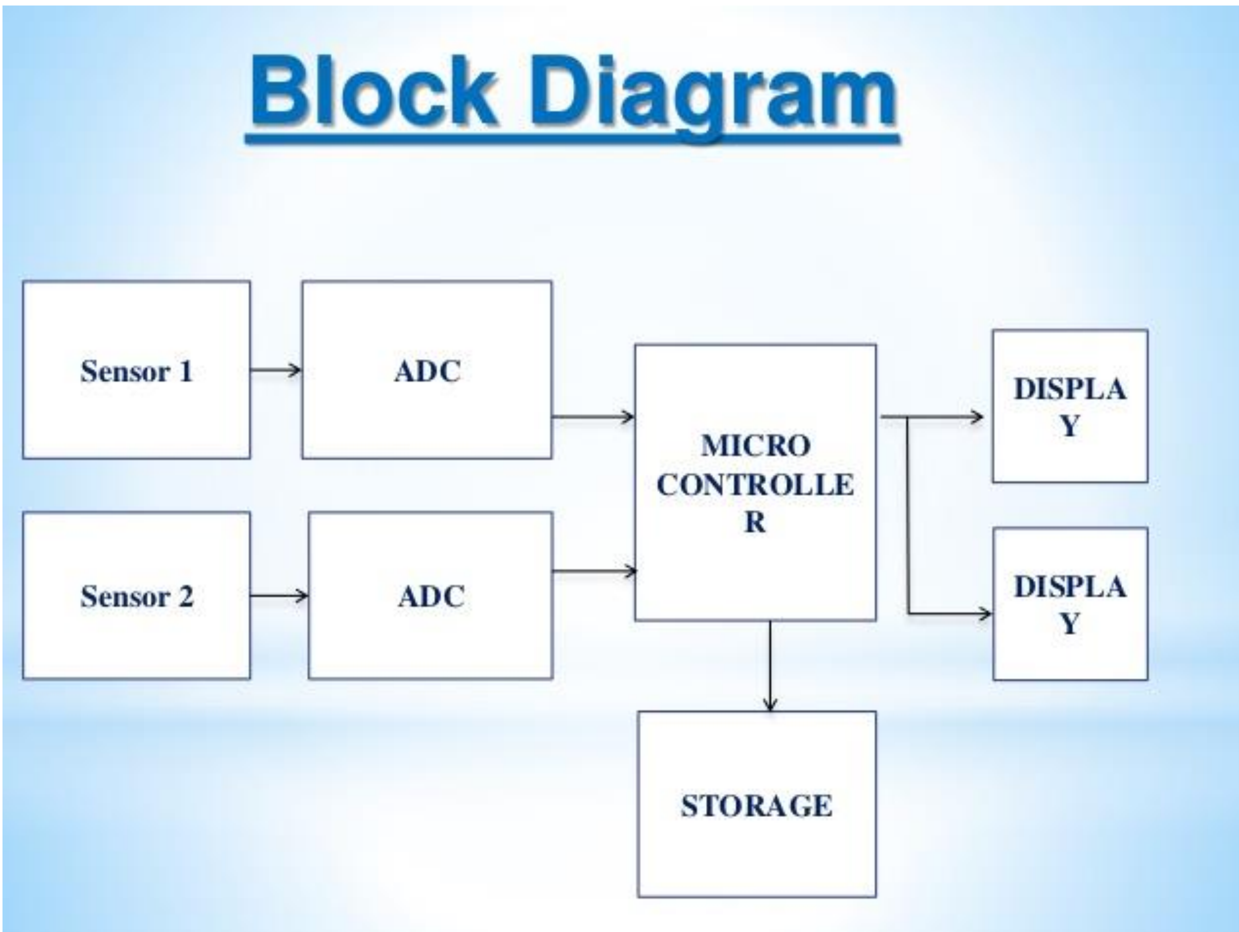
The sensors may be either analogue or digital. If they take analogue readings, an Analogue to Digital Converter will be needed to convert the signal into digital data which the computer can understand.

As the sensor takes a reading, the data is sent though a cable orwireless link to the data logger.

The device is designed to receive data from sensors and to storethe results on external non-volatile flash memory for postprocess analysis.

An integrated Liquid crystal display (LCD) is also used for realtime display of data acquired from various sensors.

The sensors can be collected data on a wide range of thingssuch as temperature, humidity, pressure, wind speed, watercurrents, electrical voltage, pH readings etc.



Building blocks of a data logger

Transducer or Sensors:_

A device that converts a physicalphenomenon such as light, temperature, pressure, or sound into ameasurable electrical signal such as voltage or current.

Analog to Digital Converter:

The data logger senses only digitalsignals and hence analog signals, it may converted to digital signal.

Microcontroller & Storage:

Microcontroller is used to convertdigital signals into binary form, storage used to store the converteddigital signal.

Display:

Some data loggers interface with a personal computer andutilize software to activate the data logger and view and analyze thecollected data, while others have a local interface device (keypad,LCD) and can be used as a stand-alone device.

Implementation and System Design

System Definition:

Broad definition of system hardware includingmicrocontroller and its interface with display, ADC, memory, keypad etc.

Circuit Design:

Selection of 8051 microcontroller and otherinterfacing devices, as per system definition. Design of hardwarecircuit and its testing on laboratory kits with some simple microcontrollersoftware routines.

PCB Design and Fabrication: Generation of schematic diagrams andthe production of circuit board layout data for the procurement of thecircuit board.

Software Design: Developing algorithm for the system, allocatingmemory blocks as per functionality, coding and testing.

Integration and Final Testing: Integrating the entire hardware and software modules and its final testing for data logging operation.

Data Logger Topologies

Stand Alone

Standalonehardwarecancontinuously measure and log datawithout connection to a PC.

PC Based

Operation require fulltime connection to a PC over anyappropriate bus technology.

ADVANTAGES

Data Logging can be used in remote or dangerous situations.Data logging can be carried out 24 hours a day, 365 days ofthe year.

Time intervals for collecting data can be very frequent andregular, for example, hundreds of measurements per second.

No need to have a person present.

Data logging is often more accurate because there is nolikelihood of human error**.**

DISADVANTAGES

If the data logging equipment breaks down or malfunctions,some data could be lost or not recorded.

Equipment can be expensive for small tasks.

The equipment will only take readings at the logginginterval which has been set up. If something unexpectedhappens between recordings, the data will not be collected.

Data loggers typically have slower sample rates than DataAcquisition System.

APPLICATIONS

- They can be used in the following applications such as:
- In unattended recording at weather stations to record parameterslike temperature, wind speed / direction, solar radiation andrelative humidity.
- For hydrographic recording of water flow, water pH, waterconductivity, water level and water depth.
- In the recording of soil moisture levels.
- To record gas pressure and to monitor tank levels.
- Vehicle Testing (including crash testing).

CONCLUSION

They are designed to operate continuously without interruptioneven in the worst industrial environments.

It is a portable measurement instrument, has a wide applicationin industries.

The digital data can be retrieved, viewed and evaluated after ithas been recorded.

Data loggers can be taken to diverse locations include:mountains, deserts, jungles, mines, etc.The specified accuracy is maintained throughout the period ofuse.

Basic GPIB concept

The GPIB or IEEE 488 bus is a very flexible system, allowing data to flow between any of the instruments on the bus, at a speed suitable for the slowest active instrument. Up to fifteen instruments may be connected together with a maximum bus length not exceeding 20 m.

A further requirement for the bus is that there must also be no more than 2 m between two adjacent test instruments.

It is possible to purchase GPIB cards to incorporate into computers that do not have the interface fitted. As GPIB cards are relatively cheap, this makes the inclusion of a GPIB card into the system a very cost effect method of installing it. That said, the falling usage of GPIB means that GPIB cards are not nearly as widely available as they used to be.

GPIB / IEEE 488 connector

Devices have a unique address on the bus. Test instruments are allocated addresses in the range 0 to 30, and no two instruments on the same bus are allowed to have the same address. The addresses on the instruments can be changed and this may typically be done via the front panel, or by using switches often located on the rear panel.

Active extenders are available and these items allow longer buses: up to 31 devices theoretically possible, along with a greater overall length dependent upon the extender.

In the original HPIB protocol, transfers utilise three wire handshaking system. Using this the maximum data rate achievable is around 1 Mbyte per second, but this is always governed by the speed of the slowest device. A later enhancement often referred to as HS-488 relaxes the handshaking conditions and enables data rates up to about 8 Mbytes / second.

The connector used for the IEEE 488 bus is standardised as a 24-way Amphenol 57 series type. This provides an ideal physical interface for the standard. The IEEE 488 or GPIB connector is very similar in format to those that were used for parallel printer ports on PCs although the type used for the GPIB has the advantage it has been changed so that several connectors can be piggy-backed. This helps the physical setting up of the bus and prevents complications with special connection boxes or star points.

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

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

- ***Listener:*** A listener is an entity connected to the bus that accepts instructions from the bus. An example of a listener is an item such as a printer that only accepts data from the bus. It could also be a test instrument such as a power supply or switching matrix that does not take measurements.
- ***Talker:*** This is an entity on the bus that issues instructions / data onto the bus.

Many items of test equipment will fulfil more than one function. For example a voltmeter which is controlled over the bus will act as a listener when it is being set up, and then when it is returning the data, it will act as a talker. As such it is known as a talker / listener.

GPIB / IEEE 488 cable

Often GPIB cards can be used in a variety of roles, but these GPIB cards are most often used as controllers as they tend to reside in the controlling computer. Most test instruments that might be intended for use with the GBIP interface would have this fitted as standard and would therefore not require and additional GPIB card.

GPIB features / parameters summary

Although the full specification for GPIB / IEEE 488 is held by the IEEE and IEC, there key features for the bus can be seen in the short table below.

IEEE 488 BUS / GPIB FEATURES SUMMARY

PARAMETER	DETAILS
Max length of bus	20 metres
Max individual distance between instruments	2 metres average 4 metres maximum in any instance.
Maximum number of instruments	14 plus controller, i.e. 15 instruments total with at least two-thirds of the devices powered on.

IEEE 488 BUS / GPIB FEATURES SUMMARY

PARAMETER	DETAILS
Data bus width	8 lines.
Handshake lines	3
Bus management lines	5
Connector	24-pin Amphenol (typical) D-type occasionally used.
Max data rate	~ 1 Mbyte / sec (HS-488 allows up to ~8Mbyte / sec).

Advantages & disadvantages of GPIB

Like any other technology, GPIB has advantages and disadvantages that need to be weighed up when considering its use.

Advantages

- Simple & standard hardware interface
- Interface present on many bench instruments
- Rugged connectors & connectors used (although some insulation displacement cables appear occasionally).
- Possible to connect multiple instruments to a single controller
-

Disadvantages

- Bulky connectors
- Cable reliability poor - often as a result of the bulky cables.
- Low bandwidth - slow compared to more modern interfaces
- Basic IEEE 422 does not mandate a command language (SCPI used in later implementations but not included on all instruments.

GPIB capability is included on a large number of bench instruments, but when opting to use the facility to build a system, it is necessary to consider all the advantages and disadvantages before committing time and cost to its use.

RS-232 INTERFACE

Introduction:

The RS-232 interface is the Electronic Industries Association (EIA) standard for the interchange of serial binary data between two devices. It was initially developed by the EIA to standardize the connection of computers with telephone line modems. The standard allows as many as 20 signals to be defined, but gives complete freedom to the user. Three wires are sufficient: send data, receive data, and signal ground. The remaining lines can be hardwired on or off permanently. The signal transmission is bipolar, requiring two voltages, from 5 to 25 volts, of opposite polarity.

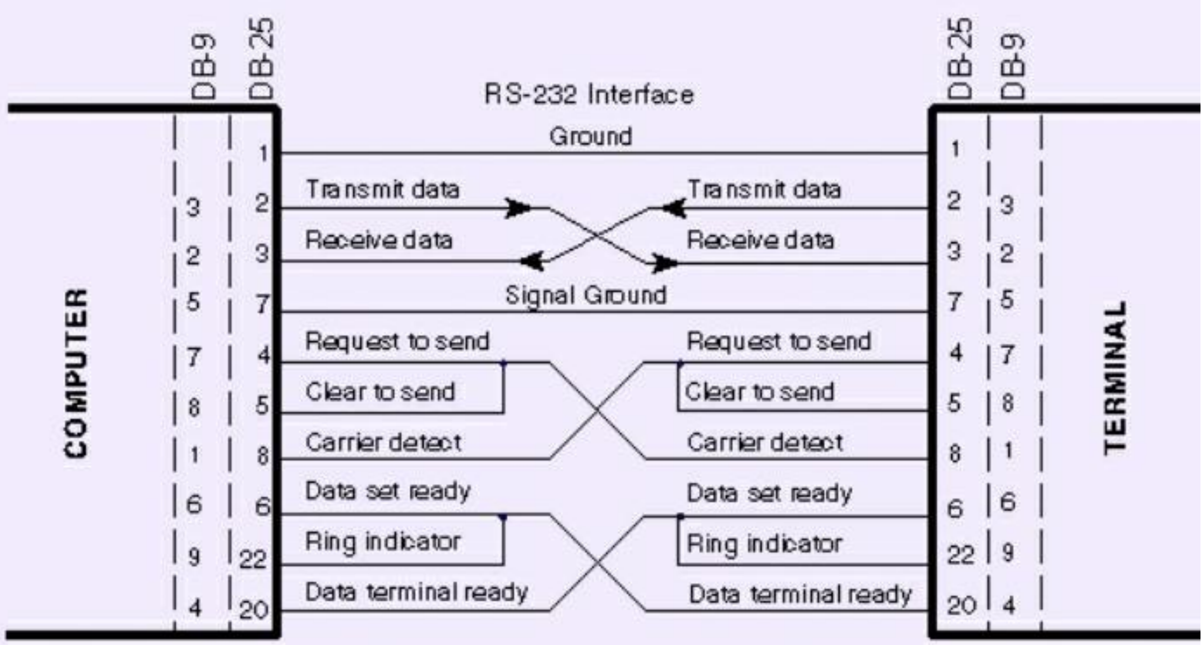


Figure 1. Direct-to-computer RS-232 Interface

Communication Standards:

The industry custom is to use an asynchronous word consisting of: a start bit, seven or eight data bits, an optional parity bit and one or two stop bits. The baud rate at which the word sent is device-dependent. The baud rate is usually 150 times an integer power of 2, ranging from 0 to 7

(150, 300, 600 ,...., 19,200). Below 150 baud, many system-unique rates are used. The standard RS-232-C connector has 25 pins, 21 pins which are used in the complete standard. Many of the modem signals are not needed when a computer terminal is connected directly to a computer, and Figure 1 illustrates how some of the "spare" pins should be linked if not needed. Figure 1 also illustrates the pin numbering used in the original DB-25 connector and that commonly used with a DB-9 connector normally used in modern compute.

Specifying compliance to RS-232 only establishes that the signal levels in two devices will be compatible and that if both devices use the suggested connector, they may be able to be connected. Compliance to RS-232 does not imply that the devices will be able to communicate or even acknowledge each other's presence.

Table 1 shows the signal names, and functions of the RS-232 serial port pinout.

Table 1. RS-232 Serial Port Pinout (with 25 pin connector)

Name	Pin	Signal Name	Function
AA	1	PG Protective Ground	This line is connected to the chassis ground of the GPIB-232CV. Since the GPIB-232CV chassis ground is not connected to earth ground, pin 1 should be connected on both serial devices.
BA	2	TxD Transmit Data	This line carries serial data from the GPIB-232CV to the serial host.
BB	3	RxD Receive Data	This line carries serial data from the serial host to the GPIB-232CV.
CA	4	RTS Request to Send	This signal line is driven by the GPIB-232CV and when asserted indicates that the GPIB-232CV is ready to accept serial data. The GPIB-232CV unasserts RTS when it is no longer ready to accept serial data because of a buffer full condition.
CB	5	CTS Clear to Send	This signal line is asserted by the serial host and sensed by the GPIB-232CV. When asserted, it indicates that the serial host is ready to accept serial data. When unasserted, it indicates that data transmission should be disabled.
AB	7	SG Signal Ground	This line establishes a reference point for all interface voltages.
CD	20	DTR Data Terminal	This signal line is asserted by the GPIB-232CV to signal that it has been powered on, and is ready to operate.

		Ready	

Light emitting diode

Introduction

LED is an acronym for Light Emitting Diode.

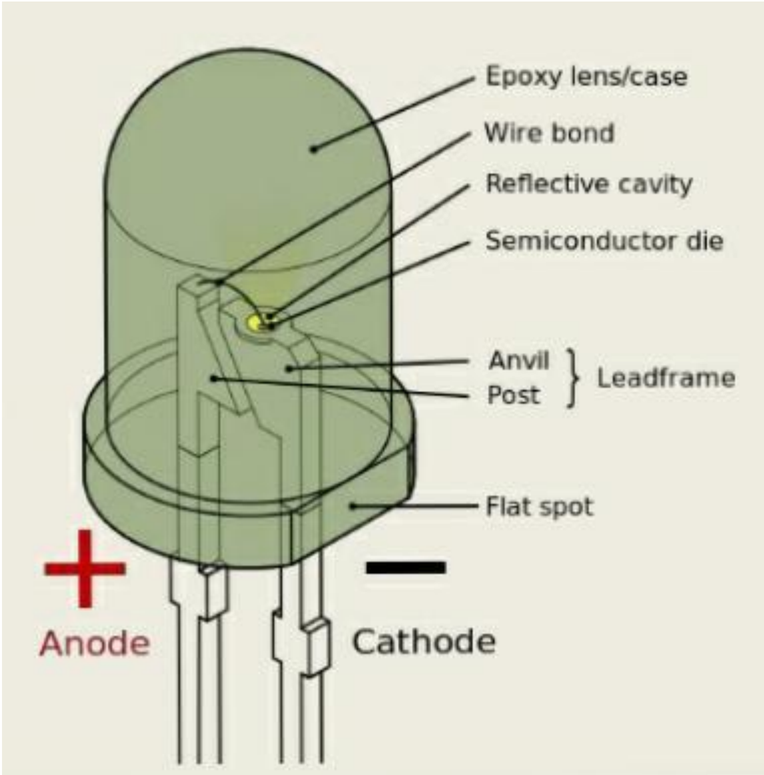
A Light Emitting Diode(LED) is a two LED semiconductorlight source.

It is a PN Junction diode.

Which emits light when activated by a suitable voltage isapplied to the leads.

Construction of LED

The LED consist of a chip ofsemiconductor material doped withimpurities to create a PN junction.



The chips are mounted in areflecting tray order to increase thelight output.

The contacts are made on thecathode side by means ofconductive adhesive and on theanode side via gold wire to the leadframe.

The plastic case encloses the chiparea of the lead frame.

NType

This type of semiconductor isobtained when a Pentavalentmaterial like Arsenic(as) added to pure silicon crystal.

Each Arsenic(As) atom formscovalent bonds with theSurrounding fourgermanium atoms with thehelp of four of its fiveelectrons.

The fifth electron issuperfluous and is looselybound to the Arsenic(As)atom.

PType

This type of semiconductor isobtained when a trivalent materiallike boron is added to pure siliconcrystal.

The three valence electrons ofboron atom form covalent bondswith four surrounding silicon atomsbut one bond is left incomplete andgives rise to a hole.

Thus, boron which is called anacceptor impurity causes as manypositive holes in a silicon crystal asthere are boron atoms therebyproducing a P-type.

Working

Wen the negative end of a circuit ishooked up to the N-type layer andthe positive end is hooked up withP-type layer than electron andholes start moving.

If you try to run current the otherway, with the P-type side connectedto the negative end of the circuitand the N-ty pe side connected tothe positive end, current will notflow.

No current flows across thejunction because the holes and theelectrons are each moving in thewrong direction.

LED: How It Works

When current flowsacross a diode.

Negative electrons move one way andpositive holes move the other way.

This energy is emitted in aform of a photon, whichcauses light .

The colour of the light is determined by thefall of the electron and hence energy levelof the photon.

Types of LEDs

LEDs are produced in a variety of shapes and sizes. The colourof the plastic lens is often the same as the actual colour oflight emitted.

Types of LEDS

Modern high-power LEDs such as those used for lighting and backlighting aregenerally found in Surface Mount Technology (SMT) (not shown here)Some main types is given below;

- Traditional Inorganic LEDs
- Multi Colour LED
- Bi-colour
- A try-color
- Organic LED
- Miniature
- High power

Applications

LED uses fall into Three main categories

- Indicators and signals
- Lighting
- Data communication and other signalling.

Indicators and signals

The low energy consumption, low maintenance and small size of LEDShas LED to uses as status indicators and displays on a variety ofequipment and installations. the are used as stadium airports andrailway stations, trains, buses, trams, and ferries etc.

Lighting

LEDs are now used commonly in all market areas from commercial tohome use: standard lighting, stage, theatrical, architectural, and publicinstallations, and wherever artificial light is used.

Data communication and other signaling

Light can be used to transmit data and analog signals.

Listening device in many theaters and similar spaces use arraysof infrared LEDs to send sound to listeners receivers.

Light-emitting diodes are used to send data over many typesof fibber optics cable, from digital audio the very high bandwidthfibber links that form the internet backbone.

Advantages & Disadvantages

Advantages

Efficiency: LEDs emit more lumens per watt than incandescent light bulbs. Theefficiency of LED lighting fixtures is not affected by shape and size, unlikefluorescent light bulbs or tubes.

Colour: LEDs can emit light of an intended colour without using any colour filters astraditional lighting methods need. Easily available many colours.

Size: LEDs can be very small smaller than 2 mm.

On/Off time: LEDs light up very quickly. A typical red indicator LEDwill achieve full brightness in under a microsecond.

Cycling: LEDs are ideal for uses subject to frequent on-off cycling,unlike incandescent and fluorescent lamps that fail faster when High intensity discharge lamps that require a long time beforerestarting.

Lifetime: LEDs can have a relatively long useful life. One reportestimates 35,000 to 50,000 hours of useful life, though time tocomplete failure may be longer.

Focus: The solid package of the LED can be designed to focus its light. Incandescent and fluorescent sources often require an externalreflector to collect light and direct it in a usable manner.

Disadvantages

- **High initial price** :LEDs are currently more expensive, price per lumen. In 2012, thecost per thousand lumens was about $6. The price was expected to reach in 2013$2/kilo lumen and March 2014 $1.
- **Light Quality**: Most cool-white LEDs have spectra that differ significant from a blackbody radiator like the sun or an incident light.
- **Temperature dependence:** Driving the LED hard in high ambient temperatures mayresult to overheating of the led package ,eventually leading to device failure.
- **Voltage sensitivity**
- **Non reparation**:

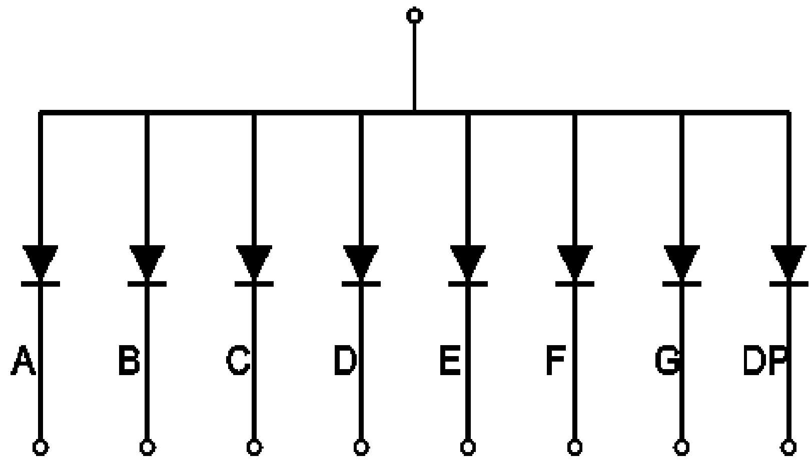
7-Segment Display

Seven-segment display is a form of electronic display used for displaying alpha-numeric characters. A seven-segment display is a set of seven LEDs elements, arranged to form a figure of 8. Each of the LEDs is turned ON and OFF and the combination of LEDs which are ON forms a character. If all elements are activated, the display shows a numeral 8. Numbers from 0-9 and few alphabets can be displayed.

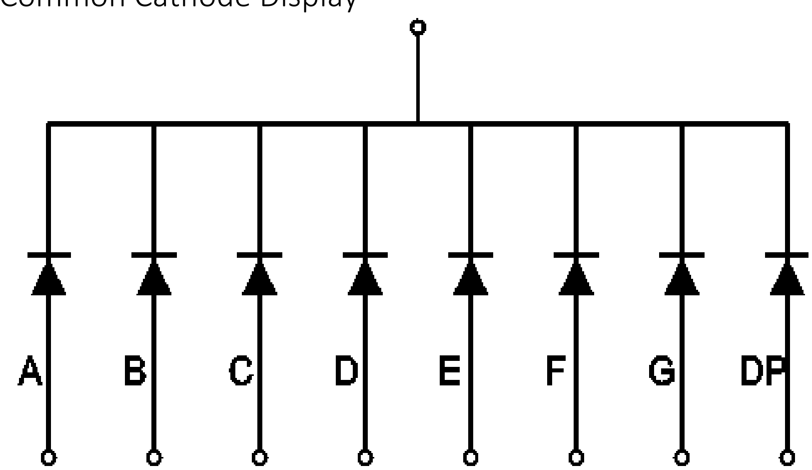
The working of 7 segment display is on the similar lines as that of and LED as the 7 segment displays is eventually made up of 7 LEDs and an LED for the decimal point.

The use of the decimal point is to display decimal numbers like 3.1 or 7.5. The 7 segment display are of two types viz. Common Anode display and Common Cathode display.

Common Anode display



Common Cathode Display

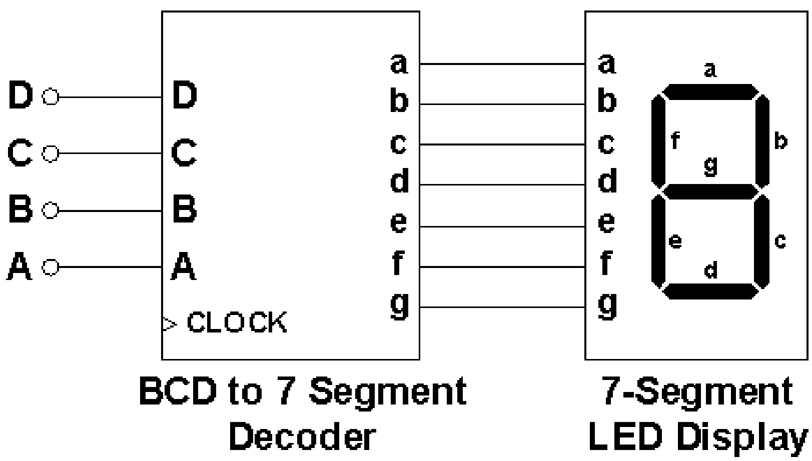


Implementation

All of the cathodes (negative terminals) or all of the anodes (positive terminals) of the segment LEDs are connected and brought out to a common pin; this is referred to as a "common cathode" or "common anode" device. Hence a 7 segment plus decimal point package will only require nine pins. Common cathode implementations require logic low (0) to turn on a segment, common anode implementations require logic high (1) to turn on a segment.

BCD to Seven Segment Conversion

The 7 segment displays are very popularly used in circuit boards and PCBs as display devices. This displays needs active nine pins of micro controller or other logic IC for driving it. And the scenario goes worst if multiple 7 segment displays are used. This makes the circuit bulky with many interconnections. To avoid this, it is essential to use a BCD to 7 segment display driver ICs like IC 7447 and IC 7448 in order to drive the displays. The inputs to the IC are 4 bit BCD value and the outputs are 7 pins which are connection to the 7 segment display.



The BCD value chart

BCD Input Data				
SW3	SW2	SW1	SW0	Numeral Displayed
0	0	0	0	0
0	0	0	1	1
0	0	1	0	2

0	0	1	1	3
0	1	0	0	4
0	1	0	1	5
0	1	1	0	6
0	1	1	1	7
1	0	0	0	8
1	0	0	1	9

Advantages

- Cost: The cost of the entire module of 7 segment display is very cheap as it only contains LEDs.
- Efficiency: LED displays in general are extremely efficient.
- Heat dissipation: The heat dissipated from this displays is very less and that increases the life of the devices.

Disadvantages

- limited characters: Seven-segment displays are capable to display only numbers from 0-9 and few alphabets.
- Type of display: The appearance of the two types of display are very similar and that causes difficulty interfacing it with controllers

Applications

- Digital watches

- electronic device display
- timers
- calculators
- Car panel displays, etc.

Liquid Crystal Diode (LCD)

Definition: The LCD is defined as the **diode** that uses **small cells** and the **ionised gases** for the **production of images**. The LCD works on the **modulating property of light.** The light modulation is t**he technique of sending and receiving the signal** through the **light**. The **liquid crystal consumes** a small amount of energy because they are the **reflector and the transmitter of light.** It is normally used for **seven segmental display.**

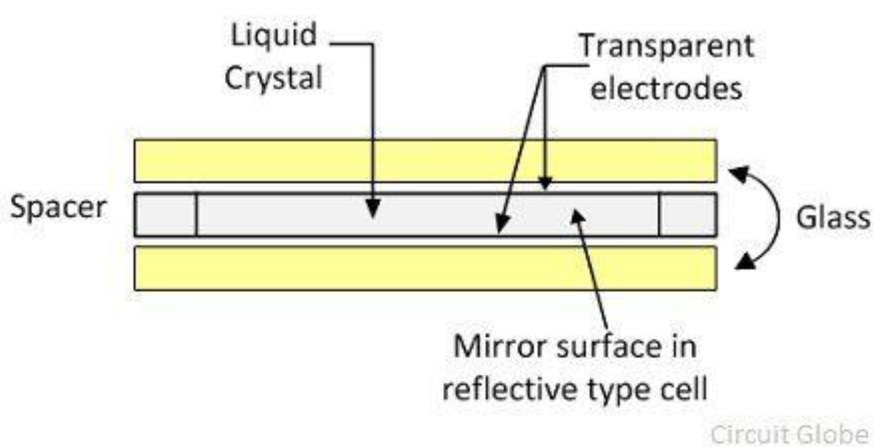
Construction of LCD

The liquid crystals are the organic compound which is in liquid form and shows the property of optical crystals. The layer of liquid crystals is deposited on the inner surface of glass electrodes for the scattering of light. The liquid crystal cell is of two types; they are Transmittive Type and the Reflective Type.

Transmittive Type – In transmitter cell both the glass sheets are transparent so that the light is scattered in the forward direction when the cell becomes active.

Reflective Type – The reflective type cell consists the reflecting surface of the glass sheet on one end. The light incident on the front surface of the cell is scattered by the activated cell.

Both the reflective and transmittive type cells appear brights, even under small ambient light conditions.

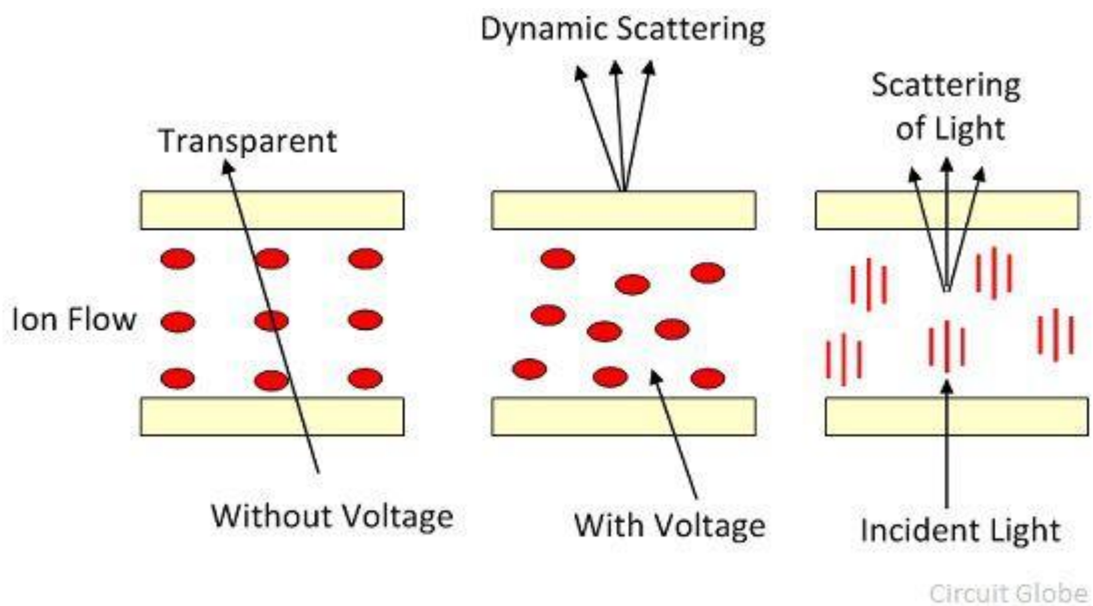


Working Principle of LCD

The working principle of the LCD is of two types. They are the dynamic scattering type and the field effects type. Their details explanation is shown below.

Dynamic Scattering

When the potential carrier flows through the light, the molecular alignment of the liquid crystal disrupts, and they produce disturbances. The liquid becomes transparent when they are not active. But when they are active their molecules turbulence causes scattered of light in all directions, and their cell appears bright. This type of scattering is known as the dynamic scattering. The construction of the dynamic scattering of the liquid crystal cell is shown in the figure



Field Effect Type

The construction of liquid crystals is similar to that of the dynamic scattering types the only difference is that in field effect type LCD the two thin polarising optical fibres are placed inside the each glass sheet. The liquid crystals used in field effect LCDs are of different scattering types that operated in the dynamic scattering cell.

The field affects type LCD uses the nematic material which twisted the unenergised light passing through the cell. The nematic type material means the liquid crystals in which the molecules are arranged in parallel but not in a well-defined plane. The light after passing through the nematic material passing through the optical filters and appears bright. When the cell has energised no twisting of light occurs, and the cell appears dull.

Advantages of LCD

The following are the advantages of LCD.

1. The power consumption of LCD is low. The seven segmental display of LCD requires about 140µW which is the major advantages over LED which uses approximately 40mW per numeral.
2. The cost of the LCD is low.

Disadvantages of LCD

The following are the disadvantages of LCD.

1. The LCD is a slow device because their turning on and off times are quite large. The turn-on time of the LCD is millisecond while there turn off time is ten milliseconds.
2. The LCD requires the large area.
3. The direct current reduces the lifespan of LCD. Therefore, the LCD uses with AC supply, having the frequency less than 500Hz.

The LCD requires AC voltage for working.

Errors

Measurements Errors

Measurements Errors

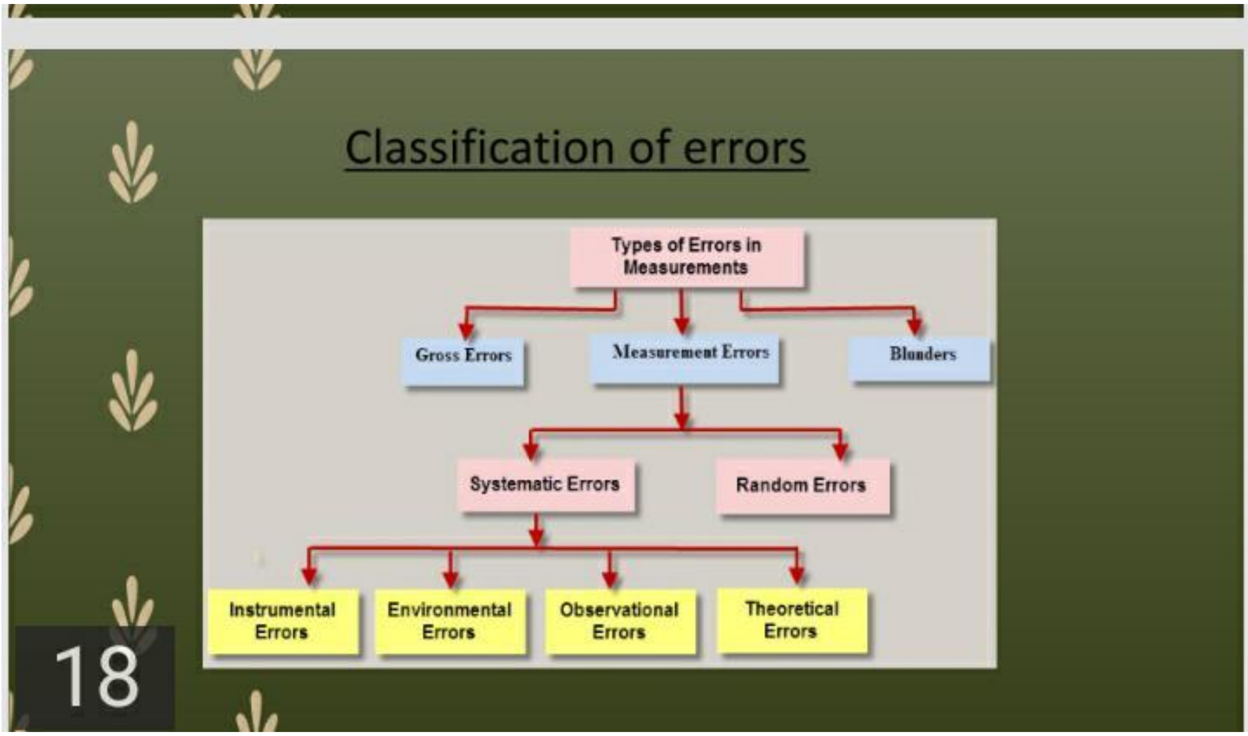
Is the difference between the true value of the sizeand the value found by measurement.

Errors pertains to me measurement not to an instrument.

Error = True Size - Actual Size

True Size: is the theoretical size obtained throughmeasurement. This type of size is free from anytype of error. It is the guide for measuring manyproperties such as accuracy of an instrument.

Actual Size: is a measured size with permissibleerror. It refers to the minimum acceptable size ofa sample.



Types of error

1. random Errors

2. Systematic Errors

3. Gross errors

Systematic Errors

Systematic errors (also called bias errors)

They are consistent, repeatable errors. For example, suppose the first two millimetres of a ruler are worn off, and the user is not aware of it. Everything he or she measures will be too short by two millimetres a systematic error.

Systematic Errors Sources

Systematic errors arise for many reasons. Here are just a few:

- *Calibration Errors:* due to nonlinearity or errors in the calibration method.
- *Loading or Intrusion Errors:* the sensor may actually change the very thing it is trying to measure.
- *Spatial Errors*: arise when a quantity varies in space, but a measurement is taken only at one location (e.g. temperature in a room usually the top of a room is warmer than the bottom).
- *Human Errors:* arise if a person consistently reads a scale on the low side, for example.
- *Defective Equipment Errors:* arise if the instrument consistently reads to0 high or too low due to some internal problem or damage.

Random Errors

- Random errors They are unrepeatable, inconsistent errors, resulting in Scatter in the output data.
- The random error of one data point is defined as the reading minus the average of readings.

- **Other Sources of Errors**

There are many other errors, which all have technical names, as defined here:

- **Zero Error:** The instrument does not read zero when the input is zero. Zero error is a type of bias error that offsets all measurements taken by the instrument, but can usually be corrected by some kind of zero offset adjustment.

- **Linearity Error**: The output deviates from the calibrated linear relationship between the input and the output. Linearity error is a type of bias error, but unlike zero error, the degree of error varies with the magnitude of the reading.

- **Sensitivity Error:** The slope of the output vs. input curve is not calibrated exactly in the
- first place. Since this affects all readings by the instrument, this is a type of systematic or
- bias error.

- **Resolution Error:** The output precision is limited to discrete steps (e.g., if one reads to
- the nearest millimetre on a ruler, the resolutionError is around(+/- 1 mm). Resolution error is a type of random or precision error.

- **Environmentalfactors:**
- Be aware of errors introduced by immediate working your environment. You may need to take account for or protect your experiment from vibrations, drafts, changes in temperature, electronic noise or other effects from nearby apparatus.

- **Reading Error**: describes such factors as parallax, interpolation, or optical resolution.

- **Loading Error:** results from the change of the measurement instrument when it is being used.

- **Effect of support.**
- **Drift**

Other Sources of Errors

- **(Cont.)**

- **Errors due to Vibrations.**

- **Metallurgical Effects.**
- **Contact Point Penetration.**
- **Errors due to Deflection.**
- **Errors due to Looseness.**
- **Errors due to Wear in Gauges.**
- **Errors due to Location.**

- **Errors due to Poor Contact.**
- **Errors due to Impression of Measuring**
- **Stylus.**

Earthing:

Earthing can simply be defined as the process of protecting against unwarranted spikes and bouts of electricity that can cause damage to life and property. Therefore it is important to remember these key differences between the two. One needs to understand that they both are referring to the same process.

Grounding:

Grounding is similar to Earthing, by which insulation against accidental currents is achieved. The main live wire is connected to a power supply to power an appliance, however, the other portion of the wire is led under the earth. This is done in case of an accidental cut in the circuit, to avoid overloading and other dangerous side effects.

Earthing VS Grounding	
Earthing	**Grounding**
This method protects human beings from electric shocks.	This method protects the entire power system from malfunctioning.
The earth wire used is green in colour.	The wire used for grounding is black in colour
Earthing is primarily used to avoid shocking the humans.	Grounding is primarily used for unbalancing when the electric system overloads.
Earthing is located under the earth pit, between the equipment body underground.	It is located between the neutral of the equipment being used and the ground.

How to minimize measurement error

Once you understand the main forms of experimental error, you can act on preventing them. The following precautions will help you reduce measurement error and yield the most accurate results.

Use quality equipment

Using quality equipment is paramount to reducing systematic measurement error. Make sure you’re using an updated and precise measuring device that doesn’t have any defects while conducting your experiment.

Calibrate your equipment properly

Before conducting an experiment, make sure to properly calibrate your measurement instruments to avoid inaccurate results.

Properly train lab staff

The imperfect nature of humans means there will always be human error when they observe and measure results. Minimize this impact by taking the time to train all applicable lab staff on how to properly use all equipment and carry out procedures when conducting an experiment.

Controlled environment

All measurements in an experiment should occur under controlled conditions to prevent systematic error. Changes in external conditions such as humidity, pressure, and temperature can all skew data, and you should avoid them.

Double-check

To reduce the impact of human error, personnel need to double-check all observations, recordings, and measurements. You can easily complete this process by double-entering all findings on two separate worksheets or files and then comparing them

Chapter-5 Operational amplifier

Op-amp | Block Diagram | Characteristics of Ideal and Practical Op-amp

What is an OP-AMP? An operation amplifier (Op Amp) is basically a multistage, high gain ($A_v>10^5$) direct coupled amplifier with two differential inputs and a single ended output and which uses feedback to control its overall response characteristics.

It may be used to perform numerous linear operations and some nonlinear operations. An important feature of operational amplifier is that by simply changing the feedback impedance, its operation may be altered. A modern Op Amp uses integrated circuit technology. The IC Op Amps are widely used as versatile, predictable, accurate and economical system building blocks. They possess all the merits of monolithic ICs.

Many analog circuits, both linear and nonlinear, are constructed using IC Op Amp as the basic building block. This IC Op Amp, along with a few external discrete components may be used for the following linear analog systems:

1. analogs computers
2. voltage-to-current converters
3. current-to-voltage converters
4. amplifier for various specific rises such as dc instrumentation, tuned amplifier, video amplifier etc.

Op Amps may also be used in the nonlinear analog systems such as

1. amplitude modulators
2. logarithmic amplifiers
3. anti-logarithmic amplifier
4. analog multipliers
5. sample-and-hold circuits
6. comparators
7. square wave generators
8. triangular wave generators etc.

Block Diagram of Operational Amplifier

The block diagram of operational amplifier is shown in figure 1.

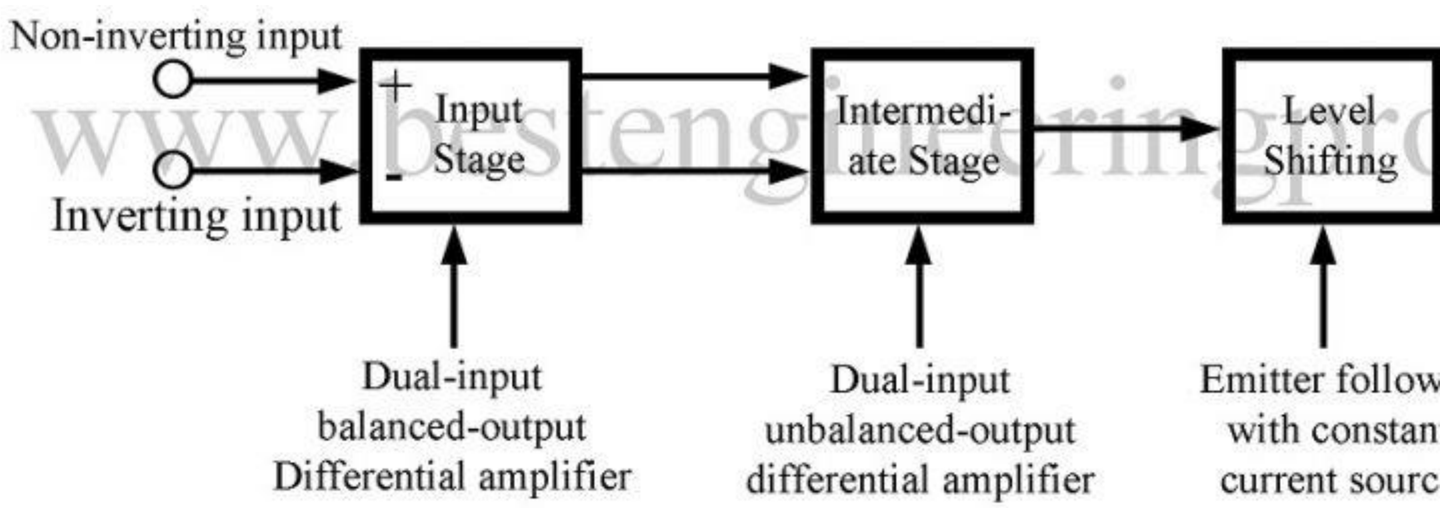


Figure 1: Block Diagram of a Typical Op

Input Stage:

1. Increases the CMRR.
2. High gain requirement is adjusted.
3. Most of the gain is adjusted.
4. Provides the input impedance very high.

Intermediate Stage:

1. Driven by output of 1st
2. Adjust the half gain of 1st
3. Error voltage is cancelled in this stage.

Level Shifting:

1. Suppress the dc level downward to zero volt with respect to ground
2. Consisting of current amplifiers as emitter followers.
3. Also minimizes the error by suppressing dc level to ground.

Output Stage:

1. This stage increases the output voltage swing and the current in supplying capability of the amplifiers.
2. Provides low output impedance.

OP-AMP Symbol | Symbol of Operational Amplifier

Standard triangular symbol for an OP-AMP is shown in Figure 2(a) though the one shown in figure 2(b) is also used often. In figure 2(b), the common ground line has been omitted. It also does not show other necessary connection such as for dc power and feedback etc.

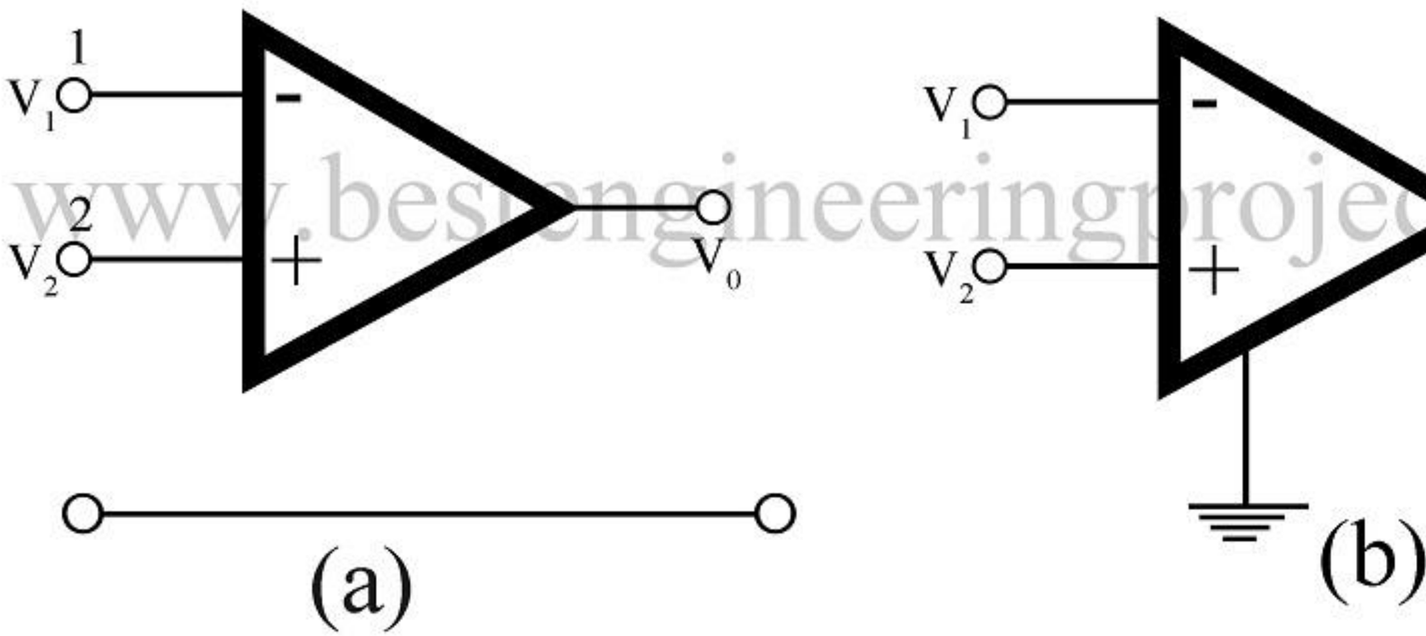


Figure 2: OP-AMP Symbol

The OP-AMP's input can be single-ended or double-ended (or differential input) depending on whether input voltage is applied to one input terminal only or to both. Similarly, amplifier's output can also be either single-ended or double-ended. The most common configuration is two input terminal and a single output.

Polarity Convention of Op-amp:

In figure 2(b), the input terminals have been marked with minus (-) and plus (+) signs. These are meant to indicate the inverting and non-inverting terminals only (figure 3). It simply means that a signal applied at negative input terminal will appear amplified but phase-inverted at the output terminal as shown in figure 3(b). Similarly, signal applied at the positive input terminal will appear amplified and in phase at the output. Obviously, these plus and minus polarities indicate phase reversal only.

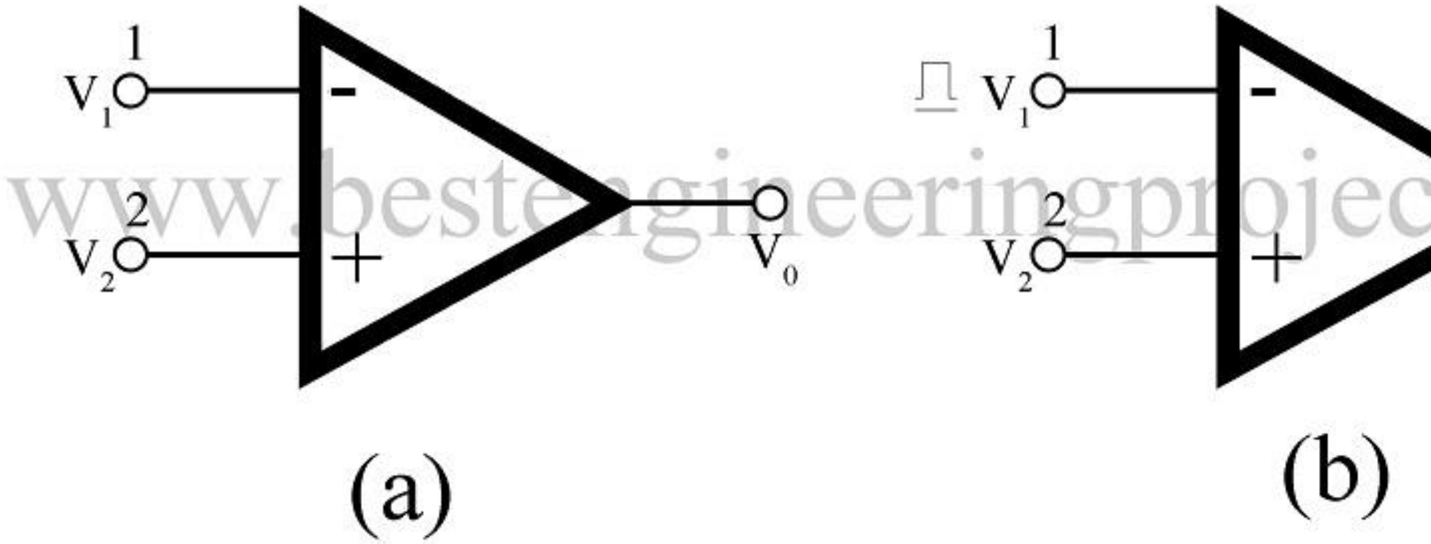


Figure 3: Polarity Conventions OP-A

It does not mean that voltage v_1 and v_2 in Figure 3(a) are negative and positive respectively. Additionally, it also does not imply that a positive input voltage has to be connected to the plus-marked non-inverting terminal 2 and negative input voltage to the negative-marked inverting terminal 1. In fact, the amplifier can be used either way up so to speak. It may also be noted that all input and output voltages are referred to a common reference usually the ground shown in figure 2(a).

Characteristics of Ideal Operational Amplifiers

An ideal op-amp would exhibit the following electrical characteristics:

1. Open loop Voltage Gain A_0 is infinity.
2. Infinity input resistance R_i so that almost any signal source can be drive it and there is no loading of the preceding stage.
3. Zero output resistance R_0 so that the output can be drive an infinity number of other devices.
4. Perfect Balance, i.e. the differential voltage in inverting and non-inverting terminals be zero.
5. Zero output voltage when input is zero.
6. Infinity bandwidth so that any frequency signal from 0 to ∞ Hz can be amplified without attenuation.

7. Infinity common-mode rejection ratio so that the output common-mode noise voltage is zero.

8. Infinity slew rate so that output voltage changes occur simultaneously with input voltage changes.

9. Zero drift of characteristics with temperature.

Characteristic of Practical Op-amp

There are practical op-amps that can be made to approximate some of these characteristics using a negative feedback arrangement. In practical, the input resistance, output resistance, and bandwidth can be brought close to ideal values by this method.

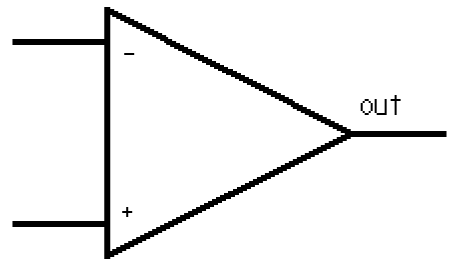
The practical op-amp has the following characteristics:

1. The open loop voltage gain A_0 is maximum and finite, typical value for practical op-amp is considered to be 200,000.
2. The input impedance Z_i is maximum and is finite i.e. in the order of 100k or more.
3. The output impedance Z_0 is minimum not zero, in the order of 100 or less.
4. The CMRR is maximum and finite.
5. Bandwidth is maximum and finite i.e. it can amplify dc to 1 MHz signal.
6. Slight drift of characteristics due to the change in temperature not null.
7. Two terminal may be virtually ground not $V_d = 0$ exactly, for all conditions.
8. Maximum slow-rate and has the finite value.
9. Output is negligible due to dc-bias, when the input is zero.

While there are a variety of op-amps, each with specific inner design features such as internal frequency compensation, FET inputs, Darlington inputs, current sources as active loads, input voltage and output current limiters, and many others, the analysis of a specific op-amp equivalent circuit will provide a good basis for understanding the inner operation and construction of the op-amp and aid in selecting a proper op-amp for a desired application.

Introduction

An operational amplifier, op-amp, is nothing more than a DC-coupled, high-gain differential amplifier. The symbol for an op-amp is



It shows two inputs, marked �+� and �-� and an output. The output voltage is related to the input voltages by� $V_{out} = A(V_+ - V_-)$. The open loop gain, A, of the amplifier is ranges from 10^5 to 10^7 at very low frequency, but drops rapidly with increasing frequency. Furthermore, A is strongly dependent on temperature, supply voltage etc. For this reason the op-amp becomes only truly useful when the overall circuit properties are primarily determined by a feedback loop instead of the open loop gain. Thus, in the following exercises, with the use of a voltage divider, part of the output voltage is fed back to the �-� input.

- An amplifier will not work without a power supply. And a more complete diagram looks like the figure below, which also indicates the standard pin configuration.

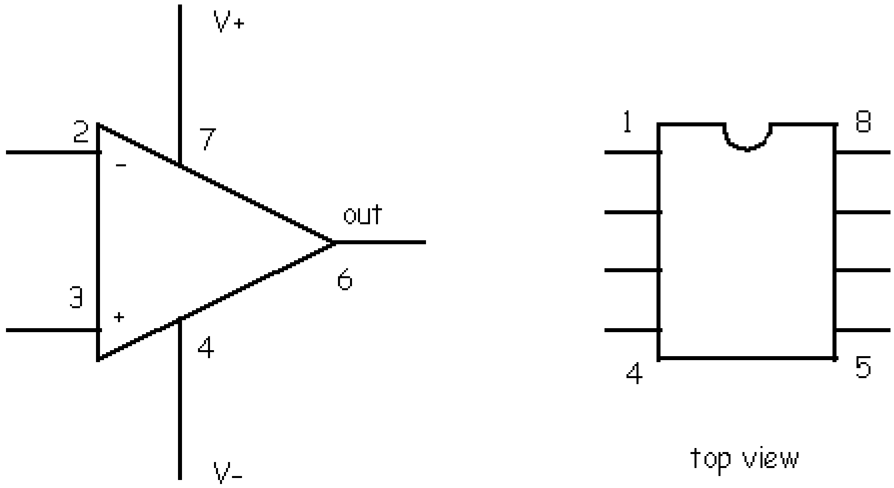


Figure 1. Op-amp with pin configuration

- The pin connections on op-amps are to a very high degree standardized.� IC pins are numbered counter clockwise (looking from the top) and for 8-pin op-amps you will always find

Pin	Function
2	Inverting input
3	Non-inverting input
4	V- supply
6	Output
7	V+ supply

The other pins are used for offset adjustment or frequency compensation, and are of less importance.

- Note that a positive and a negative supply voltage are shown, but no ground or zero potential. This doesn't mean that your ground can just float. You have to provide return paths for the input and output currents ! The absence of a ground pin only indicates that the op-amp has no intrinsic, build in reference point.

- Most of the time the connections for the power are not indicated in the circuit diagrams, and in this lab manual you will not find them either. Everywhere it is assumed that the op-amp gets connected to the +/- 12V power on the prototyping board.

- More modern op-amps are difficult to destroy, but one thing that usually does them in is interchanging the connections to the power supply. Make sure that you clearly understand the pin configuration before you wire the circuit and switch on the power.

There are a number of op-amps available in the lab. For these initial exercises you should use an OP27.

1. Inverting and non-inverting amplifiers

There are two basic types of amplifiers, the non-inverting amplifier shown in figure 2, and the inverting amplifier discussed later in this section.

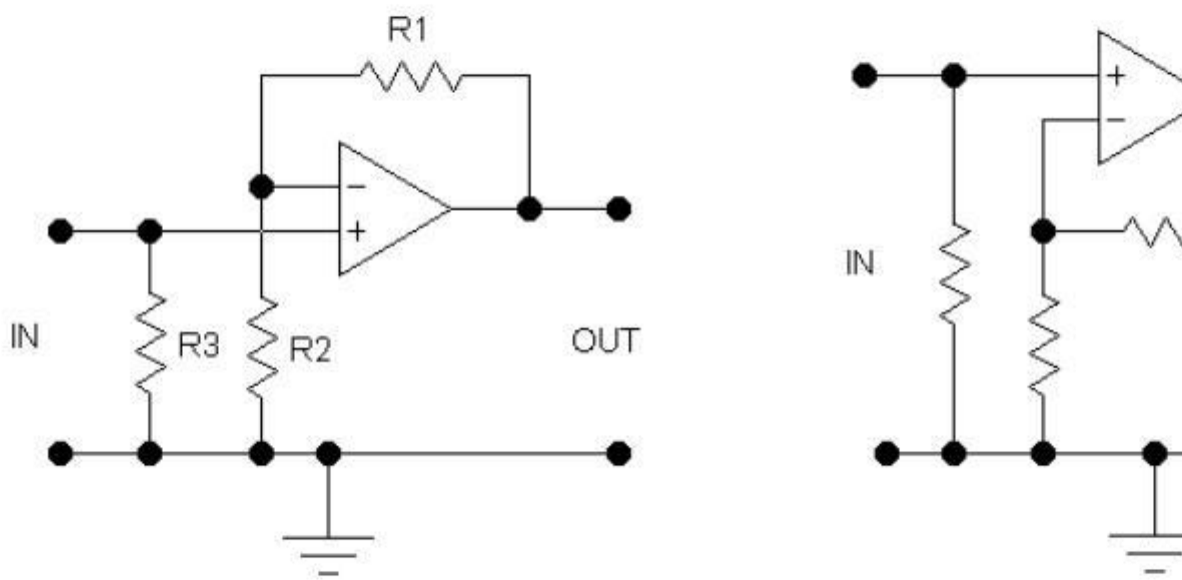


Figure 2. �������� The basic non-inverting op-amp circuit, two possible representations of the same circuit.

The low-frequency gain of the non-inverting amplifier is set by the resistors R1 and R2, A = 1 + R1/R2. For a gain of 1 these resistors can be omitted and the output is directly connected to the inverting input (Fig. 3). The input impedance of this amplifier is very high, but you should keep in mind that a path has to be provided for the input current into the non-inverting input. Here, this is take care of by R3. Using a potentiometer and series resistor to provide a dc input voltage, measure the gain of this circuit for a number of values for R1 and R2 in the 1 -- 100 kΩ range. Also check that the unity gain buffer, fig. 3, does provide a gain of exactly 1.

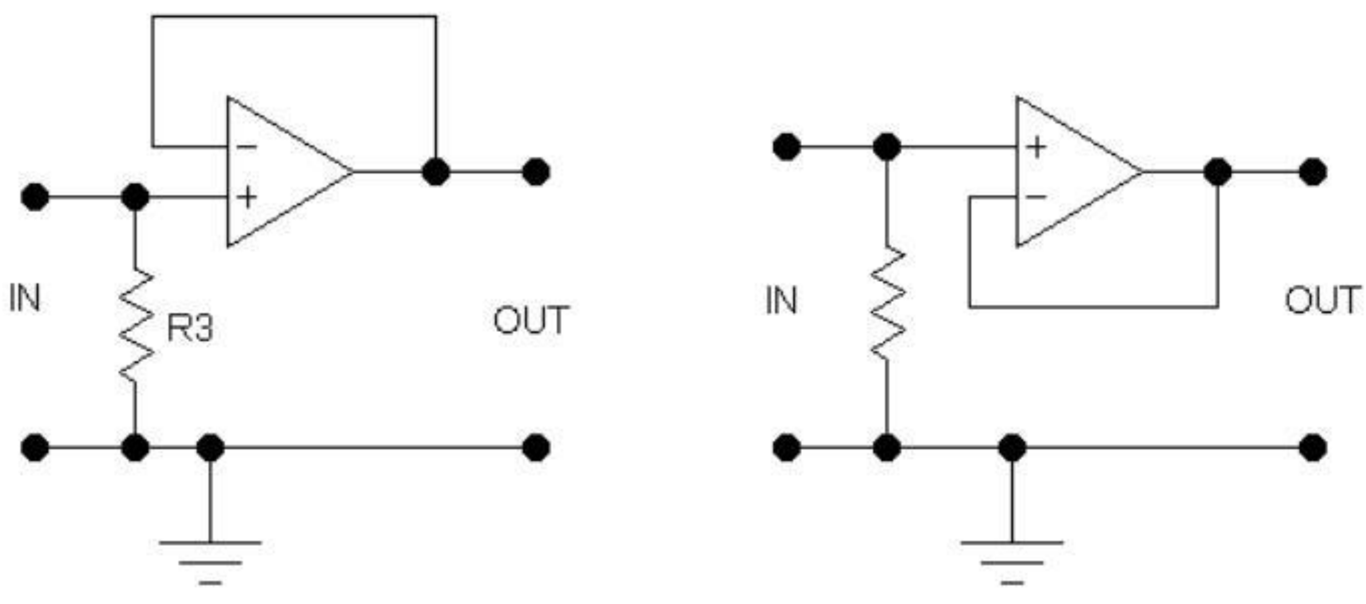
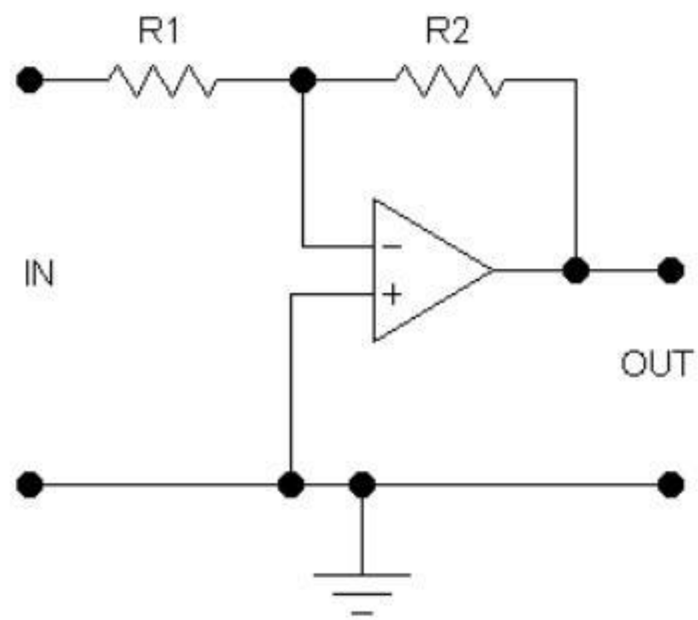


Figure 3.� The unity gain buffer.

The inverting amplifier (fig. 4) has a gain A = -R2/R1. Note that |A| can be smaller than 1. One complication with the inverting amplifier is that the input impedance is rather low

(R1), and that the gain of the circuit is influenced by the output impedance of the source. To check that this circuit works, repeat the measurements that you did for the non-inverting amplifier, preferably using the same resistors. Note the change in the sign of *A*, and that $|A_{inv}| = |A_{non\text{-}inv}| - 1$.



�Figure 4. The inverting amplifier.

2. Adding and subtracting

Operational amplifiers got their name because one can perform a number of mathematical operations with them. The simplest operations are addition and subtraction. Figure 5 shows a typical (inverting) adder. The output voltage is given by Vout = -[(Rf/R1) V1 + (Rf/R2) V2). By making R1 = R2 signals are added with equal weight, but this does not necessarily have to be the case. Test this circuit for a range of positive and negative input voltages. Do this for R_f = R1 = R2 = 10 kΩ and for R_f = 50 kΩ, R1 = 20 kΩ, R2 = 10 kΩ.

□

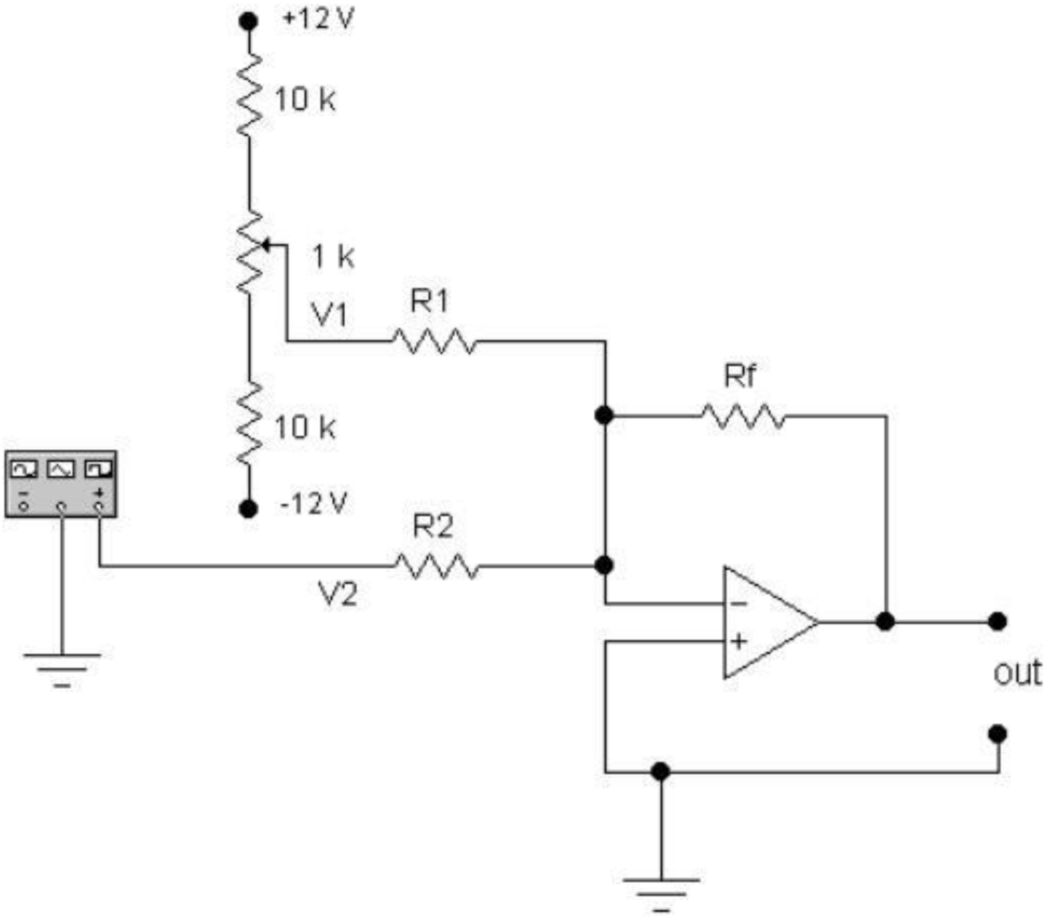


Figure 5.� The (inverting) adder. (including a resistance-potentiometer networks to set V1 and a function generator to control V2.)

Subtraction is done with a circuit that is usually called a differential amplifier (fig. 6). When R1 = R3 and R2 = R4, Vout = (R2/R1) � (V2 � V1), i.e., the output voltage is proportional to the difference between V2 and V1 and the gain A = R2/R1. Take R1 = R3 = 10 kΩ, and R2 = R4 = 100 kΩ, and again test the circuit for a number of input voltages.

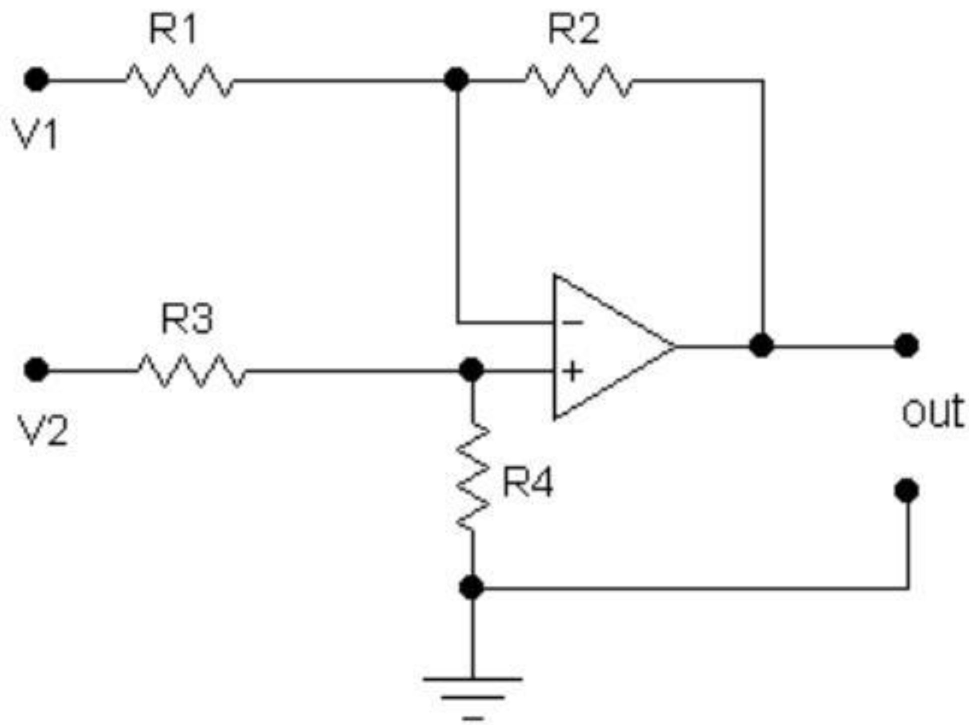


Figure 6.

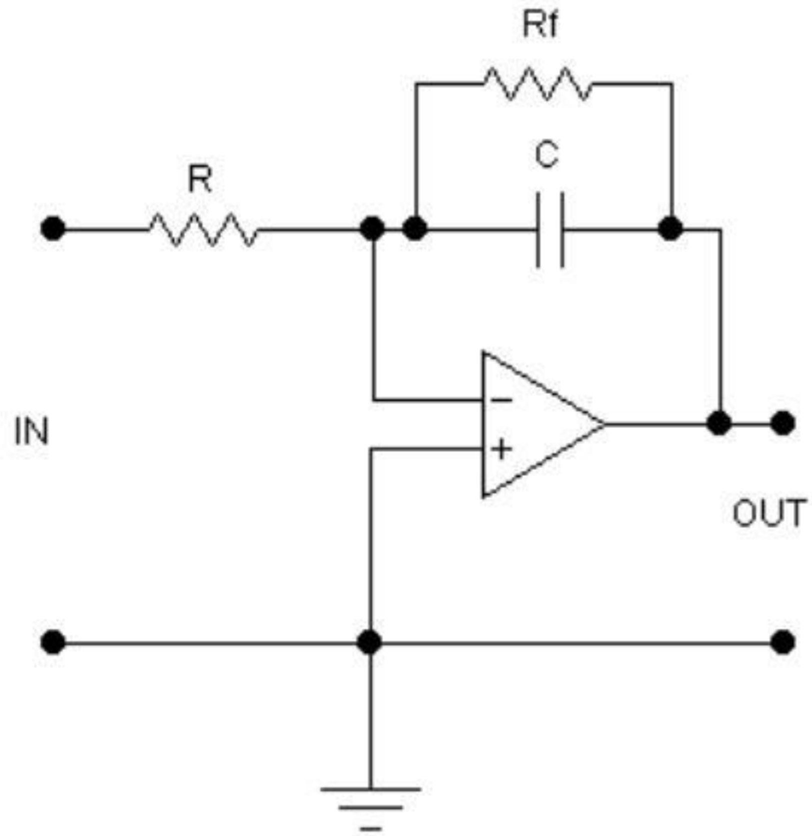
The differential amplifier

3. Integration and differentiation

Two other fairly easy operations that can be performed using op-amps are integration and differentiation. If the op-amp were ideal, an integrator (Fig. 7) would require just one resistor, R, and one capacitor, C, and the relation between the output and input voltages would be given by

$$V_{out}(t) = -\int \frac{V_{in}(t)}{RC} dt$$

However, the input offset voltage, which for a non-ideal op-amp is not zero, also gets integrated. As a result the output voltage starts to drift. To fix this R_f is added to the circuit. This makes the gain for very low frequency signals finite again, but of course this means that signals with frequency components below a certain value ($f < 1/2\pi R_f C$) are not properly integrated anymore.



The integrator is most conveniently tested using a function generator and oscilloscope. First qualitatively check that square waves are integrated to triangles, triangles to parabolas etc.� Then measure the ratio Vout/Vin as a function of frequency (with a sine-wave input signal). HuCompare with the expected behavior.

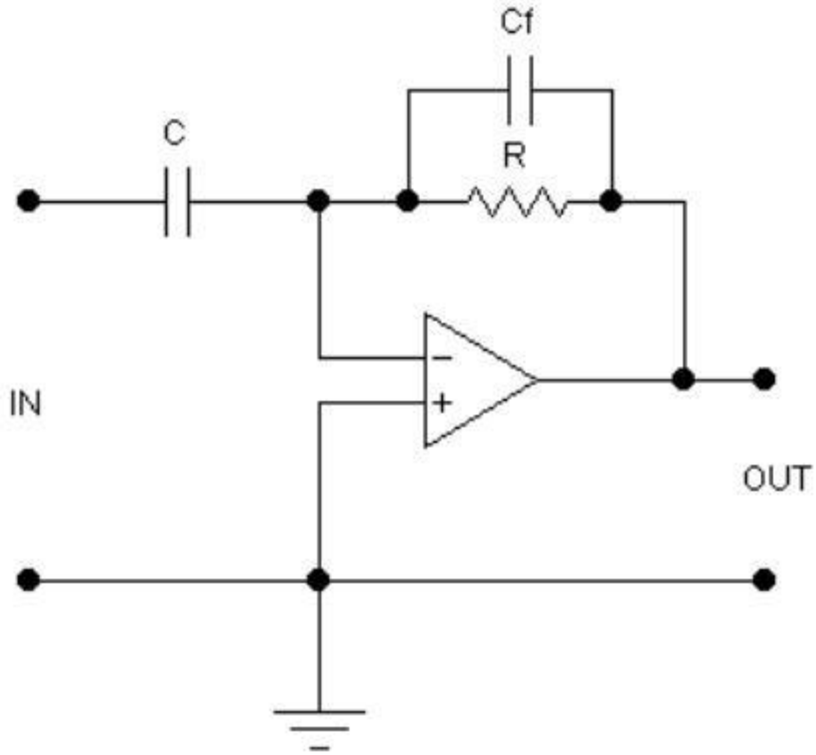
Figure 7.� The integrator

Initial values

���� ��������� $R = 10\ k\Omega$

���� ��������� $C = 10\ nF$

���� ��������� $R_f = 1\ M\Omega$



By switching R and C, you get a differentiator (Fig. 8). This circuit is intrinsically unstable and will start to oscillate a high frequency. To avoid this, you can reduce the high frequency gain of the circuit by adding C_f. (Often, stray capacitance is enough to stabilize the circuit, but it tends to be noisy.) The price you pay is that the circuit doesn�t function as a differentiator for frequencies, $f > 1/2\pi R C_f$. Again, the circuit is most conveniently tested with a function generator and an oscilloscope. A triangle wave input should be differentiated to a square wave, a square wave to alternating positive and negative going pulses.

(i) Slew Rate :

One of the important frequency related parameter of an op-amp is the slew rate. The slew rate is the maximum rate of change of output voltage caused by a step input voltage and is usually specified in V/µS. For example 1V/µS slew rate means that the output rises or falls by 1V in one microseconds. Ideally slew rate is infinite which means that op-amp's output should be changed instantaneously in response to input step voltage. Practical op-amp are available with slew rates from 0.1V/µS to well above 1000V/µS.

(ii) CMRR :

Common Mode Rejection Ratio is defined in several essentially equivalent ways by the various manufacturers. Generally, it can be defined as the ratio of the differential gain AD to the common mode gain A_{CM}ACM that is,

$$CMRR=\frac{A_D}{A_{CM}}$$ CMRR=ADACM

For 741C, CMRR is typically 90dB. CMRR is usually expressed under the test condition that the input source resistance $R_S \le 10k\Omega$. Higher the value of CMRR, better is the matching between two input terminals and smaller the output common-mode voltage.

(iii) Input offset voltage :

Input offset voltage V_{io} is the differential input voltage that exists between two input terminals of an op-amp without any external inputs applied. In other words, it is the amount of the input voltage that should be applied between two input terminals in order to force the output voltage to zero. Since this voltage could be positive or negative its absolute value is listed on the data sheet. For 741C, the maximum value is 6mV.

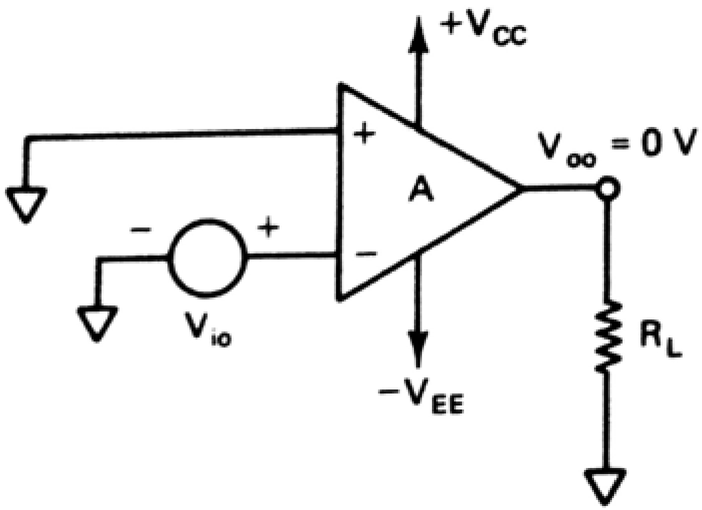


Figure 1: Input Offset Voltage in op-amp

(iv) Output offset voltage :

- The output offset voltage VOO is caused by mismatching between two input terminals. Even though all the components are integrated on the same chip, it is not possible to have two transistors in the input differential amplifier stage with exactly the same characteristics.
- This means that the collector currents in these two transistors are not equal, which causes a differential output voltage from the first stage.
- The output of first stage is amplified by following stages and possibly aggravated by more mismatching in them. Thus output voltage caused by mismatching between two input terminals is the output offset V_{OO}.

- The output offset voltage is a dc voltage; it may be positive or negative in polarity depending on whether the potential difference between two input terminals is positive or negative.

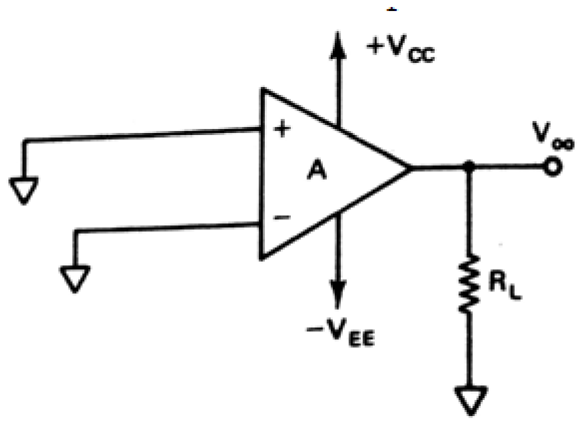


Figure 2 : Output offset voltage in op-amp

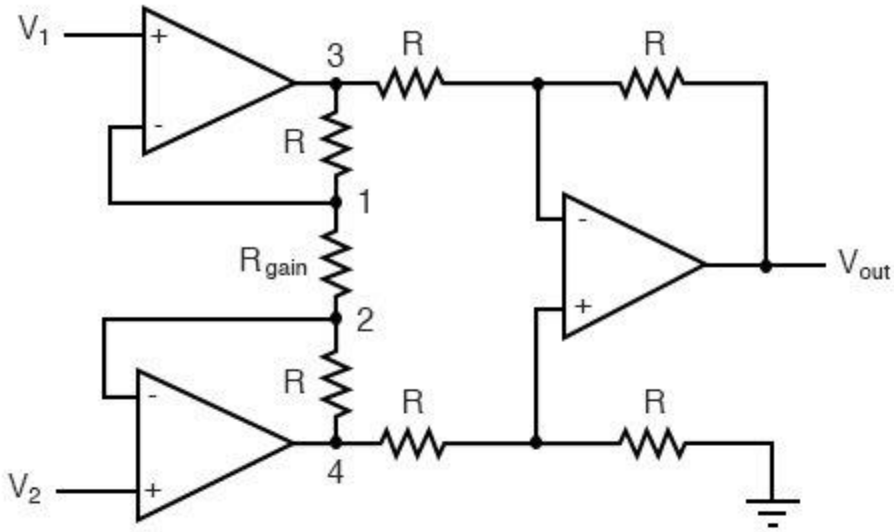
(v) PSRR :

The change in an op-amp's input offset voltage due to variations in supply voltage is called as power supply rejection ratio (PSRR) or called as supply voltage rejection ratio (SVRR). This term is expressed in microvolts per volt or decibels. For 741C, PSRR=150µV/V, lower the value of PSRR, better the op-amps.

Instrumentation Amplifier?

An instrumentation amplifier allows an engineer to adjust the gain of an amplifier circuit without having to change more than one resistor value. Compare this to the differential amplifier, which we covered previously, which requires the adjustment of multiple resistor values.

The so-called *instrumentation* amplifier builds on the last version of the differential amplifier to give us that capability:



Understanding the Instrumentation Amplifier Circuit

This intimidating circuit is constructed from a buffered differential amplifier stage with three new resistors linking the two buffer circuits together. Consider all resistors to be of equal value except for R_{gain}.

The negative feedback of the upper-left op-amp causes the voltage at point 1 (top of R_{gain}) to be equal to V_1. Likewise, the voltage at point 2 (bottom of R_{gain}) is held to a value equal to V_2. This establishes a voltage drop across R_{gain} equal to the voltage difference between V_1 and V_2. That voltage drop causes a current through R_{gain}, and since the feedback loops of the two input op-amps draw no current, that same amount of current through R_{gain} must be going through the two “R” resistors above and below it.

This produces a voltage drop between points 3 and 4 equal to:

$$V_{3\text{-}4} = (V_2 - V_1)\left(1 + \frac{2R}{R_{gain}}\right)$$

The regular differential amplifier on the right-hand side of the circuit then takes this voltage drop between points 3 and 4 and amplifies it by a gain of 1 (assuming again that all “R” resistors are of equal value).