SENSORS AND MEASURING INSTRUMENTS

(22EC101135)

Module 1

MEASUREMENTS AND MEASURING DEVICES

Introduction

A wide variety of instruments are used by scientists, engineers, and other people to conduct measurements. These tools can be as basic as stopwatches, rulers, and scales, or as complex as particle accelerators and electron microscopes used by scientists and engineers.

An instrument is a device or system designed to maintain a functional relationship between the physical variables being measured and their specified properties. It allows communication between a human observer and the operator of a machine or other piece of equipment. The aforementioned functional relationship is only valid as long as the system's static calibration remains constant. The instrument performance of a measurement system is typically described in terms of a combination of its static and dynamic characteristics.

Functional Elements of a Measurement System

Measurement systems must be systematically organized and analyzed in order to comprehend a measuring instrument or system. Functional elements can be used to provide a general description of how a system or measuring device operates. Every functional element consists of one or more components that carry out specific and necessary steps in the measurement. The fine details of an instrument's or system's physical components are not provided by the functional elements. These could be considered fundamental components, the extent of which is defined by how well they work rather than how they are made.

The main functional elements of a measurement system are:

i) Primary sensing element

ii) Variable conversion element

iii) Variable manipulation element

iv) Signal conditioning element

v) Data transmission element

vi) Data presentation element.

Primary sensing element

Initial contact with the quantity or variable being measured is established by a measurement system's primary sensing element. Accordingly, the measurement is initially detected by the primary sensor or detector. Following then, an analog electrical signal is instantaneously created from the measurement. A transducer serves this purpose. In general, a transducer is a device that changes the form of energy used. There are only a few measuring systems where this definition is useful. Transducers are instruments that convert physical quantities into electrical quantities. There may be a difference in the analogous form of the detector element and sensor's output when measuring a quantity. An electrical signal is subsequently produced from this output by a transducer.

Variable conversion element

The variable sensing element's output can produce any kind of signal. There could be an electrical or mechanical signal coming from it. It could be an electrical parameter such as voltage, frequency, etc., or the deflection of an elastic member. The sensor's output may occasionally not be suitable for the measurement system. For the instrument to work as intended, it might be necessary to convert this sensor's output signal into a different suitable format while preserving its informational value. For example, a transducer called a stain gauge can help convert the sensing element's output, which is a very small displacement that is difficult to measure mechanically, into a corresponding electrical signal for further processing.

Variable manipulation element

A signal of any type can be produced by the variable sensing element's output. Signals from mechanical or electrical sources could be the source. It might be the deflection of a flexible component or a voltage, frequency, or other electrical parameter. A sensor's output may occasionally not be appropriate for the measurement system. The output signal from the sensor may need to be converted into a different, acceptable format while keeping the information contained in it in order for the instrument to function as intended. For instance, a transducer known as a stain gauge can be used to convert the ultra-small displacement that is produced by the sensing element and is challenging to measure mechanically into a corresponding electrical signal for additional processing.

Signal conditioning element

Information is contained in the transducers' output signal, which the system processes further. Numerous transducers typically produce a voltage or another type of electrical signal, and frequently, these signals are produced at very low voltages—of the order of mV or even μV. Unwanted signals, such as noise, may contaminate this signal as a result of an external source interfering with the original output signal. An additional issue is that the processing equipment itself may distort the signal. Before the signal can be transmitted to the following stage, any undesired contamination or distortion that has been detected in it must be eliminated. If not, we might obtain extremely distorted outcomes that are not representative of its true value.

The prevention or removal of signal distortion or contamination is the answer to these issues. Signal conditioning refers to the procedures used on the signal to eliminate signal distortion or contamination. Along with variable manipulation and conversion, the term "signal conditioning" refers to a wide range of additional tasks. Amplification, attenuation, integration, differentiation, addition, and subtraction are just a few examples of the many linear signal conditioning techniques. Certain operations, like modulation, filtering, clipping, etc., might not be linear. In order to prepare the signal for transmission to the following stage of the system, signal conditioning procedures are applied to it. The Signal Conditioning Element is the component in any instrument or instrumentation system that carries out this function.

Data transmission element

The components of an instrument are physically separated in a few different scenarios. Data transmission between elements becomes necessary in these kinds of circumstances. We refer to the element that carries out this task as a data transmission element. For instance, control stations on Earth are physically apart from satellites or aircraft. Control stations use complex telemetry systems to transmit radio signals to direct the movements of aircraft or satellites. The intermediate stage is the term used to describe the signal conditioning and transmission phase.

Data presentation element

Giving information about the quantity being measured to the personnel using the instrument or system for monitoring, controlling, or analyzing is the aim of the data presentation element. A format that is simple to read must be used to present the information. In the event that data needs to be monitored, visual display devices are necessary. These devices could be voltmeters and ammeters, or other analog or digital indicating instruments. Devices like high-speed cameras, televisions, CRT storage, printers, analog and digital computers, and magnetic tape recorders could be used if the data needed to be recorded. Control and analysis are done with computers and control components. The final stage of a measurement system is referred to as the terminating stage.

The data presentation element's job is to give information about the quantity being measured to the personnel using the instrument or system so they can monitor, control, or analyze it. An easily readable format must be used to present the information. If data is to be monitored, visual display devices must be used. These devices could be analog or digital indicating devices, like ammeters and voltmeters. Devices like magnetic tape recorders, high-speed cameras, televisions, CRT storage, printers, and analog and digital computers could be used if the data needed to be recorded. For analysis and control, computers and control components are utilized. The term "terminating stage" describes a measurement system's final stage.

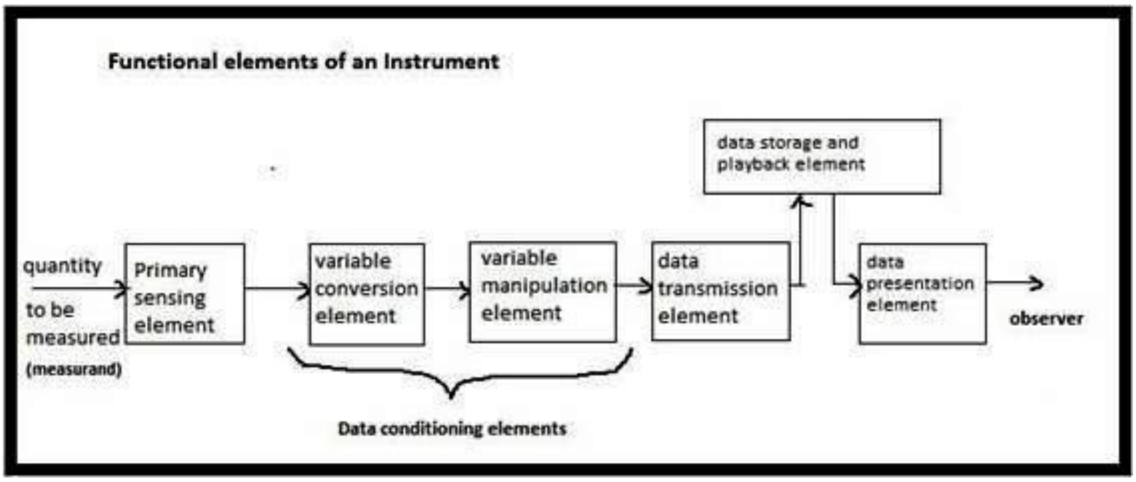


Fig. Block diagram of functional elements of a measurement system / instrument

Functional Elements of a Bourdon Pressure Gauge

Let's examine the simple Bourdon tube pressure gauge shown in the following figure as an example of a measurement system. An excellent example of a measurement system is this gauge. In this case, the variable conversion element and the primary sensing element are the Bourdon tube. It recognizes the input quantity, which is pressure in this case. Pressurization causes the closed end of the Bourdon tube to move. Thus, pressure is converted into a small displacement. The closed end of the Bourdon tube is mechanically connected to a sector-pinion gearing arrangement. The small displacement is amplified by the gearing arrangement, which rotates the pointer through a wide angle. As a result, the mechanical linkage acts as a data transmission element and the gearing arrangement as a data manipulation component. The dial scale on the gauge body represents the quantity being measured and is a component of the data presentation. With this device, analog information is transmitted.

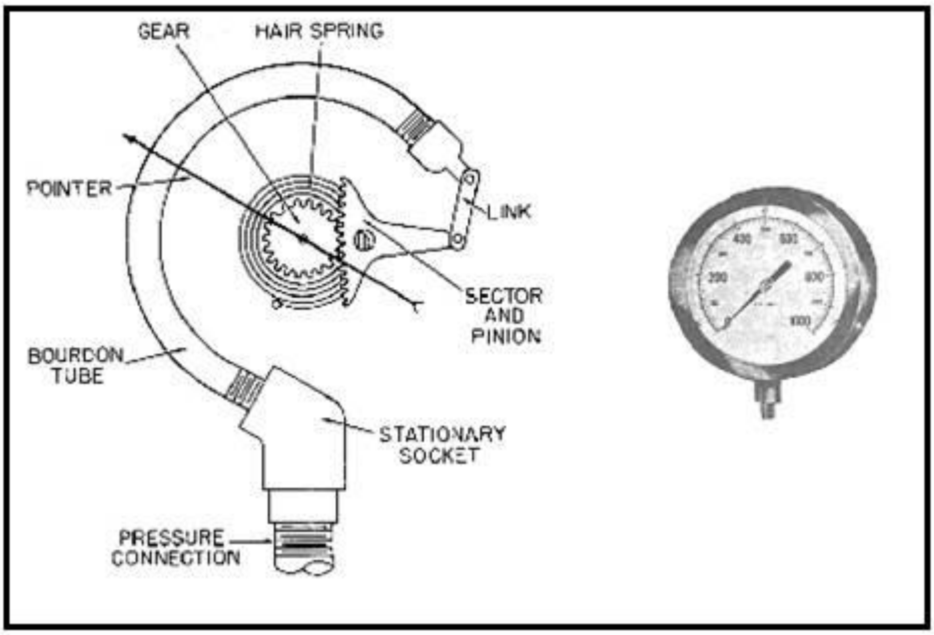


Fig. Bourdon Pressure gauge, the pressure measuring instrument

Errors:

Errors arise due to: 1. Inaccurate sighting of the measurement, or parallax error

2. Error in calibration (should the scale not be drawn precisely).

3. Zero error: This occurs when a device is either incorrectly set to zero or lacks a zero.

4. Damage (if there is any faulty or damaged equipment).

5. The measurement device's limit of reading (the measurement is only as accurate as the smallest unit

Definition of Error

1. Limit of Reading: the measuring device's smallest unit of measurement.

2. Half of the reading limit is the Greatest Possible Error, also known as the Absolute Error.

3. The Upper and Lower Limits: these represent the lowest and maximum values that a measurement can fall within.

TYPES OF ERRORS

Errors are typically divided into the following three main categories:

Gross error

This category of errors typically results from improper instrument reading, improper data recording during experimentation, or improper instrument use by the instrument operator. As long as people are involved, there will undoubtedly be some serious mistakes made. Even though it's probably impossible to completely eradicate glaring mistakes, one should make an effort to prevent them. It might be necessary to take the following steps to lessen the effects of gross errors.

When reading and documenting the data, extreme caution should be used.

Different experimenters should take two or more readings.

Systematic error

Four categories can be used to classify systematic errors:

Instrumental Error

The main causes of these errors are as follows:

due to inherent instrument shortcomings (which could be brought on by issues with the mechanical structure's design, calibration, or operation).

because the instruments were misused. One possible reason for this could be that one of the instruments' zero adjustments was missed.

because of how the instruments are loaded. These mistakes can be avoided, or at least minimized, by applying the following techniques:

Measurement protocol needs to be well thought out.

After these errors are found, correction factors need to be used.

Carefully recalibrate the device.

Make intelligent use of the instrument.

Observational Errors

because of the types, whether digital or analog, on the instrument display.

due to parallax, where the measurement point and the eye should line up exactly.

Note: Digital display instruments can be used to completely eliminate these errors.

Environmental Errors

because of factors outside the measuring device, like the surroundings of the instrument. Changes in pressure, humidity, dust, vibration, or external magnetic or electrostatic fields can all contribute to these conditions. Corrective measures like the following can be used to reduce or eliminate these errors:

Maintain the state as much as you can.

Utilize tools or equipment that is resistant to these impacts.

Use a method that gets rid of these disruptions.

Random error

Even after accounting for all systematic and obvious errors, some experiments' results vary from one to the next. It is impossible to eliminate or reduce these errors because the cases of these errors are not identified. Statistical analysis can be used to determine the best outcome when these kinds of errors occur.

Error in Measurement

The difference between a quantity's real value and the value obtained from the measurement is known as the measurement's error. The random error (triggered by the measuring instrument's accurateness boundary) can be improved (reduced) by repeating the measurement, but the systemic error (caused by an incorrect calibration of the measuring instrument) cannot be improved.).

Absolute error

It can be summed up as the discrepancy between the variable's measured and expected values. e = absolute error in this case Yn = predicted value Xn = value that was measured

$$e = Y_n - X_n \qquad \text{(Equation 1.1)}$$

c) Relative error (Percent of Error) To express the error as a percentage,

$$Percent\ error = \frac{absolute\ error}{expected\ error} \times 100\%$$

$$Absolute\ error,\ e = Y_n - X_n$$

$$Percent\ error = \frac{Y_n - X_n}{Y_n} \times 100\%$$

Problem: The expected value of the voltage across a resistor is 50V; however, measurement yields a value of 49V. Calculate

a) The absolute error
b) The percent of error

PERFORMANCE CHARACTERISTICS:

The performance characteristics of an instrument are mainly divided into twocategories:

i) Static characteristics

ii) Dynamic characteristics

Static characteristics:

"Static characteristics" refers to the set of standards established for the instruments that are used to measure quantities that exhibit either slow temporal variation or are mostly constant, meaning they do not vary with time.

The various static characteristics are:

i) Accuracy
ii) Precision
iii) Sensitivity
iv) Linearity
v) Reproducibility
vi) Repeatability
vii) Resolution
viii) Threshold
ix) Drift
x) Stability
xi) Tolerance
xii) Range or span

Accuracy:

a) It refers to how closely the reading matches the actual value of the quantity that needs to be measured. The following are some ways to express accuracy:

b) Point accuracy:

There is only one specific scale point at which this accuracy is specified.

About the accuracy at any other point on the scale, it provides no information.

c) Accuracy as percentage of scale span:

Scale range can be used to express the accuracy of an instrument with uniform scale.

d) Accuracy as percentage of true value:

Defining accuracy in terms of the actual value of the quantity being measured is the most effective way to conceptualize it. Precision can be defined as the degree of agreement between a set of measurements, given a fixed value of a quantity. It is a measure of reproducibility.

The precision is composed of two characteristics

Conformity:

Let us consider an ohmmeter measuring a resistor whose true value is 2385692. However, because there is no appropriate scale, the reader can consistently read a value of 2.4 M. It is a precision error brought about by the scale reading's limitations.

a) Number of significant figures:

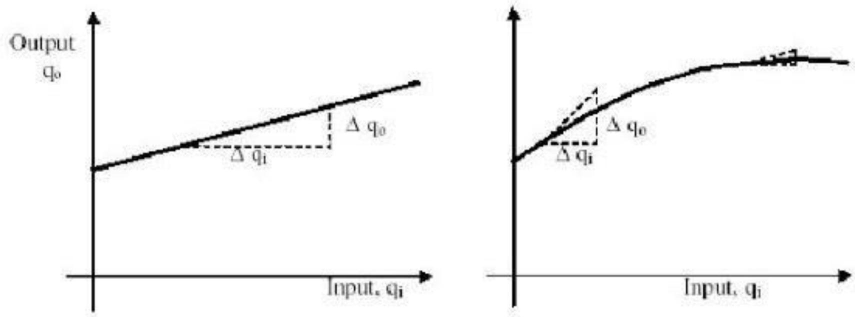
The number of significant figures used to express the reading indicates the measurement's precision. The important numbers provide precise information about the amount's magnitude and measurement accuracy.
The precision can be represented mathematically as follows:
Where, P = precision

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

Xn = Value of nth measurement
Xn = Average value the set of measurement values

Sensitivity:

The instrument's sensitivity indicates the smallest change in the measured variable that it reacts to. Its definition is the relationship between changes in an instrument's output and changes in the value of the quantity to be measured. It can be expressed mathematically as,



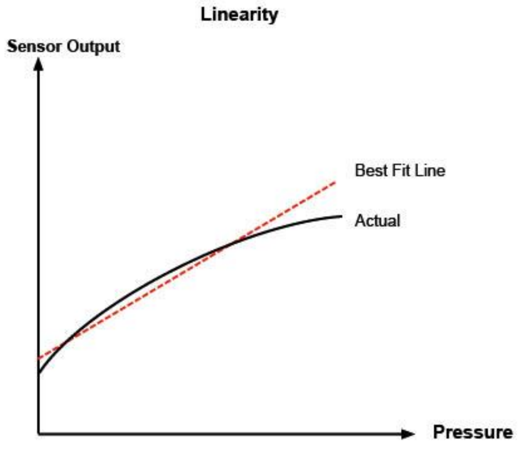
$$\text{Sensitivity} = \frac{\text{Infinitesimal change in output}}{\text{Infinitesimal change in input}}$$

$$= \frac{\Delta q_o}{\Delta q_i}$$

As a result, if the calibration curve is linear as displayed, the instrument's sensitivity is represented by the calibration curve's slope. Should the calibration curve not be linear as depicted, the sensitivity will fluctuate depending on the input. As the reciprocal of sensitivity, inverse sensitivity, also known as the deflection factor, is defined. Deflection factor, or inverse sensitivity, equals 1.

Linearity:

A measure of a measurement's consistency across its whole range is called linearity. Though it can be deceptive when used alone, it is generally a reliable indicator of a sensor's performance quality. Simply put, linearity indicates the degree to which the measurement made by the instrument matches reality.



Resolution: It will once more be discovered that the output remains unchanged until a specific increment is exceeded if the input is gradually increased from an arbitrary input value. Resolution is the name given to this increase.

Threshold: There will be a minimum value below which there is no discernible change in the output when the instrument input is increased very gradually from zero. This lowest number establishes the instrument's threshold.

Stability:

It is the capacity of an apparatus to maintain its functionality for the duration of its designated operating life.

Tolerance: The tolerance is a number that is used to define the maximum allowable error in the measurement.

Range or span: An instrument's range, or span, is the set of lowest and maximum values for a quantity that it is intended to measure.

Dynamic characteristics:

The term "dynamic characteristics" refers to the set of standards established for the instruments that are subject to quick changes over time.

The various static characteristics are:

Speed of response

Measuring lag

Fidelity

Dynamic error

Speed of response: The quickness with which a measurement system adapts to variations in the measured quantity is its definition.

Measuring lag: It is the inability of a measurement system to react quickly enough to changes in the quantity being measured. Two types of measuring lags exist:

Retardation type: Under this scenario, the measurement system starts responding as soon as the measured quantity changes.

Time delay lag: In this instance, the application of the input is followed by a dead time before the measurement system responds. A measurement system's fidelity is determined by how well it detects changes in the measurand quantity without introducing dynamic error.

Dynamic error: If no static error is assumed, it is the discrepancy between the measurement system's indicated value and the actual value of the quantity that changes over time. Measurement error is another name for it.

Calibration

The difference between the quantity's indicated value and its actual value as determined over time by the measurement system, if no static error is assumed. It is also known as measurement error.

Definition of Calibration :

To remove the unknown accuracy of the original device, a device must be calibrated by comparing it to a known, accurate standard. A known sample of the variable to be measured must therefore be introduced precisely in order to calibrate a measuring system. The calibration process then establishes the proper output scale for the measurement system; in other words, the readout device of the measurement system needs to be adjusted until its scale accurately reads the known sample of the variable that has been introduced.

Purpose of Calibration :

1) To obtain meaningful results, any measuring system must be calibrated.

2) If the measuring and sensing systems are not the same, then the system must be calibrated as an integrated whole in order to account for each component's propensity to produce error.

3) The readout device should display an output equal to the known measured input close to the full-scale input value after calibration, which is typically accomplished by making adjustments so that it produces zero output for zero-measured input.

4) Any calibration of a measuring system must be carried out in an environment that is as similar to the one in which the actual measurements are to be taken as feasible.

The system's calibration standard should normally be at least ten times more accurate than the accuracy of the intended measurement system. 5) It is also essential to know the reference measured input with even more precision.

Calibration procedure

There are two different methods for calibrating instruments:

(a) Primary calibration (b) Secondary calibration

(a) Primary calibration

In accordance with this process, a system is calibrated against a primary standard. Primary calibration refers to the process of calibrating flow meters where the flow is ascertained by measuring the volume or mass of fluid in addition to time.

(b) Secondary calibration

This process involves using a primary calibration-calibrated device as a secondary standard for subsequent calibration of less accurate devices.

As a secondary standard for calibrating other flow devices, a turbine-style flow meter is employed.

Secondary calibration is of two types namely

(i) Direct calibration

(ii) Indirect calibration

(i) Direct calibration

The device to be calibrated is connected in series with a standard device in this procedure. Comparing the two devices' readings over the intended range allows for calibration to be completed.

(ii) Indirect calibration

In this procedure, a standard device and the device to be calibrated are connected in series. Calibration can be finished by comparing the readings from the two devices over the designated range.

Errors Due To Calibration:

Before being used, every instrument needs to be calibrated. The process of calibrating a measurement system involves providing it with a known input and taking the appropriate steps to ensure that the system's output and input match.

A reading with a higher degree of error will be displayed if the instrument is not calibrated correctly which is called as calibrationerror. These errors are fixed because they were introduced into the measurement system due to incorrect calibration.

Statistical Analysis of Random Uncertainties

All instruments must be calibrated before being used. Giving a measurement system a known input and taking the necessary actions to make sure the system's output and input match are the steps involved in calibrating the system.

If the instrument's calibration is off, a reading with a larger degree of error will be shown. This is referred to as a calibration error. Because of improper calibration, these errors were introduced into the measurement system and have been corrected.

With one more example, we review the idea of random error. Let's return to the previously discussed stopwatch example. We came to the conclusion that our ability to determine when to stop the stopwatch is not entirely certain. We could stop the stopwatch a little too early or a little too late, depending on how random we are in our decisions. This will show up as random error with a normal, or Gaussian, distribution over the course of multiple measurements.

As was previously mentioned, systematic errors are mistakes brought on by instruments or other forms of recurring bias. Assume we have created a five-trial experiment where we use a scale to measure the mass of a substance. Unbeknownst to us, the scale doesn't zero correctly even though we zero it before every measurement. Hence, a systematic error results from the mass measurement being off by the same amount for each trial. In situations where systematic errors are suspected, statistics should not be used because it is incapable of detecting such errors. Rather, by employing calibration standards and other verification methods, an experimentalist should try to minimize systematic errors.

Mean and Standard Deviation

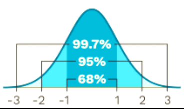
Statistical methods can be employed to characterize the data set once we are certain that systematic errors have been adequately reduced and that the residual error is probabilistic. The best estimate of the true quantity, x, given N measurements of a given quantity, is the mean, $\bar{x}$, of the measurements:

$$\overline{X} = \frac{\sum X}{N}$$

The error, σx, can also be estimated. In order to achieve this, we consider the deviation of each measured value from the mean. The deviation of a specific trial from the mean is represented by the value xi - x (also called a residual). Since the residuals always add up to zero due to the way the definition of x is constructed, we are unable to sum the residuals. Subsequently, the square the residuals, add them up, and calculate the square root of the total to obtain the standard deviation, or σ:

$$s_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

n = The number of data points
x_i = Each of the values of the data
$\bar{x}$ = The mean of x_i



Normal Distribution Curve

The average uncertainty of measurements x1,__, xN is described by the standard deviation. The term "root-mean-squared" (RMS) deviation is another name for it occasionally. Moreover, the term "standard deviation" is occasionally defined differently, substituting the value of "N" in (28) with "N - 1". In particular, when N is small, the result of x obtained from this second definition is more conservative. However, the differences between the two forms are often minimal. It is safest to use the form with (N – 1) if we are not sure which method to use.

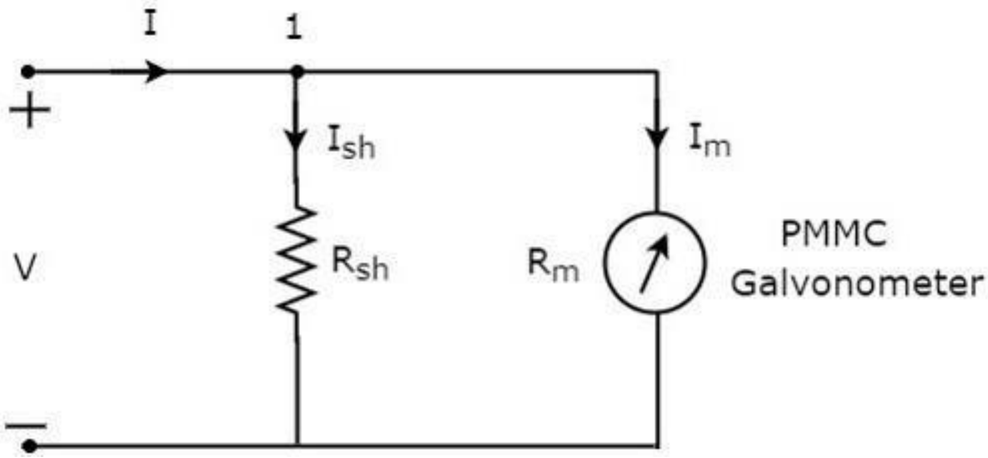
Measuring Instrumenting

DC Ammeters

The rate of electric charge flow is known as current. Direct Current (DC) is the term used to describe the current that results when this electric charge only flows in one direction. DC ammeter is the name of the device that measures direct current.

The Permanent Magnet Moving Coil (PMMC) galvanometer can function as a DC ammeter when a resistor is connected in parallel with it. Another name for the parallel resistance found in DC ammeters is shunt resistance, or just shunt. In order to measure the large value DC current, the resistance value should be taken into consideration.

The figure below displays the DC ammeter circuit diagram.



The electrical circuit branch where the DC current is to be measured and this DC ammeter must be connected in series. The elements share the same voltage and are connected in parallel. Because the two components in the circuit above are connected in parallel, the voltage across the galvanometer voltage across resistance, Rm, and the shunt resistor, Rsh, are therefore equal.

Mathematically, it can be written as

$$I_{sh} R_{sh} = I_m R_m$$

$$R_{sh} = I_m R_m / I_{sh} I_{sh}$$

The **KCL equation** at node 1 is

$$-I + I_{sh} + I_m = 0$$

(Equation 1)

$$-I + I_{sh} + I_m = 0$$
$$\Rightarrow I_{sh} = I - I_m$$

Substitute the value of I_{sh} in Equation 1.

$$R_{sh} = \frac{I_m R_m}{I - I_m} \qquad \text{(Equation 2)}$$

Take, I_m as common in the denominator term, which is present in the right hand side of Equation 2

$$R_{sh} = \frac{I_m \quad R_m}{I_m \left(\frac{I}{I_m} - 1\right)}$$

$$\Rightarrow R_{sh} = \frac{R_m}{\frac{I}{I_m} - 1} \qquad \text{(Equation 3)}$$

Where,

R_{sh} is the shunt resistance

R_m is the internal resistance of galvanometer

I is the total Direct Current that is to be measured

I_m is the full scale deflection current

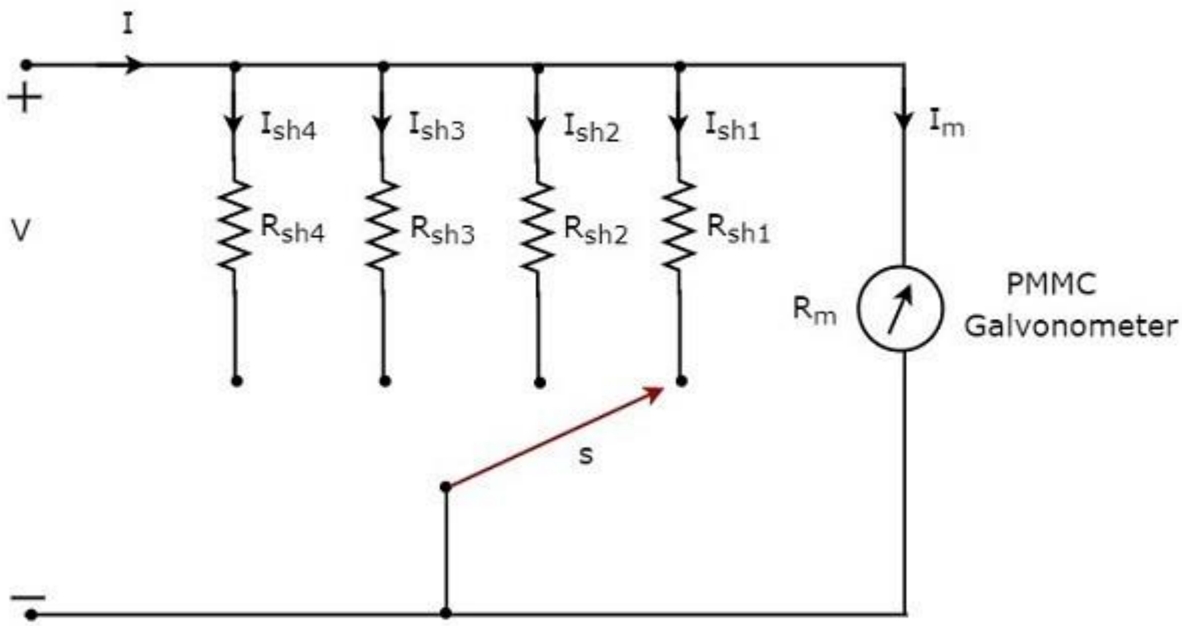
The ratio of total Direct Current that is to be measured, I and the full scale deflection current of the galvanometer, I_m is known as **multiplying factor, m**. Mathematically, it can be represented as

$$m = \frac{I}{I_m} \qquad \text{(Equation 4)}$$

$$R_{sh} = \frac{R_m}{m-1} \qquad \text{(Equation 5)}$$

Multi Range DC Ammeter

This DC ammeter needs to be connected in series with the electrical circuit branch where the DC current is to be measured. With a parallel connection, all of the components have the same voltage. The circuit above has two components connected in parallel, which means that the voltage across the shunt resistor, Rsh, and the galvanometer voltage across resistance, Rm, are exactly equal.



Attach this multi-range DC ammeter in series with the branch to measure the necessary direct current range in an electric circuit. The desired range of currents can be chosen by connecting the switch to the proper shunt resistor.

Let m1, m2, m3, and m4 be the multiplying factors of the DC ammeter when we consider the total direct currents to be measured as I1, I2, I3, and I4, respectively. The following lists the formulas for each multiplying factor.

$$m_1 = I_1 / I_m$$

$$m_2 = \frac{I_2}{I_m}$$

$$m_3 = \frac{I_3}{I_m}$$

$$m_4 = \frac{I_4}{I_m}$$

In above circuit, there are four **shunt resistors**, $R_{sh1}, R_{sh2}, R_{sh2}$ and R_{sh4} . Following are the formulae corresponding to these four resistors.

$$R_{sh1} = \frac{R_m}{m_1 - 1}$$

$$R_{sh2} = \frac{R_m}{m_2 - 1}$$

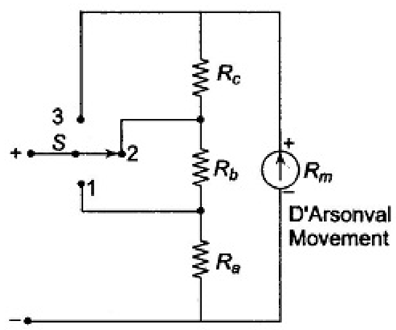
$$R_{sh3} = \frac{R_m}{m_3 - 1}$$

$$R_{sh4} = \frac{R_m}{m_4 - 1}$$

The above formulae will help us find the resistance values of each shunt resistor.

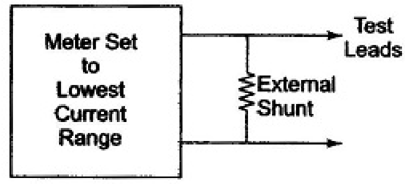
The Aryton Shunt or Universal Shunt:

The Aryton shunt makes it impossible for the meter to be in the circuit without one. The slight increase in overall resistance is the cost incurred to obtain this benefit. The circuit of an Aryton shunt ammeter is depicted in Figure. When the switch is in position "1," resistance R is in parallel with the series combination of R R and the meter movement in this circuit. Because of this, the shunt's current flow is greater than the meter movement's, protecting the latter and reducing its sensitivity. When the switch is in the "2" position, the meter movement is connected in series with resistance R and R connected in parallel. The circuit must have an Aryton shunt in order for the meter to work. There is a price for this benefit: a small rise in overall resistance. Figure shows the circuit of an Aryton shunt ammeter. Resistance R is connected in parallel to the circuit's series combination of R R and the meter movement when the switch is in position "1." This reduces the meter movement's sensitivity and protects it by allowing the shunt to have a higher current flow than it does. Resistance R and R are connected in parallel when the switch is in the "2" position, and the meter movement is connected in series with them.



Aryton Shunt

Extending of Ammeter Ranges:

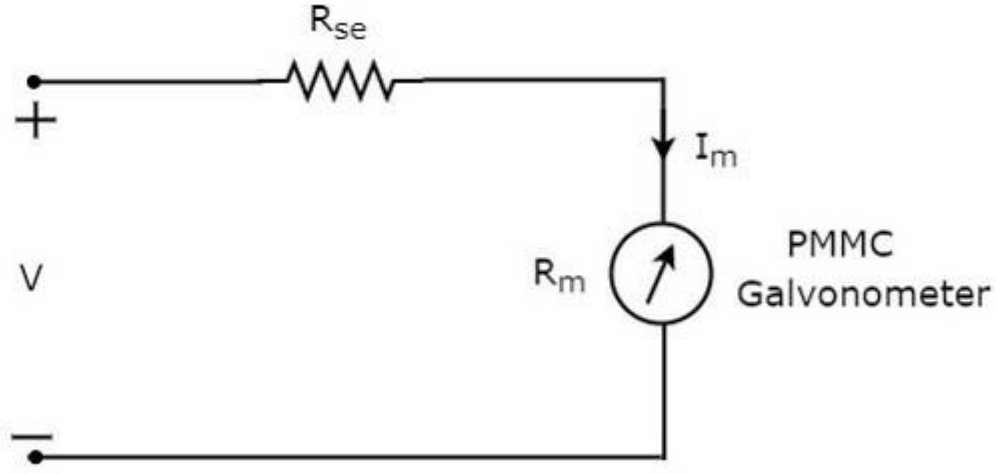


Extending of Ammeters

As illustrated in Fig., the range of an ammeter can be extended to measure high current values by connecting external shunts to the basic meter movement, which is typically the lowest current range. Remember that you cannot shorten the range of the basic meter movement. (If the meter is used to measure 1 μA using a 100 μA movement with 100 scale division, for example, it will deflect by only one division. As a result, it is practically impossible to go below the fundamental range.)

DC Voltmeters

The DC voltage across any two points in an electric circuit can be measured with a DC voltmeter. The Permanent Magnet Moving Coil (PMMC) galvanometer and resistor combined function as a DC voltmeter if they are connected in series. Alternatively known as series multiplier resistance, or just multiplier, the series resistance used in DC voltmeters belongs to this category. It basically restricts the current passing through the galvanometer so as to keep the current flowing through the meter from going over the full deflection value of the scale. Below is a figure that displays the DC voltmeter circuit diagram.



This DC voltmeter must be positioned between the two points in an electric circuit where the DC voltage is to be measured.Wrap the above circuit's loop with KVL.

$$V - I_m R_{se} - I_m R_m = 0 \quad \text{(Equation 1)}$$

$$\Rightarrow V - I_m R_m = I_m R_{se}$$

$$R_{se} = (V - I_m R_m)/ I_m \quad \text{(Equation 2)}$$

R_{se} is the series multiplier resistance

V is the full range DC voltage that is to be measured

I_m is the full scale deflection current

R_m is the internal resistance of galvanometer

The voltage drop across the galvanometer, Vm, is the ratio of the full range DC voltage to be measured, Vand. This ratio is represented by the multiplying factor, m. Based on mathematics, it can be

$$m = V/V_m \quad \text{(Equation 3)}$$

The full range DC voltage that needs to be measured, V, can be found using Equation 1.

$$V = I_m R_{se} + I_m R_m \quad \text{(Equation 4)}$$

The full scale deflection current (Im) and the internal resistance (Rm) of the galvanometer multiply to produce the DC voltage drop across the device. It can be expressed mathematically as

$$V_m = I_m R_m \quad \text{(Equation 5)}$$

Substitute, Equation 4 and Equation 5 in Equation 3.

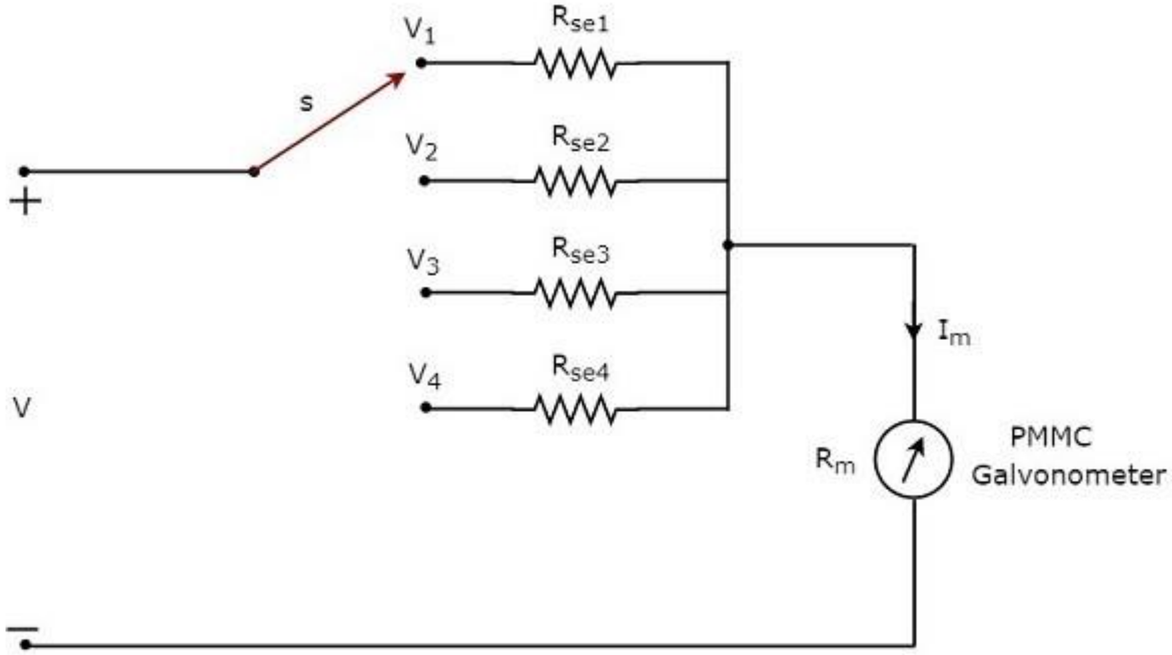
$$\Rightarrow m = \frac{R_{se}}{R_m} + 1$$

$$\Rightarrow m - 1 = \frac{R_{se}}{R_m}$$

$$R_{se} = R_m (m - 1) \qquad \text{(Equation 6)}$$

Multi Range DC Voltmeter

Measurements within a specific DC voltage range can be made with the DC voltmeter.



Using multiple parallel multiplier resistors in place of a single multiplier resistor is necessary if we want to use the DC voltmeter to measure DC voltages over a range of values. The PMMC galvanometer is connected in series with the entire stack of resistors. The figure below displays the circuit diagram for a multi-range DC voltmeter.

One can measure a specific range of DC voltages with the DC voltmeter.

A single multiplier resistor cannot be used to measure the DC voltages of multiple ranges with a DC voltmeter; instead, multiple parallel multiplier resistors must be used, and the PMMC galvanometer is connected in series with the entire set of resistors. The multi range DC voltmeter's circuit diagram is displayed in the figure below.

$$m_1 = \frac{V_1}{V_m} \qquad m_3 = \frac{V_3}{V_m}$$

$$m_2 = \frac{V_2}{V_m} \qquad m_4 = \frac{V_4}{V_m}$$

The four series multiplier resistors in the circuit above are designated as Rse1, Rse2, Rse3, and Rse4. These four resistors' corresponding formulas are listed below.

$$R_{se1} = R_m (m_1 - 1)$$

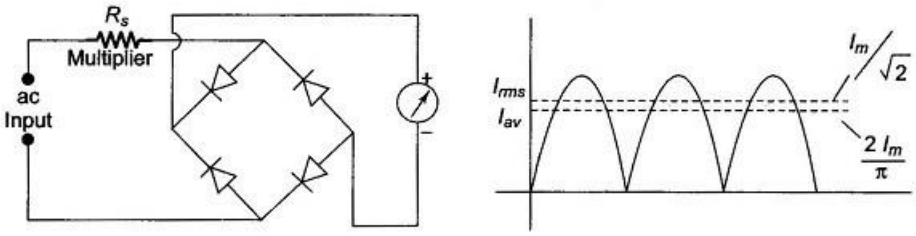
$$R_{se2} = R_m (m_2 - 1)$$

$$R_{se3} = R_m (m_3 - 1)$$

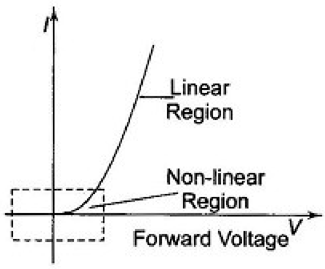
$$R_{se4} = R_m (m_4 - 1)$$

AC Voltmeter using Rectifiers:

AC Voltmeters with rectifier-based technology: These meters usually pair a PMMC movement with a rectifier configuration. The recommendation is for silicon diodes due to their low reverse current and high forward current ratings.



A multiplier, a bridge rectifier, and a PMMC movement make up the circuit of the ac voltmeter shown in Figure. An oscillating full wave dc is produced by the bridge rectifier. A consistent deflection proportional to the average current value is shown by the meter because of the movable coil's inertia. For an alternating sine wave input, the meter scale is typically calibrated to yield the RMS value.



Reducers that are useful are non-linear devices, especially when the forward current is low. As a result, on a low range voltmeter, the meter scale is typically crowded at the lower end and is not linear. Because of the diode's high forward resistance in this section, the meter's sensitivity is low. Additionally, the temperature affects the diode resistance.

The rectifier tends to bypass higher frequencies and displays capacitance characteristics when reverse biased. For every 1 kHz increase in frequency, the meter reading could be off by as much as 0.5%.

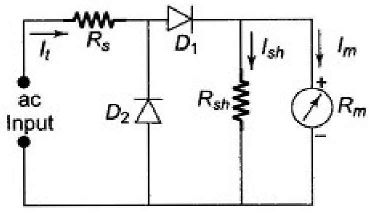
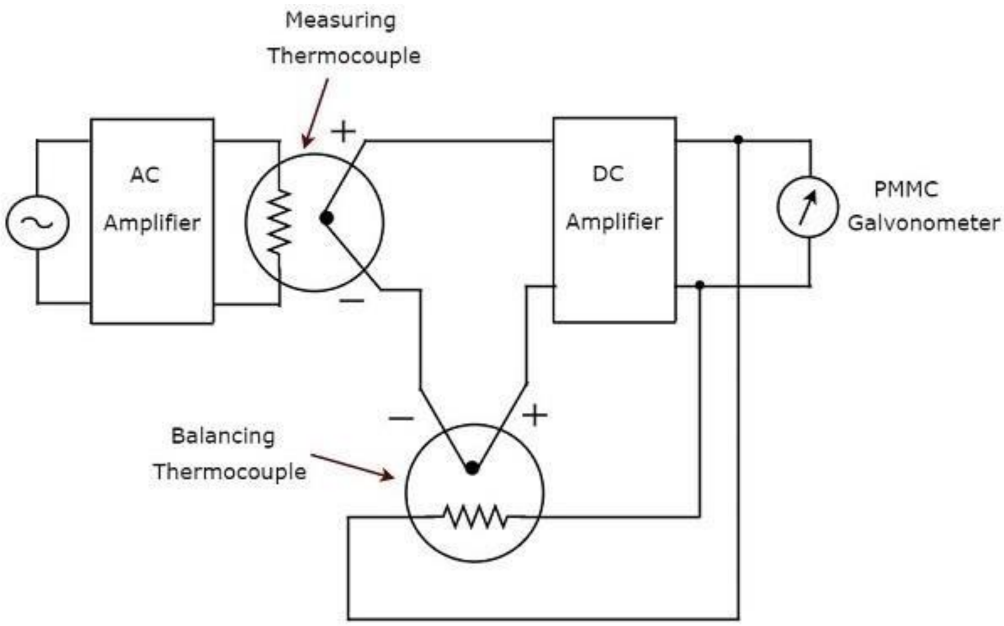


Figure shows an example of a common rectifier type ac voltmeter setup. In response to the average value of this half cycle, diode D1 conducts during the positive half of the input cycle, which deflects the meter. In order to move the operating point into the linear region of the characteristic curve and draw more current through the diode D1, the meter movement is shunted by a resistor. Diode D2 conducts and the measuring circuit's current flows in the opposite direction during the negative half-cycle.

True RMS Responding AC Voltmeter

Simply put, the true RMS responding AC voltmeter responds to the true RMS values of the AC voltage signal, as suggested by its name. This voltmeter determines the RMS values of the AC voltage. A real RMS responding AC voltmeter's circuit diagram can be seen in the figure below.



The circuit described above includes a PMMC galvanometer, two thermocouples, a DC amplifier, and an AC amplifier. The signal from the AC amplifier is amplified. The circuit above makes use of two thermocouples: a balancing thermocouple and a measuring thermocouple. An output voltage proportional to the RMS value of the AC voltage signal is produced by the thermocouple measurement.

Any type of thermocouple can change an input quantity square into a normal quantity. This indicates that there is a non-linear relationship between a thermocouple's input and output. One way to mitigate the impact of a thermocouple's non-linear behavior is to incorporate an additional thermocouple into the feedback circuit. The thermocouple used in the circuit above is referred to as a balancing thermocouple for this reason.

At the DC amplifier's input, a couple made up of the measuring and balancing thermocouples form a couple. Consequently, the meter reacts to the actual RMS value of the AC voltage signal without fail.

Module 2

SENSORS AND THEIR APPLICATIONS

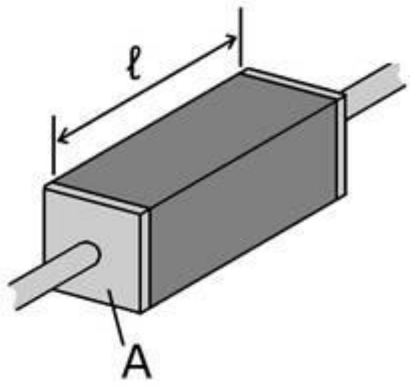
TRANSDUCERS BASED ON CHANGE IN RESISTANCE

The electrical measurements are used for measurement of electrical quantities but its use in measurement of non electrical quantities is growing. In the measurement of non electrical quantities a detector is used which usually converts the physical quantity in displacement. The displacement actuates an electric transducer, gives an output which is electrical in nature. The electrical quantity so produced is measured by standard methods used for electrical measurements. The resultant electrical output gives the magnitude of the physical quantity being measured.

The electrical signal could be a voltage, current or frequency. The production of these signals is based upon the resistive, inductive or capacitive effects. These phenomena may be combined with appropriate primary sensing elements / detectors to produce different types of transducers

Resistive Transducers

The resistive transducers or resistive sensors are also called as variable resistance transducers. The variable resistance transducers are one of the most commonly used types of transducers. They can be used for measuring various physical quantities, such as, temperature, pressure, displacement, force, vibrations etc. These transducers are usually used as the secondary transducers, where the output from the primary mechanical transducer acts as the input for the variable resistance transducer. The output obtained from it is calibrated against the input quantity and it directly gives the value of the input.
The variable resistance transducer elements work on the principle that the resistance of the conductor is directly proportional to the length of the conductor and inversely proportional to the area of the conductor.

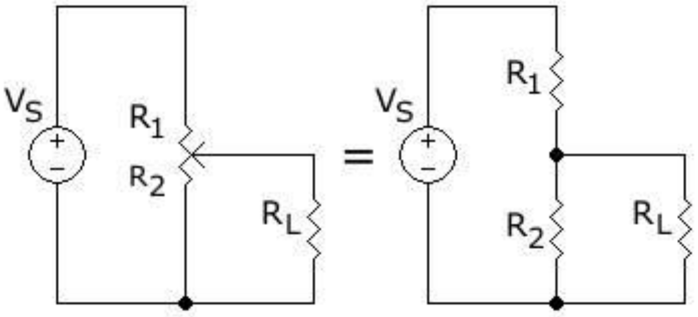


Thus, if L is the length of the conductor (m) and A is its area (m^2) as shown in Fig., then its resistance R(ohms) is given by:

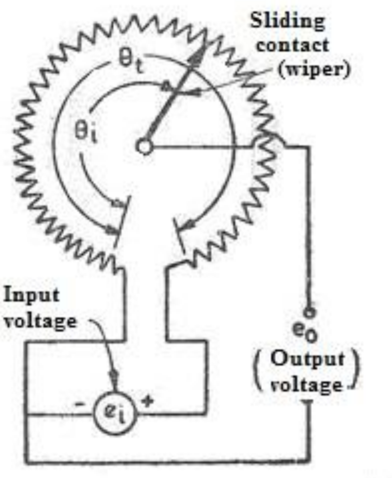
$$R = \rho L/A$$

Sliding contact devices

In the sliding contact type of variable resistance transducers, there is a long conductor whose effective length is variable. One end of the conductor is fixed, while the position of the other end is decided by the slider or the brush that can move along the whole length of the conductor. The slider is connected to the body whose displacement is to be measured. When the body moves the slider also moves along the conductor so its effective length changes, due to which it resistance also changes. The effective resistance is measured as the resistance between the fixed position of the conductor and the position of the sliding contact as shown in Fig. The value of the resistance is calibrated against the input quantity, whose value can be measured directly. One of most popular sliding contact type of variable resistance transducer is the potentiometer. These devices can be used to measured translational as well as angular displacement and are shown in Figs.



Sliding contact type of variable resistance element



Rotational potentiometer

Resistive Sensor

These sensors based on change in resistance. Both AC and DC currents can be applied to cause change in resistance.

The resistance of metal conductor is expressed as

$$R = \frac{\rho L}{A}$$

where R=Resistance in Ω

l= length of the conductor in m

A= Cross section area of the conductor in m^2

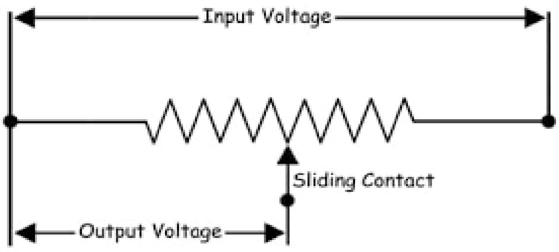
There are many ways to get change in resistance with the change in physical parameter.

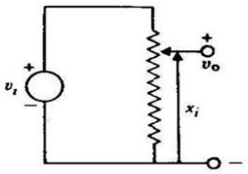
• Potentiometers

- Strain gauges
- RTD, Thermistor

Potentiometers

Simply POT. It is a Zero-order system. Consists of a Resistive Element with a sliding contact. Sliding contact is called Wiper. Motion of Sliding contact will be Translational or Rotational. Helipots: Multi-turn Rotational devices used for either translational or rotational

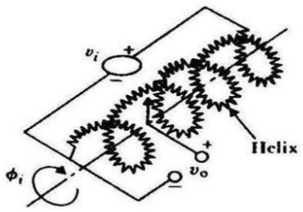


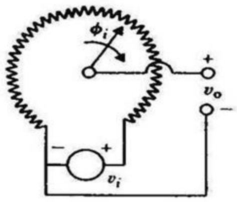


Translational

$$v_0 = \frac{R_i}{R} v_s = \frac{x_i}{l} v_s$$

Helical





Single turn

Let

e_i & e_o = input and output voltages

x_t = total length of potentiometer

x_i = displacement of wiper from its zero position

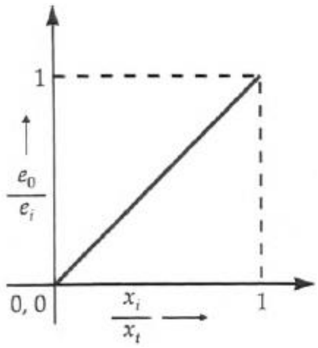
R_p= total resistance of the potentiometer

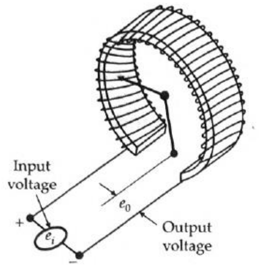
Resistance per unit length = R_p/x_t

The output voltage under ideal condition is

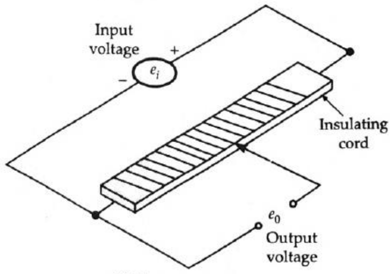
e_o= (Resistance at the output terminals/Resistance at the input terminals) x e_i

$e_o = [R_p(x_i/x_t)]/R_p = (x_i/x_t)e_i$

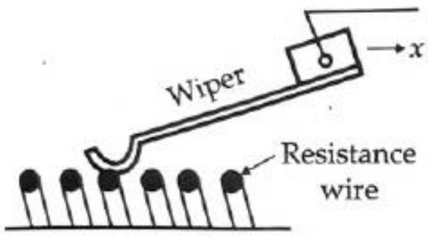


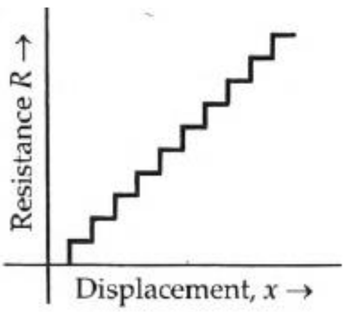


(b) Circular (Rotational) potentiometer.



(a) Linear potentiometer.





Wire Wound Potentiometers:

Materials: Platinum, nickel chromium, nickel copper.

Non-Wire Potentiometers:

Materials: Cermet, Hot moudled carbon, Carbon film, Thin metal film

Advantages:

- They don't cost much.
- easy to use
- used to quantify displacements with huge amplitudes
- Extremely high electrical efficiency means no amplification is needed.
- The resolution for Metal Film and Cermet is unlimited.

Disadvantages:

The sliding contacts (wipers) of linear pots require a lot of force to move. They can also become dirty, wear down, and produce noise.

Strain Gauges

The resistance fluctuation of a wire or semiconductor under mechanical stress is the basis for s train gauges.
Given a wire with length l, resistivity ρ, and cross section A, its electric resistance is

$$R = \frac{\rho L}{A}$$

When the wire is stressed longitudinally, R undergoes a change given by

$$\frac{dR}{R} = \frac{d\rho}{\rho} + \frac{dl}{l} - \frac{dA}{A}$$

by Hooke's law,

$$\sigma = \frac{F}{A} = E\varepsilon = E\frac{dl}{l}$$

Where E is Young's Modulus, σ is the mechanical stress, and ε is the strain

$$\frac{dA}{A} = 2\frac{dt}{t}$$

Consider a wire that in addition to a length l has a transverse dimension t. A longitudinal stress changes both l and t.

Poisson's law

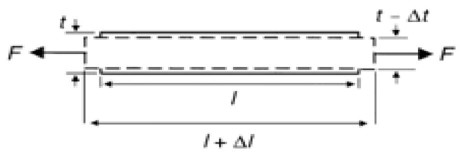
$$\nu = -\frac{d\,t/t}{d\,l/l}$$

Gauge factor,

$$G_f = \frac{d\,R/R}{d\,l/l}$$

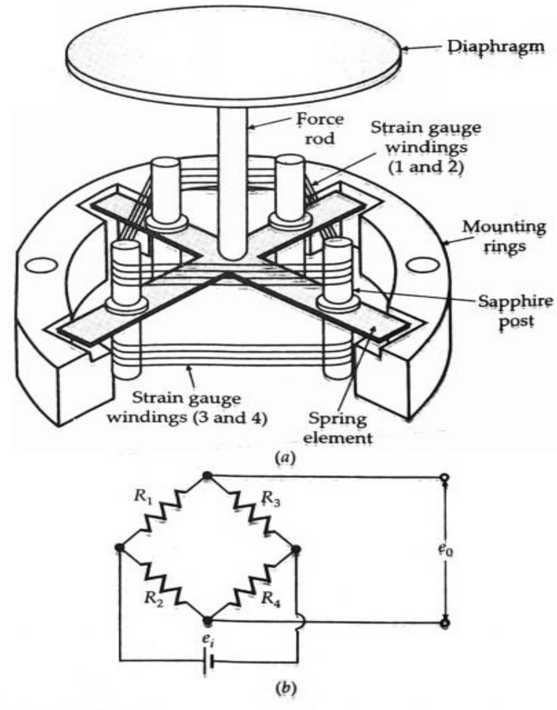
$$\frac{dR}{R} = G_f\varepsilon$$

$$\frac{dR}{R} = 1 + 2\nu + \frac{d\,\rho/\rho}{d\,l/l}$$



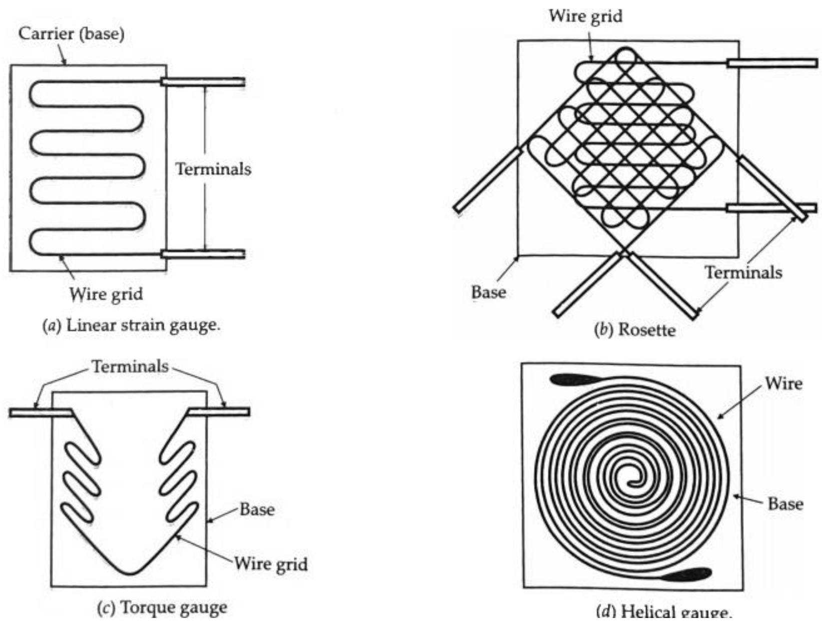
Unbonded Strain gauge

An insulating substance, such air, is used to stretch a wire between two points to provide this gauge. Different alloys of copper, nickel, chrome, or nickel iron may be used to make the wires. They have a gauge factor of 2 to 4, a diameter of around 0.003 mm, and can withstand a force of 2 mN. The wire is no longer than 25 mm. Applying pressure results in a tiny displacement of roughly 0.004 mm (full scale), which raises tension in two wires and lowers it in the other two. This increases the resistance of the two wires that are under stress while lowering the resistance of the other two wires. This throws the bridge out of balance, resulting in an output voltage that is proportionate to pressure



Bonded wire strain gauge

A resistance wire strain gauge is made out of a tiny resistance wire grid with a diameter of no more than 0.025 mm. The carrier (base), which could be a thin sheet of teflon, bakelite, or paper, is glued to the grid. A thin sheet of material is placed on top of the wire to shield it from mechanical harm. Stress can be distributed uniformly throughout the grid thanks to the wire spreading. An adhesive substance is used to fuse the carrier to the specimen being examined. This enables a good strain transmission from the carrier to the wire grid.



(a) Linear strain gauge.

(b) Rosette

(c) Torque gauge

(d) Helical gauge.

The following qualities are ideal for good and repeatable results: • High value of gauge factor

The metal has strong resistance, a low resistance temperature coefficient, no hysteresis effects, and linear properties.

• Resonant frequency response

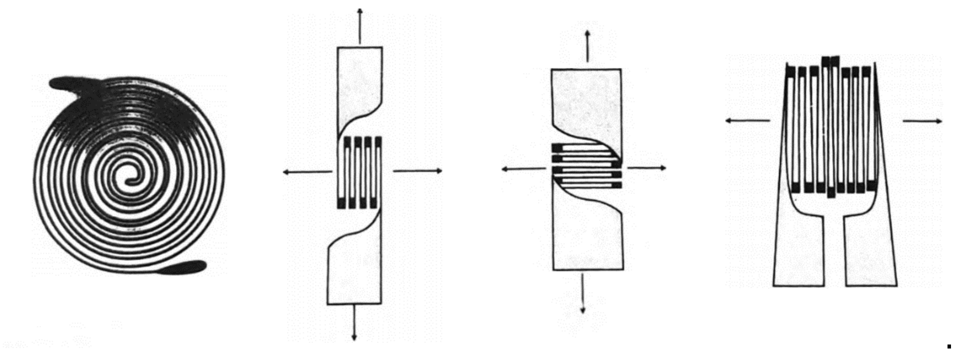
Base (Carrier): The materials that support the wires are referred to as bases or carriers. Impregnated paper, cellulose from bakelite, and epoxy

Adhesives

Adhesives are materials used for bonding. There are four types of cement: bakelite, epoxy, nitrocellucose, and ethylene glycol.

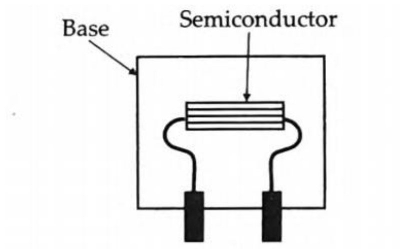
Bonded Metal Foil Strain Gauges

An expansion of the metal strain gauges with joined wires. Gauges made of foil have a far higher capacity to dissipate heat. Large surface area compared to wire strain gauge, better bonding, and same volume

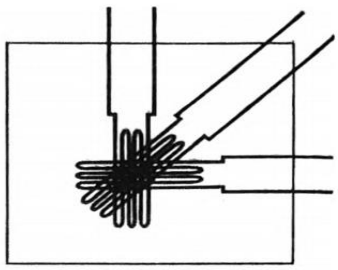


Semi-conductor Strain Gauge

the variation in resistance value brought forth by resistivity changes. elevated sensitivity as a result of a high gauge factor. These gauges are made using typical semi-conductor technology, which involves attaching semi-conducting wafers or filaments with a thickness of 0.05 mm on appropriate insulating substrates like teflon.



3-element rosette
60° planar
(Foil)



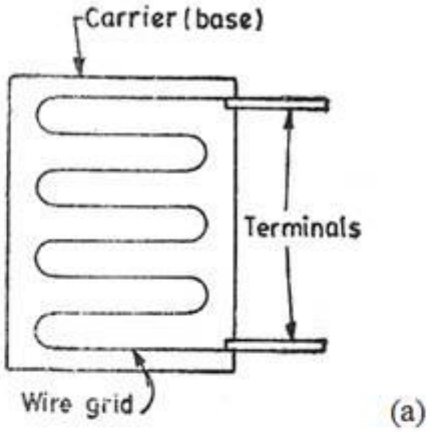
3-element rosette
45° stacked
(Wire)

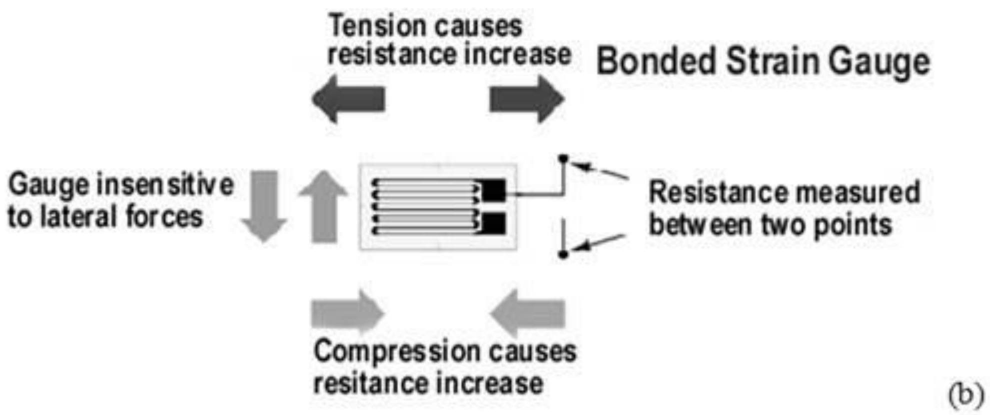
2-element rosette
90° stacked
(Foil)

A combination of strain gauges called "Rosettes".

Wire resistance strain gauge

When mechanically stressed, a fine wire—the strain gauge—changes its electric resistance. An electrical conductor will get longer and narrower when it is stretched within its elasticity's bounds without breaking or irreversibly deforming; these changes raise the conductor's electrical resistance from end to end. In contrast, a conductor will expand and contract in size to reduce its electrical resistance end-to-end when it is pressured so that it does not buckle. As illustrated in Fig., a standard strain gauge sets up a long, thin conductive strip in a zigzag pattern of parallel lines so that a little amount of stress in the direction of the parallel lines' orientation results in a multiplicatively larger strain along the effective length





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Working principle of strain gauge

The sensitivity of the strain gauge to strain is one of its key parameters. It has a quantitative expression known as the gauge factor (GF). According to its definition, gauge factor is the ratio of the fractional change in electrical resistance to the fractional change in length (or strain).

$$GF = \frac{\Delta R / R_G}{\varepsilon}$$

Generally, metallic strain gauges have a gauge factor of approximately 2.

Where: ΔR = change in resistance caused by strain

RG = resistance of the undeformed gauge

ε = strain

The bulk of strain gauges are foil kinds, which come in a variety of sizes and shapes to fit a range of applications. They are made up of a backing material placed atop a resistive foil pattern. Their working idea is that the foil's resistance alters in a predictable way when it undergoes stress. The active regions of foil gauges are usually between 2 and 10 mm^2. Strains up to a minimum of 10% can be measured with proper installation, the right gauge, and the right adhesive. Utilised for many years, the strain gauge serves as the basic sensing component for numerous sensor kinds, including as position, torque, load, pressure, and more. **Bonded Strain Gauges** These gauges are directly bonded (that is pasted) on the surface of the structure under study. Hence they are termed as bonded strain gauges. The three types of bonded strain gauges are

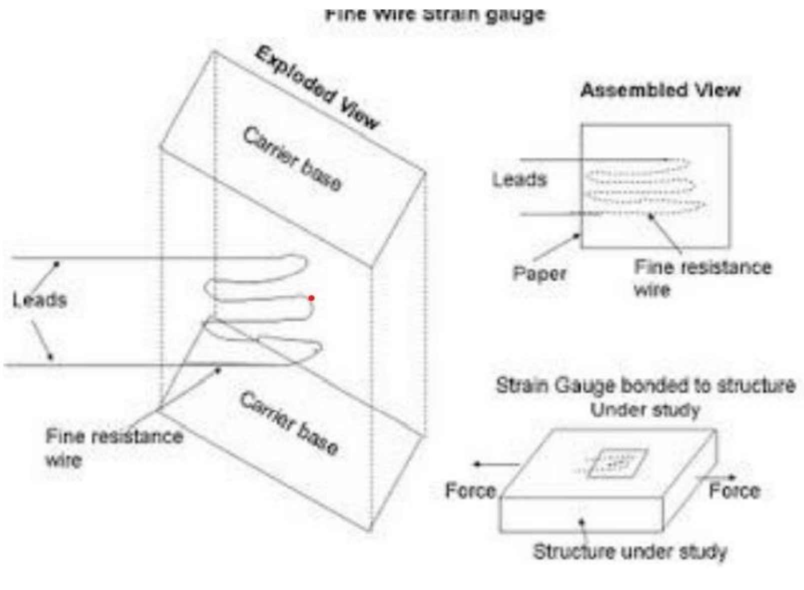
1. Fine wire strain gauge
2. Metal foil strain gauge
3. Semi-conductor gauge

1. Fine wire strain gauge

This is the first type of Bonded Strain Gauges.

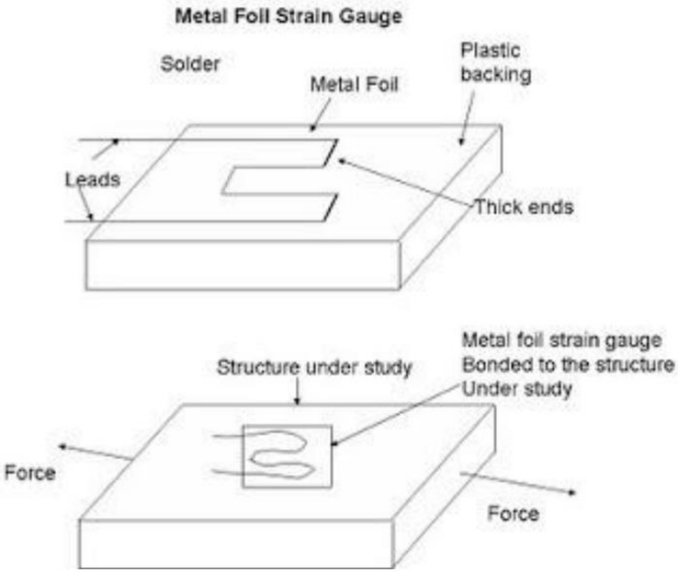
Description

The following components make up the arrangement: A fine, 0.025-mm resistance wire is bent repeatedly, as depicted in the diagram. This is done to extend the wire's length and provide a consistent distribution of stress. Between the two carrier bases (paper, Bakelite, or Teflon) that are glued to one another lies this resistance wire. Damage to the gauge is prevented by the carrier base. The strain gauge can be electrically connected to a measurement device (such as a Wheatstone bridge) using the provided leads.



Metal Foil Strain Gauge

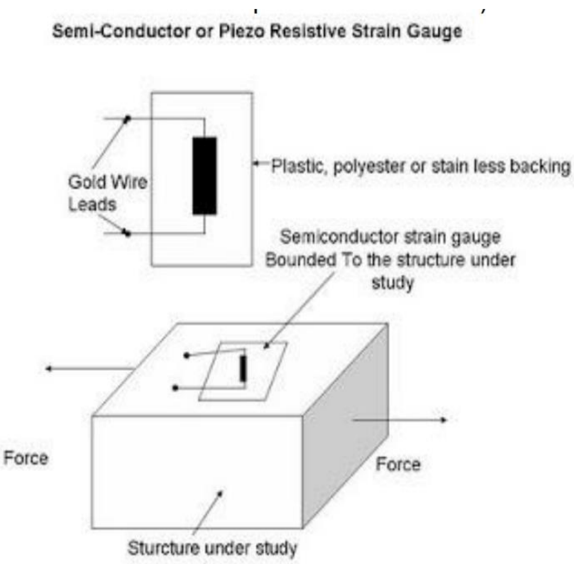
The Metal Foil Strain Gauge: An Overview The following makes up the arrangement: Using the printed circuit process, 0.02 mm thick metal foil is created. One side of the plastic backing is used to make this metal foil. In order to electrically link the strain gauge to a measurement device (heat stone bridge), leads are soldered to the metal foil.



Semi – conductor or Piezo Resistive Strain Gauge Partially-conductive or Piezo Resistive Strain Measurement The Piezo Resistive Strain Gauge: An explanation. This is how a semi-conductor strain gauge is configured: Rectangular filaments constructed from silicon or geranium crystals are used as the sensing element's wafer. To give these crystals the desired qualities, boron is added; this process is known as doping, and the resulting crystals are known as doped crystals. The plastic or stainless steel backing of this sensing element is attached to it. To electrically link the strain gauge to a measurement device (heat stone bridge), lead wires made of gold are extracted from the sensing element. Sensing elements come in two varieties, specifically:

• Negative or n-type, where the resistance decreases as the tensile strain increases.

• Positive, or P-type, resistance that rises in proportion to tensile



O**peration** The strain gauge is glued or adhered to the structure being studied with the use of adhesive material. A force (compressive or tensile) is now applied to the structure. The force will cause the structure to alter in dimension. Both the length and cross-section of the stain gauge will alter as the strain gauge bonds to the structure—that is, is stressed. A change in resistivity of the semiconductor strain gauge's sensing element (crystal) causes the strain gauge's resistance to fluctuate. Using a wheat stone bridge, the strain gauge's resistance change is measured. The strain gauge's change in resistance serves as a metric for how much the structure is deformed.

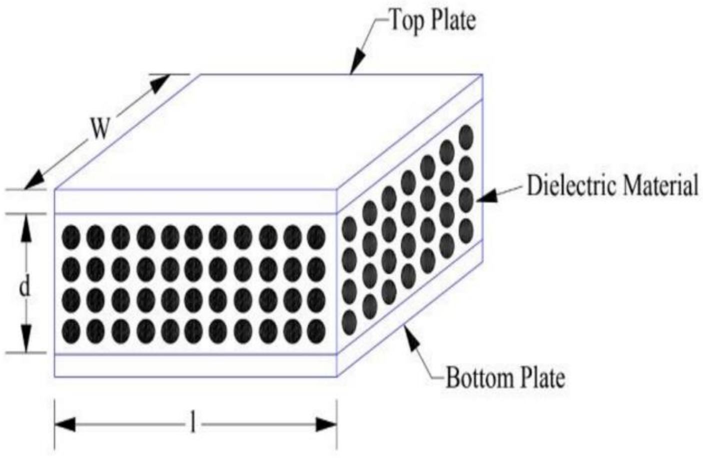
Capacitive Sensors:

A capacitive transducer is a tool that modifies its capacitance in response to variations in the physical phenomena that has to be monitored. As a passive transducer, it needed an outside power source to operate. A capacitor, which might be angular, cylindrical, or parallel plate in shape, serves as the transduction element of a capacitive transducer. It is frequently employed in linear displacement measurement.

The capacitance of the parallel plate capacitor serves as the foundation for the operation of the capacitive transducer. Given a parallel plate capacitor with plate area A separated by distance d, the capacitance (C) is as follows.

$C = (\varepsilon_o \varepsilon_r A) / d$

Where ε_o and ε_r are the permittivity of free space and the relative permittivity of the dielectric material of capacitor.



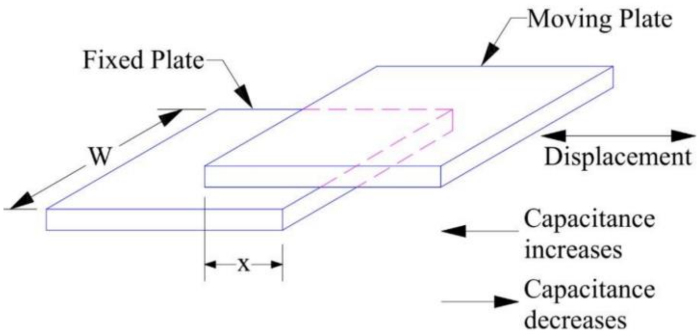
The theory behind how the capacitive transducer functions is that the following can be changed to change the capacitance:

Plate area; plate separation; and altering the dielectric material in between the plates.

Physical factors like linear displacement, angular displacement, force, pressure, and liquid level are what create the alterations mentioned above in a capacitive transducer.

Overlapping Area:

Capacitance of parallel plate capacitor is directly proportional to the area of plate



Let us assume that

The width of plate is W

The length at any time t is X.

Thus,

the area of plates of parallel plate capacitor so formed at time t will be (WX).

Therefore, the capacitance at any time t is given as below.

$C = \varepsilon_o \varepsilon_r A / d$

$C = [\varepsilon_o \varepsilon_r (WX) / d]$

it is clear that the displacement X is directly proportional to capacitance C. Hence, measurement of capacitance will directly tell us the magnitude of displacement. Thus, physical quantity displacement is converted into electrical quantity capacitance which is the required function of a transducer.

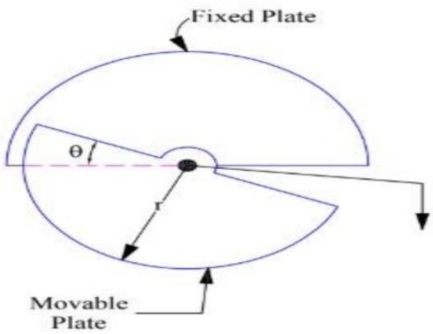
Sensitivity of a device is the rate of change of output with respect to input. Thus, the sensitivity of capacitive transducer will be the rate of change of capacitance (C) with respect to displacement (X).

Sensitivity (S) = dC / dx

$= \varepsilon_o \varepsilon_r W / d$

it may be stated that the sensitivity of a capacitive transducer is constant and depends on the width & separation between the plates. This is a great feature of capacitive transducer and exploited for measurement of linear displacement ranging from 1 mm to 10 mm. The accuracy is as high as 0.005%.

The principle of change of capacitance with change in area is also employed for the measurement of angular displacement.



The angular displacement changes the effective area between the plates and hence, a corresponding change in capacitance.

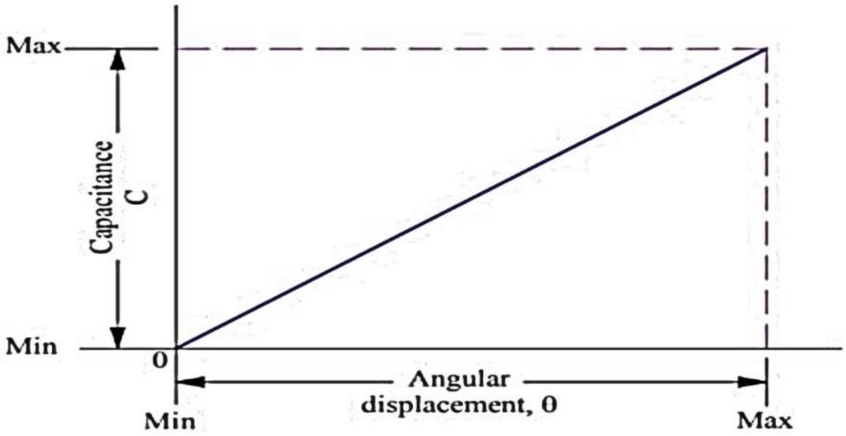
Let, at any time t, the angular overlapping position is Θ. Since the area of entire plate is (πr^2

/2) for angular overlapping of π radian, therefore, the area (A) of plate for angular overlapping of Θ radian will be

$A = (\pi r^2/2\pi)\Theta = \Theta r^2/2$

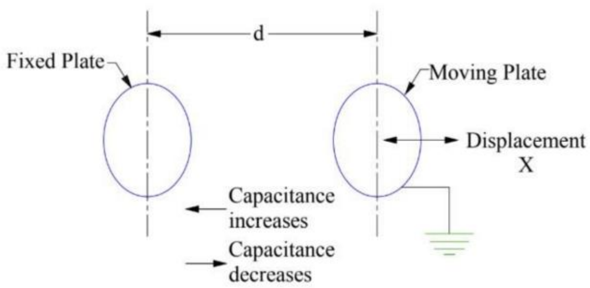
Capacitance = $[\varepsilon_o \varepsilon_r \Theta r^2/(2d)]$

it is obvious that the capacitance is directly proportional to the angular movement. Hence, measurement of capacitance is a direct indication of angular movement. The graph between the capacitance and angular position is a straight line and shown below



Distance between the Plate:

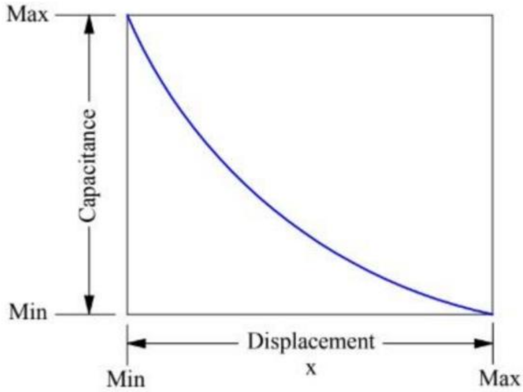
One of the capacitor's plates can be fastened to the moving object while the other plate remains fixed to enable a capacitive transducer to react to linear displacement. The capacitance changes as a result of the object moving and altering the distance between the plates. The distance between the plates has an inverse relationship with the variation of capacitance with separation. The following graphic depicts a basic schematic of a capacitive transducer that makes use of the idea of change in capacitance with change in distance between the plates.



The separation between the plate is x at any time t. Hence, capacitance is given as

$C = \varepsilon A/x$

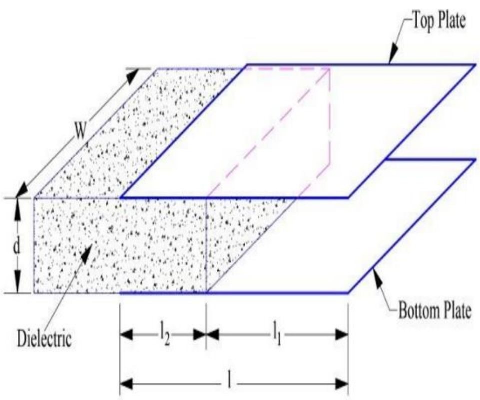
The characteristics of this transducer is, thus, non-linear. Actually, it is hyperbolic as shown below



This transducer's sensitivity fluctuates according to how far apart the plates are from one another. The sensitivity really increases with decreasing distance x. This implies that the gadget will react to a smaller displacement value. If the displacement value is higher, it won't react. For applications requiring the measurement of incredibly little displacement, this kind of capacitive transducer is employed. It is a drawback.

Dielectric Constant:

That isn't the case, though. Just take a look at the capacitive transducer's sensitivity using the changes in area and distance between the plates. For the former, the sensitivity is constant, but for very minor displacement, it increases. Thus, in order to measure extremely little displacement, a transducer that uses



Capacitor plates cannot be removed. On the other hand, a moving object with a dielectric constant

The plate is being moved inside by €r. Our goal is to quantify the object's displacement. Allow the object to be inside the plates by the l2 length at any intermediate point. As a result, the capacitor is filled with dielectric up to l2 length, with a dielectric constant of \r, whereas l1 length is filled with air. You may find the capacitance in this combination as indicated below.

$$C = \frac{\varepsilon_0 W}{d}[l_1 + \varepsilon_r l_2]$$

it is clear that, as the object moves into the capacitor, the value of l_2 increases and hence the capacitance C increases. By measuring this capacitance, the linear displacement can be predicted.

Advantage:

- The major advantages of capacitive transducer are:
- Because it requires extremely little force to function, this transducer is used in small systems.
- They are quite perceptive. Up to 0.005% accuracy is achieved.
- This transducer's high input impedance results in a little loading impact.
- These transducers make it simple to reach a resolution on the order of 2.5×10-3.
- A capacitive transducer is not impacted by stray magnetic fields, whereas an inductive transducer's measurement is.
- Capacitive transducers take less electricity to function since they require less force.Disadvantage:

The disadvantages of a capacitive transducer are:

- The metallic components of a capacitive transducer must be isolated from one another. The capacitance value will drop to zero if they get short. Above all, this transducer's frame needs to be earthed in order to prevent the measurement from being impacted by stray capacitance.
- The action of edges can occasionally lead the capacitive transducer to behave nonlinearly. Guard rings take care of this effect.
- Another potential source of mistake when measuring minute physical changes is the cable that connects to the transducer. The source of loading that causes sensitivity loss could be the cable. Additionally, loading deteriorates the low frequency response.
- Dust, moisture, and other factors may alter the capacitance.
- Because of their sensitivity to temperature, they are negatively impacted by any changes in performance.
- Because of the lower capacitance value, the capacitive transducer's output impedance (1/2πfC) is relatively large, and the instrumentation circuitry utilised with it is fairly sophisticated. The loading effect results from this. The frequency of the signal used to assess capacitance determines the output impedance. The frequency utilised must provide an output impedance in the range of 1 kΩ to 10 MΩ for capacitances between 10 and 500 pF. Because of the high output impedance, it is necessary to maintain a high insulation resistance to prevent excessive capacitance shunting and sensitivity reduction.

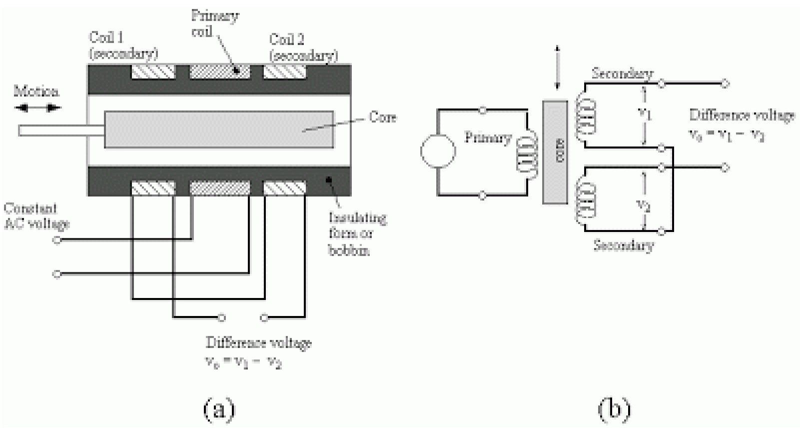
Inductive Sensors

Linear Variable Displacement Transducer (LVDT):

Principle of LVDT:

With the help of the mutual induction principle, LVDTs can convert non-electric displacement energy into electrical energy.

Construction of LVDT:



The one primary winding is located in the center of the cylindrical former, and there are two secondary windings on either side of the former to complete the LVDT. Due to the fact that the two secondary windings have the same number of turns but are oriented in opposite directions—that is, if the left secondary winding is turning clockwise, the right secondary winding will be turning counterclockwise—the net output voltages will be the difference in voltages between the two secondary coils. S1 and S2 are the symbols for the two secondary coils. As seen in the figure, an esteem iron core is positioned in the center of a cylindrical former that can move back and forth. 50 to 400 Hz is the operating frequency, and the AC excitation voltage is 5 to 12 V.

Working of LVDT:

Based on the location of the iron core within the insulated former, there are three scenarios.

Situation 1: If the core remains motionless in the null position when an external force, such as displacement, is applied, the voltage induced in both secondary windings is equal, resulting in zero net output, or Esec1-Esec2=0.

Situation 2:

In comparison to the induced emf in secondary coil 2, the induced emf voltage in the secondary coil is larger when an external force is applied and the steel iron core tends to move in a leftward direction. Esec1-Esec2 will be the net output as a result.

Situation 3: The induced voltage of the induced emf in secondary coil 2 is higher than that of secondary coil 1 when an external force is applied and the steel iron core moves in a rightward direction. thus Esec2-Esec1 will be the net output voltage.

The LVDT has the following benefits:

- It has infinite resolution
- It has a high output
- It provides Good linearity, ruggedness, low hysteresis, low friction, high sensitivity, and low power consumption are all advantages of LVDT.

The low voltage differential transformer (LVDT) has certain drawbacks.

- Firstly, it requires a very high displacement to generate high voltages.
- Secondly, because it is sensitive to magnetic fields, shielding is necessary.
- Thirdly, vibrations can affect the transducer's performance.
- Lastly, Temperature variations have a significant impact on it.

Utilizing LVDT in Applications:

- The displacement between a fraction of a millimeter and a centimeter can be measured using an LGDT.

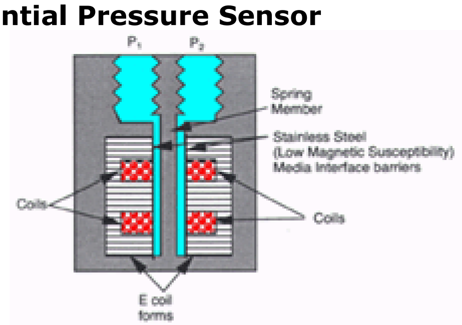
- Force, weight, pressure, and other quantities can be measured with an LVDT, which functions as a secondary transducer.

Variable Reluctance Sensor:

Depending on pressure, force, or acceleration, the parameter input of the strain-based variable reluctance sensor creates a magnetic circuit and causes the spring member to mechanically deflect.

The oscillator and demodulator system for variable reluctance sensors must internally limit the operating temperature range of -40 C to +120 C in order to provide a static output capability. Positioned centrally between two coils, as depicted, the spring member is made of a magnetic material with a high permeability.

Variable Reluctance Differential Pressure Sensor



Nonmagnetic stainless steel barriers are welded to keep the coils isolated from the measurand. The differential pressure transducer causes the two coils' inductance (L) to modulate because of the pressure differential between them. This distortion occurs towards the magnetic pole piece on the low-pressure side of the spring member.

The variable reluctance sensor is powered by an alternating voltage source operating in the 1 KHz to 10 KHz range, forming an inductive half-bridge electrical configuration. The spring member positioned in the center creates an inductive push-pull arrangement in which the deflection of the spring member causes a difference in coil impedance by decreasing the inductance of one coil and increasing the inductance of the other.
As a function of the parameter input, the effective inductance modulation is generated by changes in the magnetic reluctance.

Eddy current sensor

Eddy current sensors uses the principle of eddy current formation to sense displacement. These sensors measure shaft displacement in rotating machinery and have been around for many years as they offer manufacturers high-linearity, high-speed measurements, and high resolution.

Operating Principle:

Electromagnetic Induction:

In order to create an alternating current (AC) magnetic field, the sensor is made up of one or more coils.

A conductive substance experiences eddy currents when this magnetic field interacts with it.

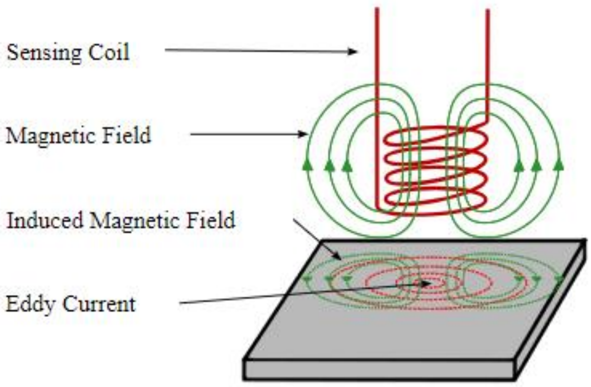


Fig. A coil inducing an eddy current in a conductive plate

Eddy currents are formed when a moving or changing magnetic field intersects a conductor or vice versa.

The relative motion causes a circulating flow of electrons, or currents, within the conductor. These circulating eddies of current create electromagnets with magnet fields that oppose the effect of applied magnetic field. The stronger the applied magnetic field, or greater the electrical conductivity of the conductor, or greater the relative velocity of motion, the greater the currents developed and greater the opposing field. Eddy current probes senses this formation of secondary fields to find out the distance between the probe and target material.

Eddy Currents Interaction:

The induced eddy currents in the conductive material produce counteracting magnetic fields to the original magnetic field's change.

The impedance of the sensor coil or coils varies as a result of this opposition.

Detection and Measurement:

Because eddy currents are present and have certain characteristics, the sensor detects changes in the induced AC signal's impedance, phase, or amplitude.
A material's conductivity, permeability, thickness, and defect presence can all be determined by varying these parameters.

Hall Effect Sensor

It is in 1879 that Edwin Hall discovers hall voltage. The way current flows through a conductor causes the Hall Effect. This theory of Hall Effect was applied to many inventions. Additional applications of this theory include pressure, fluid flow, and current sensors. A device that has been developed to measure magnetic field is the Hall Effect sensor.

Hall Effect Sensor Definition

In order to determine the strength of the magnetic field, linear transducers called Hall-effect sensors are employed. These sensors measure the magnetic flux density by producing a Hall voltage in response to the presence of a magnetic field. This process is based on the Hall Effect.

The Hall Effect Sensor's Operation

A fundamental working principle of the Hall Effect sensor is the concept of Hall voltage. Applying electricity causes electrons on a thin strip of a conductor to flow in a straight line. Electron motion is perpendicular to the magnetic field, and this charged conductor deflects the electrons when it comes into contact with it.

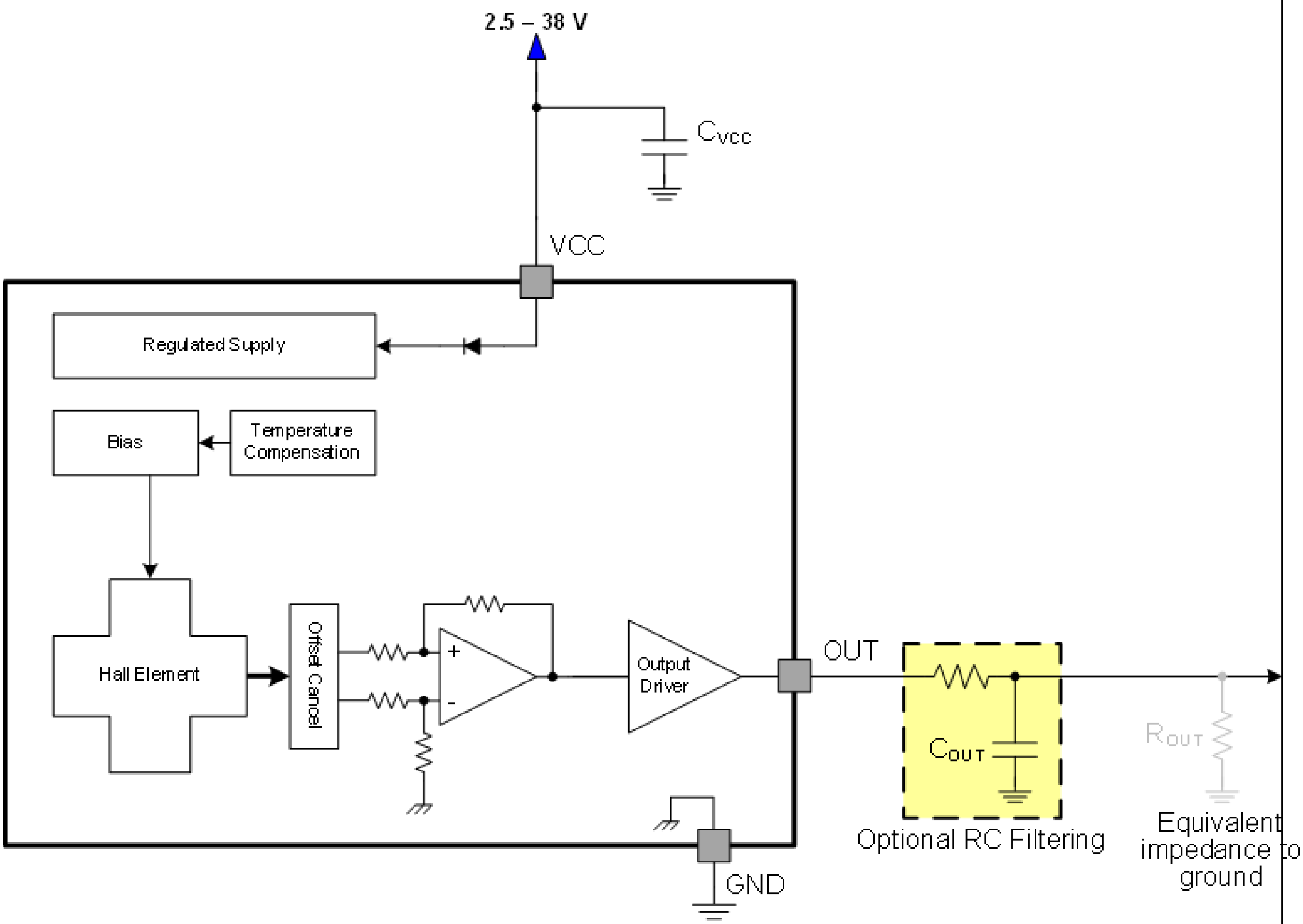
On one side, some electrons gather, and on the other, on the other. As a result, one conductor plane exhibits negative charging behavior while the other displays positive charging behavior. Voltage is produced when this produces a potential difference. The Hall voltage is the name given to this charge.

Once a balance is reached between the force acting on charged particles as a result of an electric field and the force causing the magnetic flux that caused this change, the electrons will continue to move from one side of the plane to the other. The magnetic flux density can be measured at the moment the separation stops by calculating the hall voltage.

Two types of Hall Effect sensors exist based on the relationship between magnetic flux density and hall voltage. The output voltage and magnetic flux density in the linear sensor are related linearly. Every magnetic flux density will cause the threshold sensor's output voltage to drop sharply.

Utilizing Hall Effect Sensors

- Together with threshold detection, they function as a switch.
- Keyboards and other applications requiring extremely high reliability employ these.
- Wheels and shafts are timed by means of Hall Effect sensors.
- In brushless electric DC motors, these are employed to locate the permanent magnet.
- Digital electronic devices incorporate Hall Effect sensors in addition to linear transducers.
- In industrial applications, detecting the existence of a magnetic field.
- Use this on your smartphone to see if the flip cover accessory is closed.
- The Hall Effect sensor is used to measure DC current in current transformers without making contact.
- This serves as a sensor to identify the fuel level in cars.



Piezoelectric Transducer

Physical quantities such as temperature, pressure, and mechanical stress applied on metal must be measured in a variety of situations that arise in daily life.To measure these unknown quantities in units and calibrations that we are familiar with is necessary for all of these applications. The TRANSDUCER is one such gadget that is very helpful to us. Any physical quantity can be converted into a proportionate electrical quantity, such as voltage or electrical current, using a transducer, which is an electrical device.

A piezoelectric transducer is an electrical transducer that operates by converting any kind of physical quantity into a measurable electrical signal. Piezoelectric transducers are electrical devices that convert physical quantities into electrical signals by utilizing the properties of piezoelectric materials.

When any type of physical quantity is converted into a measurable electrical signal, an electrical transducer known as a piezoelectric transducer works. Piezoelectric transducers are electrical devices that use the characteristics of piezoelectric materials to transform physical quantities into electrical signals.

Classification of Piezoelectric Substances

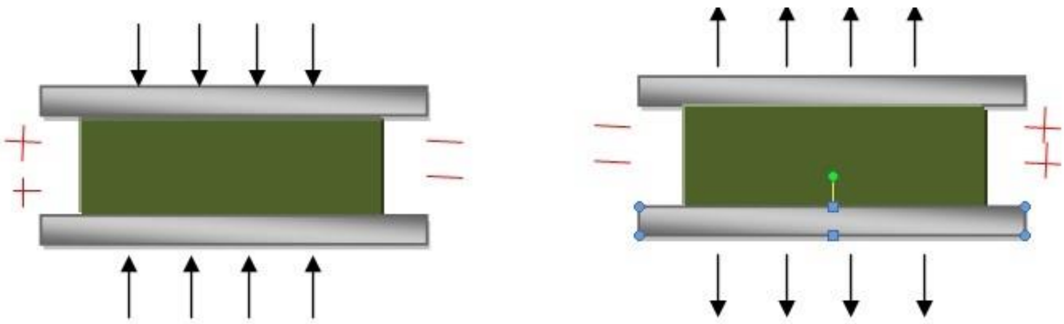
Piezoelectric materials come in a variety of forms.

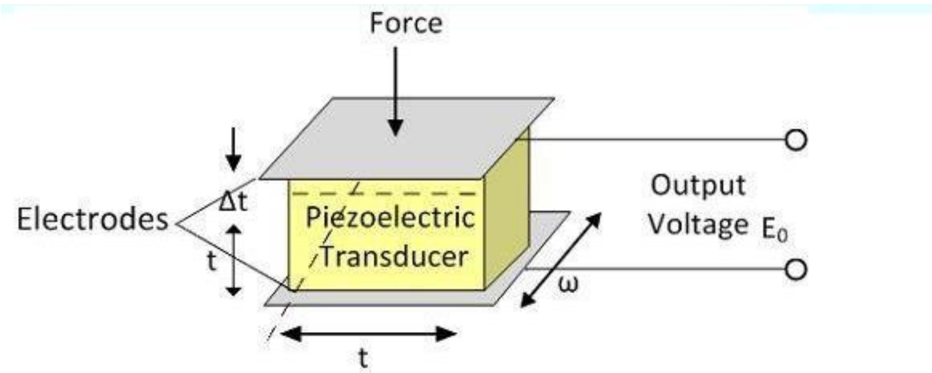
Minerals found in nature: Tourmaline-group minerals, quartz, Rochelle salt, topaz, and certain organic materials like silk, wood, enamel, bone, hair, rubber, and dentin. Potassium niobate, Lithium niobate, Lithium tantalate, Barium titanate, Lead titanate, Lead zirconate titanate (PZT), Polyvinylidene difluoride, PVDF or PVF2, and other lead-free piezoelectric ceramics are examples of artificially manufactured piezoelectric materials.

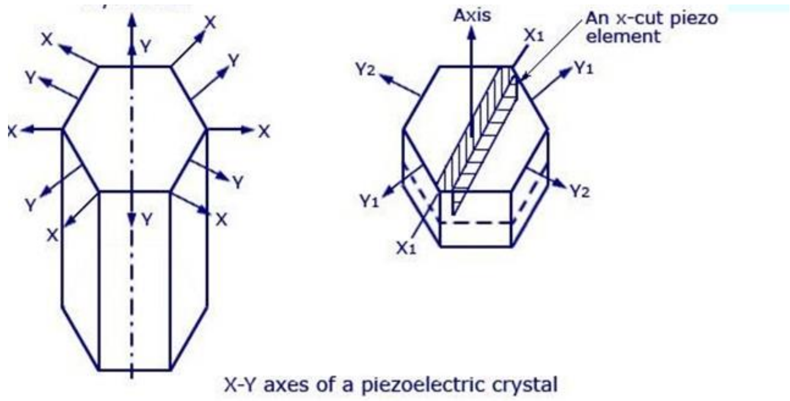
Piezoelectric transducers are not compatible with all types of piezoelectric materials. For piezoelectric materials to be used as transducers, they must meet specific requirements. The materials used for measurement should be flexible enough to be manufactured into different shapes without affecting their properties, have high output values, be insensitive to extremes of temperature and humidity, and have frequency stability. Regretfully, no piezoelectric material exists that possesses all of these characteristics. Despite having low output levels, quartz is a very stable crystal that is found naturally. Quartz is a useful tool for measuring parameters that vary slowly. Although Rochelle salt has the highest output values, it cannot be used above 1150F due to its sensitivity to environmental factors.

Functioning of Pizezoelectric Transducer

The principle of piezoelectricity is used by piezoelectric transducers. Silver or some other thin conducting material is applied to the faces of piezoelectric material, which is typically quartz. When a material is under stress, its ions migrate away from one conducting surface and towards the other. Charge is created as a consequence of this. Stress calibration is done with this charge. The direction in which the stress is applied determines which way the generated charge is polarized. As demonstrated below, stress can be applied in two different ways: compressively and tensilely.

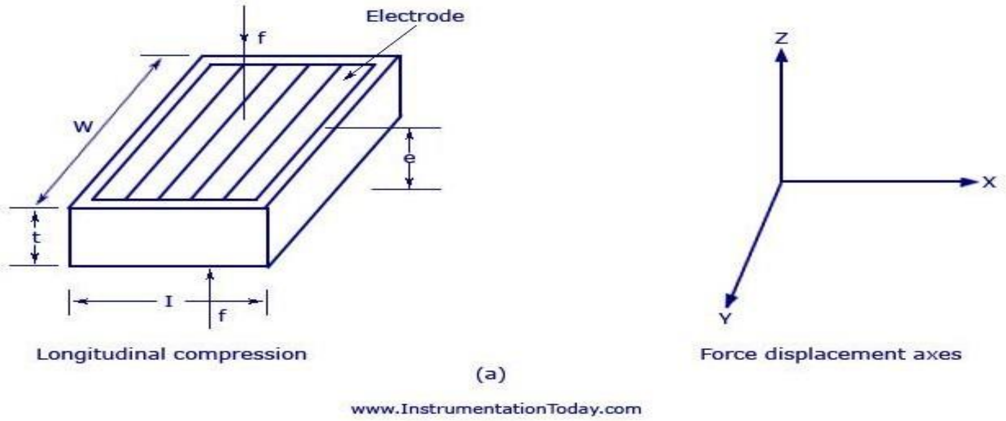




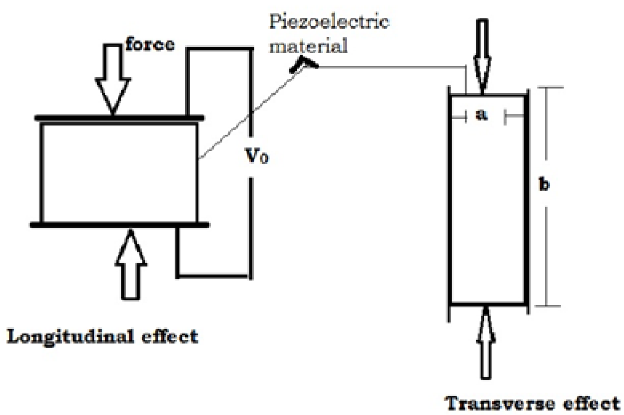


X-Y axes of a piezoelectric crystal

Modes of Operations



The formula for a piezoelectric transformer
The crystal's orientation has an impact on the voltage produced as well. A transducer's crystal may be positioned transversely or longitudinally.

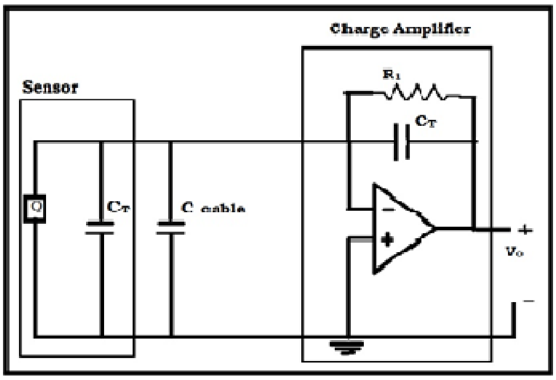


Longitudinal and Transverse Effect
The charge generated in the longitudinal effect is given by Q = F * d.
where F is the applied force and d is the crystal's piezoelectric coefficient.
Quartz crystals have a piezoelectric coefficient of d of about 2.3 * 10-12 C/N.

The charge produced by the transverse effect is expressed as Q = F * d * (b/a).
The amount of charge produced by transverse arrangement will exceed that produced by longitudinal arrangement when the ratio b/a is greater than 1.

Network of Piezoelectric Transducers

The following figure illustrates how a simple piezoelectric transducer operates.



Piezoelectric Transducer Circuit

As stress is applied to this silver-coated quartz crystal, it functions as a sensor to produce a voltage. Measurement of the generated charge without dissipation is done using a charge amplifier. With a high resistance R1, very little current can be drawn. The lead wire capacitance that links the piezoelectric sensor and transducer has an impact on the calibration as well. Thus, it is common practice to position the charge amplifier very close to the sensor.
To calibrate applied stress, a charge amplifier is used to enhance the proportionate electric voltage that a piezoelectric transducer generates when mechanical stress is applied.

Potential Uses of Piezoelectric Transducers

- The main applications of piezoelectric materials are in vibration pickup, accelerometers, and surface roughness measurement because they are not able to measure static values.
- To detect vibrations in rockets, seismographs employ them.
- For the purpose of measuring force, stress, vibrations, etc., strain gauges
- Engine detonation is measured by the automotive industry using this tool.
- In medical applications, these are employed for ultrasonic imaging.

Benefits and Drawbacks of Piezoelectric Transducers

Piezoelectric transducers have the following benefits and drawbacks.

Benefits

These transducers are active, meaning they don't need external power to function and can generate their own energy. Their high-frequency response makes them a good option for a variety of applications.

Limitations: the transducer can only measure changing pressure; therefore, it is useless for measuring static parameters. Temperature and environmental conditions can also affect the transducer's behavior.

Ultrasonic Transducer

The amount of signals or waves that can appear in a given amount of time is known as frequency. There are Hertz (Hz) units for frequency. In accordance with the frequency values, these frequencies are separated into multiple ranges. The frequencies that they correspond to are Extremely High Frequencies (EHF), Ultra-High Frequencies (UHF), Super High Frequencies (SHF), Medium Frequencies (MF), High Frequencies (HF), Very High Frequencies (VHF), Low Frequencies (LF), and Medium Frequencies (MF). The frequency range may vary depending on the type of frequencies. The frequency range of VLF is 3–30 kHz. LF operates in the frequency range of 30 kHz to 300 kHz. MF operates between 300 and 3000 kHz in frequency. HF operates in a frequency range of 3 MHz to 30 MHz. UHF frequencies span from 300 MHz to 3000 MHz. SHF operates between 3 GHz and 30 GHz in frequency. The EHF frequency spectrum spans from 30 GHz to 300 GHz.

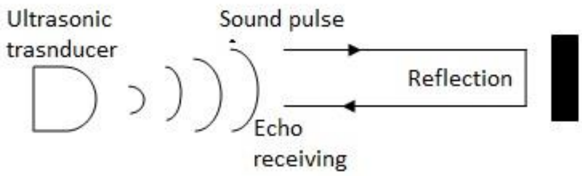
One kind of sensor that is related to sound is the ultrasonic transducer. These transducers transfer electrical signals to the target, whereupon the signal returns to the transducer. During this procedure, the transducer gauges the object's distance rather than its sound intensity. These transducers measure a few parameters using ultrasonic waves. It is widely applicable in many

different fields. Ultrasonic waves have frequencies that are higher than 20 kHz. The primary applications for these are in distance measurement.
.

These transducers are characterized as transducers that convert one form of energy into an ultrasonic vibration. This transducer determines the object's distance using these ultrasonic vibrations. They come in two varieties: active and passive.

Operational Framework

This transducer produces a sound wave when an electrical signal is applied, causing it to vibrate within a certain frequency range. When an obstruction arises, the sound waves travel and reflect the transducer's echo information. Additionally, this echo transforms into an electrical signal at the transducer's end. Here, the transducer determines how long it takes for the sound wave to be sent and for the echo signal to be received. At 40 kHz, the ultrasonic sensor generates an ultrasonic pulse that travels through the atmosphere. These transducers are superior to infrared sensors because they are impervious to substances like smoke and dark materials. When it comes to reducing background interference, ultrasonic sensors excel.



The primary application of ultrasonic transducers is the use of ultrasonic waves to measure distance. Use the following formula to calculate the distance.

D equals ½ * T * C.

D in this case denotes the distance.

T is the amount of time that passes between sending and receiving ultrasonic waves.

The sonic speed is represented by C.

Applications

Numerous fields, including industrial and medical, can benefit from the use of these transducers. Thanks to ultrasonic waves, these are finding greater uses. The use of ultrasonic transducers is beneficial in locating targets, measuring object distances from targets, determining object positions, and calculating levels.

Ultrasonic transducers are useful in the medical field for various purposes such as internal organ testing, cardiovascular disease, uterine and eye exams, cancer treatment, and diagnostic testing.

Ultrasonic transducers have limited significant applications in the industrial field. These transducers are useful for a variety of tasks, including wire break detection, liquid level control, production line management, vehicle detection, people counting, and many more. They can also be used to measure an object's distance in order to prevent a collision.

The benefits and drawbacks

Benefits

It is possible to measure in any kind of material with these ultrasonic transducers. All kinds of materials are sensed by them.

Dust, water, or any other element has no effect on the ultrasonic transducers.

The ultrasonic transducers demonstrate good performance in all types of environments.

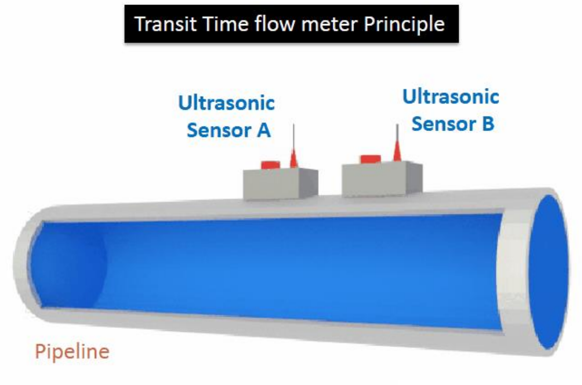
High sensing distances can also be measured by it.

Drawbacks:

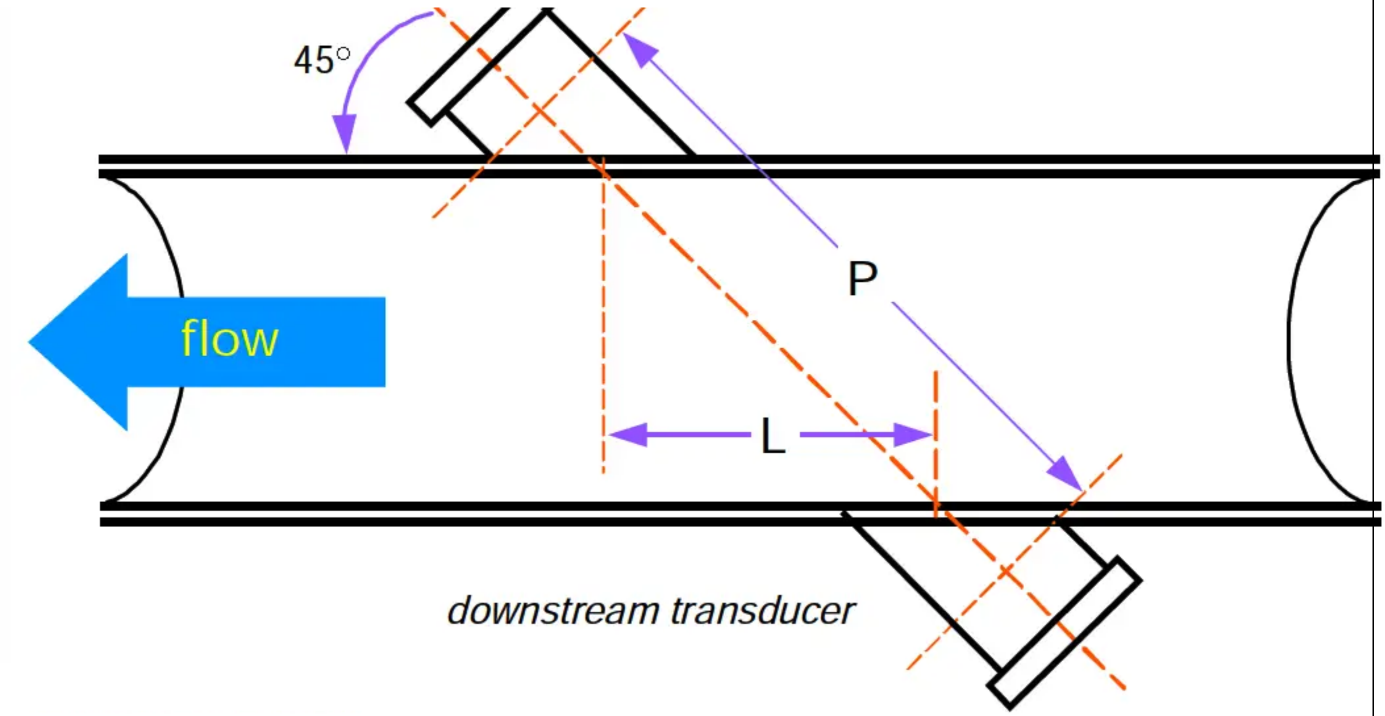
Temperature variations can affect ultrasonic transducers. The ultrasonic reaction could be altered by this temperature variation. It will also have trouble reading reflections from thin, soft, and small objects.

Ultrasonic Flow meter

An ultrasonic signal sent from one transducer to another, across a pipe, and back is measured in time by a transit time flow meter. We compare time measurements upstream and downstream. Both directions would have the same transit time in the absence of flow. Sound travels more quickly in the flow's direction and more slowly in the opposite direction.



Although extremely precise timing circuits are necessary, 1% accuracy is generally acceptable when the transducers are installed on a section of pipe with uniform flow.The fluid should not have a high concentration of solids or bubbles (less than 2%), as the ultrasonic signal needs to travel through the pipe to reach a transducer for reception.Should the high frequency sound be allowed to pass through the pipe unaltered, it will become too weak.Water/glycol solutions, hydraulic oil, fuel oils, chemicals, and drinkable water are a few examples of applications.Radio frequencies in the range of 1-2 MHz are usually used by transit time transducers. Generally, smaller pipes use higher frequency designs, while larger pipes with a diameter of several meters use lower frequencies.



Transducers installed on uniformly flowing sections of pipe can typically tolerate 1% accuracy, even with the requirement for extremely precise timing circuits.It is important that the fluid contain less than 2% of solids or bubbles because the ultrasonic signal must pass through the pipe to be received by a transducer.It will grow too weak if the high frequency sound is permitted to travel through the pipe unchanged.Some examples of applications are fuel oils, chemicals, drinkable water, hydraulic oil, and water/glycol solutions.Transit time transducers typically use radio frequencies between one and two megahertz. More than a few meters in diameter, larger pipes typically use lower frequencies, while smaller pipes typically use higher frequency designs.

$$v = \frac{KP^2}{2L}\left(\frac{1}{t_d} - \frac{1}{t_u}\right)$$

where, v = *measured velocity,*
L = *distance btw transducers*
P = *fluid path length diagonally from transducers*
t_u = *transit time upstream*
t_d = *transit time downstream*
K = *meter factor*

Single traverse Ultrasonic Flow meter
When two transducers are positioned across from one another on a pipe, the signal they transmit only once at a 45-degree angle through the fluid (figure 1). This is known as a single-traverse configuration.

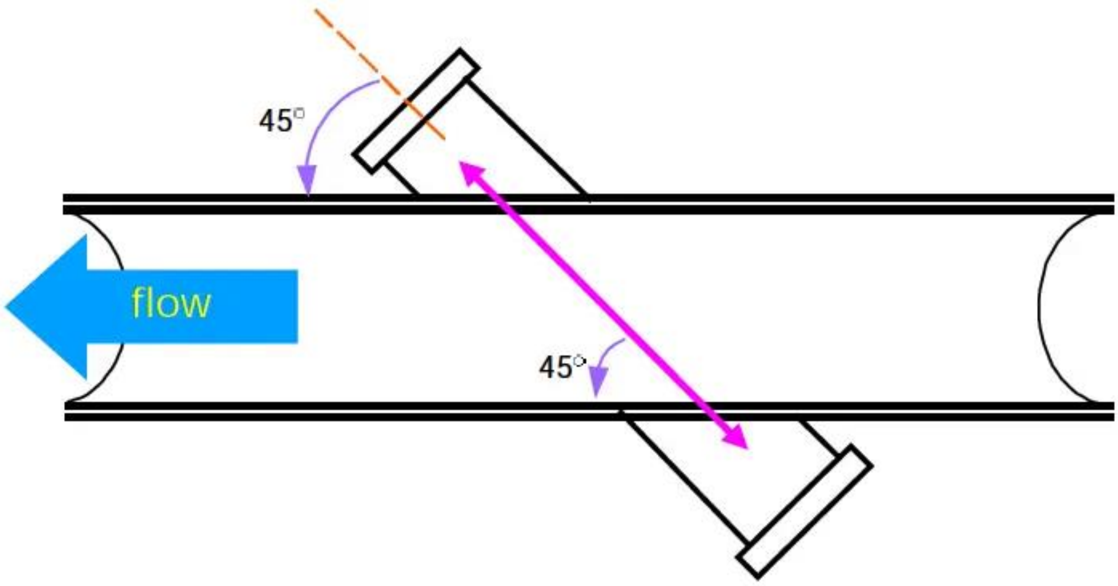
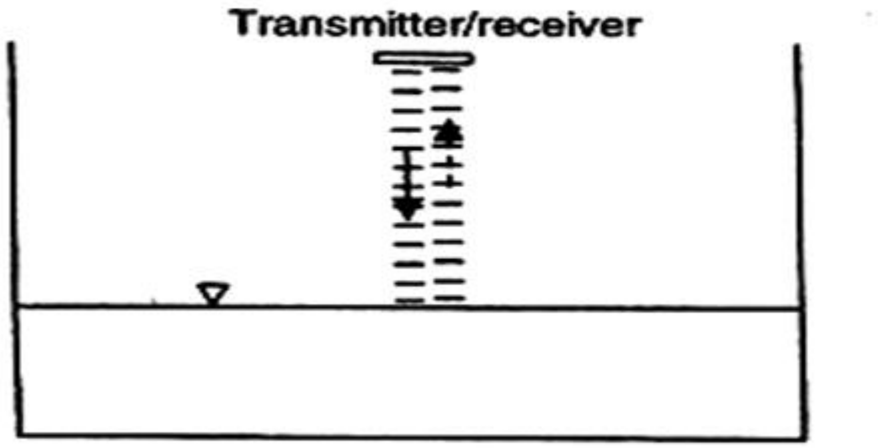
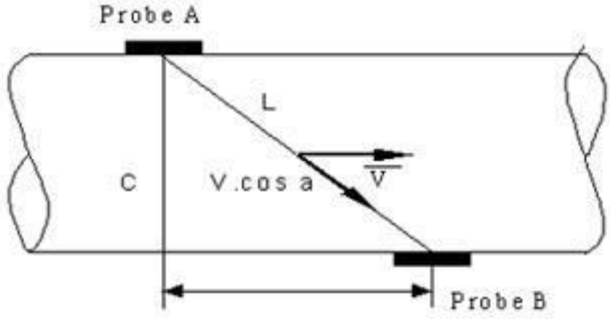


Figure 1 : Single-traverse Flowcell : L = pipe ID



The time interval between the emission and reception of a signal burst is measured by ultrasonic level sensors to determine the distance from the transducer to an impedance discontinuity.

The operating principle is: For measuring flow, the basic hardware needed is a flow meter, two probes, and an interconnection cable.



Probes A and B both function as "Trans-Receivers." The event is memorized when the electronic unit pulses probe A during the first cycle. Probe B acknowledges the acoustic beam's return to velocity and generates the "ECHO" signal. An electronic device memorizes time upon receiving the ECHO. The time of flight, or TAB (Time Taken to Travel from Probe A to Probe B), is calculated by an electronic device. The event is memorized when the electronic unit pulses Probe

B during the second cycle. Probe A recognizes the sound beam that enters against the direction of motion. The time of flight (TBA) is computed by an electronic device (Time taken to travel from Probe B to Probe A). The flow is calculated by an electronic device in the following way.

$$T_{AB} = \frac{L}{C + V\cos a}$$

$$T_{BA} = \frac{L}{C - V\cos a}$$

$$\frac{1}{T_{AB}} - \frac{1}{T_{BA}} = \frac{2V\cos a}{L} = \frac{2VD}{L^2}$$

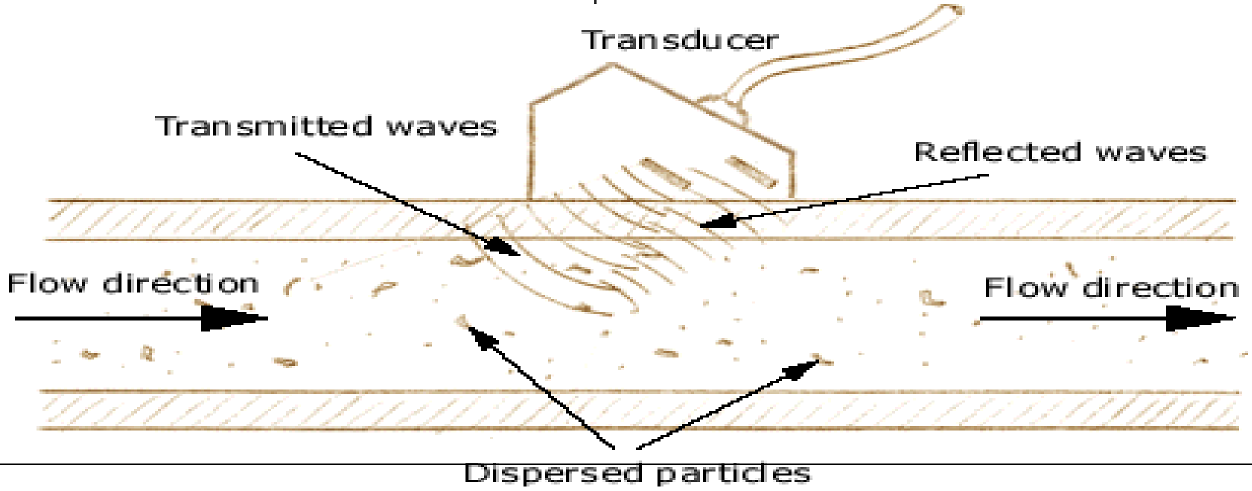
$$V = \frac{L^2}{2D}\left(\frac{1}{T_{AB}} - \frac{1}{T_{BA}}\right)$$

$$V = \frac{L^2}{2D}\left(\frac{\Delta T}{T_{AB} \times T_{BA}}\right)$$

The projected velocity V cos should be used in place of the velocity V because the transducer's input signal forms an angle with the direction of flow. The observed frequencies will be present in the acoustic waves moving upstream and downstream.

$$\begin{cases} f_u = \dfrac{f}{1 - \dfrac{V\cos\theta}{c}} \\ f_d = \dfrac{f}{1 + \dfrac{V\cos\theta}{c}} \end{cases}$$

Doppler ultrasonic flowmeters use the Doppler effect to connect the flow velocity to the frequency shifts of acoustic waves. In most cases, some particles in the flow are necessary for the signals to be reflected. As a general rule, for transducers operating at 1 MHz or higher, 25 PPM suspended solid or bubbles with a diameter of 30 microns or greater is recommended. Filter conditions may need to be "dirtier" for transducers operating at lower frequencies.



When an object moves toward an observer at a velocity V, the Doppler formula for that object is

$$f_{ref} = \frac{f}{1 - \frac{V}{c}}$$

$$\Delta f = f_u - f_d = \frac{2f\,\frac{V\cos\theta}{c}}{1 - \left(\frac{V\cos\theta}{c}\right)^2}$$

$$\approx 2f\,\frac{V\cos\theta}{c}$$

$$V = \frac{c\Delta f}{2f\cos\theta}$$

Temperature Sensors:

Temperature Indicators:

Temperature: A numerical representation of heat or cold. It can be detected by particle velocity, kinetic energy, heat radiation, or by observing how a thermometric material behaves in bulk.

Degrees Celsius (oC), Fahrenheit (oF), and Kelvin (oK) are the units of measure.

Unit of absolute Celsius is kelvin.

Use: Process Industries: Viscosity, level, flow, pressure, etc.

Ideal gas relations used to measure temperature.

$Pv = nRT$

P = Pressure
v = specific volume
n = amount of substance (No of moles)
R = Ideal or universal gas constant
T = temperature

$Q_{n+1}/Q_n = T_{n+1}/T_n$

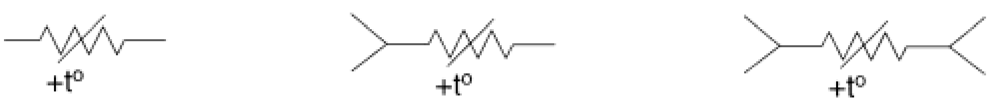
Q = heat
T = isotherm temperature

Based on range 4 instruments are recommended.

1) Gas thermometer
2) Platinum resistance thermometer
3) Platinum/Platinum-rhodium thermocouple
4) Radiation pyrometer.

Resistance temperature detector (RTD):

In essence, an etched grid on a substrate or a long, small diameter metal wire wound in a coil make up a resistance temperature detector, or RTD for short.
The most common metal used in RTDs is platinum.
The resistor is shown to change linearly by the straight line that crosses it diagonally.
The change is induced by temperature and has a positive coefficient, according to the label next to that line.



Connecting lead measurement errors are minimized by using three- and four-wire resistors (b, c diagrams).
The operation of RTDs is dependent upon the resistance of a conductor having a positive temperature coefficient.
Temperature has little effect on the quantity of electrons that can conduct electricity in a conductor.
However, as the temperature rises, the amplitude of the atoms' vibrations around their equilibrium positions increases.
The electrons become more dispersed as a result, which lowers their average speed.
As a result, resistance rises with rising temperatures. One way to express this relationship is as

$$R = R_0[1 + \alpha_1(T - T_0) + \alpha_2(T - T_0)^2 + \cdots + \alpha_n(T - T_0)^n]$$

where R_0 is the resistance at the reference temperature T_0.
At fixed-point temperatures, resistance measurements can be used to calculate the coefficients.
In the respective linear range of metals utilized as RTD probes, (1)and reduces to

$$R = R_0[1 + \alpha(T - T_0)]$$

Where ɑ, or temperature coefficient of resistance, is represented by ɑ, which is derived from resistance measurements made at two reference temperatures, such as 100 ^{0}C and 0 ^{0}C:

$$\alpha = \frac{R_{100} - R_0}{(100\,^\circ\mathrm{C})R_0}$$

ɑ is sometimes termed relative sensitivity

Construction of RTD:

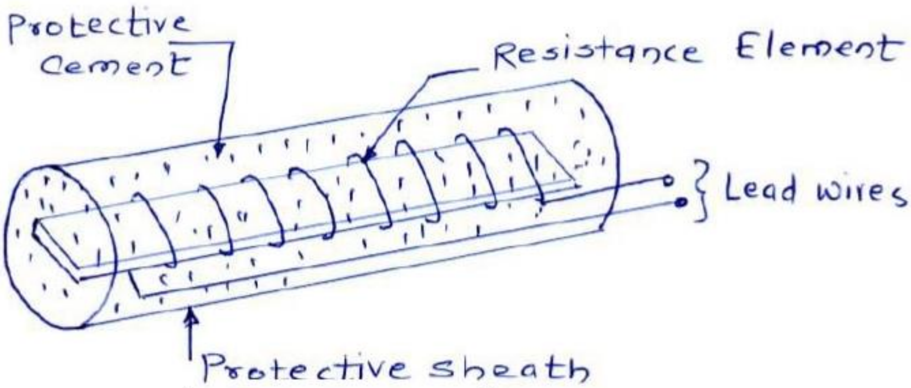


Fig: - RTD

Using resistance measurement, RTD functions as an electrical transducer, translating temperature changes into voltage signals.
Since they have low resistivities, gold and silver are rarely used to construct RTDs.
While it is suitable for high temperature applications, tungsten has a relatively high resistivity.
Occasional RTD element uses include copper. Although its low linearity and low cost make it an affordable alternative, its low resistivity forces the element to be longer than the platinum element. Approximately 120°C is its maximum temperature.
Brass, copper, and platinum are frequently found materials in RTD sensors.

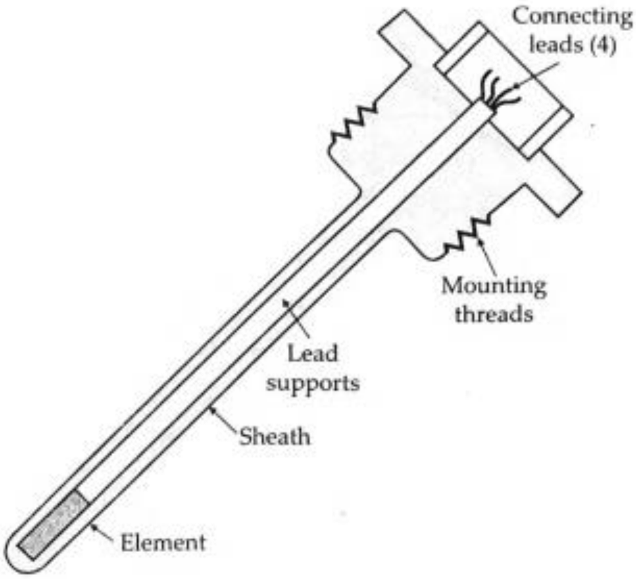
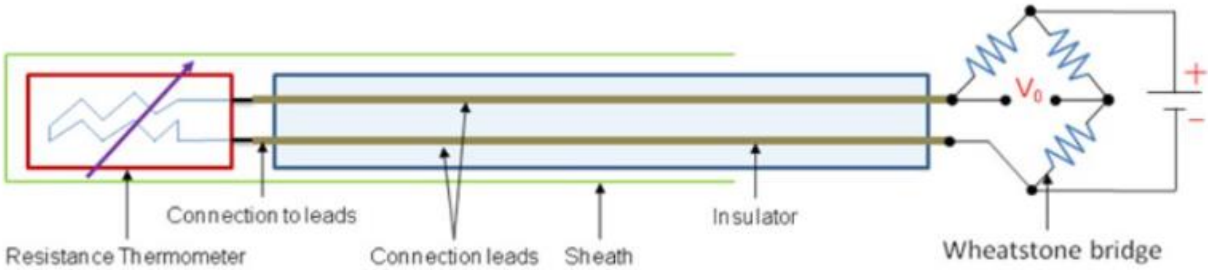


Fig. Industrial platinum resistance thermometer



The bridge's ratio arms are resistors R1 and R2. They use the ratio of the two variable resistances to calculate the ammeter's current flow. R3, sometimes referred to as the standard arm, is a variable resistor that can be tuned to match the unknown resistor.
The current flowing through the bridge circuit can be seen visually with the sensing ammeter. An examination of the circuit reveals that when R3 is set to zero current on the ammeter, the resistance of the bridge circuit's two arms is equal.

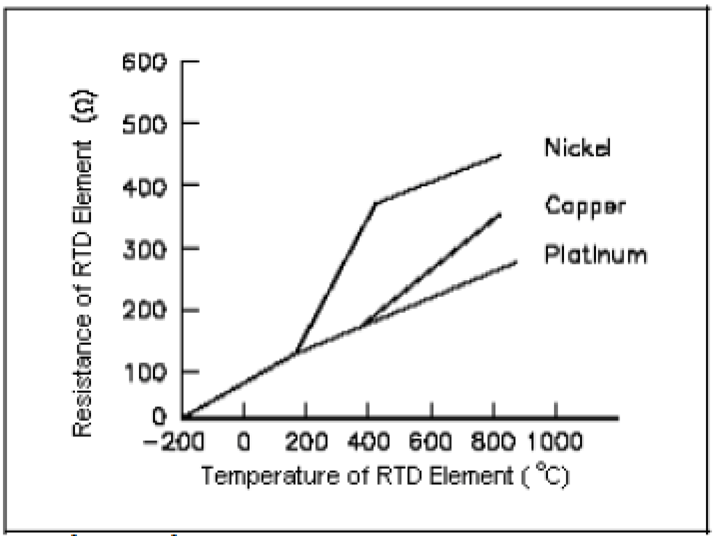
The resistance relationship between the bridge's two arms can be stated as $\frac{R_1}{R_3} = \frac{R_2}{R_x}$

Resistors R1 and R2 of the bridge are its ratio arms. To determine the ammeter's current flow, they use the ratio of the two variable resistances. R3 is a variable resistor that can be adjusted to match the unknown resistor. It is also known as the standard arm.
The detecting ammeter allows one to visually see the current flowing through the bridge circuit. Examining the circuit shows that the resistance of the two arms of the bridge circuit is equal when R3 is set to zero current on the ammeter.

The bridge's two arms' resistance relationship can be expressed as

$$R_x = \frac{R_2 R_3}{R_1}$$

Plotting the properties of different materials used to make resistance thermometers is what defines the characteristics of RTD.



Electrical Resistance-Temperature Curves

Advantages:

1. There is great accuracy in the measurement.
Moreover, controllers, recorders, and indicators can be used.
The same indicating/recording device can be equipped with multiple resistance elements.
4. Installation and replacement of the temperature-sensitive resistance element are simple tasks.
5. The measuring circuit's accuracy can be quickly verified by replacing the resistive element with a standard resistor.
6. It is possible to measure differential temperature using resistive elements.
7. Resistance thermometers can measure temperatures between −200°C and +650°C and have a broad working range without losing accuracy.
8. It takes between two to ten seconds for the resistive element to respond.
9. The resistive element can have dimensions of between 6 and 12 mm in diameter and 12 and 75 mm in length.
10. Highly precise temperature monitoring.
11. Performance stability over extended durations.

The Resistant Limits Temperature Measurement

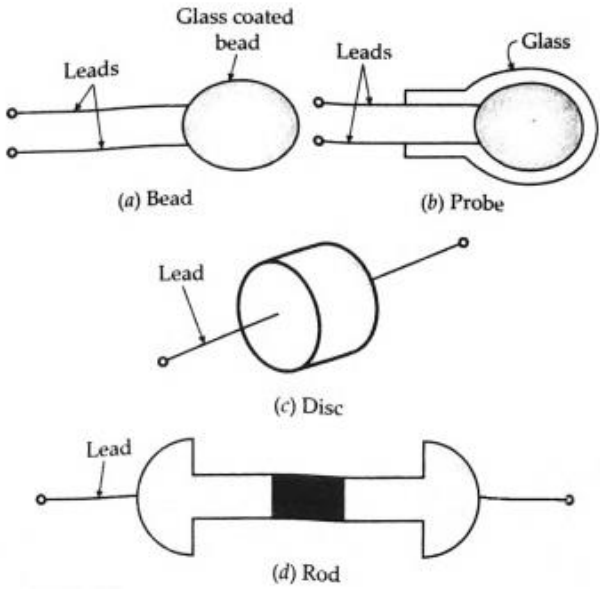
1. Expensive price
2. Requirement for power source and bridge circuit
3. The ability to heat oneself
4. Larger than a thermocouple bulb size

Thermistor:

A resistor whose electrical resistance fluctuates in response to temperature variations is called a thermistor, also known as a thermal resistor. As a passive transducer, thermoswitches function. When the temperature rises, the resistance of most thermistors decreases, exhibiting a negative coefficient of temperature resistance. These make temperature measurements reliable, affordable, and accurate. For every 1°C increase in temperature, the resistance of a thermistor at room temperature can drop by as much as 5%. Applications involving measurements between - 60°C and 15°C frequently use thermocouples. A thermocouple's resistance can be anywhere between 0.5 and 0.75 MΩ. One very sensitive device is the thermocouple.

Construction of Thermistor:

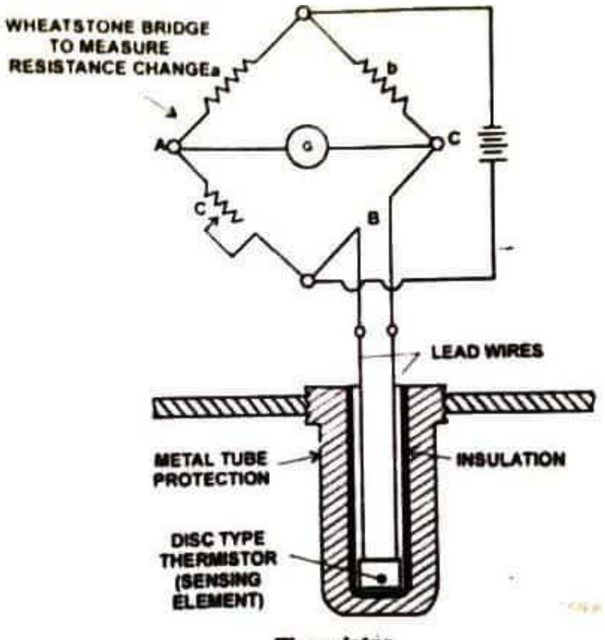
Thermistor oxides are composed of metals like copper, uranium, nickel, manganese, and cobalt. It comes in a range of sizes and shapes. Rod type, Bead type, and Disk type are frequently used configurations.



When more power dissipation is needed, the rod type and disc type thermistors are utilized. A high power handling capacity is possessed by the rod type thermistor. Bead type thermistors are the smallest thermistors in these configurations. It only has a 0.15 mm diameter. Usually, a glass probe contains the measurement element. Glass probes come in a range of lengths from 6 to 50 mm, with a diameter of roughly 2.5 mm. It is frequently employed to determine the temperature of liquids. Solid glass rods can be sealed with beads to create probes that might be simpler to mount than beads alone. Materials with diameters ranging from 2.5 mm to 25 mm are compressed under intense pressure into cylindrical, flat forms to create discs.

Fundamental Thermistors Operation:

Thermistors operate on the straightforward theory that a temperature change will alter their resistance. As the temperature of these thermistors varies, their resistance will also change. This means that the applied temperature can be found by measuring the change in resistance value. The thermistor begins to self-heat its components when the outside temperature changes. By using a Wheatstone bridge circuit, one can determine how temperature variations affect resistance. It is possible to determine temperature by measuring the resistance value because resistance varies in response to temperature changes. Utilizing a wheat stone bridge, the initial resistance of the thermistor sensing element is measured after a known constant current is run through it. The medium whose temperature needs to be measured now has a thermistor added to it. The temperature changes (declines) and causes a change in the sensing element. Assume the temperature change is positive. Keep in mind that during the measurement process, the sensing element receives the same steady current. Nowadays, the wheat stone bridge is used to measure this change in the thermistor's sensing element's resistance. With calibration, this variation in resistance turns into a temperature indicator.



Thermistor

Resistance-Temperature Characteristics of Thermistors:

The following is the formula that describes the relationship between a thermistor's resistance and its absolute temperature:

$$R_{T1} = R_{T2} \exp\left[\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$

where the thermistor's resistance at absolute temperature T1; °K is represented by RT1. The constant β depends on the thermistor material and ranges from 3500 to 4500 °K. RT2 denotes the thermistor's resistance at absolute temperature T2 in °K.

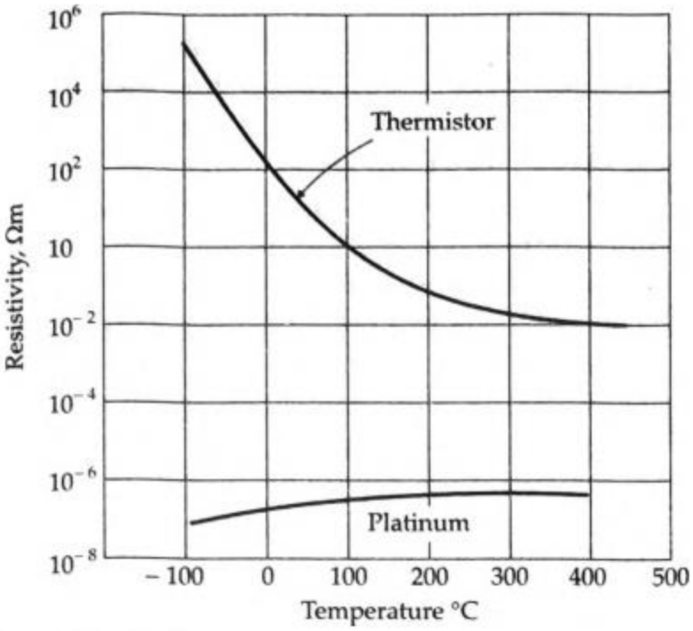


Fig. Resistance-temperature characteristics of a typical thermistor and platinum

Thermistor Types:

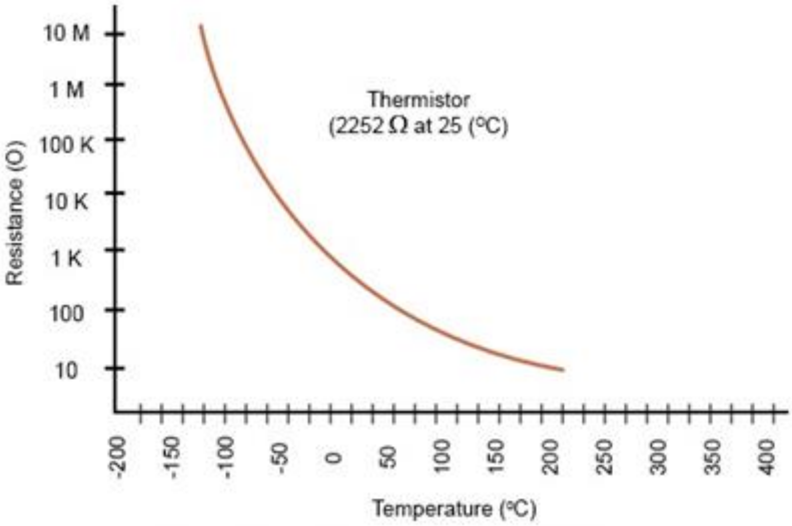
• A temperature increase causes the resistance to increase if the temperature coefficient of resistance (k) has a positive value.

Positive Temperature Coefficient Thermistor, or Posistor, is another name for this kind of device (PTC).

• The term "negative temperature coefficient resistor" (NTC) refers to a device in which a rise in temperature results in a decrease in the resistance value since the value of k is negative.

NTC Thermistor

• Resistance falls in an NTC thermistor as temperature rises. Resistance also rises with a drop in temperature. Temperature and resistance are therefore inversely proportional in an NTC thermistor. The most prevalent kind of thermistor is this one.



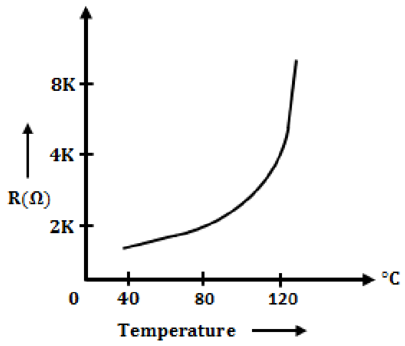
Thermistor Characteristic NTC Curve

Where temperature resistance is represented by RT. T. (K)
Resistance at temperature is denoted by R0. T0 (K)
T0 is the standard temperature, which is typically 25 oC.
β is a constant, and the properties of the material determine its value. We take 4000 as the nominal value.

• The temperature range between -55°C and 200°C is where an NTC thermistor typically provides the most accurate readings. On the other hand, some specifically made NTC thermistors are used at -273.15°C, or absolute zero, and some can be used above that temperature.

Positive Temperature Coefficient or PTC Thermistor:

• This kind of thermistors responds better to heat; that is, they have a positive temperature coefficient. The illustration below depicts it.



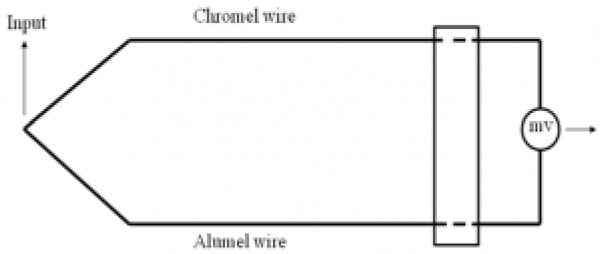
Resistance Temperature Characteristics of PTC Thermistor

PTC thermistors are primarily used as protective elements in electric machinery for the protection of windings in transformers, motors, and other electrical equipment. They are typically made of titanates of barium, lead, and strontium.
The PTC thermistor resistance increases sharply when an electrical apparatus overheats, and they are used as a device to prevent overheating in various types of apparatus. The equipment is unplugged from the supply and the relay coil is de-energized.

Thermistors' benefits

• Cheaper.
• Sensitiver than alternative sensors.
• Quick reaction.
• Tiny in dimensions.

Thermistors' shortcomings
• Strict temperature tolerance.
• There is nonlinear correlation between resistance and temperature ratio.
• The self-heating effect could result in an inaccurate measurement.
• Easily damaged.
Utilizations
• Temperature readings are taken using NTC thermistors, typically over small temperature ranges.
• The gadget has the ability to restrict the abrupt overcurrent that flows through supply circuits.
• The temperature of incubators is measured with this apparatus.
• While batteries are being stored for charging, NTC thermistors are used to measure and monitor them.
• They are employed to monitor the coolant and oil temperatures inside automobile engines.
Thermocouples:
Any type of temperature sensor that measures the temperature at a single point in the form of an electric current or electromagnetic field is known as a thermocouple. Two distinct metal wires are connected at a single junction to form this sensor. This junction allows for the measurement of temperature, and voltages are stimulated by changes in the metal wire's temperature.



Very sensitive devices must be used to calculate the amount of electromagnetic field (EMF) produced in the circuit because the amount generated in the device is extremely small (millivolts). Common tools for determining the e.m.f. are the standard galvanometer and the voltage balancing potentiometer. A mechanical or physical balancing potentiometer is made from these two.

Principle of Thermocouple Operation

The three effects—Seebeck, Peltier, and Thompson—are the primary foundation of the thermocouple principle.

Refer to the Beck effect

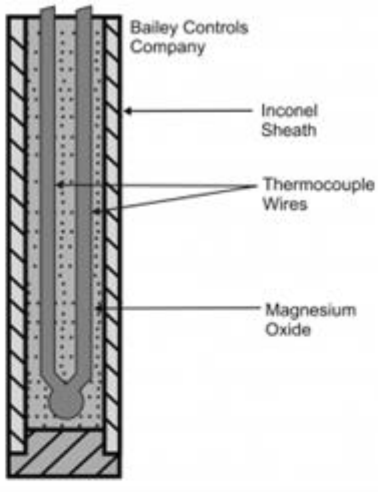
This kind of effect happens between two different metals. The flow of electrons from hot to cold metal wire occurs when heat is applied to any one of the metal wires. Direct current thus stimulates the circuit.

In contrast to the Seebeck effect is the Peltier effect. This phenomenon indicates that any two dissimilar conductors can develop a temperature difference by introducing a potential variation between them.

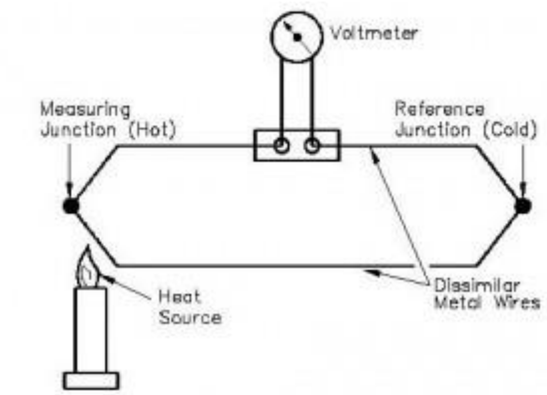
Thompson effect

According to this effect, the voltage causes the entire conductor's length because of the temperature gradient as two different metals fix together and, if they form two joints. The rate and direction of temperature change at a specific location are shown physically by this word.
Construction of Thermocouple:

The construction of the device is shown below. It comprises two different metal wires and that are connected together at the junction end. The junction thinks as the measuring end. The end of the junction is classified into three type’s namely ungrounded, grounded, and exposed junction.



Working of thermocouple:
The device's construction is displayed below. It is made up of two distinct metal wires that are joined at the junction end. The junction serves as the endpoint for measurement. There are three types of junction ends: exposed, grounded, and ungrounded.



There will be no current flow through the circuit if the temperature at the junction end becomes equivalent. This will result in the production of both the equivalent and reverse electromagnetic force. The circuit experiences a potential variation when the temperature at the junction end becomes unbalanced.

Which kind of material is used to make the thermocouple affects how much of an electromagnetic force is induced in the circuit. The measurement tools calculate the total current flow across the circuit. Equation (1) computes the electromagnetic force induced in the circuit.

E is equal to a (∆) + b (∆).Two

If a and b are constants, then ∆ is the temperature difference between the hot thermocouple junction end and the reference thermocouple junction end.

Kinds of Thermocouples

Form K: Another name for this kind of thermocouple is Nickel-Chromium/Nickel-Alumel. It's the type that's most commonly used. It can function over a wider temperature range and has the qualities of improved precision, affordability, and dependability.

These are the temperature ranges:

Thermocouple grade wire: -2700C to 12600C (-454F to 2300F)

Wire extension (00C to 2000C)

The accuracy level of this K-type is

Normal limits are +/- 2.2C, or +/-0.75%, and exceptional limits are +/- 1.1C, or 0.4%.

Type J: This is an iron/constantan mixture. This kind of thermocouple is also the most popular. Its qualities include increased precision, affordability, and dependability. When used in a wide range of temperatures, this device has a limited operating temperature range and a short lifespan.

These are the temperature ranges:

-346F to 1400F (-2100C to 7600C) is the thermocouple grade wire.

Wire extension (00C to 2000C)

The accuracy level of this J-type is Standard +/- 2.2C, or +/-0.75%, and the special limits are +/- 1.1C, or 0.4%.

Type T: A mixture of copper and constantan. The T type thermocouple is more stable and is typically used in lower temperature applications, such as cryogenics and ultra-low temperature freezers.

These are the temperature ranges:

-454F to 700F (-2700C to 3700C) is the thermocouple grade wire.

Wire extension (00C to 2000C)

The accuracy level of this T-type is Standard +/- 1.0C, or +/-0.75%, with special limits of +/- 0.5C, or 0.4%.

Type E: This is a nickel-chromium/constantan mixture. Operating at ≤ 1000F, it exhibits superior signal ability and accuracy over Type K and J thermocouples as well.

These are the temperature ranges:

Thermocouple grade wire: -2700C to 8700C (-454F to 1600F).

Wire extension (00C to 2000C)

Standard +/- 1.7C or +/-0.5% is the accuracy level for this T-type, and the special limits are +/- 1.0C or 0.4%.

Type N: This thermocouple is also referred to as a Nisil thermocouple. Type N is comparable to type K in terms of temperature and precision levels. However, type K is less expensive than this type.

These are the temperature ranges:

-454F to 2300F (-2700C to 3920C) is the thermocouple grade wire.

Wire extension (00C to 2000C)

The accuracy level of this T-type is Standard +/- 2.2C, or +/-0.75%, and the special limits are +/- 1.1C, or 0.4%.

Type S: This type of thermocouple is classified as 10%/Platinum or Platinum/Rhodium. High-temperature range applications, like those found in biotech and pharmacy companies, heavily utilize the S type of thermocouple. Its greater precision and stability even lead to its use in applications with a smaller temperature range.

Those are the temperature ranges:
Wire of thermocouple grade: -58°F to 2700°F (-500°C to 14800°C).
00C to 2000C extension wire
Special limits are +/- 0.6C or 0.1%, and the accuracy level for this T-type is Standard +/- 1.5C or +/-0.25%.

The Type R thermocouple is classified as either platinum/rhodium or 13%/platinum. Applications involving a high temperature range make extensive use of the S type thermocouple. Compared to Type S, this type has more rhodium, which increases the device's cost. Type R and S perform and have features that are almost identical. Since it is more accurate and stable, it is even utilized for applications with a smaller temperature range.

These are the temperature ranges:

-58F to 2700F (-500C to 14800C) is the thermocouple grade wire.
Wire extension (00C to 2000C)
Standard +/- 1.5C, or +/-0.25%, is the accuracy level for this T-type; special limits are +/- 0.6C, or 0.1%.

Type B – The percentage of Platinum Rhodium thermocouple that it makes up is either 30% or 60%. The higher temperature range of applications makes extensive use of this. Type B is the one with the highest temperature limit among all the types mentioned above. The type B thermocouple will exhibit greater accuracy and stability at the raised temperature levels.

Those are the temperature ranges:

32°F to 3100°F (00°C to 17000°C) is the thermocouple grade wire.
00C to 1000C extension wire
An accuracy level of Standard +/- 0.5% is maintained by this type T.
Noble metal thermocouples fall into three categories: S, R, and B. Their long lifespan and excellent accuracy make them the preferred option, even at high temperatures.

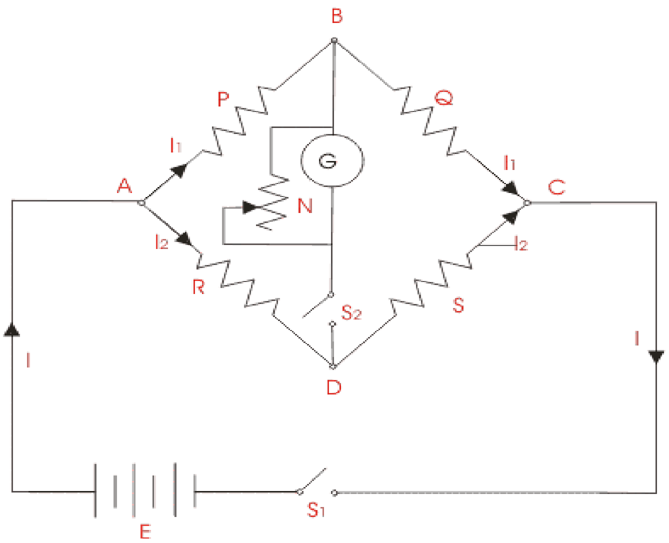
MODULE - III

BRIDGES

Medium Resistance measurement:

Wheatstone bridge:

Wheatstone bridge is widely used to measure electrical resistance accurately. As seen below, a bridge-like connection is made up of two known resistors, one variable resistor, and one unknown resistor. The variable resistor can be adjusted to zero current through the galvanometer. The ratio of two known resistors and the ratio of the adjusted value of variable resistance and the value of unknown resistance are exactly equal when the current through the galvanometer is zero. Using a Wheatstone bridge, the value of an unknown electrical resistance can be readily determined in this manner.



Wheatstone Bridge

Working:

The figure below depicts the general layout of a Wheatstone bridge circuit. This circuit is a four-arm bridge, with electrical resistancesP,Q,S, and R in arms AB, BC, CD, and AD, respectively.

P and Q, two of these resistances, are known to be fixedelectrical resistances; together, these twoarms are called ratioarms. Through switch S2, a precise and sensitivegalvanometer is linked to terminalsB andD. As indicated, a switch S1 connects the voltagesource of this Wheatstonebridge toterminals A and C. Between point C and point D is connected a variable resistor S. By changing the value of the variable resistor, the potential at pointD can be changed. Assume that currentsI1 andI2 are moving via, respectively, the paths ABC and ADC. Since the voltage across A and C is fixed, changing the electrical resistance value of arm CD will also change the value of current I2. One scenario where voltagedrop across resistorS, or I2, could occur if we keep adjusting the variable resistance. S becomes precisely equal to I1.Q, the voltagedrop acrossresistor Q. As a result, the potential difference between these two points is zero, meaning that the current flowing through the galvanometer is zero and the potential at point B equals the potentialat pointD. When the switch S2 is closed, the galvanometer's deflection is zero.

Now, from the circuit of Wheatstone Bridge

$$\boxed{\text{current } I_1 = \frac{V}{P+Q}}$$

and

$$\boxed{\text{current } I_2 = \frac{V}{R+S}}$$

The voltagedropacross the resistorQ isthe only thing that represents the potentialof pointB with respect to point C.

$$I_1.Q = \frac{V.Q}{P+Q} \text{-------------------(i)}$$

Once more, the voltagedrop acrossresistor S is the only thing that determines the potential of point D with respect to point C.

$$I_2.S = \frac{V.S}{R+S} \text{-------------------(ii)}$$

When we solve equations (i) and (ii), we obtain,

$$\frac{V.Q}{P+Q} = \frac{V.S}{R+S} \Rightarrow \frac{Q}{P+Q} = \frac{S}{R+S}$$
$$\Rightarrow \frac{P+Q}{Q} = \frac{R+S}{S} \Rightarrow \frac{P}{Q} + 1 = \frac{R}{S} + 1 \Rightarrow \frac{P}{Q} = \frac{R}{S}$$
$$\Rightarrow R = SX\frac{P}{Q}$$

Since the values of S and P/Q in the equation above are known, figuring out the value of R is simple.

Ratio arms and S, the electrical resistances P and Q of the Wheatstone bridge, are composed of specific ratios like 1:1, 10:1, or 100:1. One can continuously adjust the rheostat arm between 1 and 1,000 Ω or between 1 and 10,000 Ω.

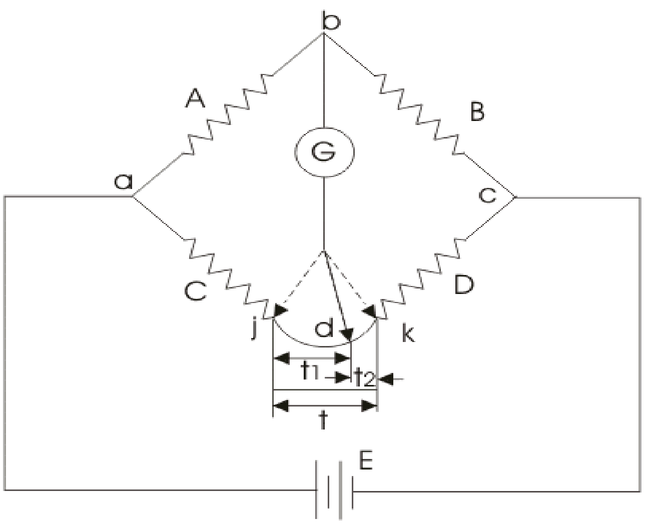
Kelvin Bridge:

High accuracy is offered by the Kelvin Bridge, a modified Wheatstone bridge. The question that now needs to be asking itself is: Where do we need the modifications? The simple answer to this is that there is an increase in net resistance because of the parts of the leads and contacts that need to be modified.

Let's examine the modified circuit for the Kelvin or Wheatstone bridges shown below: Here, t represents the lead's resistance.

The resistance that is unknown is C.

The standard resistance, or D, has a known value.



Now let's mark points j and k. The resistance t is added to D when the galvanometer is connected to the j point, resulting in an excessively low value of C. Now that the galvanometer is connected to the k point, the resistance C, which is unknown, will be high.

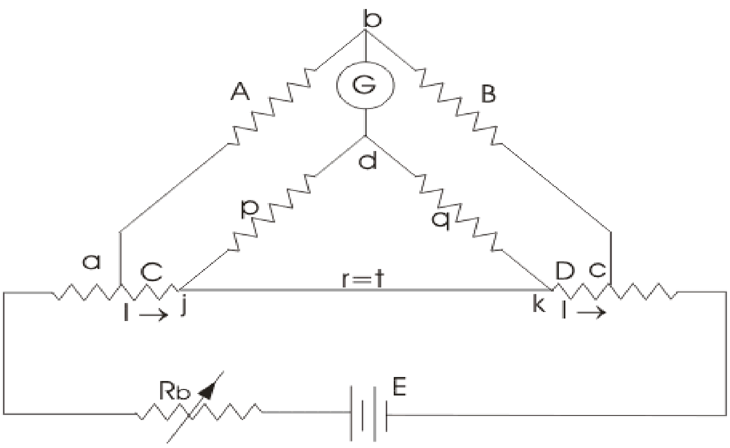
As we can see from the above figure, if we connect the galvanometer to point d, which is located between j and k and divides t into the ratios t1 and t2, there will be no error.

Low resolution measurement:

Kelvin Double Bridge:

The second set of ratio arms is incorporated, as indicated below:

To counteract the effect of theconnecting leadof electricalresistancet, the galvanometer is connected at the proper point between j and k using the ratio arms p and q. Voltagedrop between aandb, orE, is equal to F (voltage drop between aandc) under the balance condition.
E = F for a zero galvanometer deflection. We arrive at the same conclusion once more: t is ineffective. Equation (2), however, is helpful since it provides error when:



$$or\ \frac{A}{A+B} \times I\left(C + D + \frac{p+q}{p+q+t} \times t\right) = I \times \left(C + \frac{p}{p+q+t} \times t\right)$$

$$\Rightarrow C = \frac{A}{B} \times D + \frac{q}{p+q+t}\left(\frac{P}{Q} - \frac{p}{q}\right) \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

$$If\ \frac{A}{B} = \frac{p}{q}\ then\ C = \frac{A}{B} \times D$$

High resistance measurement:

Direct Deflection Method:

The HighResistanceMeasurement using the DirectDeflectionMethod is a technique employed to measure the electrical resistance of high-resistance components or materials. This method is particularly useful when dealing with resistances that are beyond the range of typical ohmmeters. Here's a simplified explanation of the Direct Deflection Method:

Components:

Voltage Source:

A stable and known voltage source is connected to the resistor under test.

Amplifier:

An amplifier is utilized to amplify the small current passing through the high-resistance element.

Sensitive Galvanometer:

A sensitive galvanometer, with a high resistance, is connected in parallel to the resistor being measured. The galvanometer provides a direct deflection proportional to the current passing through it.

Calibrated Scale:

The galvanometer is associated with a calibrated scale, allowing the user to read the deflection in terms of resistance.

Operation:

Application of Voltage:

The known voltage is applied across the high-resistance component.

Current Flow:

Due to the applied voltage, a smallcurrent flowsthrough the high-resistancematerial.

Galvanometer Deflection:

The current passing through the resistor causes a deflection in the sensitive galvanometer. Thedeflection isproportional to theresistance of thehigh-resistance component.

Calibration:

The scale associated with the galvanometer is calibrated so that the deflection can be directly read as resistance.

Reading:

The user reads the calibrated scale to determine the resistance of the high-resistance element.

Advantages:

Suitability for High Resistances:

This method is particularly useful for measuring resistances that are beyond the measurement range of standard ohmmeters.

Direct Deflection:

The deflection of the galvanometer provides a direct indication of the resistance, simplifying the measurement process.

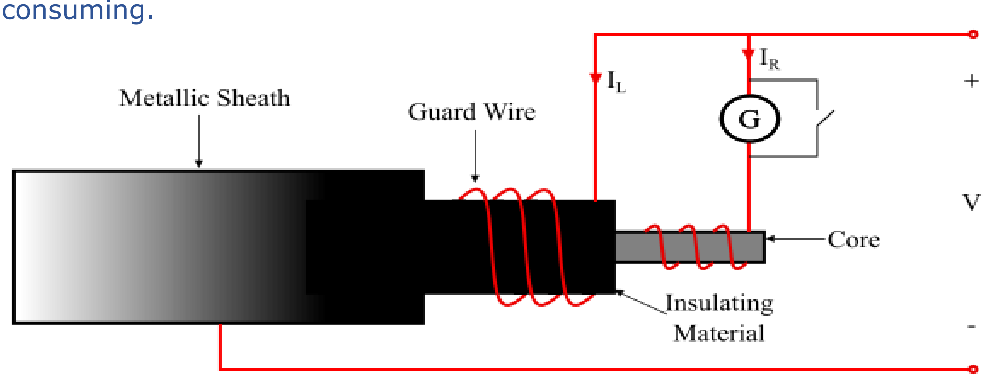
Limitations:

Sensitivity:

The accuracy ofthis methoddepends on the sensitivityof thegalvanometer and the stability of the voltage source.

Time-Consuming:

Compared to modern electronic methods, the Direct Deflection Method may be relatively time-consuming.

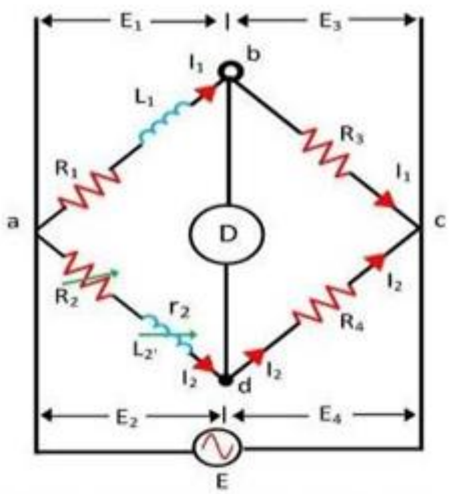


As seen in the figure, the currentIR between theconductor core and the metal sheath is measured by the galvanometer (G). The guard wire wound on the insulation carries the leakage current (IL) over the insulating material's surface; the IL does not pass through the galvanometer. Consequently, R=V/Ir represents the cable's resistance.

Measurement of inductance:

Maxwell's Bridge:

Definition: The Maxwell bridge is the type of bridge used to measure the circuit's self-inductance. This is the wheatstone bridge in its enhanced form. The Maxwell bridge operates on the comparison principle, which states that an unknown inductance's value can be ascertained by comparing it to a known or standard value. By comparing the unknown resistance in these kinds of bridges to the known value of the standard self-inductance, the resistance's value can be ascertained. The figure below displays the connection diagram for the balancing Maxwell bridge.



Maxwell's Inductance Bridge

Let L1 be the resistance's unknown inductance. R1. L2: Variable resistance with fixed inductance r1.

Inductor L2 isconnected in serieswith variable resistanceR2. The non-inductance resistance is known as R3, R4.

$$L_1 = \frac{R_3}{R_4} L_2$$

At balance,

$$R_1 = \frac{R_3}{R_4}(R_2 + r_2)$$

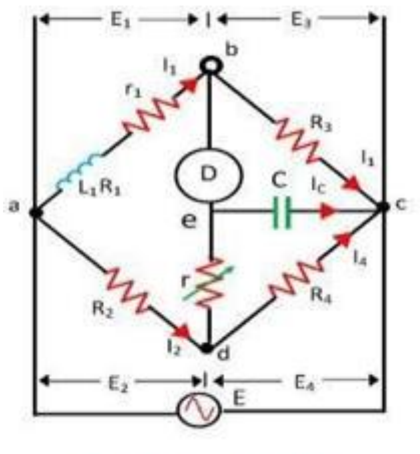
With the aid of the resistance box, the resistance values of the R3 and R4 range from 10 to 1000 ohms. Sometimes more resistance is added to the circuit in order to balance the bridge.

Anderson’s Bridge:

Definition: The circuit's self-inductance can be accurately measured using the Anderson's bridge. The bridge is an improved version of the inductance-capacitance bridge developed by Maxwell. The standard fixed capacitance that connects the two arms of the Anderson bridge is compared to the unknown inductance.

Constructions of Anderson’s Bridge:

There are four arms on the bridge: ab,bc,cd, andad. The resistance and unknown inductance make up the arm ab. The threeremaining arms are made up of purely resistive arms that are linked in series with the circuit. Together with the CD arm, the variableresistor and static capacitor areconnected inseries. The terminals aandc receive the voltage source.



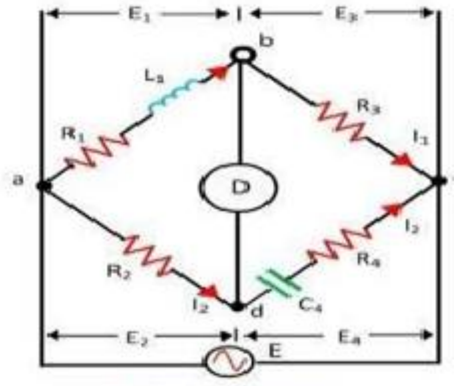
Anderson's Bridge

Hay’s Bridge:

Definition: In the arm ad, current I2 is the result of adding current IC and I4. The pointa,d, and e as well as the emf across the arm ab are equal when the bridge is in balance. There will be voltage dropsacross thearm ab due to the phasor sum of the voltage across the arms ac and de.

Construction of Hay’s Bridge:

The resistance R1 and the unidentified inductor L1 are positioned in arm ab. The standard capacitorC4, which is connectedacross the armCD, is compared to this unknown inductor. The capacitorC4 and resistance R4 are connected in series. The armsad andbc, respectively, are connected to the remaining two non-inductive resistors, R2 and R3. In order to create a balanced bridge, the C4 and R4 are adjusted. No current passesthrough thedetector, which is connected to pointsb andc, respectively, when the bridge is in a balanced state. Similar to how the potentialdropsacross the arms adand cdareequal, so too are they across the arms ab and bc.



Hay's Bridge

Measurement of capacitance:

Schering Bridge:

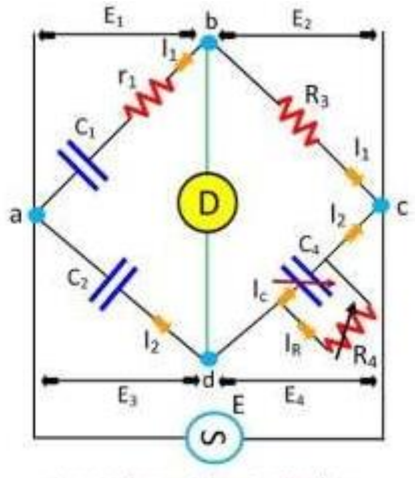
The bridge circuit typically consists of known resistors, capacitors, and an inductor, along with the unknown capacitor (the one being measured) and the unknown resistance (representing the dielectric loss). By adjusting the values of the known components until the bridge is balanced, one can determine the capacitance and dissipation factor (a measure of dielectric loss) of the unknown capacitor.

Let's The capacitor C1, whose capacitance needs to be calculated, and the series resistance r1, which stands for the capacitor's loss, C1.

Thecapacitor C2is a standardcapacitor, which implies that it has no loss. A noninductive resistanceis R3.

A variablecapacitor is C4.

Parallel to the variable capacitor C4 is a variable non-inductive resistance, R4.



Low Voltage Schering Bridge

$$\left(r_1 + \frac{1}{jwC_1}\right)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = \frac{1}{j\omega C_2} . R_3$$

$$\left(r_1 + \frac{1}{jwC_1}\right)R_4 = \frac{R_3}{jwC_2}(1 + j\omega C_4 R_4)$$

$$r_1 R_4 - \frac{jR_4}{\omega C_1} = -j\frac{R_3}{\omega C_1} + \frac{R_3 R_4 C_4}{C_2}$$

Zero current flows through the detector when the bridge is in the balanced state, indicating that there is zero potential across the detector. Under equilibrium, Z1/Z2 = Z3/Z4 and Z1Z4 = Z2Z3.

$$r_1 = \frac{R_3 C_4}{C_2} \dots\dots\dots . equ(1)$$

$$C_1 = C_2\left({}^{R_4}/_{R_3}\right) \dots\dots\dots equ(2)$$

,

Thus, when comparing real and imaginary equations, equations (1) and (2) are obtained, which are balanced and frequent. A phasor diagram is used to determine the dissipation factor. The rate of energy loss due to vibration in electronic and mechanical instruments is determined by the dissipation factor.

De sauty's bridge:

If we ignore dielectric losses in the bridge circuit, this bridge gives us the best way to compare the two values of the capacitor. Below is a diagram of De Sauty's bridge.

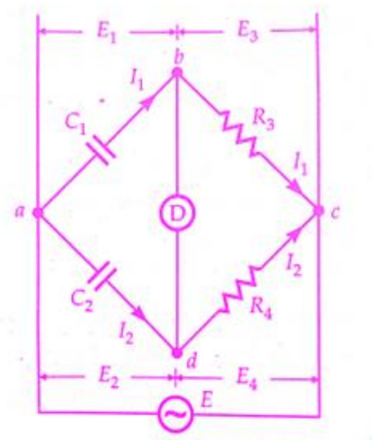
Between terminals 1 and 4, battery is applied. Arms 1-2 and 3-4 are made up of the capacitor c1, whose value is unknown, which carries current i1, as shown; arm 4-1 is made up of a standard capacitor, the value of which is already known; and arm 2-4 is made up of a pure resistor, which we assume to be non-inductive in nature. Let's find the expression for capacitor c1 using resistors and a standard capacitor.

It implies that the value of capacitor is given by the expression

$$\frac{1}{j\omega c_1} \times r_4 = \frac{1}{j\omega c_2} \times r_3$$

$$c_1 = c_2 \times \frac{r_4}{r_3}$$

We must change the values of either r3 or r4 without affecting any other bridge element in order to determine the balance point. This is the most effective way to compare the two capacitor values if all of the circuit's dielectric losses are disregarded.



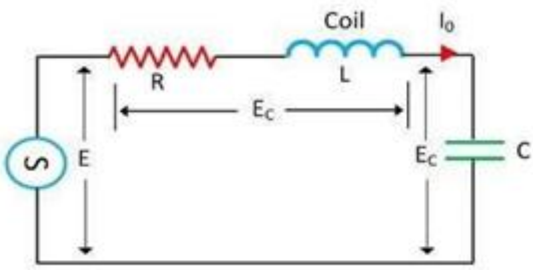
(a)

Definition of Q Meter: A Qmeter is a type of instrument that measures the electrical circuit's quality factor or storage factor at radio frequencies. One of the oscillatory system's parameters that illustrate the relationship between stored and dissipated energy is the quality factor.

The circuit's quality factor, which displays the total energy dissipated by it, is measured by the Q meter. The characteristics of the coil and capacitor are also explained. In a lab, the Q meter is used tomeasure the radiofrequency of thecoils.

Working Principle of Q meter:

The Qmeter is series resonant in operation. When the circuit's capacitance and inductance reactance have equal magnitudes, a state known as resonance occurs. They create an oscillating electric and magnetic field in the inductor and capacitor, respectively.
The resistance,inductance, andcapacitance characteristics of the resonant series circuit serve as the foundation for the Q-meter. A coil ofresistance,inductance,and capacitanceconnected inseries with the circuit is depicted in the figure below.



Resonant RLC Series Circuit

At frequency of resonance f0,

Capacitivereactance is equalto inductivereactance.

Capacitance reactance's value is

$$X_c = \frac{1}{2}\pi f_0 C = \frac{1}{\omega_0 C}$$

Inductive reactance at,

$$X_L = \frac{1}{2}\pi f_0 L = \frac{1}{\omega_0 L}$$

When the frequency resonant,

$$f_0 \frac{1}{2\pi\sqrt{LC}}$$

and at resonance, current turns into

$$I_0 = \frac{E}{R}$$

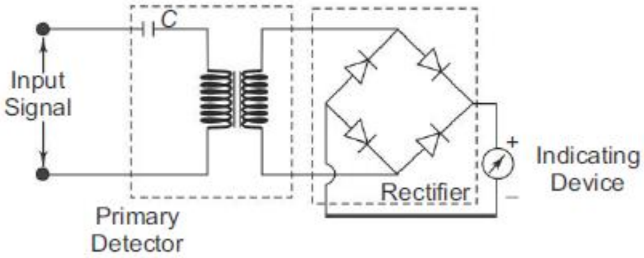
Module-4
SIGNAL ANALYZERS AND OSCILLOSCOPES

WAVE ANALYZERS:

Analyzing the relative amplitudes of individual frequency components within a complex waveform is the purpose of a wave analyzer. The amplitude, frequency, and phase angle of the harmonic components can all be determined by analyzing the waveform. Within the audible frequency range (20Hz to 20 KHz), the wave analyzer's extremely narrow pass-band filter portion can be set to a specific frequency.

BASIC WAVE ANALYZER:

A rudimentary wave analyzer is depicted in the following figure. The primary detector is a basic LC circuit that makes up this setup. For the purpose of measuring a certain harmonic component, the resonance frequency of this LC circuit is set.

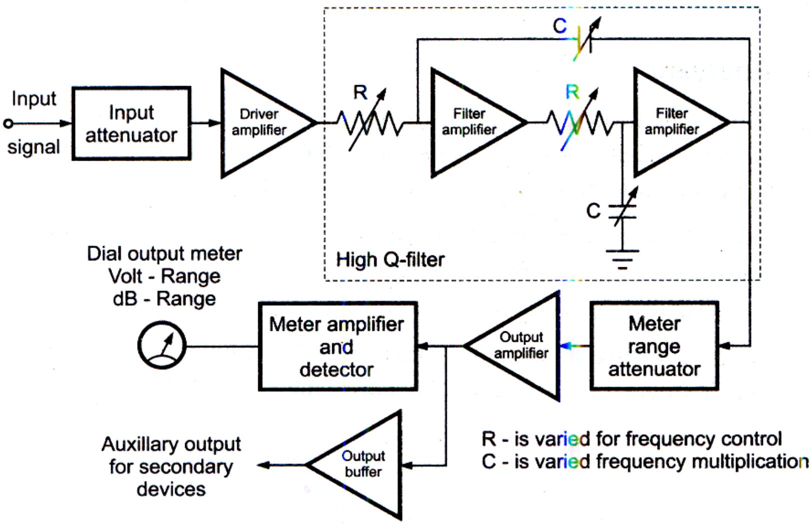


The full wave rectifier is the intermediate stage, which is used to determine the input signal's average value. With calibration set to read the peak value of the sinusoidal input voltage, the indicating device is a basic DC voltmeter. All other frequencies are rejected by the LC circuit, which is only tuned to one frequency, and only passes the frequency to which it is tuned. A practical Wave analyzer would require several fine-tuned filters connected to the indicating device via a selector switch.

Types of wave analyzer

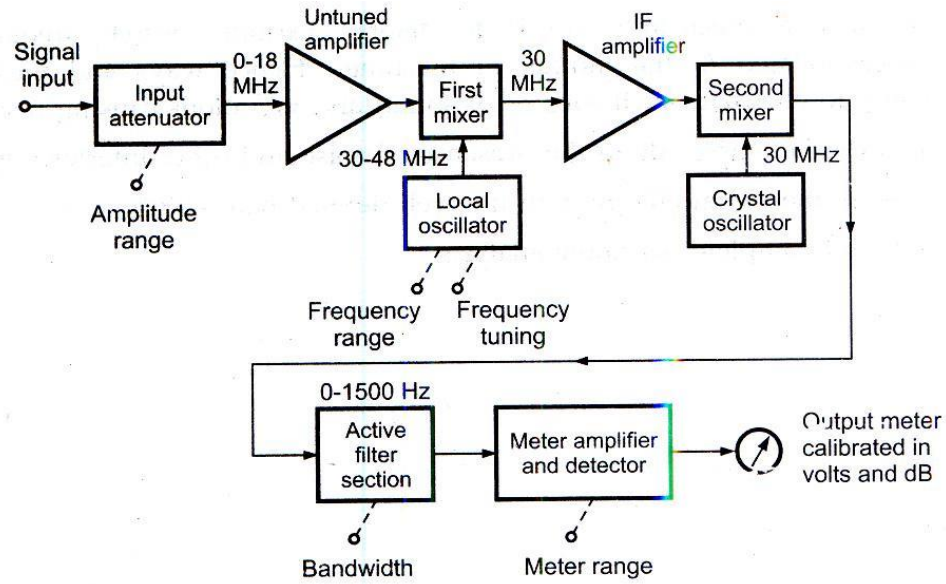
- ☐ Frequency selective wave analyzer.
- ☐ Heterodyne wave analyzer.

Frequency selective wave analyzer



An adjustable attenuator filters the waveform that will be examined. This multiplies the range. The waveform is fed to a high Q filter by the driver amplifier. The RC resonant portions and filter amplifiers are arranged in a cascade fashion to create this filter. The capacitors are employed to alter the range. Within the chosen pass band, the potentiometer is used to adjust frequency.
In the RC sector, the switching capacitors cover the entire AF range in decade steps. The chosen signal is sent to the meter circuit and an untuned buffer amplifier by the last amplifier step. Driving output devices, such as recorders and electronic counters, is the purpose of the buffer amplifier. Low input distortion is required for the analyzer input. The meter is marked with multiple voltage ranges and a decibel scale. It is powered by a detector of the average reading rectifier type.

Heterodyne wave analyzer



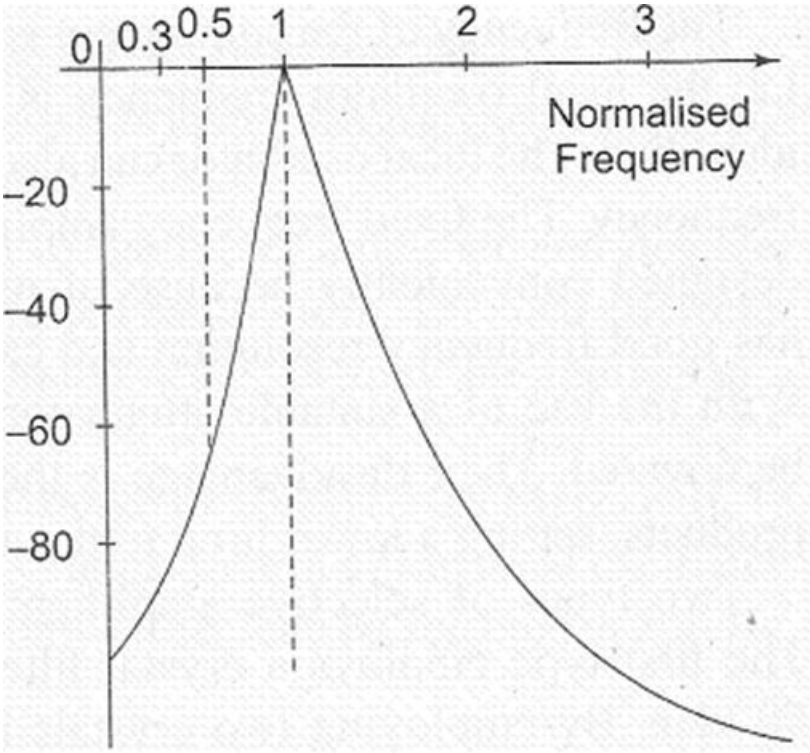
The heterodyning, or mixing, principle underlies the operation of this RF range analyzer.

This kind of wave analyzer uses an internal local oscillator to heterodyne the input signal to a higher intermediate frequency (IF).A local oscillator's tuning causes the different signal frequency components to move into the IF amplifier's pass band.The metering circuit is then fed with the rectified output of the IF amplifier.In the attenuator part, the input is applied first. In the range of 0 to 18 MHz, this indicates the output frequency.This signal is sent to the first mixer by the untuned amplifier, which enhances it.First, a local oscillator's frequency is used to heterodyne the input in the mixer. With a frequency range of 30-48 MHz, this oscillator.

The 30 MHz difference in frequency of the first mixer's output.This signal is amplified by the IF amplifier before being sent to the second mixer.Using a crystal oscillator operating at 30 MHz, the second mixer heterodynes the signal.Consequently, the zero difference frequency is produced at the mixer's output.After selecting the desired component, the meter amplifier and detector receive it via the active filter, which has a regulated bandwidth and symmetrical slopes of 72 dB per octave.The output meter, which has a decibel calibrated scale, is then utilized to provide the final indication based on the output from the meter detector.One possible application for the detector's output is a recording device.

Applications of wave analyzer

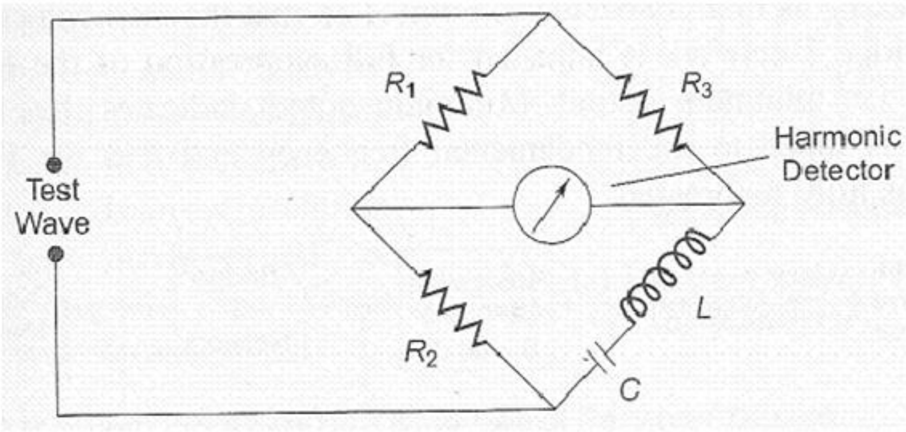
- Measurement of an amplifier's harmonic distortion
- To do a comprehensive harmonic analysis
- To use a well-defined bandwidth to quantify the signal energy



Marked on the meter are decibel grades and multiple voltage levels. A rectifier type detector with an average reading powers it. Extremely low input distortion that the wave analyzer itself cannot detect is a requirement. As seen by the response characteristics shown in figure, the instrument's band width is exceedingly narrow, often about 1% of the selective band.

HARMONIC DISTORTION ANALYZER:
Fundamental Suppression Type
Rather than measuring the distortion brought on by each component individually, a distortion analyzer examines the total harmonic power contained in the test wave. The easiest technique is to use a high pass filter with a cut-off frequency that is slightly above the fundamental frequency to suppress the fundamental frequency. Measuring the overall harmonic distortion is possible once this high pass lets only the harmonics pass through. The following are further varieties of fundamental suppression-based harmonic distortion analyzers:

1. **Employing a Resonance Bridge**



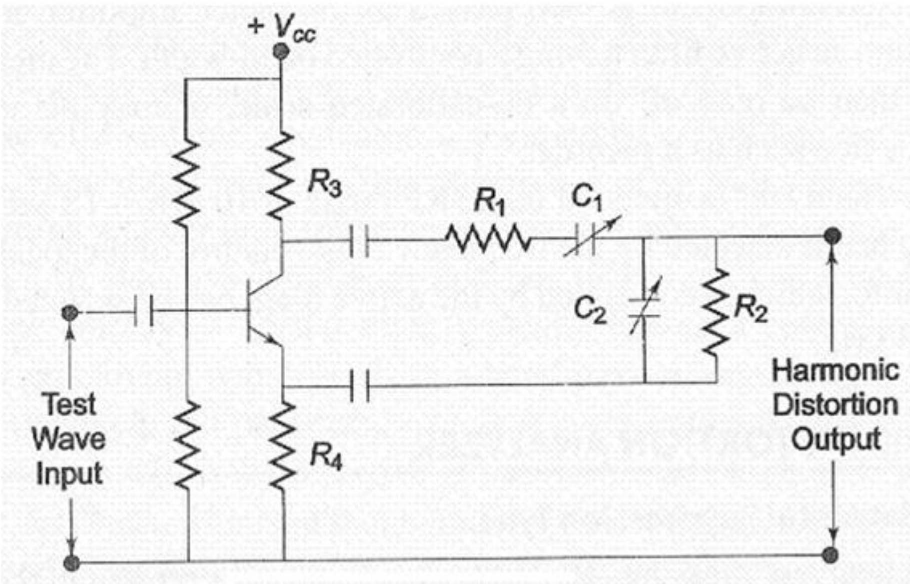
L and C are tuned to the fundamental frequency in Figure, which is balanced for the fundamental frequency. Only harmonic power will be available at the output terminal and measurable since the bridge is not balanced for harmonics. Rebalancing the bridge is necessary if there is a change in the fundamental frequency. Only when the test wave has a set frequency is this procedure appropriate if L and C are fixed components. Thermocouples and square law VTVMs are two types of indicators. This shows each harmonic's rms value.

2. **Wien's Bridge Method**

As seen in figure above, a Wien bridge configuration is utilized when a continuous adjustment of the fundamental frequency is necessary. A basic frequency balance is maintained in the bridge. Within the bridge circuit components, the fundamental energy is lost. To the output terminals alone come the harmonic components. You can then use a meter to measure the output of harmonic distortion.

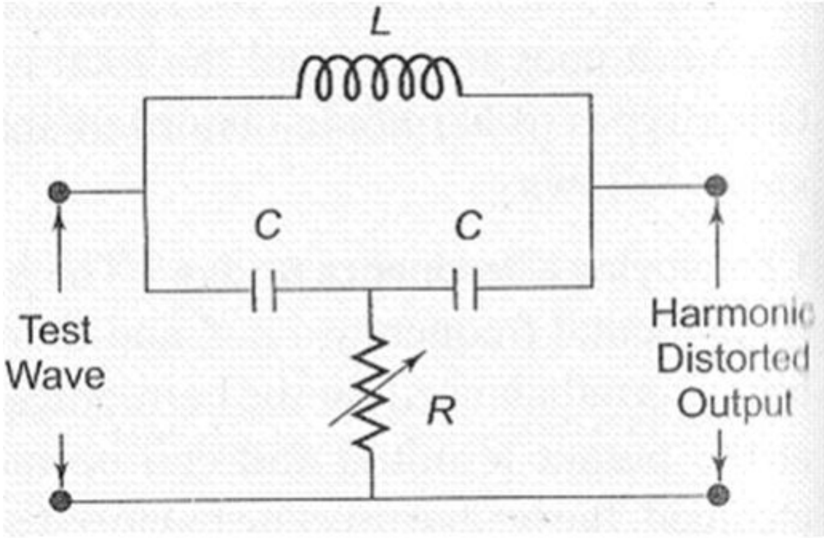
For balance at the fundamental frequency

$C_1=C_2=C$, $R_1=R_2=R$, $R_3=2R_4$.

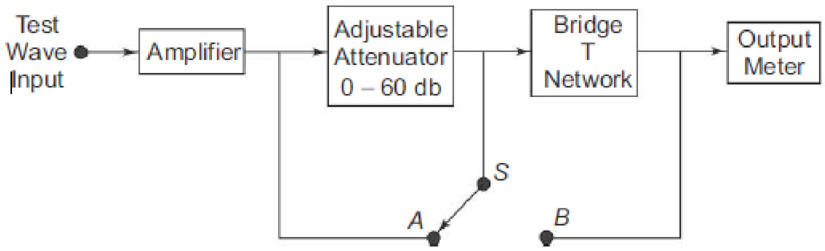


3. **Bridged T-Network Method**

The L and C frequencies in Figure are tuned to the fundamental frequency, but the R is modified to avoid the fundamental frequency. The fundamental energy will circulate in the tank and be circumvented by the resistance as the tank circuit is adjusted to the fundamental frequency.



The bridge T-network is set up for complete suppression of the fundamental frequency, or minimal output, after switch S is initially linked to point A. This excludes the attenuator. The minimum output shows that the fundamental frequency is completely muted and that the bridged T-network is tuned to it.



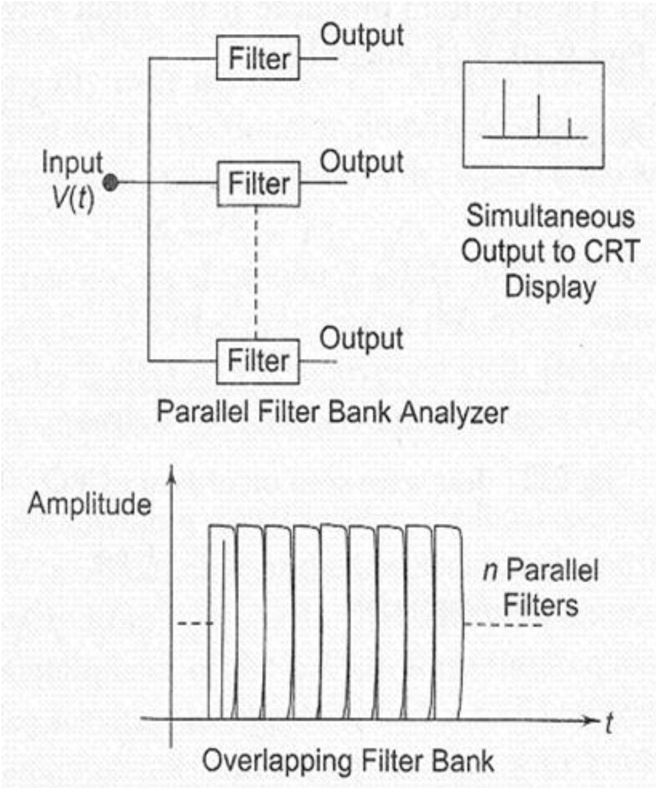
Next, the switch is linked to terminal B, meaning that the bridged T-network is not included. The attenuation is changed until the meter reads the same amount. The overall rms distortion is shown by the attenuator measurement. With a wave analyzer, distortion can also be measured and the harmonic distortion may be computed by knowing the frequency and amplitude of each component.

However, compared to wave analyzers, distortion meters based on fundamental suppression are less expensive and easier to develop. Their inability to provide the magnitude of individual distortion components, just the overall distortion, is a drawback.

SPECTRUM ANALYZER:

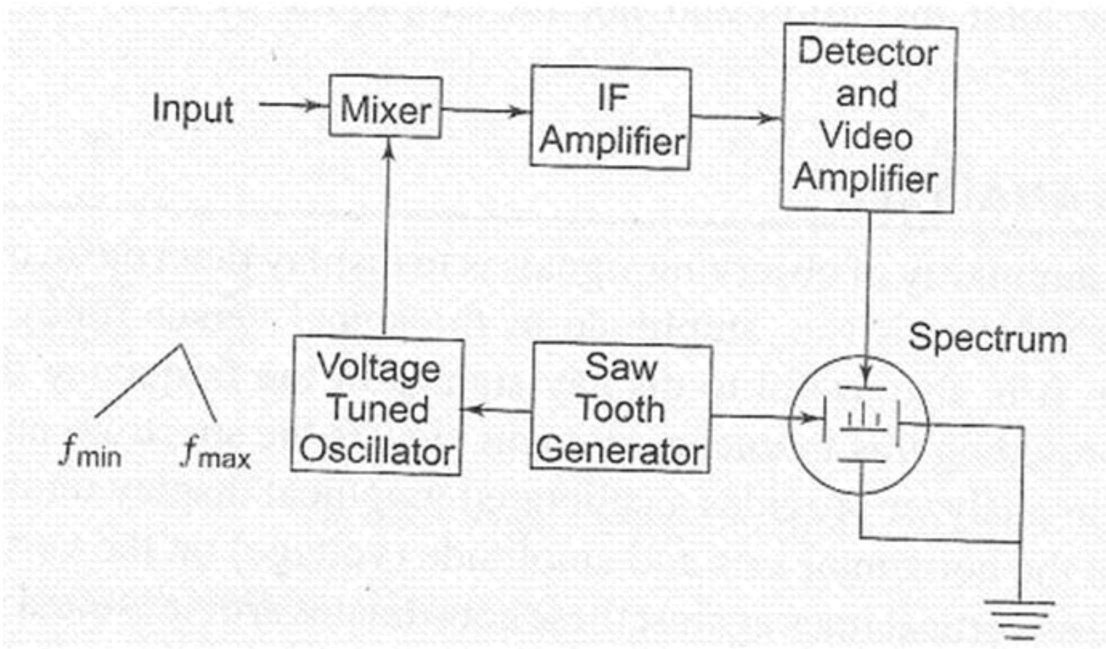
Signals are most commonly observed by plotting them on an oscilloscope with time as the X-axis (i.e., signal amplitude vs time). The temporal domain is this. The presentation of signals in the frequency domain is also beneficial. The spectrum analyzer is what provides this image of the frequency domain.

With frequency on the horizontal axis and amplitude (voltage) on the vertical, a spectrum analyzer's CRT displays a calibrated graphical display.

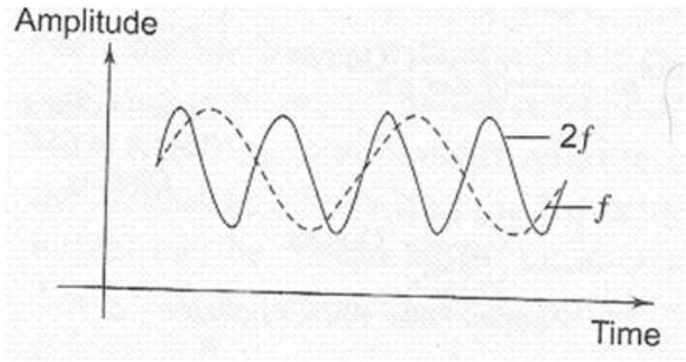


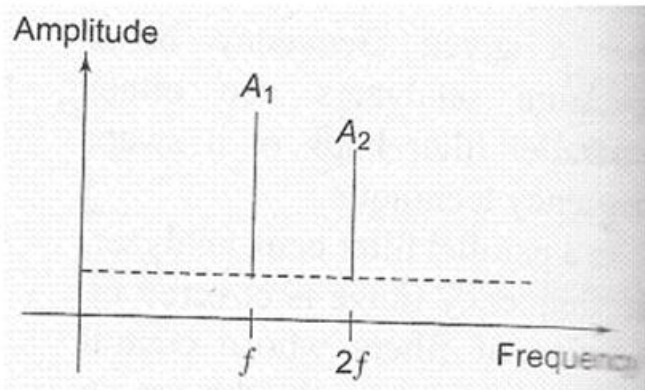
The sinusoidal components that make up the input signal are shown as vertical lines against these coordinates. The horizontal position denotes frequency, while the height denotes absolute magnitude. The frequency spectrum for a certain frequency band is displayed by these devices. Both swept frequency and parallel filter banks are employed by spectrum analyzers.
Figure shown above illustrates how a set of filters with well chosen core frequencies and bandwidths overlap each other to cover the frequency range in a parallel filter in a parallel filter bank analyzer.
These filters cover a third of an octave apiece, and an audio analyzer typically has 32 of them.
Wide band narrow resolution analysis is best performed using the Sweep Technique, especially for RF or microwave signals.

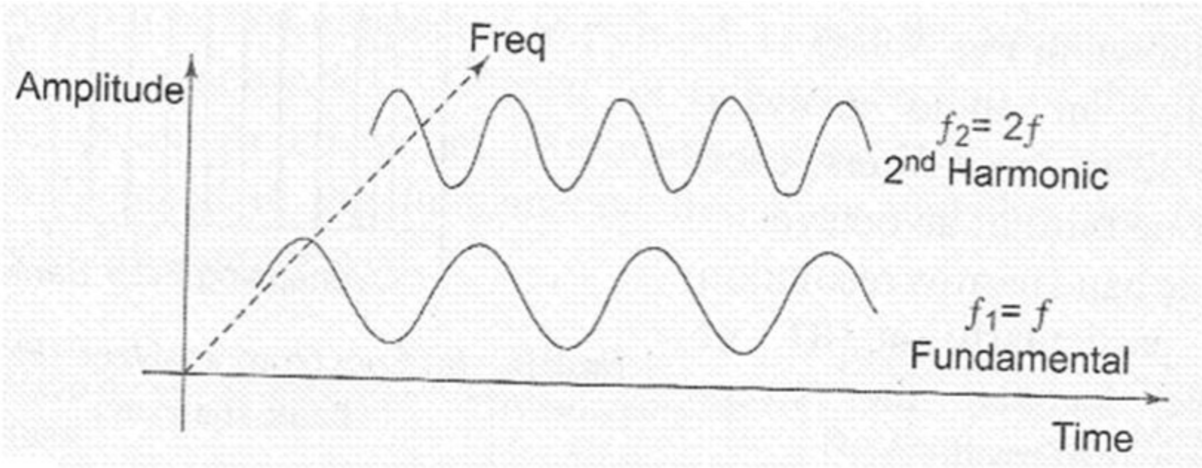
Basic Spectrum Analyzer Using Swept Receiver Design
The saw tooth voltage, which powers the scope's horizontal axis element and is the frequency-controlled component of the voltage-tuned oscillator, is provided by the saw tooth generator, as shown in the block diagram of Figure shown below. The oscillator beats with the frequency component of the input signal while it sweeps at a linearly repeating rate from fmin to fmax of its frequency band. Whenever a frequency component is reached during its sweep, the oscillator produces an IF.



In below figures, the spectrum generated if the input wave is a single toned A.M.

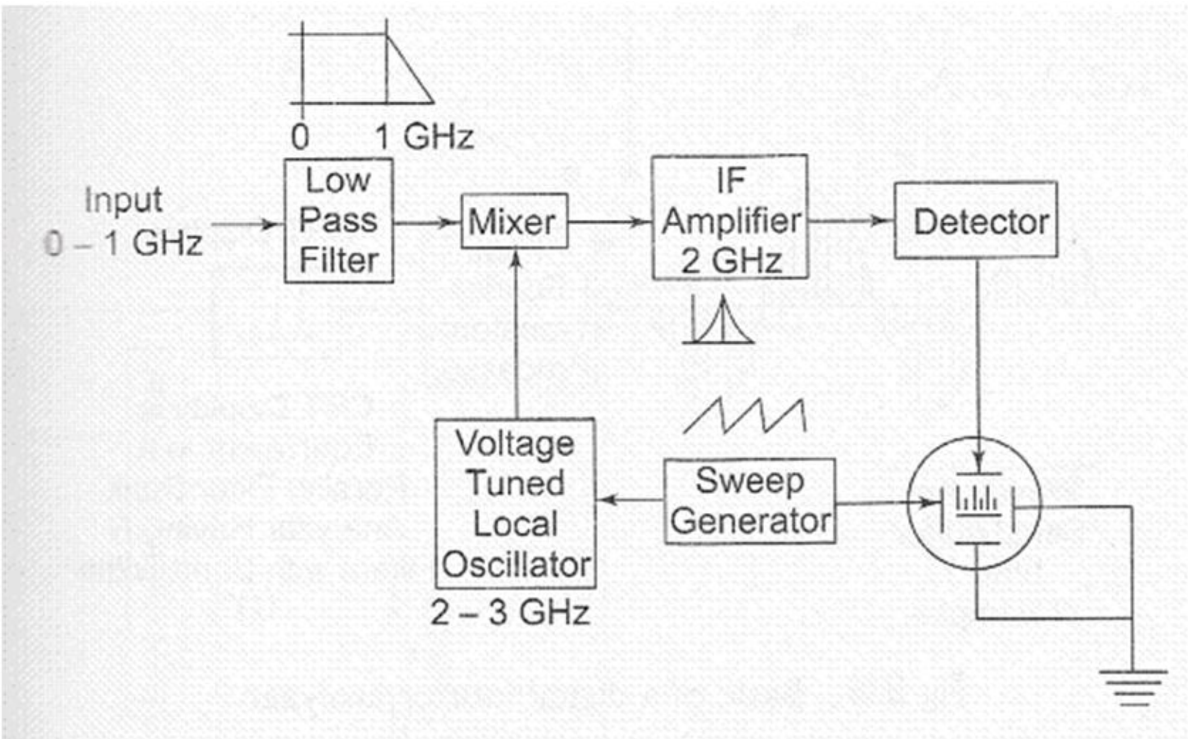






The analysis of the radio frequency spectrum generated by microwave devices has been a primary use for spectrum analyzers. In a microwave instrument, the horizontal axis can show a highly magnified picture of any small section of the spectrum at as narrow as 30 kHz, or as wide as 2 - 3 GHz for a broad survey. Individual signals at microwave frequencies separated by a few KHz are visible.

This device operates in the frequency range of I MHz to 40 GHz. The fundamental block diagram shows a spectrum analyzer operating in the super heterodyne type range of 500 kHz to 1 GHz.



The mixer receives the input signal and is powered by a local oscillator. Over the frequency range of 2 to 3 GHz, this oscillator can be electrically tuned linearly. The mixer outputs two signals that are the same frequency as the input signal plus the difference between the input signal and the local oscillator frequency. These signals are proportionate in amplitude to the input signal.

Only inputs that are separated from the local oscillator frequency by 2 GHz will be converted to the IF frequency band, pass through the IF frequency amplifier, get rectified, and cause a vertical deflection on the CRT. The IF amplifier is tuned to a narrow band around 2 GH4. This is because the local oscillator is tuned over a range of 2 - 3 GHz.

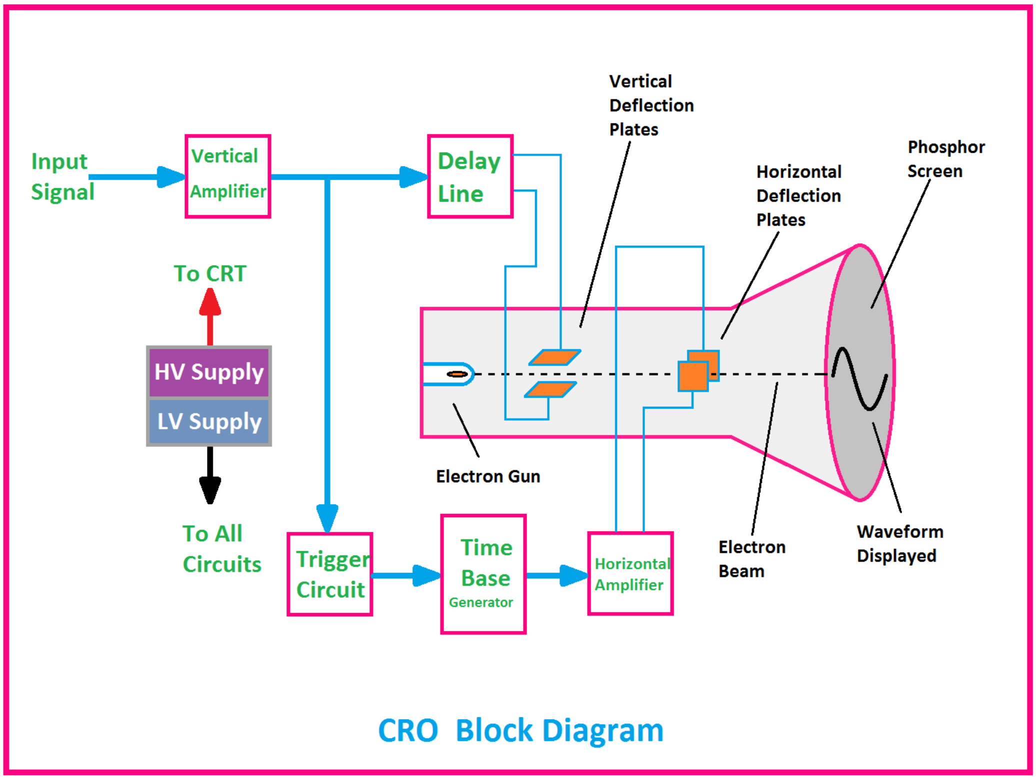
This leads to the observation that the local oscillator likewise sweeps linearly between 2 and 3 GHz when the saw tooth signal does. A swept receiver, which sweeps linearly from 0 to 1 GHz, is how the spectrum analyzer is tuned. The CRT's horizontal plates receive the saw tooth scanning signal as well, forming the frequency axis. (Signals from 4–5 GHz, also known as the super heterodyne's picture frequency, can also be detected by the spectrum analyzer. These erroneous signals are suppressed by an input low pass filter with a cutoff frequency exceeding I GHz.) Radars, oceanography, and the biomedical sciences all make extensive use of spectrum analyzers.

Cathode Ray Oscilloscope

An electrical device that shows a voltage waveform is called an oscilloscope. The Cathode Ray Oscilloscope (CRO), the most basic oscilloscope, shows a signal or waveform that varies over time.

Block Diagram of CRO

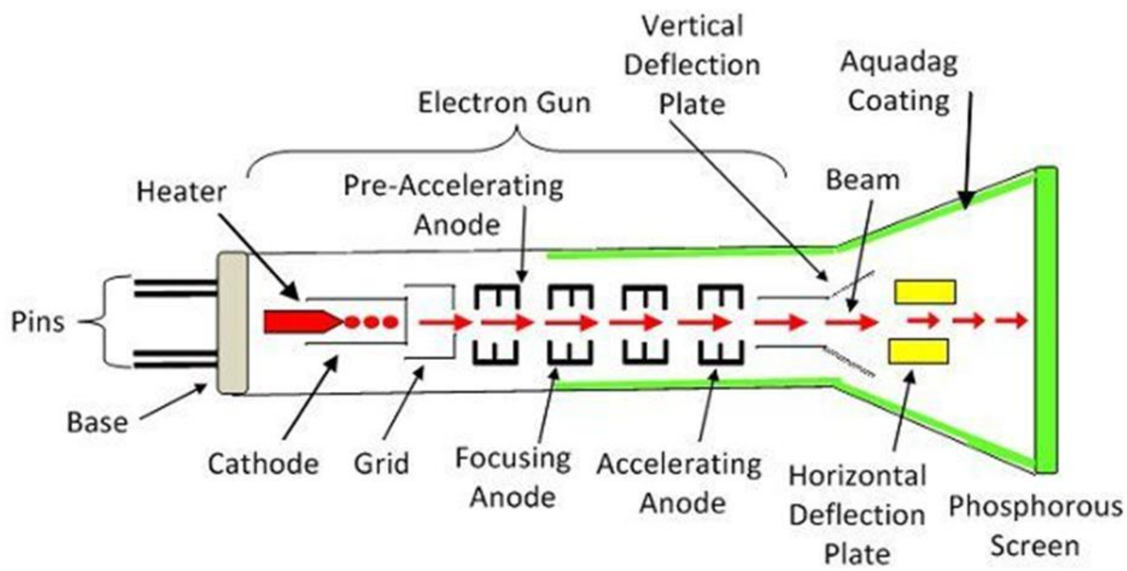
Blocks comprise the Cathode Ray Oscilloscope (CRO). These include a power supply, a horizontal amplifier, a time base generator, a vertical amplifier, a delay line, a trigger circuit, and a television tube (CRT). In the graphic below, the CRO block diagram is displayed.



The **function** of each block of CRO is mentioned below.

- **Vertical Amplifier :** Using a vertical amplifier, the input signal intended to be shown on the CRT screen is amplified.
- **Delay Line :** The signal obtained at the output of the vertical amplifier is given a certain degree of delay by the delay line. Then, the CRT's vertical deflection plates get this delayed signal application.
- **Trigger Circuit :** The trigger circuit generates a signal to synchronize the deflections of the electron beam in both the horizontal and vertical directions.
- **Time base Generator :** One important tool for deflecting an electron beam horizontally is the Time Base Generator, which generates a sawtooth signal.
- **Horizontal Amplifier :** The sawtooth signal is first amplified before being connected to the CRT's horizontal deflection plates via a horizontal amplifier.
- **Power supply:** It generates voltages that are both high and low. To the CRT and other circuits, the corresponding high and low voltages are applied, correspondingly.
- **Cathode Ray Tube (CRT) :** The fundamental component of CRO, the cathode ray tube (CRT), is made up of four key elements. These are fluorescent screens, electron cannons, and horizontal and vertical deflection plates.

Two vertical and two horizontal deflection plates, respectively, deflect the electron beam that is created by an electron cannon in both directions. Finally, on the fluorescent screen, the deflected beam will show up as a spot.
The input signal will be applied and shown on the CRT screen using CRO in this manner. In this way, we may use CRO to analyze the signals in the temporal domain.



Definition: A display screen that generates images from a video signal is called a CRT. This particular kind of vacuum tube produces images when it strikes a phosphorescent surface with an electron beam fired from electron cannons. Put otherwise, in order to create the images on the phosphorous screen and make the beam visible, the CRT creates the beams, accelerates them at a high speed, and deflects them.

The electron beams that are produced by electron guns are accelerated at high voltage and produce a luminous spot when they strike a fluorescent screen. The electron beams exit the electron gun and pass through pairs of electrostatic deflection plates, which deflect the beams when voltage is applied across them. The first pair of plates moves the electron beam upward, while the second pair moves it from one side to the other. The electrons move independently in both the horizontal and vertical directions, allowing the electrons to be positioned anywhere on the screen.
A vacuum glass envelope encloses the CRT's working components, allowing the electrons that are released to flow freely from one end of the tube to the other.

Construction of CRT

Important components of the CRT are the glass envelope, base, fluorescent screen, electron gun assembly, and deflection plate assembly. Emitted from the electron cannon, the electron beam hits the phosphorous screen by way of deflecting plates.

Electrons Gun Assembly

The source of the electron beams is the electron gun. The electron cannon comprises of an accelerating anode, focusing anode, pre-accelerating anode, grid, and heater. The strongly emitted cathode is the source of the electrons. The cathode has a cylinder-shaped structure, and at its end is a layer of strontium and barium oxide that produces a high electron emission at the tube's end.
The electron travels through each individual electron in the tiny grid. The nickel material used to make this control grid has a hole in the middle that runs parallel to the CRT axis. Pre-accelerating and accelerating anodes are subjected to a high positive potential applied by the electrons that are fired from the electron cannon and travel through the control grid.
The focusing anode concentrates the beam. Each of the cylindrical focusing and accelerating electrodes has a tiny aperture in the center of it. The beams go via the horizontal and vertical deflecting plates after leaving the focusing anode. The positive high voltage of approximately 1500V is connected to the pre-accelerating and accelerating anodes, while the lower voltage of approximately 500V is connected to the focusing anode.The electron beam can be focused in two different ways. These are the electromagnetic focusing and the electrostatic focusing beam.

Electrostatic Deflection Plates

The uniform electrostatic field is produced by the deflection plate only in one direction. The electrons in the electron beam that enters the deflection plates will only accelerate in one direction; they will not move in any other direction.

Screen For CRT

The face plate is the term for the CRT's front. Fiber optics, which have unique properties, make up the entire face plate of the CRT. Phosphorus is applied to the inside surface of the faceplate. Light energy is produced from electrical energy by the phosphorus. When electron beams strike phosphorous crystals, their energy level increases. The term cathodoluminescence refers to this phenomena.
Fluorescence is the name for the light that results from phosphorous excitation. A quantum of light energy known as phosphorescence or persistence is released by the phosphorous crystals when the electron beam stops and they return to their original position.

Aquadag

The Aquadag, which is linked to the anode's secondary, is an aqueous graphite solution. In order to maintain electrical equilibrium on the CRT screen, secondary released electrons must be collected by the Aquadag.

With CRO, we are able to perform the following measurements: Amplitude measurement, Time period measurement, Frequency measurement, and Period measurement.

Measurement of Amplitude

The voltage signal is shown on CRO's screen as a function of time. The voltage signal's amplitude remains constant, but we can adjust the number of vertical divisions covering it by adjusting the volt/division knob on the CRO panel. Consequently, we will use the following formula to obtain the signal's amplitude that is displayed on the CRO screen.

$A=j\times nv$

Where,

A is the amplitude

J is the value of volt/division

Nv is the number of divisions that cover the signal in vertical direction.

Measurement of Time Period

CRO shows the voltage signal on its screen as a function of time. The period of that periodic voltage signal is always the same, but by adjusting the time/division knob on the CRO panel, we may change the number of divisions that make up a single horizontal cycle of energy.

Thus, we can use the following formula to obtain the Time period of the signal that is displayed on the CRO screen.

$T=k\times nh$

Where,

T is the Time period

j is the value of time/division

nv is the number of divisions that cover one complete cycle of the periodic signal in horizontal direction.

Measurement of Frequency

A periodic signal's frequency, f, is equal to the reciprocal of its time period, T.

Mathematically, it can be represented as

$$f=1/T$$

So, we can find the frequency, f of a periodic signal by following these two steps.

First, ascertain the periodic signal's time period.

Step 1 yields the periodic signal's time period, which is then taken as the reciprocal in Step 2.

Dual beam oscilloscope

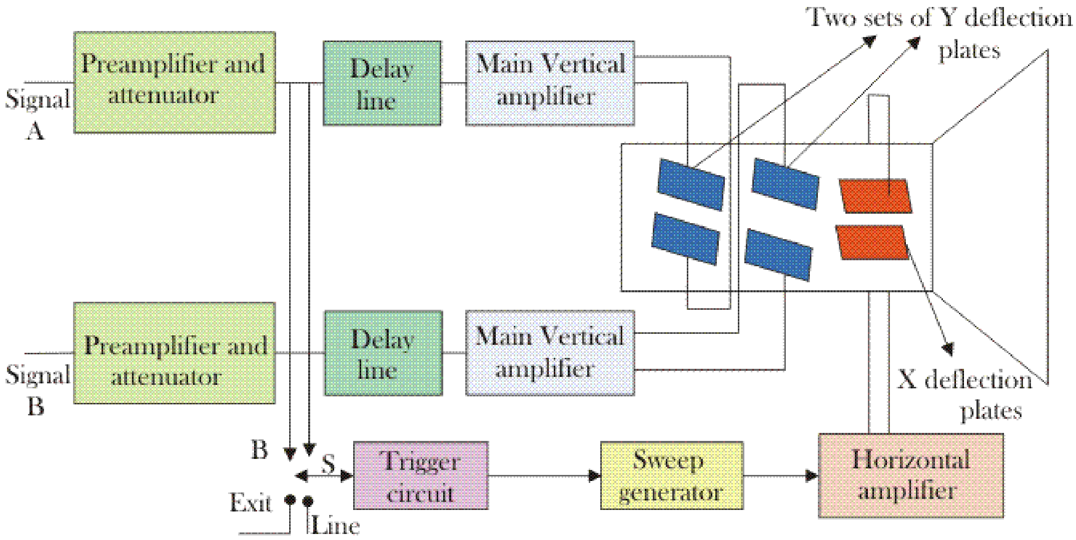
The dual beam oscilloscope can be operated independently or in tandem to produce two electron beams that are seen concurrently on a single scope. The dual beam oscilloscope differs greatly from the dual trace oscilloscope in both design and operation. Both the construction of the tubes and the overall cost have increased.

Through beam generation or deflection, a unique kind of double beam oscilloscope may display two electron beams. These days, double beam oscilloscopes are obsolete since digital scopes can accomplish the same task more effectively and don't need a dual-beam display. A single electron beam is captured by the digital scope, which splits it into multiple channels simultaneously.

Construction of Double Beam Oscilloscope

For two electron beams emanating from separate sources, there are two separate vertical input channels. Every channel possesses a separate pre-amplifier and attenuator. Consequently, it will soon be possible to alter each channel's amplitude.

Different sweep rates are possible depending on whether the two channels have independent or shared time base circuits. Every beam traverses distinct channels for independent vertical deflection prior to crossing a solitary set of horizontal plates. The sweep generator compiles the horizontal amplifier, which drives the plate and provides a common horizontal deflection. Parallel passage of both electron beams across the screen is made possible by the horizontal plates.



Duel beam oscilloscope with common time base

Dual beam oscilloscope: With a twin electron gun tube or by splitting the beam, a dual beam oscilloscope can produce two electron beams inside the cathode ray tube. Each beam's focus and brightness are adjusted independently using this manner. However, the oscilloscope appears hefty and is larger and heavier due to its two tubes.

The alternate approach uses a split beam tube and only requires one electron cannon. The last anode and the Y deflection plate are separated by a horizontal splitter plate. Between the two vertical deflection plates along the tube's length, the plate's potential is the same as that of the final anode. As a result, the two channels are isolated.

The brightness of the resulting beam is half of the original beam when it splits into two. It functions as a drawback at high frequencies. Having two sources rather than one in the final anode to allow beams to come from it is an alternate method to increase the brightness of the resulting beam.

Dual Trace oscilloscope

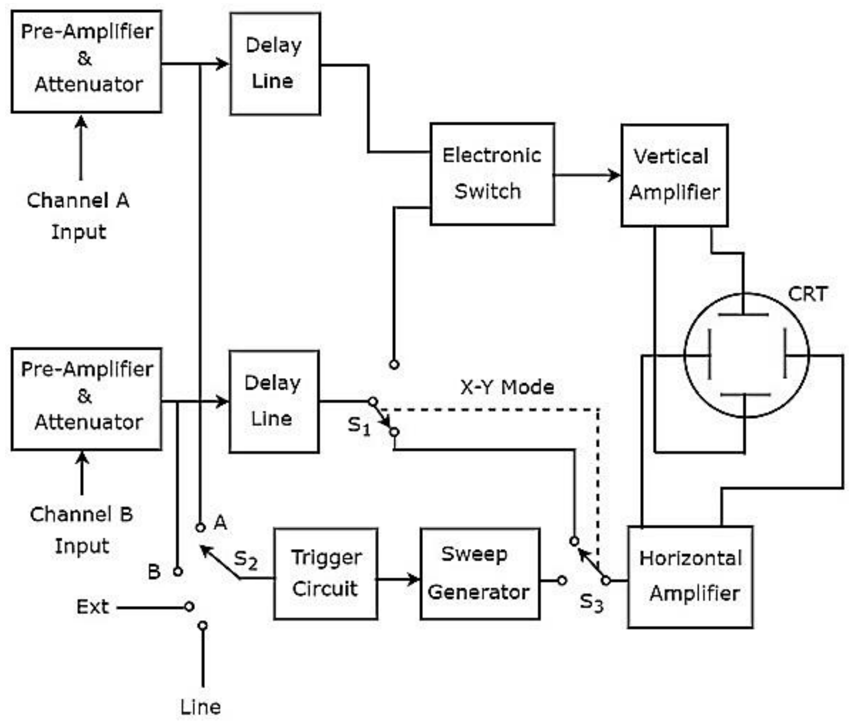
In a dual trace oscilloscope, two traces are produced by a single electron beam and are deflected by two different sources. Essentially, two techniques—the chopped mode and the alternate mode—are employed to create two distinct traces. The two switch operating modes are another name for these. The comparing of voltages is a crucial step in the analysis and research of multiple electrical circuits. So, one can utilize numerous oscilloscopes to compare the various circuits. However, it's a challenging operation to simultaneously activate each oscilloscope's sweep. In order to give two traces using a single electron beam, we have employed dual trace oscilloscopes.

Working: Its two distinct vertical input channels are called A and B. The preamplifier and attenuator stages receive separate feeds of each inputs. After that, the electronic switch receives the outputs from the two independent preamplifiers and the attenuator stage. Only one channel input, specifically at a time, is passed to the vertical amplifier by this switch. A trigger selection switch on the circuit enables the circuit to be triggered by an external signal or by an input from either the A or B channel. The sweep generator or switches S0 and S2 on channel B receive the signal from the horizontal amplifier and feed it to the electronic switch.

The oscilloscope operates by means of the CRT receiving the vertical signal from channel A and the horizontal signal from channel B. This oscilloscope mode allows precise X-Y readings. It is called the X-Y mode. Essentially, the oscilloscope's modes of operation depend on the controls selected from the front panel. Similar to how a trace of channel A or channel B must be obtained independently, or both, depending on the situation. Dual trace oscilloscopes operate in two different modes, as we have already mentioned.

ALTERNATE MODE OF DUAL TRACE OSCILLOSCOPE The alternate mode allows for the alternating connection between the two channels whenever it is activated. Each subsequent sweep starts with this alternation, or flipping, between channels A and B. Additionally, there is synchronization between the sweep rate and the switching rate. This results in the detection of each channel's traces in a single sweep. For example, if traces of channel A are detected in the first sweep, the CRT will evaluate traces of channel B in the subsequent sweep. This completes the alternate connection between the vertical amplifier and the two-channel input.

For the duration of the flyback sweep, the electronic switch changes from one channel to another. The transition from one channel to another will occur during the flyback period when the electron beam becomes invisible. The screen will therefore show the entire sweep signal from a single vertical channel. While the signal from a different vertical channel will be seen on the following sweep. By using this technique, we can keep the signals from channels A and B in the correct phase relationship.
Nevertheless, this method is also linked to a drawback in addition to its benefits. The alternate mode results in a display that shows both signals occurring at separate times. In reality, though, the two things happen at the same time. Furthermore, the low-frequency signal cannot be represented using this method. The oscilloscope's alternate mode waveform is depicted in the following figure:



Analog Storage Oscilloscope

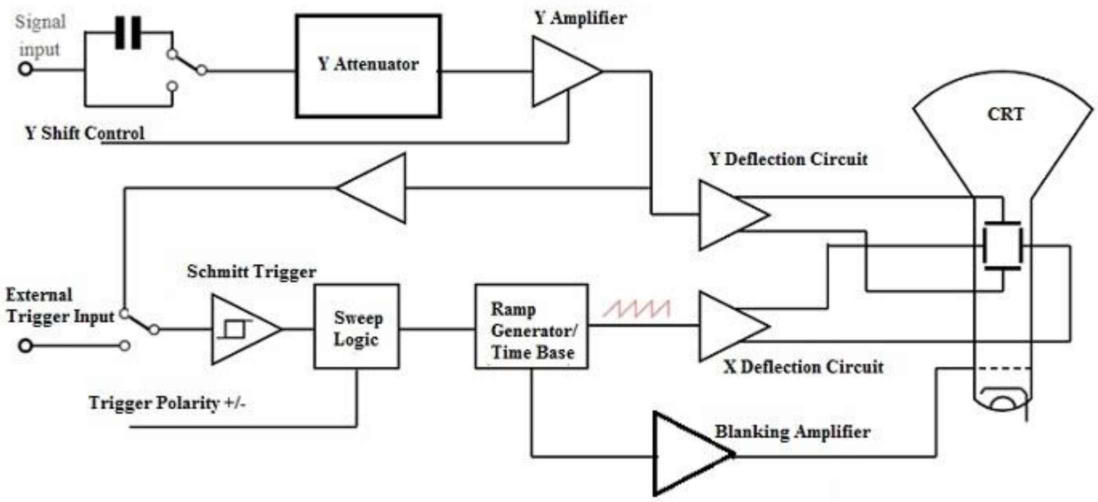
Waveforms can be stored for subsequent visualization with an analog storage oscilloscope, which is one kind of oscilloscope. Since these oscilloscopes were relatively expensive and had very basic performance, they were typically reserved for specialized uses. With a long persistence facility, these oscilloscopes use a unique cathode ray tube. Though these CRTs might be set to different persistence levels, there's a risk of permanently burning traces on the screen if very bright traces are maintained above long periods of time. As such, careful use of these displays is necessary.

An unique CRT with extended persistence is used by analog storage oscilloscopes. In order to prolong the fluorescence's duration beyond that of typical displays, a unique CRT structure is utilized to store charge inside the display region where the electron beam had struck.

All that this oscilloscope needs to function is to apply a voltage that can be directly measured to an electron beam that travels over its screen. The beam is focused on a screen that has been coated with phosphor, which causes the screen to glow. The signal then deflects the beam, allowing it to trace the waveform on the screen.The beam will be correspondingly deflected up and down by the voltage in order to trace the waveform on the display. As a result, a waveform image is displayed instantly.

Block Diagram

The following block diagram illustrates an analog storage oscilloscope that makes use of a CRT. In order to provide significantly faster electron stream control and enable analog oscilloscopes to operate at very high frequencies, this oscilloscope uses an electrostatic CRT type rather than a magnetic deflection type. An stable image of the incoming waveform can be obtained from the analog oscilloscope, which has several circuit blocks.



Signal Inputs

The Y-axis or signal input on the display is connected to a number of controls. Often, signals under a DC bias will be overlaid. Consequently, in order to ensure that the DC is blocked, a capacitor must be connected in series through the input. Selecting AC will indicate that there may be limitations on low-frequency transmissions when a capacitor is used.

Y Attenuator

The purpose of the Y attenuator is to ensure that the signals are sent to the Y amplifier at the appropriate level.

Y Amplifier:

All that the oscilloscope's Y amplifier does is amplify the signal to provide the desired output. Since it will determine the oscilloscope's accuracy, this amplifier is primarily linear.

Y Deflection Circuit:

The Y deflection circuit receives the amplified signal from the Y amplifier and provides the necessary levels to the CRT plates. Because it offers the high-speed deflection needed for this oscilloscope, the CRT's deflection is electrostatic.

Trigger Circuitry:

Whether a stable waveform appears on the display or not is determined by the trigger system. Every cycle of the incoming signal that needs to be examined must have the ramp signal set to begin at the same location. In this way, the display will display a similar spot on the waveform at a similar position.

A signal is received from the output of the Y amplifier and sent to another conditioning amplifier in the block diagram above. Subsequently, it is routed via a Schmitt trigger circuit, which offers a single switch point for both rising and falling waveforms. Either the increasing or decreasing edges of the waveform that can be picked before being delivered to the ramp circuit, or wherever the trigger signal supplies the start point for the ramp, is the necessary sense that is chosen for the trigger.
It is also possible to employ a signal from an external source. Given that the trigger may need to be obtained from a source other than the incoming signal, this functionality can be highly appropriate.

Blanking Amplifier

During this fly-back phase, a blanking amplifier is used to clear the screen. All that is needed to generate a pulse that is sent to the CRT grid is the reset element of the ramp. This effectively blanks the display and lowers the electron flow for the duration.

Ramp Generator (Time Base)

The analog storage oscilloscope's time base control is one of its most important controls. This will be significantly different in speed and time for every section on the scope CRT. In order to display the specific waveform that is needed, it is crucial to choose the appropriate timebase speed.
With this analog storage oscilloscope, signals are displayed in both the horizontal and vertical axes on the CRT. The ramp waveform usually represents the horizontal axis, and the instantaneous incoming voltage value typically represents the vertical axis. A horizontal trace slides across the display as the voltage of the ramp waveform increases. The waveform returns to zero and the trace restarts at the beginning of the screen once it reaches the conclusion. With this method, amplitude is represented by the vertical axis, while time is represented by the horizontal two. The common waveform plots can therefore be shown on the CRT in this way.

Advantages and Disadvantages

The **advantages of analog storage oscilloscope** include the following.

- The oscilloscopes that have analog storage typically have lower costs. They can offer a reasonable performance range for many laboratory and service scenarios.
- Especially for laboratory operations, these oscilloscopes deliver precise performances.
- These oscilloscopes don't need an ADC, microprocessor, or acquisition memory in order to measure anything.

The **disadvantages of analog storage oscilloscopes** include the following.
These oscilloscopes are not intended for the analysis of sharp-rise-time transients at higher frequencies found in electronic circuits, and they do not provide any extra capabilities over digital oscilloscopes. Additionally, operating these oscilloscopes requires hands-on expertise.

Applications

The **applications of analog storage oscilloscopes** include the following.

- It shows waveforms with a single shot and a long duration.
- Stable incoming waveform pictures are produced by the analog oscilloscope.
- These oscilloscope types are often utilized for real-time observation of one-time events.
- Very low-frequency signals are displayed using it.
- The major application for these oscilloscopes is in situations where the screen display time is insufficient to verify the signals that need to be monitored.
- The oscilloscope employs an electron beam to map and show the continuously varying input voltages of the signal.

Digital Storage Oscilloscope

Definition: Oscilloscopes with digital storage allow users to save digital waveforms or digital copies of them. Digital signal processing techniques can be used to the signal and it enables the storing of the waveform or signal in digital format and digital memory. Both the scope's sampling rate and the type of converter affect the highest frequency that may be measured with a digital signal oscilloscope. In just a few seconds, the vivid, well-defined traces in DSO are shown.

Block Diagram of Digital Storage Oscilloscope

An analyzer circuits, memory, digitizer, and amplifier make up the digital storage oscilloscope's block diagram. Cathode ray tubes (CRTs), horizontal amplifiers, vertical and horizontal plates, triggers, clocks, and time base circuitry are included in waveform reconstruction. Below is a figure that displays the digital storage oscilloscope block diagram.

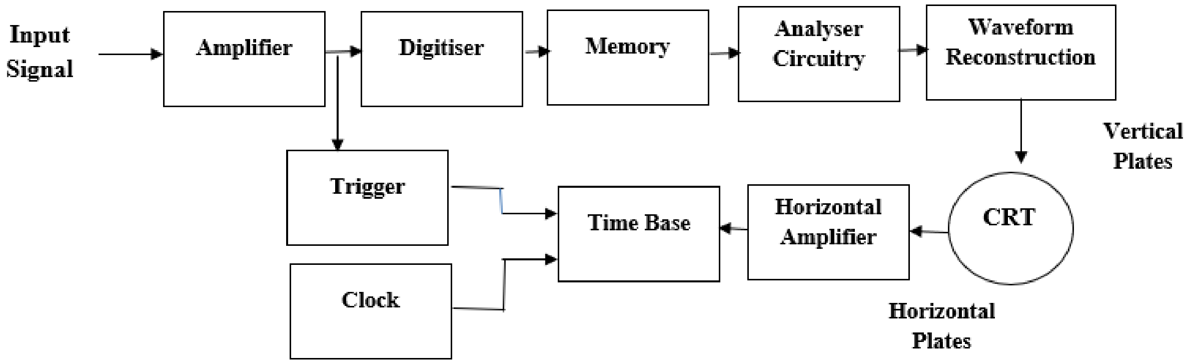


Figure above illustrates how the analog input signal is first digitized by a digital storage oscilloscope and then amplified by an amplifier if necessary. The digitizer then digitalizes the signal once it has been amplified, and memory stores the digitalized signal. Following the digital signal's processing by the analyzer circuit, the waveform is rebuilt (converting the digital signal into analog form once more), and the signal is subsequently applied to the cathode ray tube's vertical plates (CRT).

The inputs of the cathode ray tube are twofold: vertical and horizontal. The "X" axis represents the horizontal input signal and the "Y" axis the vertical input signal. Because the time base circuit is activated by both the trigger and the clock input signal, it will produce a ramping time base signal. The horizontal amplifier will then send the input to the horizontal plate after amplifying the ramp signal. The input signal's waveform versus time will be displayed on the CRT screen.

An input waveform sample is taken at regular intervals to facilitate digitization. Meaning that we take signal samples at the periodic time interval, which occurs when half of the time cycle has elapsed. The sampling theorem should be adhered to when digitizing or selecting samples. The rate of sample taking should be more than double the highest frequency found in the input signal, according to the sampling theorem. Aliasing is the result of improper conversion of the analog signal into digital format.

As soon as the analog signal is appropriately converted to digital, the A/D converter's resolution is reduced. An A/D converter can operate at up to 100 mega samples per second when it can read out the input signals from analog store registers at a much slower rate than it can from digital stores, where the digital output is stored. A digital storage oscilloscope operates on this principle.

DSO Operation Modes

Three modes of operation are available for the digital storage oscilloscope: roll mode, store mode, and hold or save mode.

Roll Mode: The display panel changes very quickly when the roll mode is activated.

Store Mode: When in store mode, the signals are stored in RAM.

Hold or Save Mode: When in hold or save mode, a portion of the signal will be held for a while before being stored in memory.

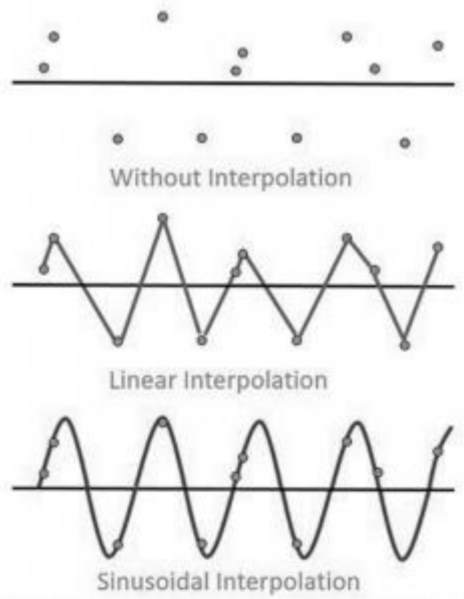
These are the three oscilloscope operation modes for digital storage.

Waveform Reconstruction

Linear interpolation and sinusoidal interpolation are the two types of waveform reconstructions.

Linear Interpolation: The dots are connected by a straight line in linear interpolation.

Sinusoidal Interpolation: In sinusoidal interpolation, a sine wave connects the dots.



Waveform Reconstruction of Digital Storage Oscilloscope

Sampling Oscilloscope

Understanding the fundamentals and operation of a standard oscilloscope is required. It is an apparatus that concurrently projects the waveform onto the screen after receiving one or more electrical impulses. The sampling oscilloscope is a more sophisticated model of the digital oscilloscope that has additional functions and is intended for specialized applications.

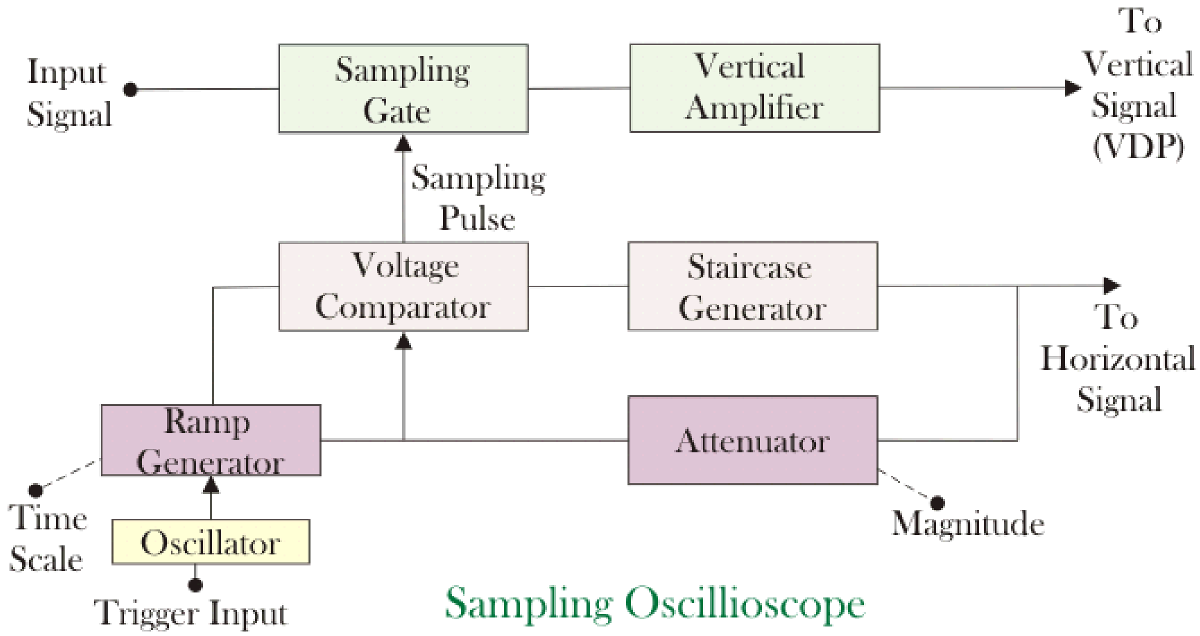
Its purpose is to sample multiple wave forms one after the other in order to produce an extremely high-frequency function. The sampling theorem is used by this type of oscilloscope to create a waveform from several input signals. A portion of the motion may be seen by utilizing strobe light, but when several pictures are taken, a very quick mechanical motion is noticed. The sampling oscilloscope is a tool for observing extremely fast electrical impulses that works similarly to the stroboscopic approach. A waveform requires about a thousand points to be created.

Functioning of Sampling Oscilloscope

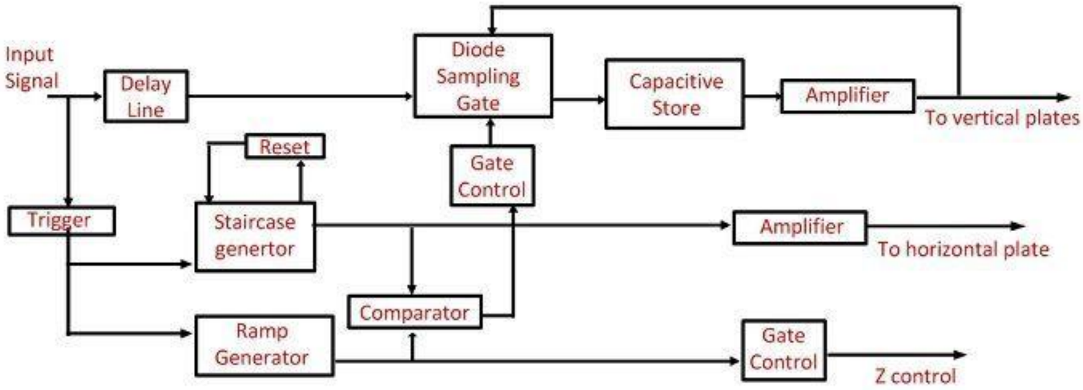
As implied by the name, it gathers data from many waveforms and uses the combined information to create a whole image of the waveform. The resulting waveform is displayed on the screen after being amplified using a low band pass filter. The entire shape of this waveform is created by connecting numerous dots that are connected to one another.

The vertical deviation of the progressive layer's point in each subsequent cycle of a staircase waveform is represented by each dot on the wave. They are employed to keep an eye on high-frequency communications that reach at least 50 GHz. The waveform that is being presented has a frequency that exceeds the scope's sample rate. It has a huge amplifier bandwidth of roughly 15 GHz and approximately 10 pieces per division or more. Signals are low-frequency during the sampling step, and they combine with an attenuator to achieve a large band-width.

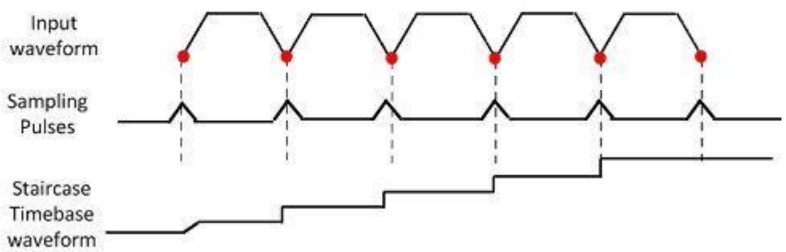
However, the instrument's dynamic range is diminished. The sampling oscilloscope can only detect repeating signals; it cannot detect sporadic occurrences. Only when the range is restricted do they exhibit high frequency.



Sampling Oscillioscope



Sampling Oscilloscope Block Diagram



Principle of Sampling Oscilloscopes

Below is a figure that displays the sampling scope block diagram. To the delay line—where the signal is delayed—the input signal is sent. The precise timing difference that forms between the input and output signals is indicated by the signal delay. To the diode sampling gate is passed the output obtained from the delay line. In the capacitor is stored the signal sampled from the diode gate. Following amplification, it is supplied into the amplifier and sent to the display screen's vertical axis. From the amplifier to the diode gate, there is just one feedback. Based solely on the variation in the internal signal between samples, the feedback indicates that the voltage stored on the capacitor increases.

The following figure displays the waveform of a staircase. There is a reset after a number of steps, as the waveform indicates. In order to create the waveform, the screen contains more than 1000 points. In a cathode ray tube, the staircase waveform is employed. The spot on the screen is removed using it.

Delayed Sweep in sampling Oscilloscope

This method involves extending the duration of the scope sweep from its beginning to its triggering point. This enhances the instrument's versatility. One way to enhance the undelayed signal is via a delayed sweep oscilloscope. Numerous other applications can also benefit from it, such as determining the waveform's rising time or pulse time modulation.

Sampling Method

An oscillator and liner voltage are produced prior to every sample cycle by means of the trigger pulse. A sampling gate is opened to allow for an input voltage sample when the amplitudes of the two voltages are equal. The staircase moves one step forward and generates a sampling pulse. The staircase generator's step size determines how well the waveform resolves. Two methods are frequently employed, while there are other approaches as well. Both the equivalent sample approach and the real-time sample are used.

Real Time Sample Method

The high speed of the digitizer in the real-time approach allows it to register the most points in a single sweep. Its primary goal is to accurately record transitory occurrences with high frequency. Because the transient waveform is so distinct, it is impossible to correlate its voltage or current level at any one moment with those of its closest counterparts. Since they don't happen again, these occurrences must be recorded as soon as they happen. The sampling rate is approximately 100 samples per second, and the frequency is a relatively high 500 MHz. It takes a high-speed memory to store a waveform with such high frequency.

Equivalent Sample Method

The analogous technique of sampling operates on the premise of prediction and approximation, which can only be achieved with a recurring waveform. Similar to this, a digitizer obtains samples from numerous signal repetitions. For every iteration, it might use one or more samples. This improves the precision of signal capture. The resulting waveform's frequency is far more than the scope's sample rate. There are two ways to accomplish this kind of sampling: sequential and random.

Random Method of Sampling

The most popular sampling technique is the random method. It operates on an internal clock that has been set up so that it operates in response to input signals and continually records signal trigger samples, independent of the location of the trigger. The samples are taken on a regular basis in terms of timing, but they are randomly selected in terms of trigger.

Sequential Method of Sampling

This method of taking samples is independent of time setting and is triggered-agnostic. Sample recording occurs with a slight delay after each trigger detection. A very brief but well defined delay is what you want. In comparison to the preceding trigger, the next one is registered with a slight time delay. From a few microseconds to a few seconds, the delayed sweep can be used. In this way, samples are obtained repeatedly with incremental delays until the time frame is filled. Assuming the delay for the first time is "t," the delay for the second time will be somewhat greater than "t."

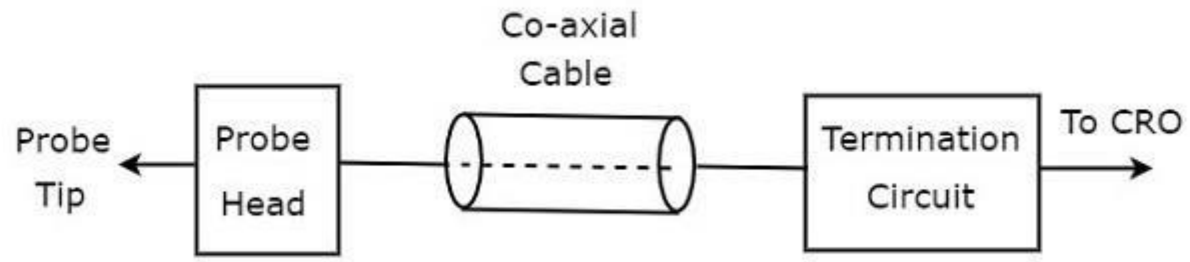
CRO Probes

Every test circuit can be connected to an oscilloscope using a probe to create an oscilloscope. The probe attached to the CRO oscilloscope, which is a simple oscilloscope, is also known as the CRO probe. The test circuit should not have any loading problems as a result of the probe that we have chosen. so that the test circuit with the signals accurately analyzed on the CRO screen.

CRO probes should have the following characteristics.

- ✓ High impedance
- ✓ High bandwidth

The block diagram of CRO probe is shown in below figure



The three blocks that make up the CRO probe are mostly depicted in the figure. The probe head, coaxial cable, and terminating circuit are those. The probe head and termination circuit are merely connected by coaxial cable.

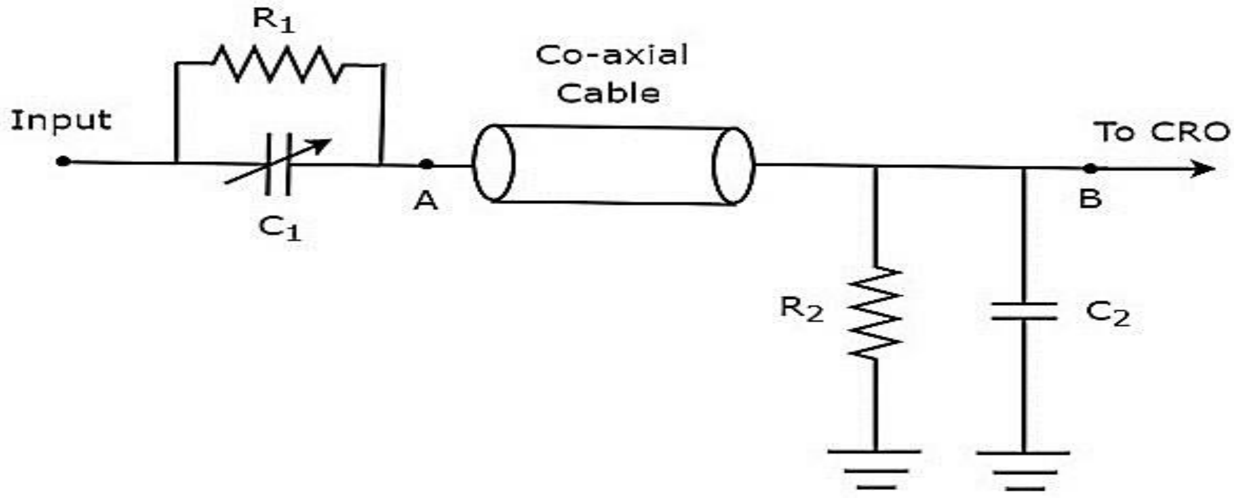
Types of CRO Probes

The two categories of CRO probes are as follows.

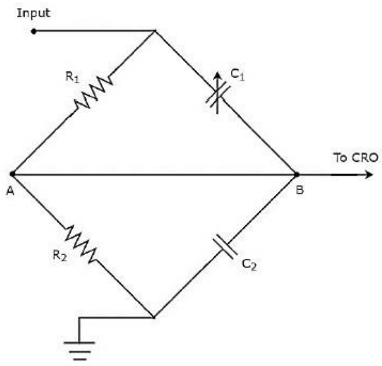
1. **Passive Probes**
2. **Active Probes**

Passive Probes

A probe is considered passive if its head is made up entirely of passive components. The passive probe's circuit diagram is displayed in the image below.



The probe head, as depicted in the picture, is made up of a variable capacitor, C1, and a resistor, R1, combined in parallel. Likewise, the circuit for termination has a parallel arrangement of resistor R2 and capacitor C2. The updated bridge circuit version of the preceding circuit diagram is depicted in the picture below.



Adjusting the value of variable capacitor C1 will allow us to balance the bridge.

Z1Z4 = Z2Z3

In the equation above, replace the impedances Z1, Z2, Z3, and Z4 with R1, 1jωC1, R22, and 1jωC21, respectively.

R1(1/jwc2)=R2(1/jwc1)

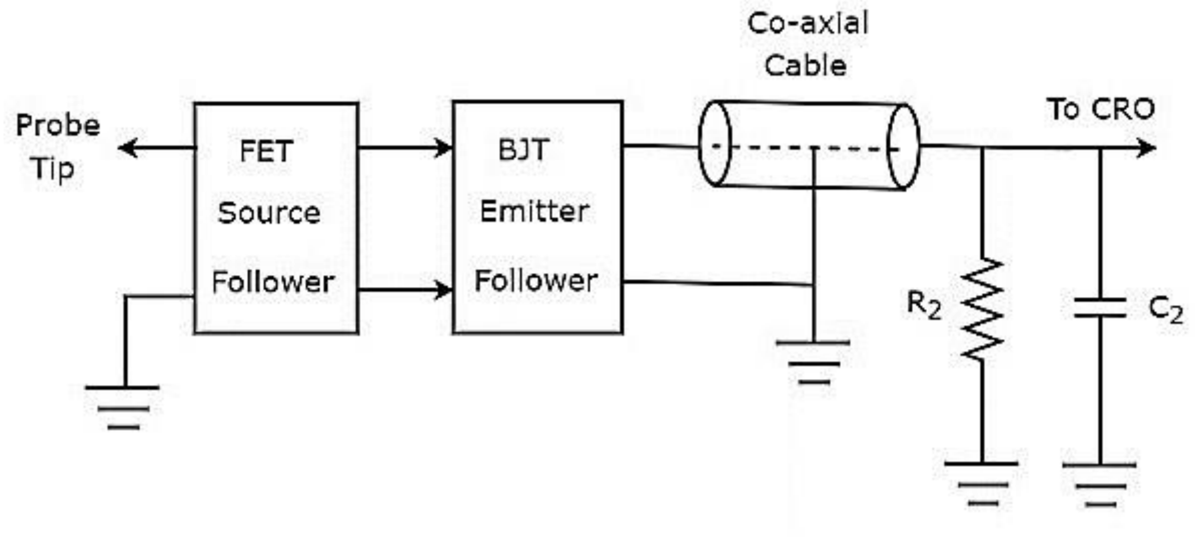
R1C1=R2C2

The voltage across resistor R2 can be obtained using the voltage division method as V0=Vi(R2R1+R2)

Input voltage (Vi) to output voltage (V0) is the ratio known as the attenuation factor. Thus, we may obtain the attenuation factor, ɑ, from the equation above as

ɑ=ViV0=R1+R2R2

Active Probes



If the probe head consists of active electronic components, then it is called active

The term "active probe" refers to a probe head that has active electronic components. Figure following displays the active probe's block diagram.

The probe head is comprised of a BJT emitter follower and a FET source follower in cascade, as depicted in the image. Low output impedance and high input impedance are provided by the FET source follower. In contrast, the aim of the BJT emitter follower is to prevent or remove impedance mismatching.

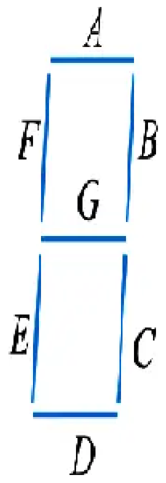
In both active and passive probes, the other two components—the termination circuit and coaxial cable—remain the same.

Module 5

DISPLAY DEVICES AND RECORDERS

Seven Segment Display Working Principle

Typically, a seven-segment display is made up of several LEDs. An illustration of a seven-segment display's front is provided below. Seven LEDs in the shape of an eight are present in it: A, B, C, D, E, F, and G. A segment refers to each LED. One or more LEDs will light up and emit a bar of light if they are forward biased. One can display any number between 0 and 9 by forward biasing different combinations of seven LEDs. By forward biasing LEDs A, B, C, D, and G, for instance, to light up, the display will show the number 3. In a same vein, the display will display the number 6 if LEDs C, D, E, F, A, and G are lit. In order to obtain. All but G are lit in order to obtain the number 0.



In the field of electronics, we refer to the process of allowing current to flow across a diode junction of a 7-segment display to trigger the emission of photons as electroluminescence.

The mixture of different impurities added to the semiconductor materials used to produce the light determines the spectral wavelength of the visible light emitted by an LED, which can range in color from blue to red to orange. The primary benefits of light emitting diodes over conventional bulbs and lamps are their small size, extended lifespan, availability, affordability, and ease of integrating with other electronic parts and digital circuits. Some other advantages are their availability in a variety of colors. But light emitting diodes' primary benefit is that, due to their small die size, multiple of them can be connected together to form what is commonly referred to as a 7-segment display inside of a single, tiny package.

Seven LEDs are arranged in a rectangular pattern as indicated by the 7-segment display, also known as the "seven segment display," hence its name. As a portion of a decimal or hexadecimal number that is to be displayed, each of the seven LEDs is referred to as a segment when it is lit. Sometimes, to display numbers larger than ten, two or more 7-segment displays are connected together, and an extra 8th LED is used within the same package to allow the indication of a decimal point (DP).

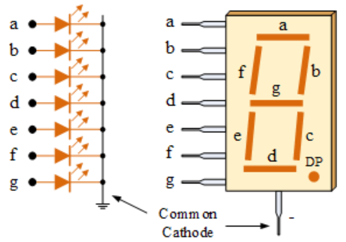
With one of its connection pins taken straight out of the rectangular plastic package, each of the seven LEDs in the display is assigned a positional segment. Each individual LED is represented by a through g on these pins that are designated for individual LEDs. A common pin is formed by connecting and wiring the other LED pins together.

Thus, the desired character pattern of the number can be generated on the display by forward biasing the appropriate pins of the LED segments in a specific order, causing some segments to be light and others to be dark. The ten decimal digits, 0 through 9, can now all be seen on the same 7-segment display thanks to this.The common pin on the display is typically used to determine the kind of 7-segment display. Common Cathode (CC) and Common Anode (CA) are the two types of LED 7-segment displays because each LED has two connecting pins, one of which is referred to as the "Anode" and the other as the "Cathode."

The difference between the two displays, as their name suggests, is that the common cathode has all the cathodes of the 7-segments connected directly together and the common anode has all the anodes of the 7-segments connected together and is illuminated as follows.

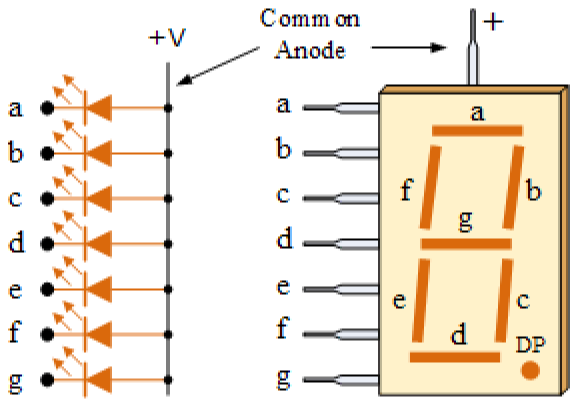
1. **The term "Common Cathode" (CC)** refers to a display where all of the LED segment cathode connections are collectively connected to ground or logic "0." A "HIGH" or logic "1" signal is applied to each individual segment to forward bias the individual anode terminals (a-g) and illuminate them through a current limiting resistor.

Common Cathode Configuration



The common anode (CA) display is made up of all the anode connections from the LED segments connected to logic "1". Through the use of an appropriate current limiting resistor, a ground, logic "0," or "LOW" signal is applied to each segment's cathode (a–g) to illuminate it.

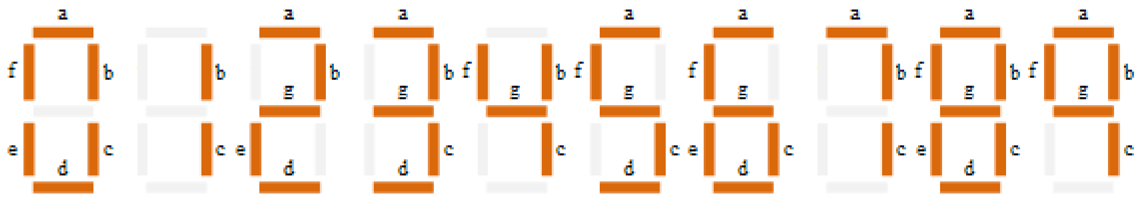
Common Anode Configuration



Since many logic circuits are able to sink more current than source, common anode displays are generally more widely used. Additionally, keep in mind that connecting common cathode displays to common anode displays and vice versa in a circuit is equivalent to connecting LEDs in reverse, which prevents light emission.

This specific set of LEDs is forward biased based on the decimal digit to be displayed. For example, we will need to turn on six of the LED segments that correspond to a, b, c, d, e, and f in order to display the number 0. A 7-segment display can thus be used to display the different digits from 0 through 9 as shown.

Digital Segments for all Numbers



The individual segments that must be illuminated in order to produce the necessary decimal digit from 0 to 9 can then be found in the truth table that we can create for a 7-segment display, as shown below.

7-segment Display Truth Table

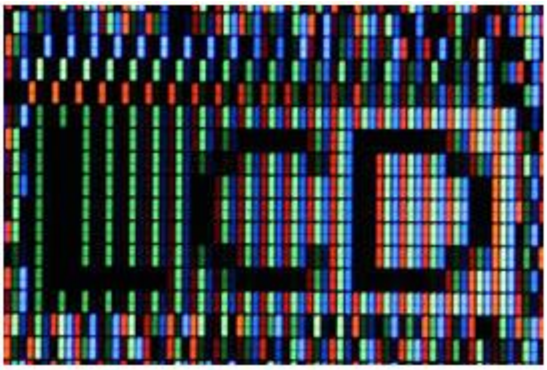
Segments (✓= ON)							Display	Segments (✓= ON)							Display
a	b	c	d	e	f	g		a	b	c	d	e	f	g	
✓	✓	✓	✓	✓	✓		0	✓	✓	✓	✓	✓	✓	✓	8
	✓	✓					1	✓	✓	✓			✓	✓	9
✓	✓		✓	✓		✓	2	✓	✓	✓		✓	✓	✓	A
✓	✓	✓	✓			✓	3			✓	✓	✓	✓	✓	b
	✓	✓			✓	✓	4	✓			✓	✓	✓		C
✓		✓	✓		✓	✓	5		✓	✓	✓	✓		✓	d
✓		✓	✓	✓	✓	✓	6	✓			✓	✓	✓	✓	E
✓	✓	✓					7	✓				✓	✓	✓	F

LCD Display

Though they didn't develop right away, liquid crystal displays (LCDs) are ubiquitous today. The development of the liquid crystal and the numerous LCD applications came about over a very long period of time. A botanist from Austria named Friedrich Reinitzer created the first liquid crystals in 1888. A substance similar to cholesterol benzoate dissolved in it, and he saw that the fluid initially became hazy before clearing up as the temperature increased. Before finally crystallizing, the fluid turned blue after cooling down. Hence, the RCA Corporation created the first experimental liquid crystal display in 1968. Following then, the LCD manufacturers have progressively created clever modifications and advancements on the technology, expanding the capabilities of this display device to an amazing extent. Therefore, the LCD has finally advanced in terms of development.

An LCD is defined by its own name: liquid crystal display. The two states of matter—solid and liquid—combine to form it. A visible image is produced by LCD using a liquid crystal. Cell phones, laptop computers, TVs, and portable video games are common devices that use liquid crystal displays, which are incredibly thin technological display screens. Displays made with LCD technologies can be significantly thinner than those made with cathode ray tube (CRT) technology.

One layer of a liquid crystal display is composed of two polarized panel filters and an electrode sheet. Using LCD technology, images can be displayed in notebooks and other electronic devices like mini computers. Light is projected via a lens onto a layer of liquid crystal. Combining colored light with the grayscale image of the crystal produced when an electric current flows through it yields the colored image of the crystal. This image appears on the screen thereafter.



An active matrix display grid or a passive display grid make up an LCD. While some older smartphones still use passive display grid designs, the majority of smartphones with LCD technology use active matrix displays. Liquid crystal display technology is the mainstay of most electronic devices' displays. The liquid has the distinct benefit of using less power than an LED or cathode ray tube.

Instead of producing light, the liquid crystal display screen blocks light in order to function. Since LCDs don't produce light, they need a backlight. Our gadgets are all composed of LCD displays, which have taken the place of cathode ray tubes in many applications. In comparison to LCDs, cathode ray tubes are larger, heavier, and require more power.

Two pieces of polarized glass act as the filter that we need to create the liquid crystal, as was previously mentioned. To create microscopic grooves on the surface of the polarized glass filter, a particular polymer must be rubbed on glass that is not coated in a polarized film. The grooves and the polarized film must face one another.

Two pieces of polarized glass are the filter we need to make the liquid crystal. It is necessary to rub a specific polymer on glass that isn't covered in a polarized film in order to create tiny grooves on the polarized glass filter's surface. It is necessary to face the polarized film and the grooves in the same direction.

Light is therefore directed by a molecule to the next layer after passing through each layer. The molecule tends to modify its plane of vibration as the angle of the light varies. The final layer of the molecule vibrates at an angle that coincides with the angle at which light vibrates at the distant end of the liquid crystal substance. The device only lets light in when the second layer of polarized glass lines up with the last layer of the molecule.

LCD Working principle:

The basic principle behind LCDs is that when an electrical current is applied to a liquid crystal molecule, it has a tendency to untwist. This alters the light's path through the polarized glass molecule as well as the angle of the top polarizing filter. In that particular region of the LCD, this results in a tiny amount of light passing through the polarized glass.

LCDs are based on the fundamental principle that a liquid crystal molecule tends to untwist when an electrical current is applied to it. Both the angle of the top polarizing filter and the angle at which light passes through the polarized glass molecule are altered by this. This results in a tiny amount of light entering that particular region of the LCD through the polarized glass.

The next glass piece has an electrode shaped like a rectangle on the bottom and a second polarizing film on top. It is important to remember that both pieces are kept at right angles. Light enters the LCD through the front, reflects off the mirror, and then bounces back when there is no current. The liquid crystals that are sandwiched between the common-plane electrode and the rectangular electrode will untwist when the electrode is powered by a battery. Light cannot flow through as a result. That particular rectangle appears to have empty space in it.

Different Types of LCD

There are the various LCD types:

Twisted Nematic Display

All industries use TN (Twisted Nematic) LCDs, which are manufactured fairly regularly, as the most prevalent type of display. Gamers are most likely to use these screens because of their inexpensive price and quick response time in comparison to other displays. These displays' main shortcomings are poor quality, viewing angles, and color reproduction, in addition to partial contrast ratios. These devices are sufficient for daily tasks, though.

With these screens, quick refresh rates and quick response times are both achievable. Hence, these are the only gaming monitors with 240 hertz (Hz). These displays have low color and contrast due to the highly inaccurate otherwise precise twist device.

In-Plane Switching Display

Because they offer superior color accuracy, sharpness, and contrast, as well as superior image quality, IPS displays are regarded as the best LCD. Most graphic designers use these displays, and in some other applications, LCDs must be able to reproduce images and colors to the highest possible standards.

Vertical Alignment Panel

The Twisted Nematic and in-plane switching panel technologies are centered around the vertical alignment (VA) panels. These panels have better features, as well as the best color reproduction and viewing angles when compared to TN type displays. These panels have a quick response time. However, these are more sensible and appropriate for daily use.

Comparing this panel's structure to the twisted nematic display, the former produces better colors and deeper blacks. Additionally, compared to TN type displays, multiple crystal alignments may allow for better viewing angles.

Advanced Fringe Field Switching (AFFS)

When it comes to performance and color reproduction, AFFS LCDs outperform IPS displays. AFFS's applications are very complex because it can reduce color distortion without compromising a wide viewing angle. Most sophisticated and professional settings, like operational airplane cockpits, are where one can find this kind of display.

Passive and Active Matrix Displays

In order to provide charge to a particular pixel on the LCD, passive-matrix type LCDs use a straightforward grid. Starting with two substrates known as glass layers, the grid's design can be completed silently. A transparent conductive substance such as indium-tin oxide is used to design rows, while one glass layer produces columns.

The rows and columns of this display are connected to integrated circuits (ICs) to control when a charge is transmitted in the direction of a particular row or column. The liquid crystal material is positioned between the two glass layers in areas where a polarizing film can be applied to the substrate's exterior. An IC can turn on the ground in the precise row of one substrate and transmit a charge down the precise column of the other substrate to activate a pixel.

The slow response time and imprecise voltage control are two of the passive-matrix system's main shortcomings. The display's ability to update the displayed image is primarily indicated by its response time. The easiest method for determining a display type's slow response time is to quickly move the mouse pointer from one side of the screen to the other.

The main component of active-matrix LCDs is TFT (thin-film transistors). These transistors are small switching transistors and capacitors arranged in a matrix on top of a glass substrate. When the corresponding row is turned on, a charge can be sent down the precise column to a particular pixel. The capacitor next to the designated pixel is the only one that receives a single charge because all other rows that the column intersects are turned off, making this possible.

How Colored Pixels Works in LCDs?

How the Pixels of LCD Switched OFF

- ✓ Light flows through the LCD from the back to the front.
- ✓ When a horizontal polarizing filter is positioned in front of a light, only horizontally vibrating light signals will be blocked. A transistor allows current to flow through its liquid crystals, causing the crystals to sort out and maintaining the constant light supply through them, thereby turning off a pixel in the display.
- ✓ Horizontal vibrations of light signals emanate from the liquid crystals.
- ✓ Only vertically vibrating light signals are blocked when a vertical type polarizing filter is placed in front of liquid crystals. The light vibrating horizontally will pass through the liquid crystals, blocking their passage through the vertical filter.
- ✓ The LCD screen is dark at this position, making light impossible to reach.

How the Pixels of LCD Switched ON

- ✓ The backlight of the display stays bright as it did previously.
- ✓ The horizontal polarizing filter in front of the light blocks all light signals, with the exception of those that vibrate horizontally.

- ✓ To enable pixel activation, a transistor interrupts the liquid crystals' electrical current, allowing the crystals to rotate. As the light passes through these crystals, it is turned ninety degrees.
- ✓ Light signals that enter the liquid crystals that vibrate horizontally will exit them and vibrate vertically.

- ✓ Any light signal that isn't vibrating horizontally is blocked by the horizontal polarizing filter that is placed in front of the light. The light that emerges from the liquid crystals will now be vibrating vertically, and it can pass through the vertical filter.

- ✓ After the pixel is turned on, it starts to take on color.

Difference between Plasma & LCD

Only light signals that vibrate vertically will pass through the vertical polarizing filter placed in front of the liquid crystals. This causes the light to vibrate vertically, allowing it to pass through the vertical filter as it emerges from the liquid crystals. Upon activation, the pixel begins to acquire color.

Advantages

Liquid crystal displays have the following benefits.

- Compared to CRT and LED, LCDs require less power to operate.
- Compared to mill watts for LEDs, microwatts are used in the display of LCDs.
- When compared to cathode-ray tubes and LEDs, LCDs are less expensive, offer superior contrast, and are lighter and thinner.

Disadvantages

These are some of the drawbacks of liquid crystal displays.

- Need extra sources of light.
- LCDs require an AC drive because their operating temperature range is limited, their reliability is low, and their speed is extremely low.

Applications

Below are some examples of how liquid crystal displays are used.

- ✓ Scientific and engineering fields, as well as the electronics industry, have significant uses for liquid crystal technology.
- ✓ This liquid crystal display technology can also be used to visualize radio frequency waves in a waveguide and is utilized in medical applications. It is also applicable to liquid crystal thermometers and optical imaging.

BCD to Seven Segment Display

Binary or digital decoders are digital combinational logic circuits that can translate one type of digital code into another.

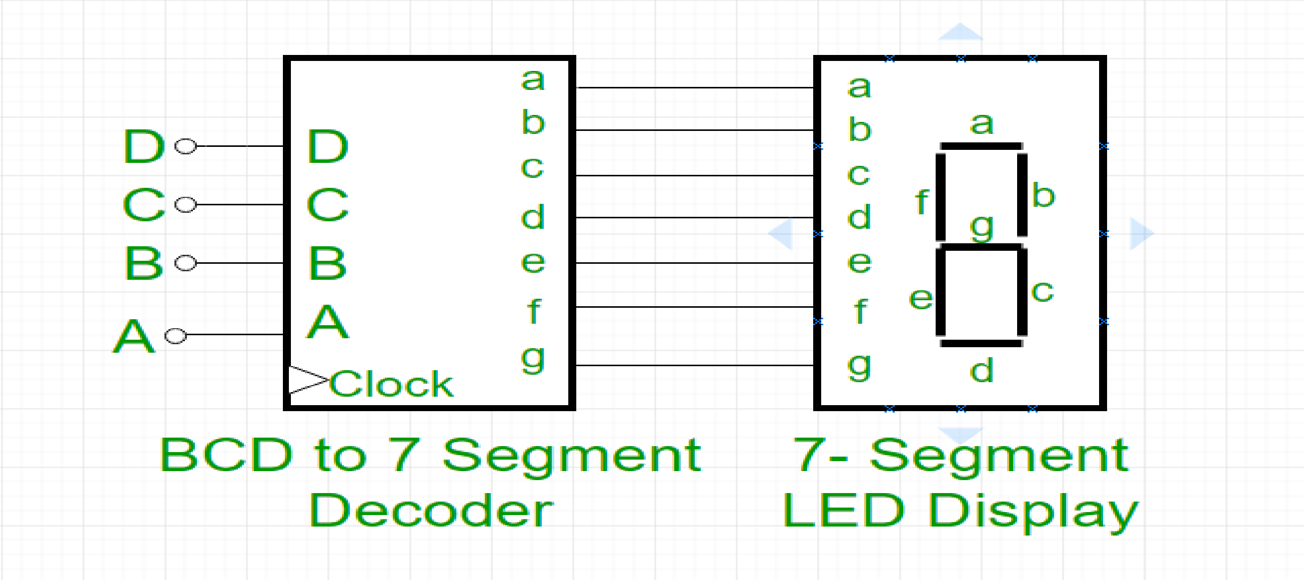
Binary coded decimals can be converted into a format that is easily readable by a 7-segment display using a special decoder called a BCD to 7-segment display decoder.

Binary Coded Decimal is referred to as BCD. Four bits of binary numbers can be used to represent each decimal number in this digital numbering system.

In a decimal system, there are ten numbers. We require 10 pairings of 4 binary bits to represent all 10 digits.

Digits	A	B	C	D
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1

Large numbers in binary format are easily understood and readable by digital systems such as computers. But big binary numbers are not readable by humans. In order to solve this problem, we must use a 7-segment display to display it as a decimal digit.



Decimal Digit	Input lines				Output lines							Display pattern
	A	B	C	D	a	b	c	d	e	f	g	
0	0	0	0	0	1	1	1	1	1	1	0	0
1	0	0	0	1	0	1	1	0	0	0	0	1
2	0	0	1	0	1	1	0	1	1	0	1	2
3	0	0	1	1	1	1	1	1	0	0	1	3
4	0	1	0	0	0	1	1	0	0	1	1	4
5	0	1	0	1	1	0	1	1	0	1	1	5
6	0	1	1	0	1	0	1	1	1	1	1	6
7	0	1	1	1	1	1	1	0	0	0	0	7
8	1	0	0	0	1	1	1	1	1	1	1	8
9	1	0	0	1	1	1	1	1	0	1	1	9

Plasma-Display

A television's fundamental component is the cathode ray tube (CRT). For the past 75 years, we have been utilizing this technology.

However, there are numerous drawbacks to a CRT. The screen is enormous, and the display is not very clear. The size of them increases as the screen width increases because the tube's length must also increase. Thus, the weight is increased.The best solution for this is a plasma display. Their main benefits are their compact size, wide screen display, and high definition clarity.

Plasma

One term for a fluorescent light's primary component is plasma. With ions and electrons, it is actually a gas. The galaxies only contains uncharged particles under typical circumstances. Stated differently, the quantity of positively charged protons and negatively charged electrons will be equal. The gas is now balanced as a result. If a voltage is applied to the gas, it could lead to an imbalance because there would be more electrons. As these liberated electrons collided with the atoms, additional electrons were released. Since the component now has a greater positive charge due to the missing electron, it turns into an ion.

Encouraging an electrical current to flow through plasma releases energy in the form of photons. Interaction results from the attraction of the ions and electrons to one another. Energy is created as a result of this collision. Henon and xenon atoms are primarily used in plasma displays. They produce light as a result of the energy released during collision. UV photons make up the majority of these light particles. They are crucial in stimulating the photons that are visible to us even though they are invisible to us.

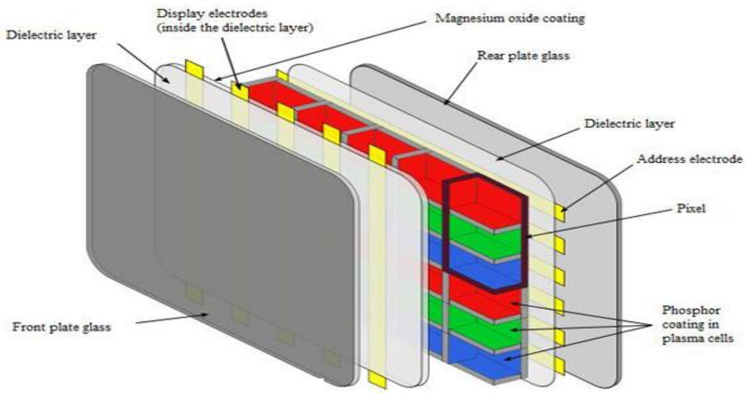
Electron beams are fired from an electron cannon into a standard television. The pixels light up when these electrons strike the screen. The composite pixel colors on the TV come in three different varieties, and they are all evenly spaced across the screen. The colors are blue, green, and red. These colors can be combined in various ratios to create other colors. Thus, all the necessary colors are produced by the TV.

The fluorescent lights in a plasma display create the image that is seen on the screen. There are three composite fluorescent color lights in each pixel, just like in a CRT TV. When these fluorescent lights are turned on, a variety of colors are created by mixing the composite colors.

Working of Plasma Display

Between two glass plates, millions of microscopic cells containing gases like xenon and neon are positioned. Additionally, electrodes are arranged inside the glass plates so that they are behind and in front of every cell. The address electrodes on the back glass plate are positioned so that they are behind the cells. Enclosed by a dielectric material and a layer of magnesium oxide on all sides, the transparent display electrodes are attached to the front glass plate. They're held in front of the enclosure.

As previously explained, the electrodes become charged when a voltage is applied, which ionizes the gas and produces plasma. This also includes the photon light that is released when ions and electrons collide.



Differentiating between color and monochrome plasma determines the ionization state. An insignificant voltage is inserted between the electrodes for the latter. Each cell must have phosphor coated on the back in order to produce color plasma. Photons are ultraviolet particles that emit light when they do. These UV rays cause phosphor to react, producing colored light. It has already been explained how pixels function. There are three composite colored sub-pixels for every pixel. The right color is produced when they are combined proportionately. Depending on each color's brightness and contrast, thousands of colors exist. The pulse-width modulation method is used to control this brightness. Thousands of times per second, the current pulse that passes through every cell is controlled using this technique.

Characteristics of Plasma Display

- It is possible to create large-scale plasma displays up to 150 inches diagonal.

- Extremely high contrast and low illumination, akin to a "dark room"
- The thickness of the plasma display panel is approximately 2.5 inches, resulting in a maximum total thickness of 4 inches.
- Darker-colored images require a 50-inch display to have a power consumption of between 50 and 400 watts.
- In shop mode, all displays are sold out and use more energy than what is mentioned above. It has a home mode setting.
- Has nearly 100,000 hours in its lifetime. Following this time, the TV's brightness drops to half.

Advantages of Plasma Display

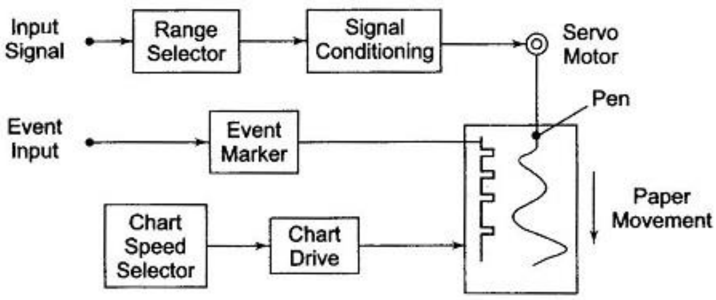
- The thinnest display of them all
- Extremely elevated contrast ratios [1:2,000,000]
- Compared to CTRs, it is lighter and less bulky.
- Greater viewing angles [178 degrees] in comparison to other displays.
- Suitable for mounting on walls.
- Superior color reproduction due to high clarity. [16.7 million/224 as opposed to 68 billion/236]
- Exceptionally low motion blur because of fast refresh rates and reaction times.
- Contains roughly 100,000 hours of life left in it.

Disadvantages of Plasma Display

- ✓ Cost is significantly higher than that of other displays, and energy consumption is higher.
- ✓ Causes reflections to create glares.
- ✓ There are no displays available in sizes smaller than 32 inches.
- ✓ The glass screen that is included to protect the display weighs more even though the display itself doesn't weigh much.
- ✓ ☐ Unsuitable for use at high elevations. A buzzing sound or transient damage could result from the pressure differential between the gas and the air.
- ✓ Flickering may occur in the area.

Strip Chart Recorder Working Principle:

A continuous roll of chart paper that moves at a constant speed is used to record data in a strip chart recorder according to its basic operating principles. The recorder captures the variation of one or more variables over time. A long roll of vertically moving chart paper, a pen (stylus) for marking on movable paper, a pen (stylus) driving system, a chart paper drive mechanism, and a chart speed selector switch are the essential parts of a strip chart recorder working principle.



Basic Strip Chart Recorder

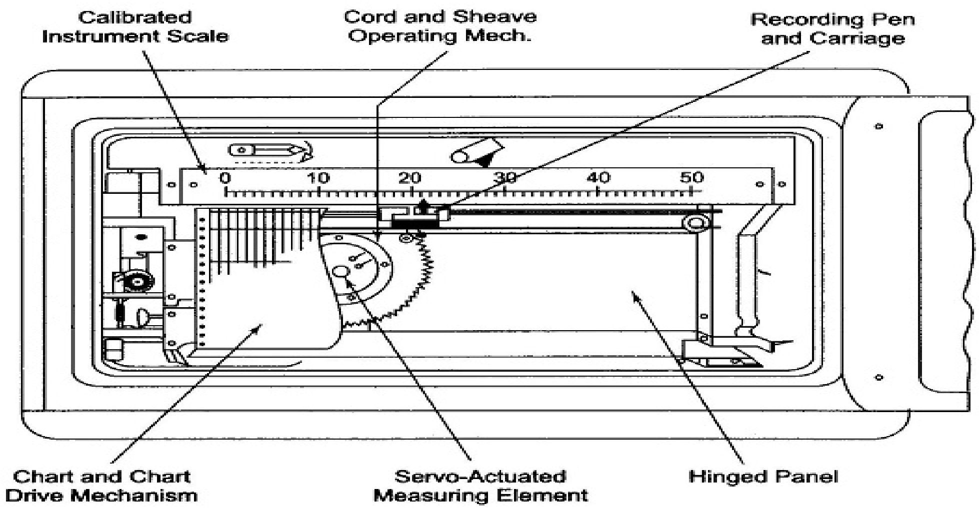
A pointer attached to the stylus is used by most recorders to measure the instantaneous value of the quantity being recorded directly on a calibrated scale. Figure depicts the assembly of a working principle for a strip chart recorder. Servo driven, this recorder only needs one pen.

For the purpose of ensuring that the movement of the pen (or stylus) across the paper matches the input voltage within the required frequency range, most strip chart recorders employ a servo feedback mechanism.

The position of the writing head (stylus) is typically measured using a potentiometer system.

Typically, a chart paper drive system consists of a stepping motor that maintains a steady pace for the movement of the paper.

There are several ways to record the data on the strip chart paper.



Assembly of a Single Pen Servo Operated Strip Chart Recorder

Pen and Ink Stylus:
Through capillary action, the stylus receives ink from a refillable reservoir. Disposable fiber tip pens have supplanted these with modern technology. Moreover, multichannel operation is possible, meaning that up to six pens can be used simultaneously to record data. To prevent mechanical interference when using multiple pens, the pens must be spaced out.
Impact Printing:
When the impact system was first introduced, the data recording ink was supplied by a carbon ribbon that was positioned between the paper and pointer mechanism. Using the pointer mechanism, the mark was made on the paper. Up to 20 variables can be recorded simultaneously with impact printing, which gives it an advantage over pen and ink methods. A wheel and matching ink pad that supplies the ink for the wheel's symbol are used to accomplish this. With each variable that is recorded, the wheel is moved across the paper.
Pressure-sensitive paper is utilized in certain mechanisms. The chopper bar is used to mark the paper by applying pressure to the surface. A single chopper bar occurs once every second.
Thermal Writing:
A unique movable pen that receives thermal heating from an electric current is employed in this system. For this system, thermally sensitive paper that changes color when heated is needed. A unique movable pen that receives thermal heating from an electric current is employed in this system. For this system, thermally sensitive paper that changes color when heated is needed.
Electric Writing:

The basis of this method is the electrostatics principle.

An unique chart paper is needed for this method. This paper is made up of a thin layer of aluminum coated on a paper base that has been colored (black, blue, or red) with dye.

A tungsten wire that moves across an aluminum surface makes up the stylus, or pen. Marks can be made on paper by providing the stylus with a potential of 35 V. The aluminum is removed by an electric discharge that results from this, exposing the colored dye.
Optical Writing:

A unique type of photo-sensitive chart paper that is susceptible to ultraviolet light is used for this writing technique. Galvanometer systems are the main application for this technique.

The use of ultraviolet light helps mitigate the negative effects of ambient light. In contrast to ordinary light, which cannot be developed under artificial or daylight lighting, the paper can be developed without the need for specialized chemicals.

The pointer on most recorders is fastened to the stylus. The value of the quantity being recorded is displayed by this pointer as it moves along a calibrated scale.

Paper drive system: The paper drive system should provide consistent speed for the paper. Most systems can make use of a spring wound mechanism. To drive the paper, a synchronous motor is employed.

Chart speed: Chart speed is the unit of measurement used to describe how the recording paper moves in a strip chart recorder. It depends on mechanical gear trains and is expressed in in/s or mm/s. If one knows the chart speed, one can calculate the recorded signal's period as follows:

$$\text{Period} = \frac{\text{time}}{\text{cycle}} = \frac{\text{time base}}{\text{chart speed}}$$

and the formula for frequency is f = 1/period.

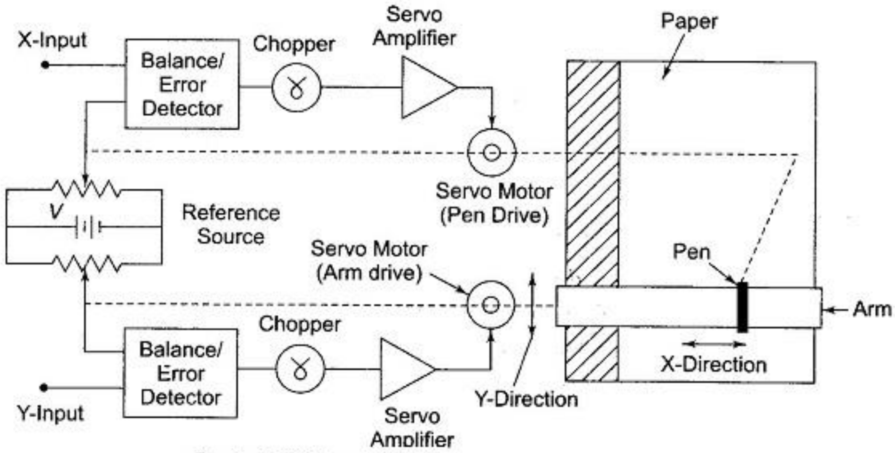
XY Recorder Working – In most research fields, it is often more convenient to plot the instantaneous relationship between two variables [Y = f(x)] rather than plotting each variable separately as a function of time. When this occurs, one variable is plotted against another using the X-Y recorder. An analog X-Y recorder deflects its writing head in either the x or y direction on a fixed graph chart paper. Typically, the graph paper is square in shape and is secured in place either by vacuum or electrostatic attraction.

To control the writing head, either a self-balancing potentiometer or a servo feedback system is employed. Depending on the use, the writing head has one or two pens in it. In an X-Y recorder, one emf is plotted as a function of another emf in real life.

X-Y recorders can also be used to plot one physical quantity (displacement, force, strain, pressure, etc.) as a function of another physical quantity. By utilizing a suitable transducer, which produces an output (EMF) proportionate to the physical quantity, this is achieved.

Utilizing a stationary chart paper as a reference, the servo system drives the motion of the recording pen in both axes. Using a sliding pen and moving arm arrangement, movement in the x and y directions is obtained.

Figure shows an example of a block diagram showing how an XY recorder works.



Basic X–Y Recorder

To enable it to function within the recorder's dynamic range, each input signal is attenuated between 0 and 5 mV. This is followed by a comparison of the attenuated signal with a fixed internal reference voltage by the balancing circuit. The difference between the reference voltage and the attenuated signal generates a dc error signal, which is the output of the balancing circuit. An ac signal is subsequently produced from this dc error signal with the aid of a chopper circuit.

An ac amplifier amplifies this ac signal since it is insufficient to operate the pen/arm drive motor. The servo motor is then activated by this amplified signal, also known as the error signal, causing the pen/arm mechanism to move in the proper direction, thereby reducing the error and bringing the system to balance. Therefore, the pen/arm attempts to maintain system balance as the input signal being recorded varies, creating a record on the paper.The aforementioned action occurs simultaneously in both axes. As a result, a record of one physical quantity relative to another is acquired.

With an accuracy of ± 0.1% of the full scale, certain X-Y recorders offer continuously variable x and y input ranges between 0.25 mV/cm and 10 V/cm. There are additional adjustments for zero offset.

X-Y recorders' acceleration and slewing rate define their dynamic performance. With a peak acceleration of 7620 cm/s and a slewing rate of 97 cm/s, an extremely fast X-Y recorder with a signal up to 10 Hz and an amplitude of 2 cm peak to peak could record signals.

The sensitivity of an XY recorder working can be as high as 10 μV/mm, its slewing speed can reach 1.5 ms, and its frequency response can reach approximately 6 Hz on both axes. About 250 by 180 mm is the size of the chart. An X-Y recorder's accuracy is within ± 0.3%.

Utilization of X-Y Recorders:

The following parameters are measured using these recorders.

- Motor speed-torque characteristics.
- Power supply regulation curves.
- Plotting the properties of active components, like transistors, rectifier diodes, zener diodes, and vacuum tubes, among others.
- Plotting curves such as hysteresis and stress-strain.
- Electrical properties of materials, like resistance against temperature.

Potentiometric Recorder Working Principle

Null Type Recorder:

The principle of self-balancing or null conditions underlies these null type recorders. A sensor or transducer provides an input to the recorder's measuring circuit, upsetting its equilibrium and generating an error voltage that drives another device to either reset the system's balance or bring it to zero.

The error signal's magnitude and direction correspond to the movement of the balance restoring device and the quantity being measured, respectively.

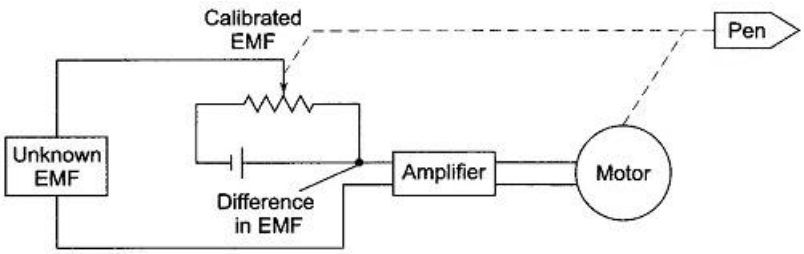
The different types of Null Type Recorder are as follows:

- Potentiometric recorders
- Bridge recorders
- LVDT recorders (Linear Variable Differential Transformer)

Potentiometric recorders
A galvanometer-style recorder's primary drawbacks are its low input impedance and restricted sensitivity. This disadvantage can be overcome by putting an amplifier in between the input terminals and the display or indicating devices. Low accuracy is exchanged for increased sensitivity and a high input impedance in this amplifier. Using a potentiometer circuit, the input signal is compared with a reference voltage to increase the instrument's accuracy.

A servo motor, whose rotational speed and direction are determined by the output of an amplifier, is used to achieve the self-balancing function. All this is in a dc system is a reversible motor, like the kind that has a permanent magnet for a field. It appears as a two-phase motor in the alternating current system.

A potentiometric or self-balancing recorder's basic circuit is shown in Figure.

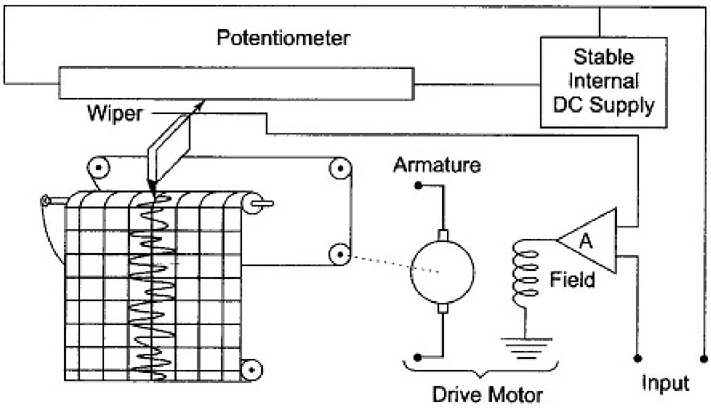


Basic Circuit of a Self-Balancing or Potentiometric Recorder

The error signal is the difference between the potentiometer voltage and the input signal. A DC motor's field coil is energized by means of an amplified error signal. Instead of rotating the voltage divider's arm to achieve a balance between the two opposing voltages in this circuit, an error current is permitted to flow in either a clockwise or counterclockwise direction, depending on which voltage is higher. The electronic detector uses this error as its input, amplifying it before feeding it to the balancing motor. This motor is configured so that its rotation reduces error by rotating the voltage divider arm, which is geared to it. The null balance is produced when the motor slows down and eventually stops at the point where the error is zero as the error decreases.

This is accomplished by mechanically attaching the wiper/variable arm to the DC motor's armature. Additionally, the wiper and pen are mechanically linked. As a result, the pen moves synchronously in the same direction as the wiper does, recording the input waveform. When the voltage of the potentiometer is balanced against the voltage of the unknown signal, the wiper comes to rest. The outcome of this method is very high input impedance graphical recorders.

Using 0.8 Hz as the bandwidth, 4 V/mm of sensitivity is achieved with an error of less than ± 0.25%. For potentiometer recorders, the chart drive is typically driven by a motor synchronized to the power line frequency. So, a gear train with varying gear ratios can be used to alter the chart drive's speeds. The main applications of potentiometer recorders are in process temperature monitoring and recording. A dc self-balancing system's basic block diagram is depicted in the figure below. Single point recorders are instruments that track variations in just one measured variable.



Block Diagram of Self-Balancing Potentiometer Recorder

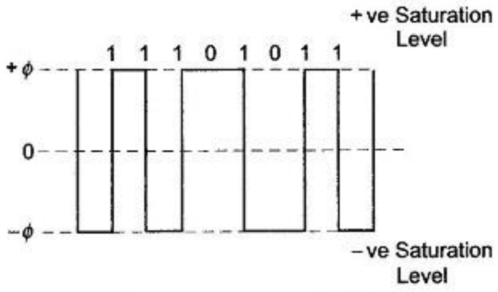
Recorders with multiple inputs recorded on one recorder are known as multipoint recorders. They can have up to 24 inputs and display traces in six different colors. Data is recorded at frequencies ranging from DC to 5 kHz on an 8-inch chart; models with up to 36 channels are also offered.

Digital Data Recorders

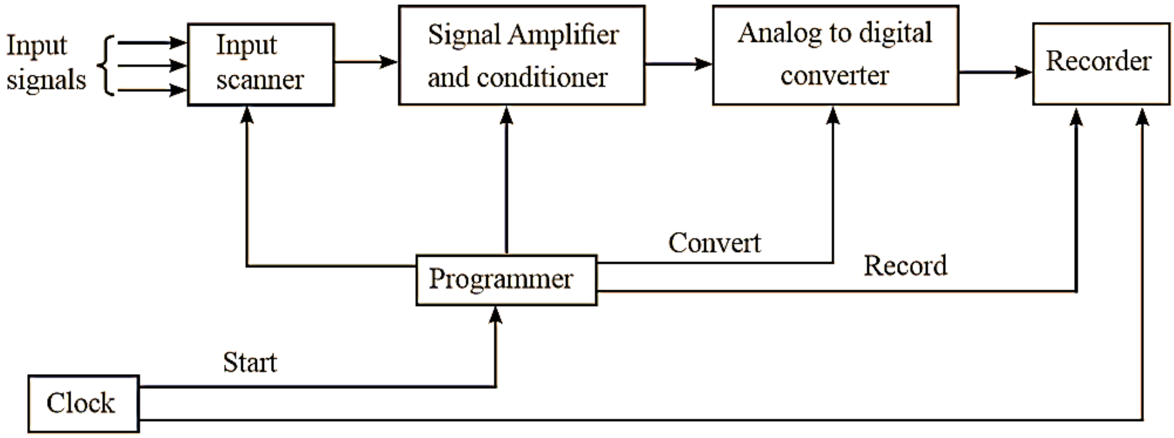
Digital Data Recording: Digital data processing applications frequently use digital magnetic tapes as storage devices. Incremental and synchronous digital tape units are the two types available. Digital recorders that are designed to record digital characters are instructed to advance (increment) with each digital character. There could be a noticeable lag or even discontinuity in the input data flow. Each character is positioned exactly and equally along the tape in this manner.

In a synchronous digital recorder, a lot of data characters are recorded while the tape advances at a steady pace of roughly 75 cm/s. Up to tens of thousands of characters per second of precise data are fed in. The tape is accelerated quickly, recording occurs, and the tape is quickly stopped. This method allows for the writing of a record, or block of characters, with each character evenly spaced along the tape. The record gap, a blank space on the tape, is typically used to divide data blocks apart from one another. The tape is started and stopped by the synchronous tape unit for every block of data that needs to be recorded.

On magnetic tape, characters are represented by a coded combination of one bit placed in the proper tracks throughout the width of the tape. The IBM format of Non-Return Zero (NRZ) recording, which is widely accepted in the industry, is the recording method used in the majority of instrumentation tape recorders.



NRZ Method of Digital Recording

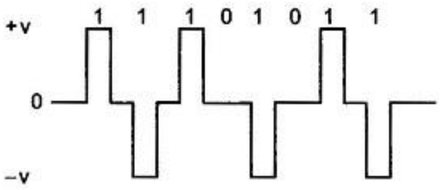


The tape is always magnetically saturated in this system, either in the positive or negative direction. The NRZ method uses a change in flux direction on the tape to represent a 1 bit and a zero bit to be indicated by no change in flux direction. Fig. provides an illustration of this method using a flux pattern in the NRZ system to represent the binary number 11101011. Reversing the recording head field's direction is the most straightforward way to code it.When recording digital data, an amplitude recording field that is big enough to create magnetic saturation across the entire thickness of the tape layer is reversed to record a 1 signal and maintained constant to record a 0 signal. Using a timing signal from a different clock track that represents the moment a 1 or 0 is recorded, this recording can be replicated.There are also self-clocking systems, in which the recording field is periodically reversed and 1 or 0 signals are recorded in between clock signals. It is clear that adjusting the field amplitude to cause the maximum longitudinal decrement to occur in the tape's surface layer yields the best resolution in NRZ recording. To guarantee more dependable recordings on a coated thicker tape, larger fields are typically used in practice. Big recording fields are used, sacrificing resolution for increased reliability in order to reduce the effects of dropouts.

Currently, there are 1500–2000 flux reversals per inch of high density data recorded on oxide powder tape. In the future, extensions up to 10,000 reversals per inch may be achievable by employing thin metallic coatings with strong coercive force.

The typical issues of non-linearity and distortion present in direct and FM recordings do not arise because magnetization is independent of frequency and amplitude and depends only on the polarity of the recording current. Only enough current with the appropriate polarity is needed for the write coils in the tape head to saturate the tape. Signal drop out and spurious pulses (losing or adding data) are two issues that arise in digital recording. When the packing density rises (a lot of bits per unit tape length), there is a significant risk of signal dropout or pulse loss.

Most tape systems have a parity check to detect dropout errors. Using an additional tape track to write a parity check pulse, this check counts the number of 1 bits of information that were originally recorded on the tape. An even parity check is one in which the number of 1s recorded is even; an odd parity check is one in which the number of 1s recorded is odd. A parity error is found when there is a dropout because the parity check does not match the real data that was recorded.



Bipolar (Alternate
Mark Inversion) NRZ

In addition to signaling that a parity error has occurred, some systems use the parity error system to correctly insert missing bits.

Fig. presents an alternate mark inversion scheme, also known as bipolar. Figure illustrates this format, which has zero power in the spectrum at zero frequency and no residual dc component. These pulses are created by inverting the polarity of alternate 1 bits and have a 50% duty cycle, meaning they are only half as wide as the pulse interval permits. A three state signal (+ V, 0 – V) is actually what the bipolar format represents.

Advantages of Digital Data Recording:

Using basic conditioning equipment, high accuracy, insensitivity to tape speed, and direct feeding of data to a digital computer for processing

Disadvantages of Digital Data Recording:

- The transducers provide analog information, so an A/D converter is needed. Poor tape economy.
- An excellent tape and a mechanism for transporting it are needed.