UNIT-1

Block Schematics of Measuring Systems

Introduction:

The measurement of any quantity plays very important role not only in science but in all branches of engineering, medicine and in almost all the human day to day activities.

The technology of measurement is the base of advancement of science. The role of science and engineering is to discover the new phenomena, new relationships, the laws of nature and to apply these discoveries to human as well as other scientific needs. The science and engineering is also responsible for the design of new equipments. The operation, control and the maintenance of such equipments and the processes is also one of the important functions of the science and engineering branches. All these activities are based on the proper measurement and recording of physical, chemical, mechanical, optical and many other types of parameters.

The measurement of a given parameter or quantity is the act or result of a quantitative comparison between a predefined standard and an unknown quantity to be measured. The major problem with any measuring instrument is the error. Hence, it is necessary to select the appropriate measuring instrument and measurement procedure which minimises the error. The measuring instrument should not affect the quantity to be measured.

An electronic instrument is the one which is based on electronic or electrical principles for its measurement function. The measurement of any electronic or electrical quantity or variable is termed as an electronic measurement.

Advantages of Electronic Measurement

The advantages of an electronic measurement are

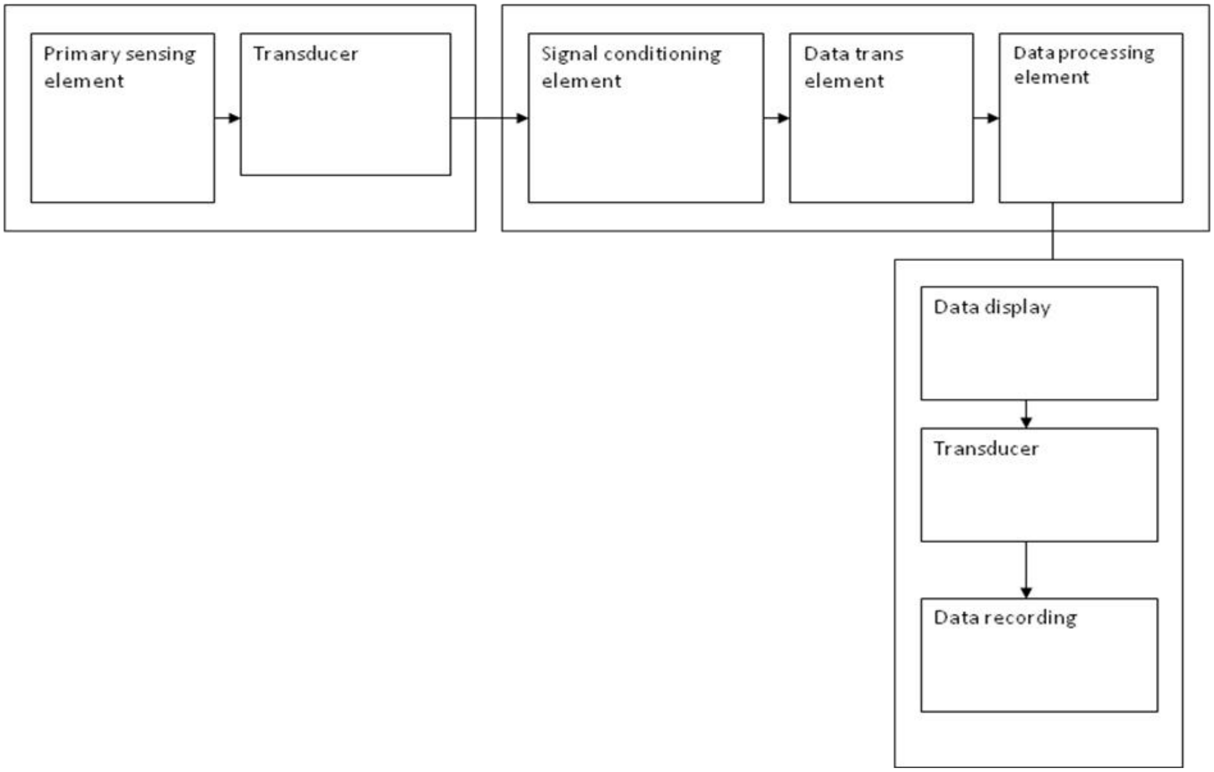
1. Most of the quantities can be converted by transducers into the electrical or electronic signals.
2. An electrical or electronic signal can be amplified, filtered, multiplexed, sampled and measured.
3. The measurement can easily be obtained in or converted into digital form for automatic analysis and recording.
4 The measured signals can be transmitted over long distances with the help of cables or radio links, without any loss of information.

5. Many measurements can be carried either simultaneously or in rapid succession.
6. Electronic circuits can detect and amplify very weak signals and can measure the events of very short duration as well.
7. Electronic measurement makes possible to build analog and digital signals. The digital signals are very much required in computers. The modern development in science and technology are totally based on computers.
8. Higher sensitivity, low power consumption and a higher degree of reliability are the important features of electronic instruments and measurements. But, for any measurement, a well defined set of standards and calibration units is essential. This chapter provides an introduction to different types of errors in measurement, the characteristics of an instrument and different calibration standards.

Functional elements of an instrument:

Any instrument or a measuring system can be described in general with the help of a block diagram. While describing the general form of a measuring system, it is not necessary to go into the details of the physical aspects of a specific instrument. The block diagram indicates the necessary elements and their functions in a general measuring system.

- **Primary sensing element:** which senses the quantity under measurement
- **Variable conversion element:** which modifies suitably the output of the primary sensing element
- **Variable Manipulation Element:** The signal gets manipulated here preserving the original nature of it
- **Data Transmission Element:** The transmission of data from one another is done by the data transmission element
- **Data presentation element** : The display or readout devices which display the required information about the measurement.



Static characteristics:

As mentioned earlier, the static characteristics are defined for the instruments which measure the quantities which do not vary with time. The various static characteristics are accuracy, precision, resolution, error, sensitivity, threshold, reproducibility, zero drift, stability and linearity.

Accuracy:

It is the degree of closeness with which the instrument reading approaches the true value of the quantity to be measured. It denotes the extent to which we approach the actual value of the quantity. It indicates the ability of instrument to indicate the true value of the quantity. The accuracy can be expressed in the following ways.

1) Accuracy as 'Percentage of Full Scale Reading : In case of instruments having uniform scale, the accuracy can be expressed as percentage of full scale reading.

For example, the accuracy of an instrument having full scale reading of 50 units may be expressed as ± 0.1% of full scale reading. From this accuracy indication, practically accuracy is expressed in terms of limits of error. So for the accuracy limits specified above, there will be ± 0.05 units error in any measurement. So for a reading of 50 units, there will be error of ± 0.05 units i.e. ± 0.1 % while for a reading of 25 units, there will be error of ± 0.05 units in the reading i.e. ± 0.2%. Thus as reading decreases, error in measurement is ± 0.05 units but net percentage error is more. Hence, specification of accuracy in this manner is highly misleading.

2) Accuracy as 'Percentage of True Value' : This is the best method of specifying the accuracy. It is to be specified in terms of the true value of quantity being measured. For example, it can be specified as ± 0.1% of true value. This indicates that in such cases, as readings get smaller, error also gets reduced. Hence accuracy of the instrument is better than the instrument for which it is specified as percent of full scale reading.

Precision:

It is the measure of consistency or repeatability of measurements.

Let us see the basic difference between accuracy and precision. Consider an instrument on which, readings upto 1/1000th of unit can be measured. But the instrument has large zero adjustment error. Now every time reading is taken, it can be taken down upto '1000th of unit. So as the readings agree with each other, we say that the instrument is highly precise. But, though the readings are precise upto 10100th of unit, the readings are inaccurate due to large zero adjustment error. Every reading will be inaccurate, due to such error. Thus a precise instrument may not be accurate. Thus the precision means sharply or clearly defined and the readings agree among themselves. But there is no guarantee that readings are accurate. An instrument having zero error, if calibrated properly, can give accurate readings but in that case still, the readings can be obtained down upto 1/10th of unit only. Thus accuracy can be improved by calibration but not the precision of the instrument.

The precision is composed of two characteristics:

- Conformity and
- Number of significant figures.

Conformity:

Consider a resistor having true value as 2385692.0Ω, which is being measured by an ohmmeter. Now, the meter is consistently measuring the true value of the resistor. But the reader, can read consistently, a value as 2.4 MΩ due to nonavailability of proper scale. The value 2.4 MΩ is estimated by the reader from the available scale. There are no deviations from the observed value. The error created due to the limitation of the scale reading is a precision error.

Significant Figures:

The precision of the measurement is obtained from the number of significant figures, in which the reading is expressed. The significant figures convey the actual information about the magnitude and the measurement precision of the quantity.

Resolution:

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

So if a nonzero input quantity is slowly increased, output reading will not increase until some minimum change in the input takes place. This minimum change which causes the change in the output is called resolution. The resolution of an instrument is also referred to as discrimination of the instrument. The resolution can affect the accuracy of the measurement.

Errors:

Static error = measured value – true value

The most important static characteristics of an instrument is its accuracy, which is generally expressed in terms of the error called static error.

Mathematically it can be expressed as, e = *At* - Am J

where e = Error
A_m = Measured value of the quantity
A_t = True value of the quantity

In this expression, the error denoted as e is also called absolute error. The absolute error does not indicate precisely the accuracy of the measurements. For example, absolute error of ± 1 V is negligible when the voltage to be measured is of the order of 1000 V but the same error of ±1 V becomes significant when the voltage under measurement is 5 V or so. Hence, generally instead of specifying absolute error, the relative or percentage error is specified.

Sensitivity:

The sensitivity is always expressed by the manufacturers as the ratio of the magnitude of quantity being measured to the magnitude of the response. Actually, this definition is the reciprocal of the sensitivity is called inverse sensitivity or deflection factor. But manufacturers call this inverse sensitivity as a sensitivity.

$$\text{Inverse sensitivity} = \text{Deflection factor}$$

$$\therefore \quad \boxed{\text{Deflection factor} = \frac{1}{\text{Sensitivity}} = \frac{\Delta q_i}{\Delta q_o}}$$

The units of the sensitivity are millimeter per micro-ampere, millimeter per ohm, counts per volt,

Drift : Gradual shift in the meassured value ,over an extended period, when there is no change in input.

Threshold: The minimum value of input for which the device just starts to respond.

Range/Span: The minimum and maximum value of quantity so that the device is capable of measuring.

Repeatability: A measure of how well the output returns to a given value when the same precise input is applied several times. Or The ability of an instrument to reproduce a certain set of reading within a given accuracy.

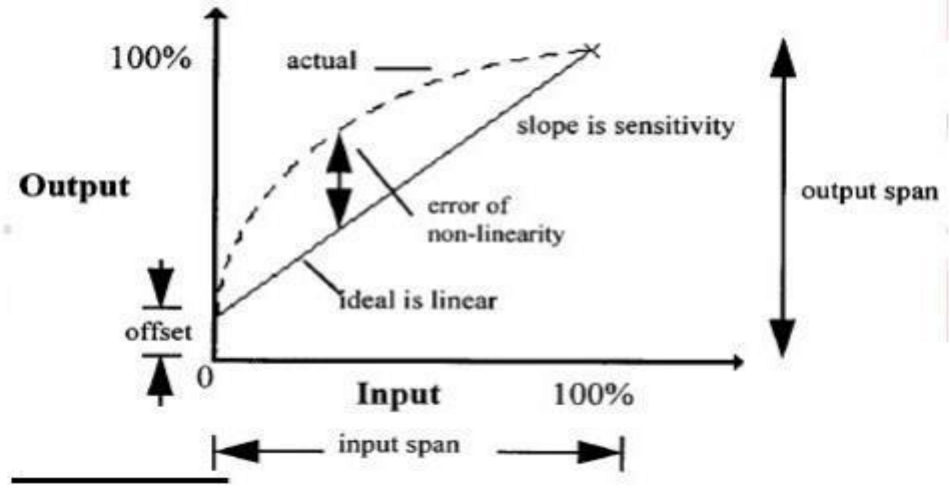
Linearity: Input output relationship of a device must be linear.

But practical systems shows small deviations from the linear shape (allowed within the specified limits)

Hysteresis: Input is increased from negative value, output increases as indicated by curve 1

- Then the input is steadily decreased , output does not follow the same path , but lag by a certain value as indicated by curve 2 •

The difference between the two curves is called Hysterisis.



DYNAMIC CHARACTERISTICS:

The response of instruments or systems to dynamic I/P s are also functions of time.

Instruments rarely respond instantaneously to changes in the measured variables.

Instead, they exhibit slowness or sluggishness due to such things as mass, thermal capacitance, fluid capacitance or electric capacitance.

- **Speed of Response**: It is the ability of a system to respond to a sudden changes in the input signal/quantity
- **Fidelity**: It is the degree to which an instrument indicates the changes in the measured variable without dynamic error (Indication of how much faithfully system responds to the changes in input).

Lag: It is the retardation or delay in the response of an instrument to changes in the measured variable. Two types : Process lag(process) and Control lag (Instrument)

Dynamic error:

It is the difference between the true value of the variable to be measured, changing with time and the value indicated by the measurement system, assuming zero static error. The Fig. 1.13 shows the dead time, i.e. time delay and the dynamic error.

Types of errors:

The static error is defined earlier as the difference between the true value of the variable and the value indicated by the instrument. The static error may arise due to number of reasons. The static errors are classified as:

1) Gross errors

2) Systematic errors

3) Random errors

Gross errors:

The gross errors mainly occur due to carelessness or lack of experience of a human being. These cover human mistakes in readings, recordings and calculating results. These errors also occur due to incorrect adjustments of instruments. These errors cannot be treated mathematically. These errors are also called personal errors. Some gross errors are easily detected while others are very difficult to detect.

Systematic errors:

The systematic errors are mainly resulting due to the shortcomings of the instrument and the characteristics of the material used in the instrument, such as defective or worn parts, ageing effects, environmental effects, etc.

A constant uniform deviation of the operation of an instrument is known as a systematic error. There are three types of systematic errors as

1) Instrumental errors 2) Environmental errors 3) Observational errors

Instrumental errors :

These errors are mainly due to following three reasons

- Short-comings of instrument

These are because of the mechanical structure of the instruments eg. Friction in the bearings of various moving parts, irregular spring tensions, hysteresis, gear backlash, variation in air gap etc.

Misuse of instrument A good instrument if used in abnormal way gives misleading results. Poor initial adjustments, Improper zero setting, Using leads of high resistance. Elimination: Use the instrument intelligently & Correctly

- Loading effects Loading effects due to Improper way of using the instrument

- **Ellimination.**

– Selecting proper instrument and the transducer for the measurement.

– Recognize the effect of such errors and apply the proper correction factors.

– Calibrate the instrument carefully against standard.

Environmental Errors (due to the External Conditions)

- The various factors : Temperature changes, Pressure, vibratons, Thermal emf., stray capacitance, cross capacitance, effect of External fields, Aging of equipments and Frequency sensitivity of an instrument.

Elimination • Using proper correction factors and using the instrument Catalogue • Using Temperature & Pressure control methods etc. • Reducing the effect of dust, humidity on the components in the instruments. • The effects of external fields can be minimized by using the magnetic or electrostatic shields of screens.

Observational Errors:

Error introduced by the observer

Few souces are:

- Parallax error while reading the meter,
- wrong scale selection,
- habits of individual obsever
- Elimination

Use the

- instrument with mirrors,
- instrument with knife edge pointers,
- Instrument having digital display

Random errors:

Some errors still result, though the systematic and instrumental errors are reduced or atleast accounted for. The causes of such errors are unknown and hence, the errors are called **random** errors. These errors cannot be determined in the ordinary process of taking the measurements.

Absolute and relative errors:

When the error is specified interms of an absolute quantity and not as a percentage, then it is called an absolute error.

Thus the voltage of 10 ± 0.5 V indicated ± 0.5 V as an absolute error. When the error is expressed as a percentage or as a fraction of the total quantity to be measured, then it is called relative error.

Generally the relative error in case of resistances is specified as percentage of tolerances. Another method of expressing error is by specifying it as parts per million (ppm), relative to the total quantity. So it is a relative error specification . Generally change in resistance with temperature is indicated in ppm/ °C shows the variation in resistance with Temperature temperature. Thus if a resistance of 100 kΩ. has a temperature coefficient of 50 *ppm/C* means 50 parts per millionth per degree celcius. Thus one millionth of 100 kohm. is 0.1 ohm and 50 such parts means 5 D.

Limiting errors:

The manufacturers specify the accuracy of the instruments within a certain percentage of full scale reading. The components like the resistor, inductor, capacitor are guaranteed to be within a certain percentage of rated value. This percentage indicates the deviations from the nominal or specified value of the particular quantity. These deviations from the specified value are called **Limiting Errors.** These are also called **Guarantee Errors.**

Thus the actual value with the limiting error can be expressed mathematically as,

$$\boxed{A_a = A_s \pm \delta A}$$

where A_a = Actual value

A_s = Specified or rated value

δA = Limiting error or tolerance

Relative limiting error:

This is also called fractional error. It is the ratio of the error to the specified magnitude of a quantity.

Thus $$\boxed{e = \frac{\delta A}{A_s}}$$

where e = Relative timing error

From the above equation, we can write,

$$\delta A = e \, . \, A_s$$

and

$$A_a = A_s \pm \delta A$$

$$= A_s \pm e \, A_s$$

$$\boxed{A_a = A_s [\, 1 \pm e \,]}$$

The percentage relative limiting error is expressed as

$$\boxed{\% \, e = e \times 100}$$

The relative limiting error can be also be expressed as,

$$\boxed{e = \frac{\text{Actual value } (A_a) - \text{Specified value } (A_s)}{\text{Specified value } (A_s)}}$$

Voltmeters and multimeters:

Basic meter:

A basic d.c. meter uses a motoring principle for its operation. It stntes that any current carrying coil placed in a magnetic field experiences a force, which is proportional to the magnitude of current passing through the coil. This movement of coil is called D'Arsonval movement and basic meter is called D'Arsonval galvanometer.

D.C instruments:

a) Using shunt resistance, d.c. current can be measured. The instrument is d.c. microammeter, milliammeter or ammeter.

b) Using series resistance called multiplier, d.c. voltage can be measured. The instrument is d.c. millivoltmeter, voltmeter or kilovoltmeter.

c) Using a battery and resistive network, resistance can be measured. The instrument is ohmmeter.

A.C instruments:

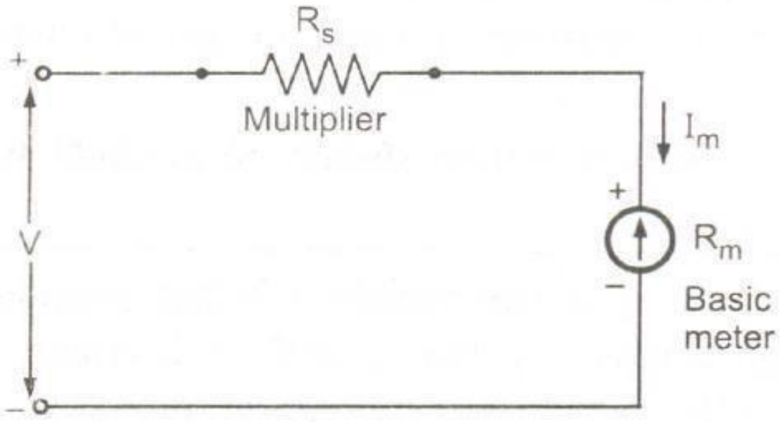
a) Using a rectifier, a.c. voltages can be measured, at power and audio frequencies. The instrument is a.c. voltmeter.

b) Using a thermocouple type meter radio frequency (RF) voltage or current can be measured.

c) Using a thermistor in a resistive bridge network, expanded scale for power line voltage can be obtained.

Basic DC voltmeter:

The basic d.c. voltmeter is nothing but a permanent magnet moving coil (PMMC) 0' Arsonval galvanometer. The resistance is required to be connected in series with the basic meter to use it as a voltmeter. This series resistance is called a **multiplier.** The main function of the multiplier is to limit the current through the basic meter so that the meter current does not exceed the full scale deflection value. The voltmeter measures the voltage across the two points of a circuit or a voltage across a circuit component. The basic d.c. voltmeter is shown in the Fig.



The voltmeter must be connected across the two points or a component, to measure the potential difference, with the proper polarity.

The multiplier resistance can be calculated as:

Let R_m = internal resistance of coil i.e. meter

R_s = series multiplier resistance

I_m = full scale deflection current

V = full range voltage to be measured

From Fig. 2.1, $\therefore\ V = I_m(R_m + R_s)$

$$\therefore \quad V = I_m R_m + I_m R_s$$

$$\therefore \quad I_m R_s = V - I_m R_m$$

$$\therefore \quad \boxed{R_s = \frac{V}{I_m} - R_m}$$

The multiplying factor for multiplier is the ratio of full range voltage to be measured and the drop across the basic meter.

Let v = drop across the basic meter = $I_m R_m$

$\therefore$ m = multiplying factor = $\frac{V}{v}$

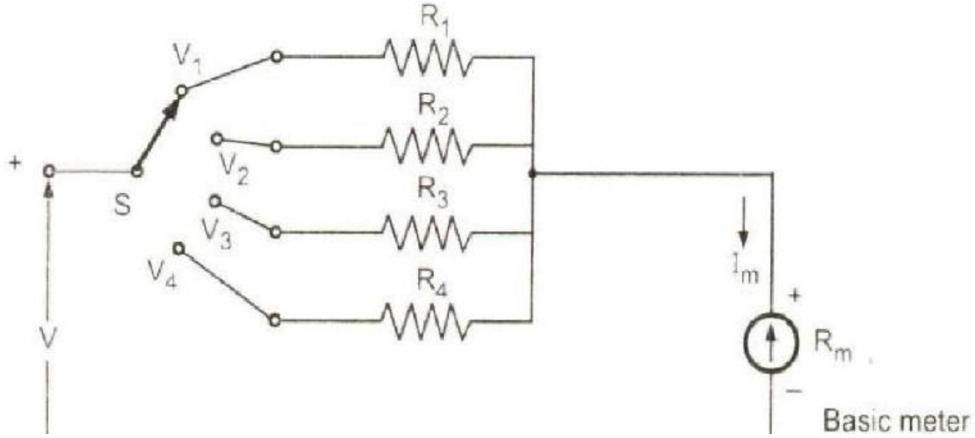
$$= \frac{I_m(R_m + R_s)}{I_m R_m}$$

Hence multiplier resistance can also be expressed as,

$$R_s = (m-1) R_m$$

Multirange voltmeters:

The range of the basic d.c. voltmeter can be extended by using number of multipliers clnd a selector switch. Such a meter is called **multirange** voltmeter.



The R1, R2, R3 and R4 are the four series multipliers. When connected in series with the meter, they can give four different voltage ranges as V1, V2, V3, and V4. The selector switch S is multiposition switch by which the required multiplier can be selected in the circuit.

The mathematical analysis of basic d.c.*voltmeter* is equally applicable for such multirange *voltmeter.* Thus,

$$R_1 = \frac{V_1}{I_m} - R_m \qquad R_2 = \frac{V_2}{I_m} - R_m \qquad \text{and so on.}$$

Sensitivity of voltmeters:

In a multirange voltmeter, the ratio of the total resistance Rt to the voltage range remains same. This ratio is nothing but the reciprocal of the full scale deflection current of the meter i.e. 1/101.

This value is called sensitivity of the voltmeter. Thus the sensitivity of the voltmeter is defined,

$$S = \frac{1}{\text{Full scale deflection current}}$$

$$\boxed{S = \frac{1}{I_m}\ \Omega/V \text{ or } k\Omega/V}$$

Loading effect:

While selecting a meter for a particular measurement, the sensitivity rating IS very important. A low sensitive meter may give the accurate reading in low resistance circuit but will produce totally inaccurate reading in high resistance circuit.

The voltmeter is always connected across the two points between which the potential difference is to be measured. If it is connected across a low resistance then as voltmeter resistance is high, most of the current will pass through a low resistance and will produce the voltage drop which will be nothing but the true reading. But if the voltmeter is connected across the high resistance then due to two high resistances in parallel, the current will divide almost equally through the two paths. Thus the meter will record the voltage drop across the high resistance which will be much lower than the true reading. Thus the low sensitivity instrument when used in high resistance circuit 'gives a lower than the true reading. This is called loading effect of the voltmeters. It is mainly caused due to low sensitivity instruments.

A.C voltmeters using rectifier:

The PMMC movement used in d.c. voltmeters can be effectively used in a.c. voltmeters. The rectifier is used to convert a.c. voltage to be measured, to d.c. This d.c., if required is amplified and then given to the PMMC movement. The PMMC movement gives the deflection proportional to the quantity to be measured.

The r.m.s. value of an alternating quantity is given by that steady current (d.c.) which when flowing through a given circuit for a given time produces the same amount of heat as produced by the alternating current which when flowing through the same circuit for the same time. The r.m.s value is calculated by measuring the quantity at equal intervals for one complete cycle. Then squaring each quantity, the average of squared v,llues is obtained. The square root of this average value is the r.m.s. value. The r.m.s means root-mean square i.e. squaring, finding the mean i.e. average and finally root.

If the waveform is continuous then instead of squaring and calculating mean, the integratioll is used. Mathematically the r.m.s. value of the continuous a.c. voltage having time period T is given by,

If the a.c. quantity is continuous then average value can be expressed mathematically using integration as,

The form factor is the ratio of r.m.s. value to the average value of an alternating quantity.

$$\boxed{K_f = \frac{\text{r.m.s. value}}{\text{average value}} = \text{form factor}}$$

$$\boxed{V_{rms} = \sqrt{\frac{1}{T}\int_0^T V_{in}^2\ dt}}$$

The $\frac{1}{T}$ term indicates the mean value or average value.

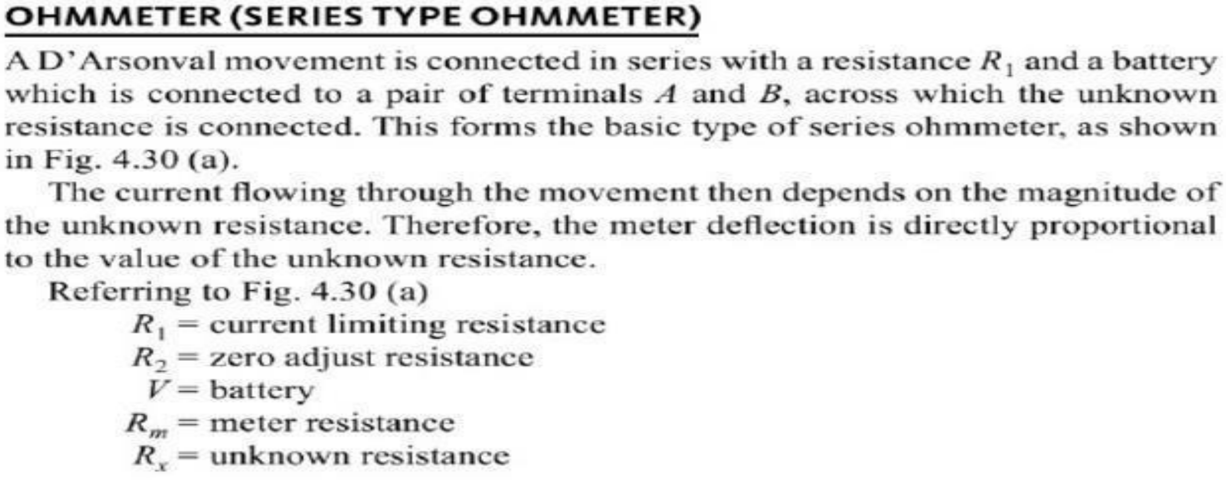
For **purely sinusoidal quantity,**

$$V \qquad 0.707\ V$$

Basic rectifier type voltmeter:

The diodes D1 and D2 are used for the rectifier circuit. The diodes show the nonlinear behaviour for the low currents hence to increase the current through diode D1, the meter is shunted with a resistance Rsh' This ensures high current through diode and its linear behaviour.

When the a.c. input is applied, for the positive half cycle, the diode 01 conducts and causes the meter deflection proportional to the average value of that half cycle. In the negative cycle, the diode D2 conducts and D1 is reverse biased. The current through the meter is in opposite direction and hence meter movement is bypassed. Thus due to diodes, the rectifying action produces pulsating d.c. and lile meter indicates the average value of the input.



OHMMETER (SERIES TYPE OHMMETER)

A D'Arsonval movement is connected in series with a resistance R_1 and a battery which is connected to a pair of terminals A and B, across which the unknown resistance is connected. This forms the basic type of series ohmmeter, as shown in Fig. 4.30 (a).

The current flowing through the movement then depends on the magnitude of the unknown resistance. Therefore, the meter deflection is directly proportional to the value of the unknown resistance.

Referring to Fig. 4.30 (a)

R_1 = current limiting resistance
R_2 = zero adjust resistance
V = battery
R_m = meter resistance
R_x = unknown resistance

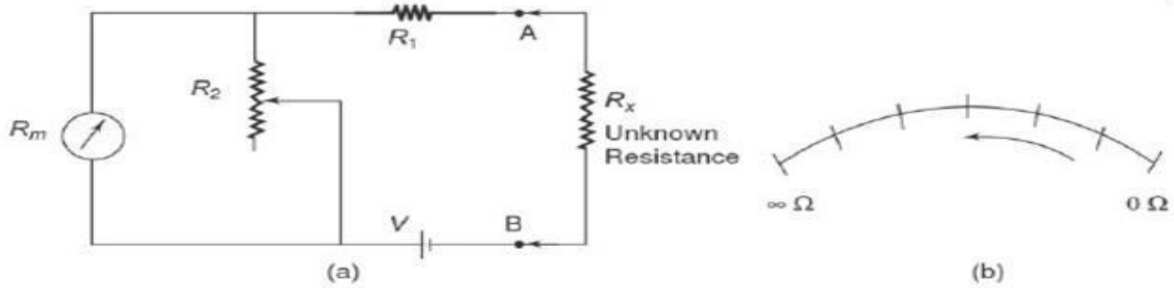


Fig. 4.30 (a) Series type ohmmeter (b) Dial of series ohmmeter

Calibration of the Series Type Ohmmeter

To mark the "0" reading on the scale, the terminals A and B are shorted, i.e. the unknown resistance $R_x = 0$, maximum current flows in the circuit and the shunt resistance R_2 is adjusted until the movement indicates full scale current (I_{fsd}). The position of the pointer on the scale is then marked "0" ohms.

Similarly, to mark the "∞" reading on the scale, terminals A and B are open, i.e. the unknown resistance $R_x = \infty$, no current flow in the circuit and there is no deflection of the pointer. The position of the pointer on the scale, is then marked as "∞" ohms.

Therefore, in a series ohmmeter the scale marking on the dial, has "0" on the right side, corresponding to full scale deflection current, and "∞" on the left side corresponding to no current flow, as given in Fig. 4.30 (b).

Values of R_1 and R_2 can be determined from the value of R_x which gives half the full scale deflection.

$$R_h = R_1 + R_2 \parallel R_m = R_1 + \frac{R_2 R_m}{R_2 + R_m}$$

where R_h = half of full scale deflection resistance.

The total resistance presented to the battery then equals $2R_h$ and the battery current needed to supply half scale deflection is $I_h = V/2\ R_h$.

To produce full scale current, the battery current must be doubled.

Therefore, the total current of the ckt, $I_t = V/R_h$

The shunt current through R_2 is given by $I_2 = I_t - I_{fsd}$

The voltage across shunt, V_{sh}, is equal to the voltage across the meter.

Therefore $\quad V_{sh} = V_m$

$$I_2 R_2 = I_{fsd} R_m$$

Therefore
$$R_2 = \frac{I_{fsd} R_m}{I_2}$$

But
$$I_2 = I_t - I_{fsd}$$

∴
$$R_2 = \frac{I_{fsd} R_m}{I_t - I_{fsd}}$$

But
$$I_t = \frac{V}{R_h}$$

Therefore
$$R_2 = \frac{I_{fsd} R_m}{V / R_h - I_{fsd}}$$

Therefore
$$R_2 = \frac{I_{fsd} R_m R_h}{V - I_{fsd} R_h}$$

As
$$R_h = R_1 + \frac{R_2 R_m}{R_2 + R_m}$$

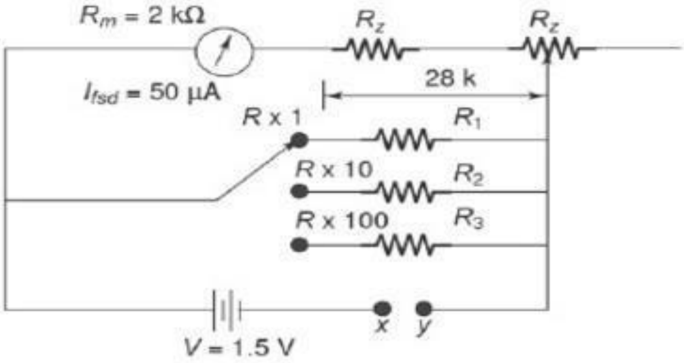
Therefore
$$R_1 = R_h - \frac{R_2 R_m}{R_2 + R_m}$$

Hence $$R_1 = R_h - \frac{\dfrac{I_{fsd}\,R_m\,R_h}{V - I_{fsd}\,R_h} \times R_m}{\dfrac{I_{fsd}\,R_m\,R_h}{V - I_{fsd}\,R_h} + R_m}$$

Therefore $$R_1 = R_h - \frac{I_{fsd}\,R_m\,R_h}{V}$$

Hence, R_1 and R_2 can be determined.

Multirange Ohmmeter The ohmmeter circuit shown in Fig. is only for a single range of resistance measurement. To measure resistance over a wide range of values, we need to extend the ohmmeter ranges. This type of ohmmeter is called a multirange ohmmeter, shown in Fig. 4.31.



SHUNT TYPE OHMMETER

The shunt type ohmmeter given in Fig consists of a battery in series with an adjustable resistor R_1, and a D'Arsonval movement

The unknown resistance is connected in parallel with the meter, across the terminals *A* and *B*, hence the name shunt type ohmmeter.

In this circuit it is necessary to have an ON/OFF switch to disconnect the battery from the circuit when the instrument is not used.

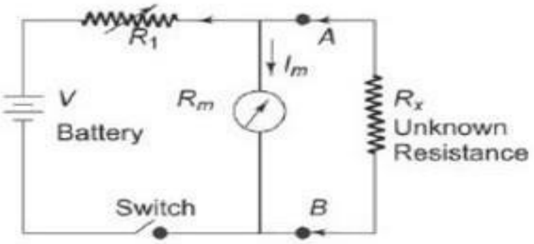


Fig. Shunt type ohmmeter

Calibration of the Shunt Type Ohmmeter

To mark the "0" ohms reading on the scale, terminals *A* and *B* are shorted, i.e. the unknown resistance $R_x = 0$, and the current through the meter movement is zero, since it is bypassed by the short-circuit. This pointer position is marked as "0" ohms.

Similarly, to mark "∞" on the scale, the terminals A and B are opened, i.e. $R_x = \infty$, and full current flows through the meter movement; by appropriate selection of the value of R_1, the pointer can be made to read full scale deflection current. This position of the pointer is marked "∞" ohms. Intermediate marking can be done by connecting known values of standard resistors to the terminals A and B.

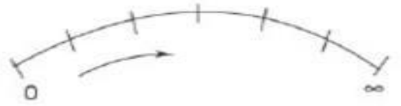


Fig. Dial of shunt type ohmmeter

This ohmmeter therefore has a zero mark at the left side of the scale and an ∞ mark at the right side of the scale, corresponding to full scale deflection current as shown in Fig.

The shunt type ohmmeter is particularly suited to the measurement of low values of resistance. Hence it is used as a test instrument in the laboratory for special low resistance applications.

CALIBRATION OF DC INSTRUMENT

The process of calibration involves the comparison of a given instrument with a standard instrument, to determine its accuracy. A dc voltmeter may be calibrated with a standard, or by comparison with a potentiometer. The circuit in Fig. is used to calibrate a dc voltmeter; where a test voltmeter reading V is compared to the voltage drop across R. The voltage drop across R is accurately measured with the help of a standard meter. A rheostat, shown in Fig. is used to limit the current.

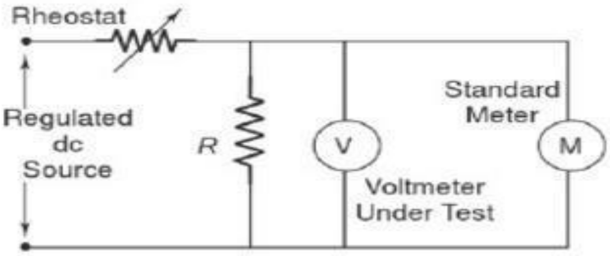


Fig. Calibration of voltmeter

A voltmeter tested with this method can be calibrated with an accuracy of ±0.01%.

Electronic multimeter:

For the measurement of d.c. as well as a.c. voltage and current, resistance, an electronic multimeter is commonly used. It is also known as Voltage-Ohm Meter (VOM) or multimeter The important salient features of YOM are as listed below.

1) The basic circuit of YOM includes balanced bridge d.c. amplifier.

2) To limit the magnitude of the input signal, RANGE switch is provided. By properly adjusting input attenuator input signal can be limited.

3) It also includes rectifier section which converts a.c. input signal to the d.c. voltage.

4) It facilitates resistance measurement with the help of internal battery and additional circuitry.

5) The various parameters measurement is possible by selecting required function using FUNCTION switch.

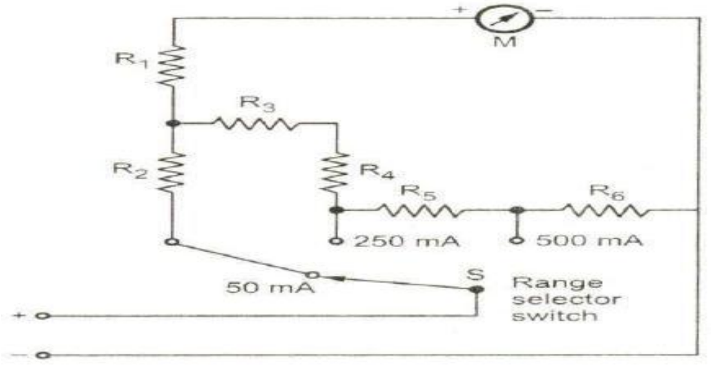
6) The measurement of various parameters is indicated with the help of indicating Meter.

Use of multimeter for D.C measurement:

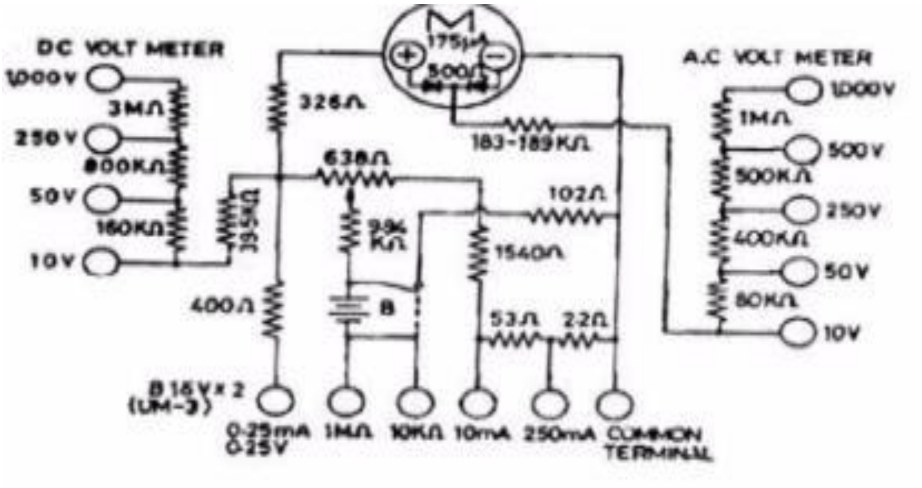
For getting different ranges of voltages, different series resistances are connected in series which can be put in the circuit with the range selector switch. We can get different ranges to measure the d.c. voltages by selecting the proper resistance in series with the basic meter.

Use of multimeter as ammeter:

To get different current ranges, different shunts are connected across the meter with the help of range selector switch. The working is same as that of PMMC ammeter



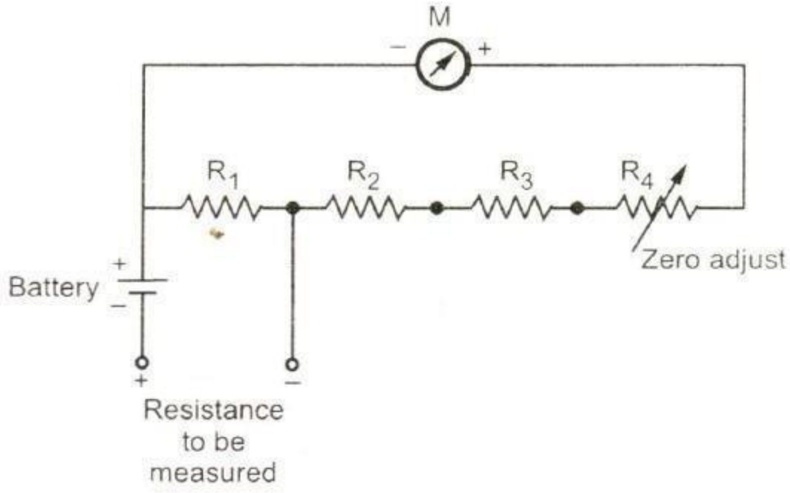
Use of multimeter for measurement of A.C voltage:


DC VOLT METER
1,000V
3MΩ
250V
800KΩ
50V
160KΩ
10V
395KΩ
M
175μA
500Ω
+
−
326Ω
183-189KΩ
638Ω
9.9K KΩ
102Ω
1540Ω
400Ω
B
53Ω
2.2Ω
B 1.5V × 2
(UM-3)
0-25mA
0-25V
1MΩ
10KΩ
10mA
250mA
COMMON TERMINAL
A.C VOLT METER
1,000V
1MΩ
500V
500KΩ
250V
400KΩ
50V
80KΩ
10V

The rectifier used in the circuit rectifies a.c. voltage into d.c. voltage for measurement of a.c. voltage before current passes through the meter. The other diode is used for the protection purpose.

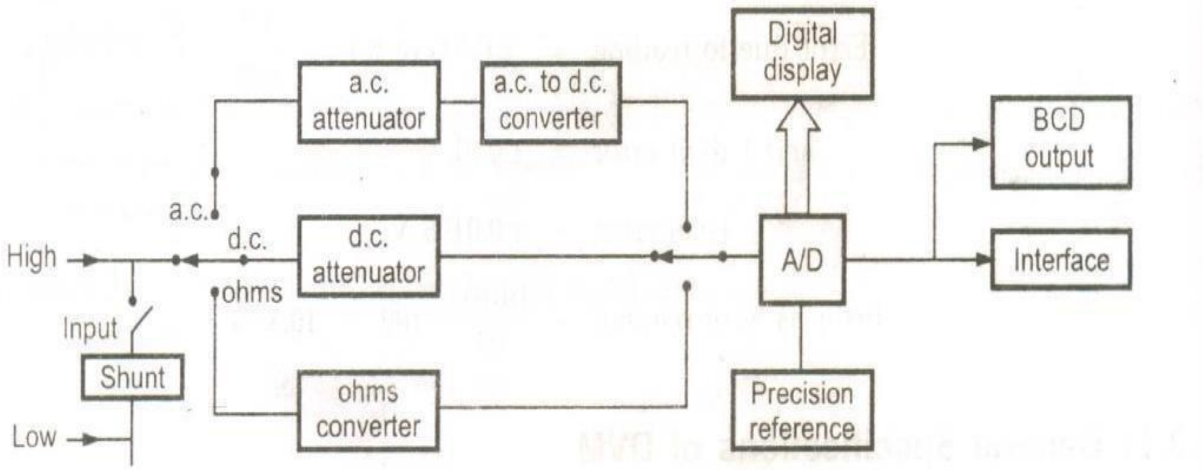
Use of multimeter for resistance measurement:

The Fig shows ohmmeter section of multimeter for a scale multiplication of 1. Before any measurement is made, the instrument is short circuited and "zero adjust" control is varied until the meter reads zero resistance i.e. it shows full scale current. Now the circuit takes the form of a variation of the shunt type ohmmeter. Scale multiplications of 100 and 10,000 can also be used for measuring high resistances. Voltages are applied the circuit with the help of battery.



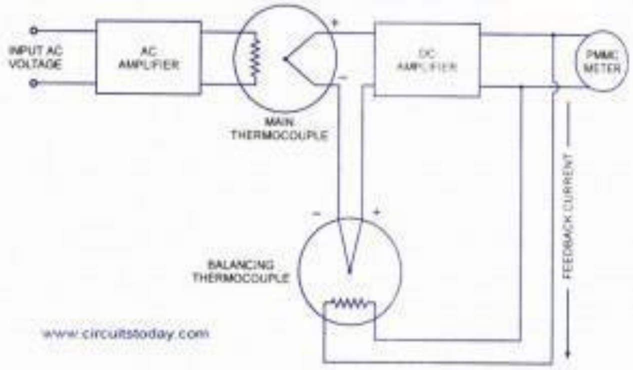
Digital multimeters:

The digital multimeter is an instrument which is capable of measuring a.c. voltages, d.c. voltages, a.c. and d.c. currents and resistances *over* several ranges. The basic circuit of a digital multimeter is always a d.c. voltmeter as shown in the Fig



The current is converted to voltage by passing it through low shunt resistance. The a.c. quantities are *converted* to d.c. by employing various rectifier and filtering circuits. While for the resistance measurements the meter consists of a precision low current source that is applied across the unknown resistance while gives d.c. voltage. All the quantities are digitized using analog to digital converter and displayed in the digital form on the display.The basic building blocks of digital multimeter are several *AID* converters, counting circuitry and an attenuation circuit. Generally dual slope integration type ADC is prefprred in the multimeters. The single attenuator circuit is used for both a.c. and d.c. measurements in many commercial multimeters.

True RMS Reading Voltmeter



Block Diagram of True RMS Reading Voltmeter

True RMS Responding Voltmeters

RMS value of the sinusoidal waveform is measured by the**average reading voltmeter** of which scale is calibrated in terms of rms value. This method is quite simple and less expensive. But sometimes rms value of the non-sinusoidal waveform is required to be measured. For such a measurement a true rms reading voltmeter is required. True rms reading voltmeter gives a meter indication by sensing heating power of waveform which is proportional to the square of the rms value of the voltage.

Thermo-couple is used to measure the heating power of the input waveform of which heater is supplied by the amplified version of the input waveform. Output voltage of the thermocouple is proportional to the square of the rms value of the input waveform. One more thermo-couple, called the balancing thermo-couple, is used in the same thermal environment in order to overcome the difficulty arising out of non-linear behaviour of the thermo-couple. Non-linearity of the input circuit thermo-couple is cancelled by the similar non-linear effects of the balancing thermo-couple. These thermo-couples form part of a bridge in the input circuit of a dc amplifier, as shown in block diagram.

AC waveform to be measured is applied to the heating element of the main thermocouple through an ac amplifier. Under absence of any input waveform, output of both thermo-couples are equal so error signal, which is input to dc amplifier, is zero and therefore indicating meter connected to the output of dc amplifier reads zero. But on the application of input waveform, output of main thermo-couple upsets the balance and an error signal is produced, which gets amplified by the dc amplifier and fedback to the heating element of the balancing thermo-couple. This feedback current reduces the value of error signal and ultimately makes it zero to obtain the balanced bridge condition. In this balanced condition, feedback current supplied by the dc amplifier to the heating element of the balance thermo-couple is equal to the ac current flowing in the heating element of main thermo-couple. Hence this direct current is directly proportional to the rms value of the input ac voltage and is indicated by the meter connected in the output of the dc amplifier. The PMMC meter may be calibrated to read the rms voltage directly.

By this method, rms value of any voltage waveform can be measured provided that the peak excursions of the waveform do not exceed the dynamic range of the ac amplifier.

UNIT -2

Oscilloscopes

Introduction:

In studying the various electronic, electrical networks and systems, signals which are functions of time, are often encountered. Such signals may be periodic or non periodic in nature. The device which allows, the amplitude of such signals, to be displayed primarily as " function of time, is called **cathode ray** oscilloscope, commonly known as C.R.O. The CR.O gives the visual representation of the time varying signals. The oscilloscope has become an universal instrument and is probably most versatile tool for the development of electronic circuits and systems. It is an integral part of electronic laboratories.

The oscilloscope is, in fact, a voltmeter. Instead of the mechanical deflection of a metallic pointer as used in the normal voltmeters, the oscilloscope uses the movement of an electron beam against a fluorescent screen, which produces the movement of a visible spot. The movement of such spot on the screen is proportional to the varying magnitude of the signal, which is under measurement.

Basic Principle:

The electron beam can be deflected in two directions : the horizontal or x-direction and the vertical or y-direction. Thus an electron beam producing a spot can be used to produce two dimensional displays, Thus CRO. can be regarded as a fast x-y plotter. The x-axis and y-axis can be used to study the variation of one voltage as a function of another. Typically the x-axis of the oscilloscope represents the time while the y-axis represents variation of the input voltage signal. Thus if bhe input voltage signal applied to the y-axis of CRO. is sinusoidally varying and if x-axis represents the time axis, then the spot moves sinusoidally, and the familiar sinusoidal waveform can be seen on the screen of the oscilloscope. The oscilloscope is so fast device that it can display the periodic signals whose time period is as small as microseconds and even nanoseconds. The CRO. Basically operates on voltages, but it is possible to convert current, pressure, strain, acceleration and other physical quantities into the voltage using transducers and obtain their visual representations on the CRO.

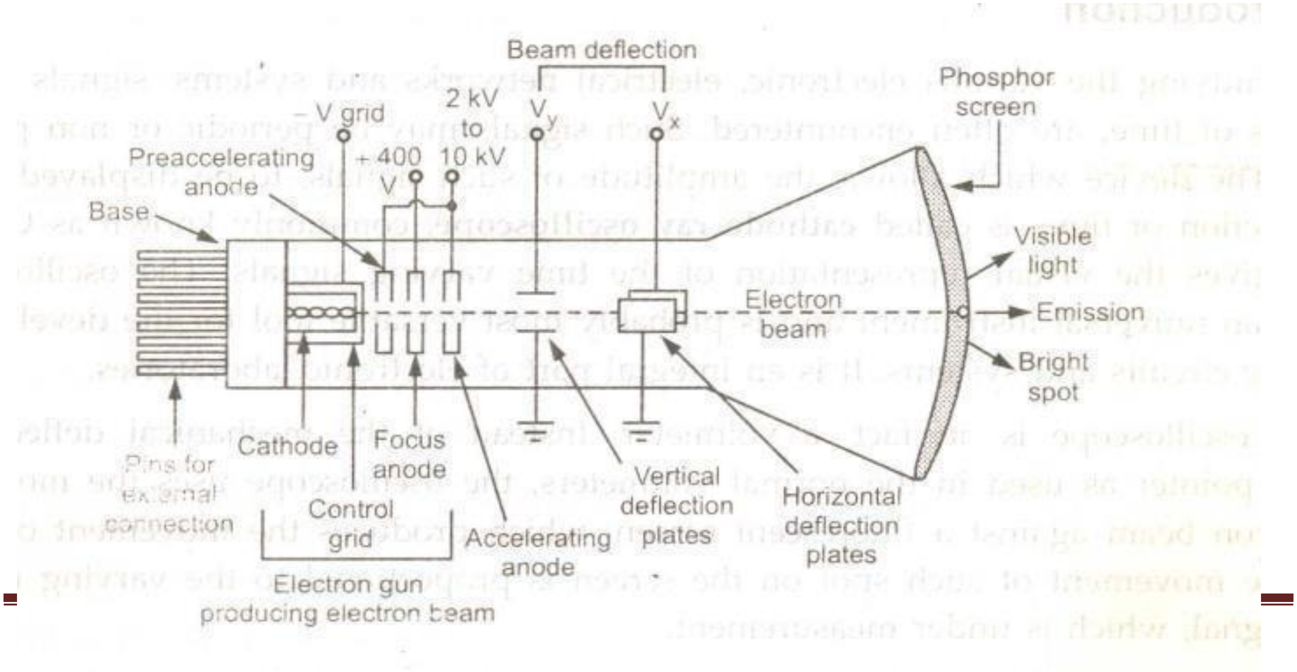
Cathode Ray Tube (CRT):

The cathode ray tube (CRT) is the heart of the CR.O. the CRT generates the electron beam, ,accelerates the beam, deflects the beam and also has a screen where beam becomes visible ,as a spot. The main parts of the CRT are:

i) Electron gun ii) Deflection system iii) Fluorescent screen

iv) Glass tube or envelope v) Base

A schematic diagram of CRT, showing its structure and main components is shown in the Fig.



Electron Gun:

The electron gun section of the cathode ray tube provides a sharply focused electron beam directed :towards the fluorescent-coated screen. This section starts from theql1ally heated cathode, limiting the electrons. The control grid is give!! negative potential with respect to cathode dc. This grid controls the number of electrons in the beam, going to the screen.

The momentum of the electrons (their number x their speed) determines the intensity, or brightness, of the light emitted from the fluorescent screen due to the electron bombclrdl1lent. The light emitted is usually of the green colour. Because the electrons are negatively charged, a repulsive force is created by applying a negative voltage to the control grid (in CRT, voltages applied to various grids are stated with respect to cathode, which is taken as common point). This negative control voltage can be made variable.

Deflection System:

When the electron beam is accelerated it passes through the deflection system, with which beam can be positioned anywhere on the screen. The deflection system of the cathode-ray-tube consists of two pairs of parallel plates, referred to as the vertical and horizontal deflection plates. One of the plates' in each set is connected to ground (0 V), To the other plate of each set, the external deflection voltage is applied through an internal adjustable gain amplifier stage, To apply the deflection voltage externally, an external terminal, called the Y input or the X input, is available.

As shown in the Fig. , the electron beam passes through these plates. A positive voltage applied to the Y input terminal (Vy) Causes the beam to deflect vertically upward due to the attraction forces, while a negative voltage applied to. the Y input terminal will cause the electron beam to deflect vertically downward, due to the repulsion forces. When the voltages are applied simultaneously to vertical and horizontcl1 deflecting plates, the electron beam is deflected due to the resultant-of these two voltages.

Fluorescent Screen:

The light produced by the screen does not disappear immediately when bombardment by electrons ceases, i.e., when the signal becomes zero. The time period for which the trace remains on the screen after the signal becomes zero is known as "persistence". The persistence may be *jS* short as a few microsecond, or as long as tens of seconds and minutes.

Long persistence traces are used in the study.. of transients. Long persistence helps in the study of transients since the trace is still seen on the screen after the transient has disappeared.

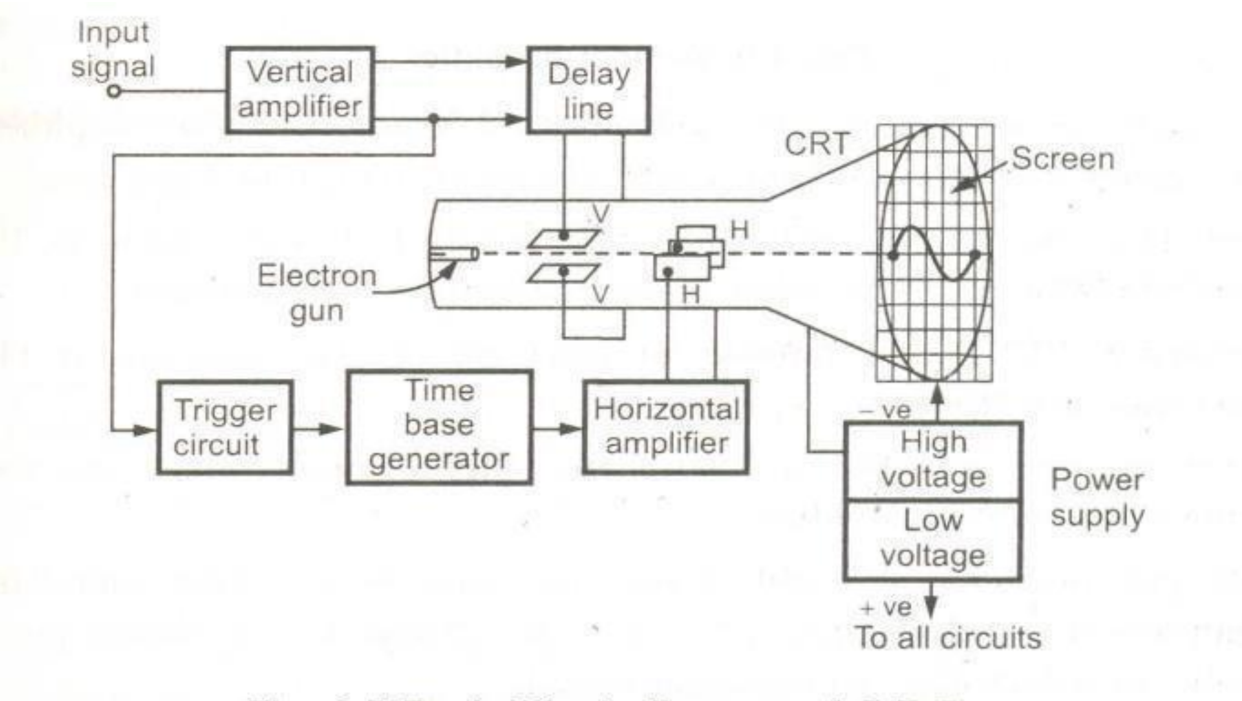
Phosphor screen characteristics:

Many phosphor materials having different excitation times and colours as well as different phosphorescence times are available. The type PI, P2, PI1 or P3I are the short persistence phosphors and are used for the general purpose oscilloscope

Medical oscilloscopes require a longer phosphor decay and hence phosphors like P7 and P39 are preferred for such applications. Very slow displays like radar require long persistence phosphors to maintain sufficient flicker free picture. Such phosphors are P19, P26 and, P33.

The phosphors P19, P26, P33 have low burn resistance. The phosphors PI, P2, P4, P7, Pll have medium burn resistance while PIS, P3I have high burn resistance.

Block diagram of simple oscilloscope:

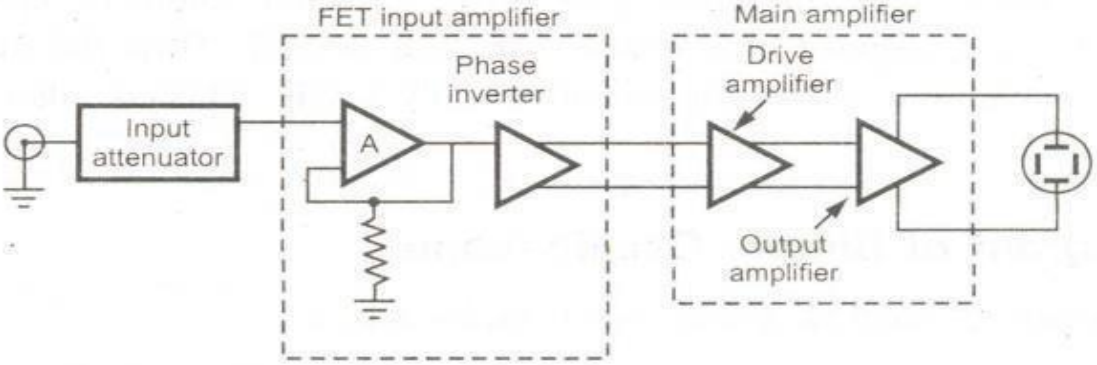


CRT:

This is the cathode ray tube which is the heart of CR.O. It is' used to emit the electrons required tostrike the phosphor screen to produce the spot for the visual display of the signals.

Vertical Amplifier:

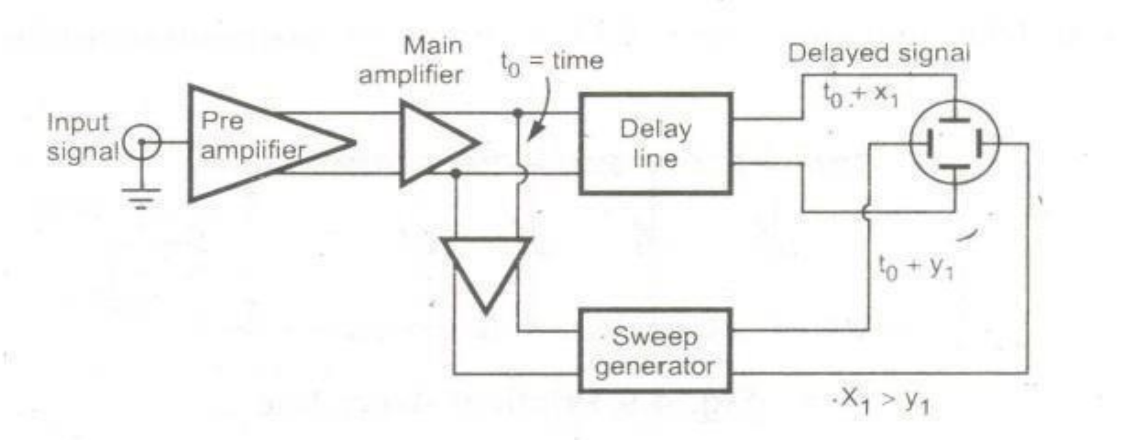
The input signals are generally not strong to provide the measurable deflection on the screen. Hence the vertical amplifier. stage is used Jo amplify the input signals. The amplifier stages used are generally wide band amplifiers so as to pass faithfully the entire band of frequencies to be measured. Similarly it contains the attenuator stages as well. The attenuators are used when very high voltage signals are to be examined, to bring the signals within the proper range of operation.



It consists of several stages with overall fixed sensltivity. The amplifier can be designed for stability and required bandwidth very easily due to the fixed gain. The input stage colrtsists of an attenuator followed by FET source follower. It has vel' high input impedance required to isolate the amplifier from the attenuator. It is followed by BJT emitter follower to match the output impedance of FET output With input of phase inverter. The phase inverter provides two antiphase output signals which are required to operate the push pull output amplifier. The push pull operation has advantages like better hum voltage cancellation, even harmonic suppression especially large 2nd harmonic, greater power output per tube and reduced number of defocusing and nonlinear effects.

Delay line:

The delay line is used to delay the signal for some time in the verticClI sections. When the delay line is not used, the part of the signal gets lost. Thus the input signal is not applied directly to the vertical plates but is delClyed bv some time using a delay line cu-cuit as shown in the Fig.



If the trigger pulse is picked off at a time t = to after the signal has passed through the main amplifier then signal is delayed by XI nanoseconds while sweep takes YI nanoseconds to reach. The design of delay line is such that the delay time XI is higher than the time YI' Generally XI is

200. nsec while tl;1.eYI is 80 ns, thus the sweep starts well in time and no part of the signal is lost. There are two types of delay lines used in CR.O. which are:

i) Lumped parameter delay line

ii) Distributed parameter delay line

Trigger circuit:

It is necessary that horizontal deflection starts at the same point of the input vertical signal, each time it sweeps. Hence to synchronize horizontal deflection with vertical deflection a synchronizing or triggering circuit is used. It converts the incoming signal into the triggering pulses, which are used for the synchronization.

Time base generator:

The time base generator is used to generate the sawtooth voltage, required to deflect the beam in the horizontal section. This voltage deflects the spot at a constant time dependent rate. Thus the x-axis' on the screen can be represented as time, which, helps to display and analyse the time varying signals.

Oscilloscope probes

Oscilloscopes are widely used for test and repair of electronics equipment of all types. However it is necessary to have a method of connecting the input of the oscilloscope to the point on the equipment under test that needs monitoring.

To connect the scope to the point to be monitored it is necessary to use screened cable to prevent any pick-up of unwanted signals and in addition to this the inputs to most oscilloscopes use coaxial BNC connectors. While it is possible to use an odd length of coax cable with a BNC connector on one end and open wires with crocodile / alligator clips on the other, this is not ideal and purpose made oscilloscope probes provide a far more satisfactory solution.

Oscilloscope probes normally comprise a BNC connector, the coaxial cable (typically around a metre in length) and what may be termed the probe itself. This comprises a mechanical clip arrangement so that the probe can be attached to the appropriate test point, and an earth or ground clip to be attached to the appropriate ground point on the circuit under test.

Care should be taken when using oscilloscope probes as they can break. Although they are robustly manufactured, any electronics laboratory will consider oscilloscope probes almost as "life'd" items that can be disposed of after a while when they are broken. Unfortunately the fact that they are clipped on to leads of equipment puts a tremendous strain on the mechanical clip arrangement. This is ultimately the part which breaks.

X1 and X10 oscilloscope probes

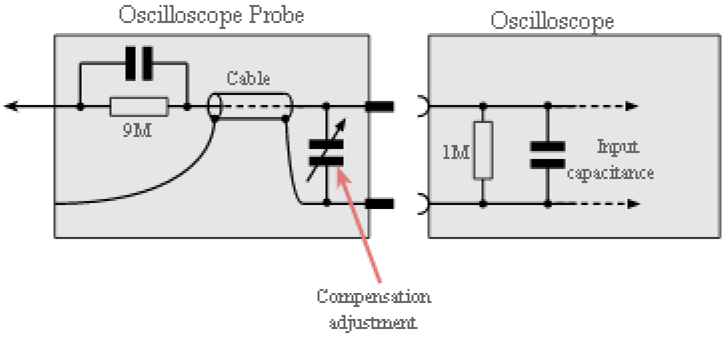
There are two main types of passive voltage scope probes. They are normally designated X1 and X10, although 1X and 10X are sometimes seen. The designation refers to the factor by which the impedance of the scope itelf is multiplied by the probe.

The X1 probes are suitable for many low frequency applications. They offer the same input impedance of the oscilloscope which is normally 1 MΩ. However for applications where better accuracy is needed and as frequencies start to rise, other test probes are needed.

To enable better accuracy to be achieved higher levels of impedance are required. To achieve this attenuators are built into the end of the probe that connects with the circuit under test. The most common type of probe with a built in attenuator gives an attenuation of ten, and it is known as a X10 oscilloscope probe. The attenuation enables the impedance presented to the circuit under test to be increased by a factor of ten, and this enables more accurate measurements to be made.

As the X10 probe attenuates the signal by a factor of ten, the signal entering the scope itself will be reduced. This has to be taken into account. Some oscilloscopes automatically adjust the scales according to the probe present, although not all are able to do this. It is worth checking before making a reading.

The 10X scope probe uses a series resistor (9 M Ohms) to provide a 10 : 1 attenuation when it is used with the 1 M Ohm input impedance of the scope itself. A 1 M Ohm impedance is the standard impedance used for oscilloscope inputs and therefore this enables scope probes to be interchanged between oscilloscopes of different manufacturers.



Oscilloscope probe circuit

The scope probe circuit shown is a typical one that might be seen - other variants with the variable compensation capacitor at the tip are just as common.

In addition to the X1 and X10 scope probes, X100 probes are also available. These oscilloscope probes tend to be used where very low levels of circuit loading are required, and where the high frequencies are present. The difficulty using the is the fact that the signal is attenuated by a factor of 100.

X10 oscilloscope probe compensation

The X10 scope probe is effectively an attenuator and this enables it to load the circuit under test far less. It does this by decreasing he resistive and capacitive loading on the circuit. It also has a much higher bandwidth than a traditional X1 scope probe.

The x10 scope probe achieve a better high frequency response than a normal X1 probe for a variety of reasons. It does this by decreasing the resistive and capacitive loading on the The X10 probe can often be adjusted, or compensated, to improve the frequency response.

Typical oscilloscope probe

For many scope probes there is a single adjustment to provide the probe compensation, although there can be two on some probes, one for the LF compensation and the other for the HF compensation.

Probes that have only one adjustment, it is the LF compensation that is adjusted, sometimes the HF compensation may be adjusted in the factory.

To achieve the correct compensation the probe is connected to a square wave generator in the scope and the compensation trimmer is adjusted for the required response - a square wave.

Compensation adjustment waveforms for X10 oscilloscope probe.

As can be seen, the adjustment is quite obvious and it is quick and easy to undertake. It should be done each time the probe is moved from one input to another, or one scope to another. It does not hurt to check it from time to time, even if it remains on the same input. As in most laboratories, things get borrowed and a different probe may be returned, etc . .

A note of caution: many oscilloscope probes include a X1/X10 switch. This is convenient, but it must be understood that the resistive and capacitive load on the circuit increase significantly in the X1 position. It should also be remembered that the compensation capacitor has no effect when used in this position.

As an example of the type of loading levels presented, a typical scope probe may present a load resistance of 10MΩ along with a load capacitance of 15pF to the circuit in the X10 position. For the X1 position the probe may have a capacitance of possibly 50pF plus the scope input capacitance. This may end up being of the order of 70 to 80pF.

Other types of probe

Apart from the standard 1X and 10X voltage probes a number of other types of scope probe are available.

- ***Current probes:*** It is sometimes necessary to measure current waveforms on an oscilloscope. This can be achieved using a current probe. This has a probe that clips around the wire and enables the current to be sensed. Sometimes using the maths functions on a scope along with a voltage measurement on another channel it is possible to measure power,
- ***Active probes:*** As frequencies rise, the standard passive probes become less effective. The effect of the capacitance rises and the bandwidth is limited. To overcome these difficulties active probes can be used. They have an amplifier right at the tip of the probe enabling measurements with very low levels of capacitance to be made. Frequencies of several GHz are achievable using active scope probes.
- ***Differential scope probes:*** In some instances it may be necessary to measure differential signals. Low level audio, disk drive signals and many more instances use differential signals and these need to be measured as such. One way of achieving this is to probe both lines of the differential signal using one probe each line as if there were two single ended signals, and then using the oscilloscope to add then differentially (i.e. subtract one from the other) to providethedifference.

  Using two scope probes in this way can give rise to a number of problems. The main one is that single ended measurements of this nature do not give the required rejection of any common mode signals (i.e. Common Mode Rejection Ratio, CMMR) and additional noise is likely to be present. There may be a different cable length on each probe that may lead to a time differences and a slight skewing between the signals.

To overcome this a differential probe may be used. This uses a differential amplifier at the probing point to provide the required differential signal that is then passed along the scope probe lead to the oscilloscope itself. This approach provides a far higher level of performance.

- ***High voltage probes:*** Most standard oscilloscope voltage probes like the X1 or X10 are only specified for operation up to voltages of a few hundred volts at most. For operation higher than this a proper high voltage probe with specially insulated probe is required. It also will step down the voltage for the input to the scope so that the test instrument is not damaged by the high voltage. Often voltage probes may be X50 or X100.

Special Purpose Oscilloscopes

Dual Beam CRO

The dual trace oscilloscope has one cathode ray gun, and an electronic switch which switches two signals to a single vertical amplifier. The dual beam CRO uses two completely separate electron beams, two sets of VDPs and a single set of HDPs. Only one beam can be synchronised at one time, since the sweep is the same for both signals, i.e. a common time base is used for both beams. Block diagram of a Dual Beam CRO.

Therefore, the signals must have the same frequency or must be related harmonically, inorder to obtain both beams locked on the CRT screen, e.g. the input signal of an amplifier canbe used as signal A and its output signal as signal

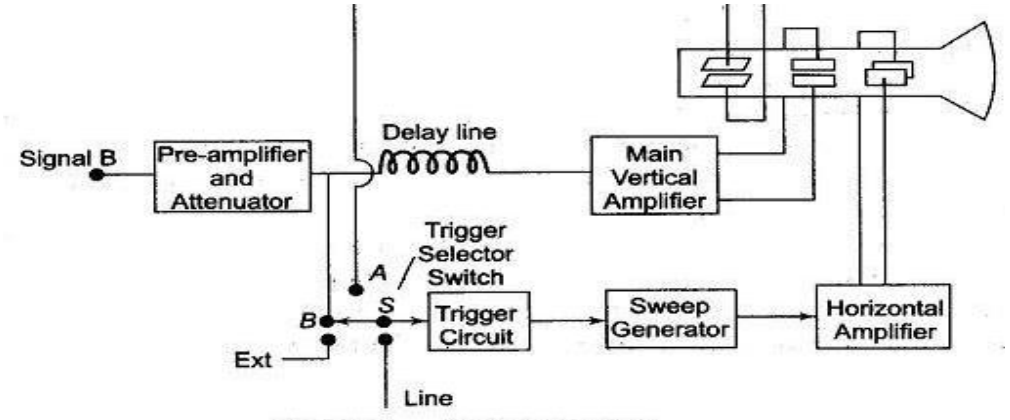


Fig. 7.18 Dual Beam CRO

DUAL TRACE OSCILLOSCOPE

This CRO has a single electron gun whose electron beam is split into two by an electronic switch. There is one control for focus and another for intensity. Two signals are displayed simultaneously. The signals pass through identical vertical channels or vertical amplifiers. Each channel has its own calibrated input attenuator and i positioning control, so that the amplitude of each signal can be ndependpntly adjusted.

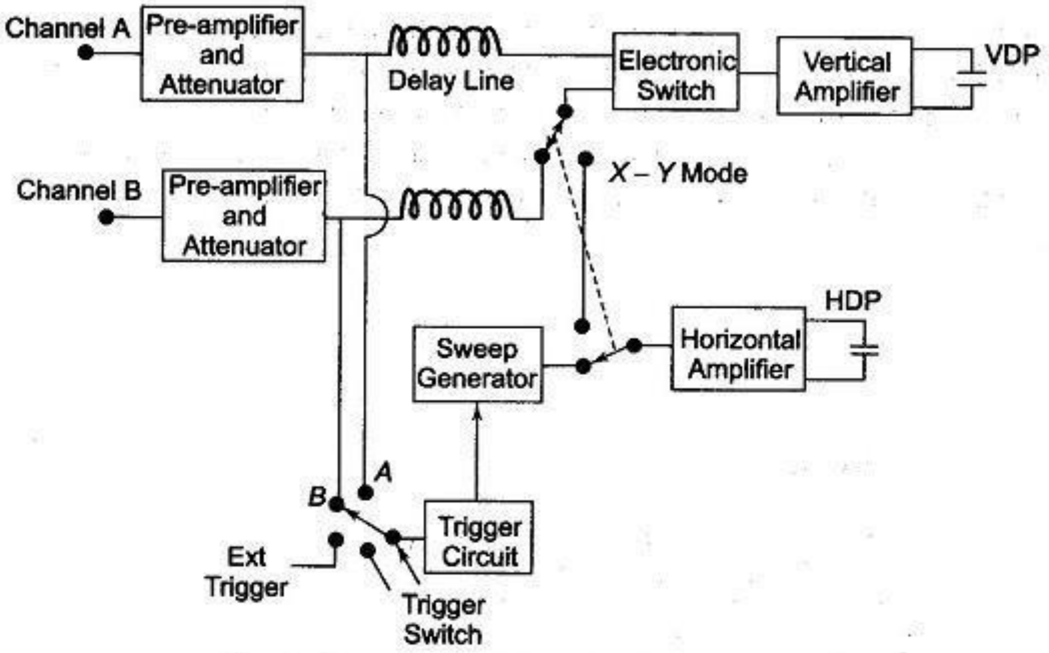


Fig. 7.19 (a) Dual Trace Oscilloscope

A mode control switch enables the electronic switch to operate in two modes. Wheri the switch is in ALTERNATE position, the electronic switch feeds each signal alternately to the vertical amplifier. The electronic switch alternately connects the main vertical amplifier to channels A and **B** and adds a different dc component to each signal; this dc component directs the beam alternately to the upper or lower half of the screen. The switching takes place at the start of each new sweep of the sweep generator. The switching rate of theelectronic switch is synchronised to the sweep rate, so that the CRT spot traces the channel A signal on one sweep and the channel B signal on the succeeding sweep [Fig. 7.19 (b)]

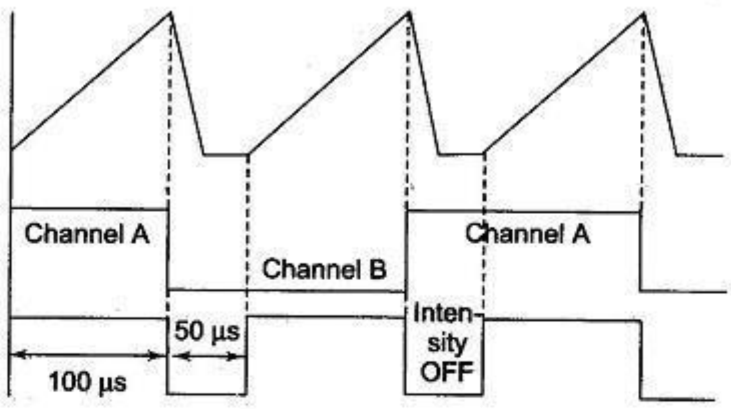


Fig. 7.19 (b) Time Relation of a Dual-Channel Vertical Amplifier in Alternate Mode

The sweep trigger signal is available from channels A or B and the trigger pick-off takes place before the electronic switch. This arrangement maintains the correct phase relationship between signals A and B.

When the switch is in the CHOP mode position, the electronic switch is free running at the rate of 100-500 kHz, entirely independent of the frequency of the sweep generator. The switch successively connects small segments of A and B waveforms to the main vertical amplifier at a relatively fast chopping rate of 500 kHz e.g. 1 i.ts segments of each waveform are fed to the CRT display (Fig. 7.19 (c)).

If the chopping rate is slow, the continuity of the display is lost and it is better to use the alternate mode of operation. In the added mode of operation a single image can be displayed by the addition of signal from channels A and B, i.e. (A + B), etc. In the X — Y mode of operation, the sweep generator is disconnected and channel B is connected to the horizontal amplifier. Since both preamplifiers are identical and have the same delay time, accurate X — Y measurements can be made.

Dual trace Oscilloscope(0-15MHz)

Block Description Y-Channels

A and B vertical channels are identical for producing the dual trace facility. Each comprises an input coupling switch, an input step attenuator, a source follower input stage with protection circuit, a pre-amplifier from which a trigger signal is derived and a combined final amplifier. The input stage protection circuit consists of a diode, which prevents damage to the FET transistors that could occur with excessive negative input potentials, and a resistor network which protects the input stage from large positive voltage swings.

As the transistors are the balanced pre-amplifier stage, they share the same IC block. The resulting stabilisation provides a measure of correction to reduce the drift inherent in high gain amplifiers. The trigger pick-off signal is taken from one side of the balanced pre-amplifier to the trigger mode switch, where either channel A or channel **B** triggering can be selected. The supply for the output of the pre-amplifier stage is derived from a constant current source controlled by the channel switching logic. Under the control of channel switching, signals from A and **B** channels are switched to the final amplifier. The combined balanced final amplifier is a direct coupled one to the Y-plates of the CRT (refer to Fig. 7.20).

Channel Switching

The front panel A and B channel selection (push button or switch), controls an oscillator in the CHOP mode. For channel switching electronic switching logic and a F/F is used. When either A or B channels are selected, the F/F is switched to allow the appropriate channel.

In the ALTERNATE mode, a pulse from the sweep-gating multivibrator via the electronic switching logic, switches the F/F, thus allowing A and B channels for alternate sweeps.

In the CHOP mode, the oscillator is switched via the logic stage to provide rapid switching of the channels via the F/F.

Triggering

A triggering signal can be obtained from the vertical amplifier of Channels A and **B** from an external source or internally from the mains supply (LINE triggering). The triggering signal is selected and normally fed via the amplifier stage to the pulse shaper, which supplies well defined trigger pulses to the sweep-gating multivibrator for starting the sawtooth generator.

Triggering from the TV line and frame signals can be obtained from the sync separator and peak detector stages. The latter stage is switched into circuit in the TOP position.

Time Base

The time base generator circuit operates on the constant current integrator principle.

The sweep-gating multivibrator, triggered by pulses from the differentiator and auto circuits, starts the sawtooth generator. Sweep signals are fed to the final X-amplifier.

A gate pulse is supplied by the sweep-gating multivibrator for unblanking the CRT during the forward sweep. In addition this pulse is supplied to an external socket for probe adjustment via a diode network.

X–Channel

Under the control of diode switching from the TIME/DIV switch, the X- amplifier receives its input signal from either the time base sawtooth generator or from an external source (X-EXT input socket via the **X** and trigger pre-amplifier). The X-MAGN (x 5) circuit is incorporated in the X-final amplifier. The output of this amplifier is direct coupled to the horizontal deflection plates of the CRT.

Cathode–Ray Tube Circuit and Power Supply

The high voltages required for the CRT, which has an acceleration potential of 1.5 kV, are generated by a voltage multiplier circuit controlled by a stabilised power supply. The CRT beam current is controlled by:

The intensity potentials network across the Extra High Tension (EHT) supply. During flyback (movement of electron beam from right to left) by the blanking pulses coming from the sawtooth generator via the beam blanking stages to blank the trace during right to left movement of the electron.

Regulation of the mains input voltage is achieved by a diode clipper network controlled by a signal fed back from an LED in the + 14 V rectifier supply.

SAMPLING OSCILLOSCOPE (VHF)

An ordinary Sampling Oscilloscope has a B.W. of 10 MHz. The HF performance can be improved by means of sampling the input waveform and reconstructing its shape from the sample, i.e. the signal to be observed is sampled and after a few cycles the sampling point is advanced and another sample is taken. The shape of the waveform is reconstructed by joining the sample levels together. The sampling frequency may be as low as 1/10th of the input signal frequency (if the input signal frequency is 100 MHz, the bandwidth of the CRO vertical amplifier can be as low as 10 MHz). As many as 1000 samples are used to reconstruct the original waveform.

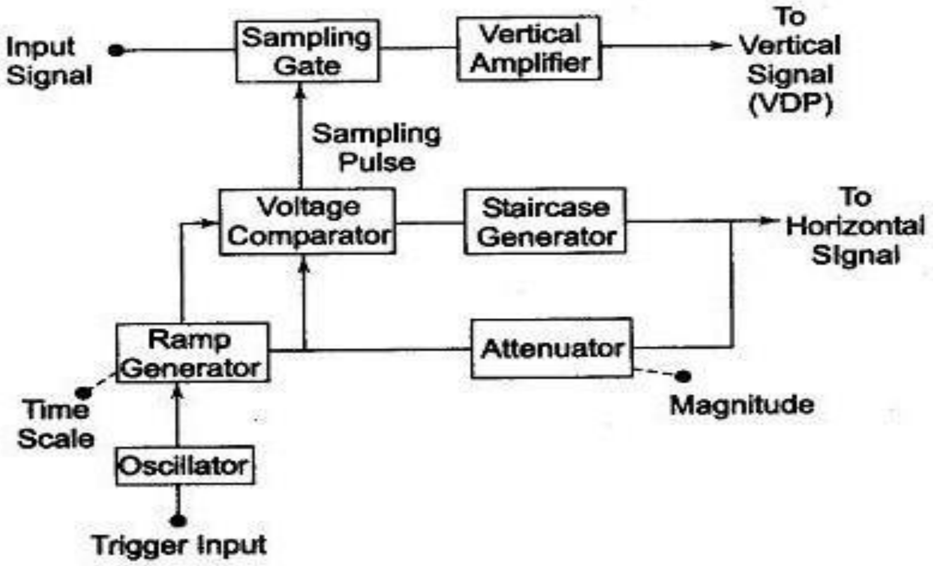


Fig. 7.24 Sampling Oscilloscope

Figure 7.24 shows a block diagram of a sampling oscilloscope. The input waveform is applied to the sampling gate. The input waveform is sampled whenever a sampling pulse opens the sampling gate. The sampling must be synchronised with the input signal frequency. The signal is delayed in thevertical amplifier, allowing the horizontal sweep to be initiated by the input signal. The waveforms are shown in Fig. 7.25.

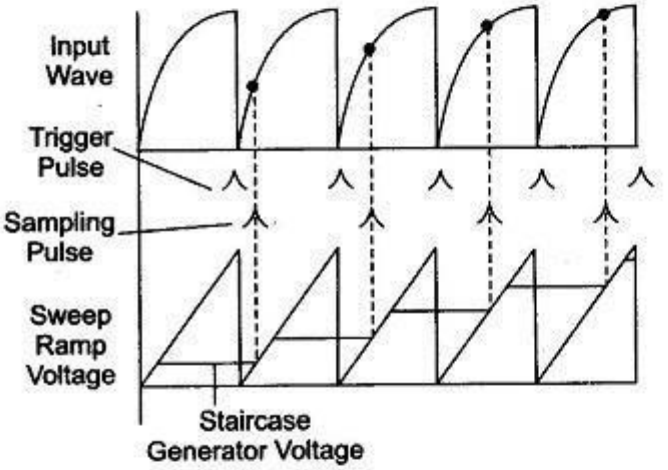


Fig. 7.25 Various Waveforms at Each Block of a Sampling Oscilloscope

At the beginning of each sampling cycle, the trigger pulse activates an oscillator and a linear ramp voltage is generated. This ramp voltage is applied to a voltage comparator which compares the ramp voltage to a staircase generator. When the two voltages are equal in amplitude, the staircase advances one step and a sampling pulse is generated, which opens the sampling gate for a sample of input voltage.

The resolution of the final image depends upon the size of the steps of the staircase generator.The smaller the size of the steps the larger the number of samples and higher the resolution of the image.

STORAGE OSCILLOSCOPE

Storage targets can be distinguished from standardphosphor targets by their ability to retain a waveform pattern for a long time, independent of phosphor peristence. Two storage techniques are used in oscilloscope CRTs, mesh storage and phosphor storage.

A mesh-Storage Oscilloscope uses a dielectric material deposited on a storage mesh as the storage target. This mesh is placed between the deflection plates and the standard phosphor target in the CRT. The writing beam, which is the focussed electron beam of the standard CRT, charges the dieletric material positively where hit. The storage target is then bombarded with low velocity electrons from a flood gun and the positively charged areas of the storage target allow these electrons to pass through to the standard phosphor target and thereby reproduce the stored image on the screen. Thus the mesh storage has both a storage target and aphosphor display target. The phosphor Storage Oscilloscope uses a thin layer of phosphor to serve both as the storage and the display element.

Mesh Storage

It is used to display Very Low Frequencies (VLF) signals and finds many applications in mechanical and biomedical fields. The conventional scope has a display with a phosphor peristence ranging from a few micro seconds to a few seconds. The persistence can be increased to a few hours from a few seconds.

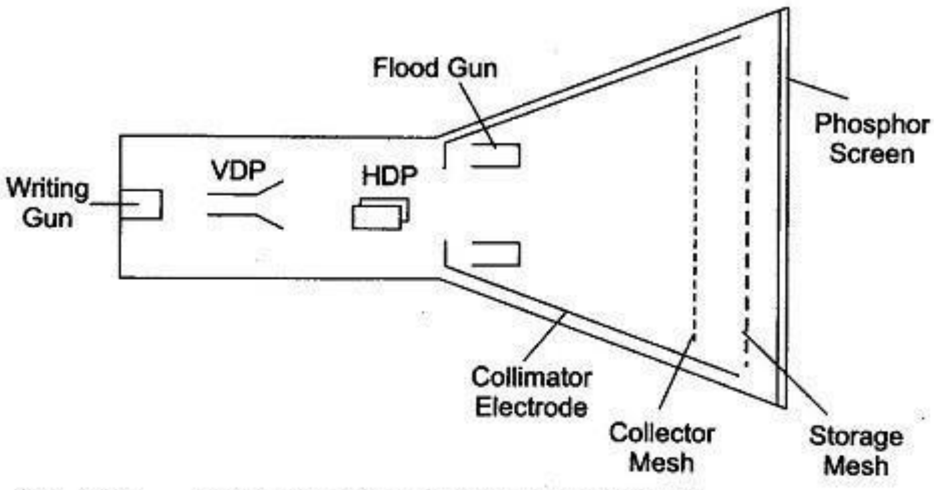


Fig. 7.26 Basic Elements of Storage Mesh CRT

A mesh Storage Oscilloscope, shown in Fig. 7.26, contains a dielectric material deposited on a storage mesh, a collector mesh, flood guns and a collimator, in addition to all the elements of a standard CRT. The storage target, a thin deposition of a dielectric material such as Magnesium Fluoride on the storage mesh, makes use of a property known as secondary emission. The writing gun etches a positively charged pattern on the storage mesh or target by knocking off secondary emission electrons. Because of the excellent insulating property of the Magnesium Fluoride coating, this positively charged pattern remains exactly in the position where it is deposited. In order to make a pattern visible, a special electron gun, called the flood gun, is switched on (even after many hours).

The electron paths are adjusted by the collimator electrode, which constitutes a low voltage electrostatic lens system (to focus the electron beam), as shown in Fig. 7.27. Most of the electrons are stopped and collected by the collector mesh. Only electrons near the stored positive charge are pulled to the storage target with sufficient force to hit the phosphor screen. The CRT will now display the signal and it will remain visible as long as the flood guns operate. To erase the pattern on the storage mesh, a negative voltage is applied to neutralise the stored positive charge.

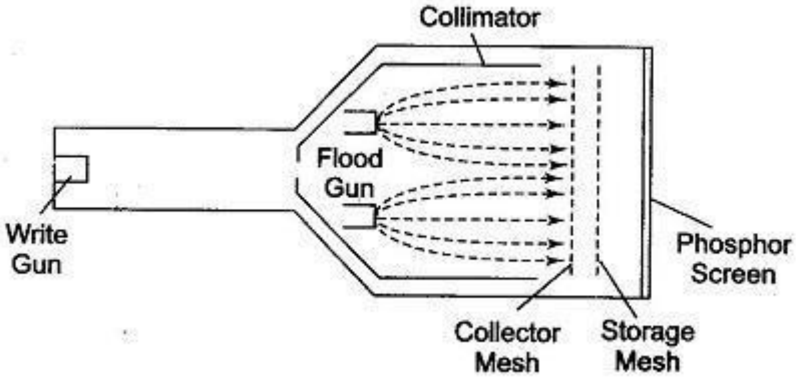


Fig. 7.27 Storage Mesh CRT

Since the storage mesh makes use of secondary emission, between the first and second crossover more electrons are emitted than are absorbed by the material, and hence a net positive charge results.

Below the first crossover a net negative charge results, since the impinging electrons do not have sufficient energy to force an equal number to be emitted. In order to store a trace, assume that the storage surface is uniformly charged and write gun (beam emission gun) will hit the storage target. Those areas of the storage surface hit by the deflecting beam lose electrons, which are collected by the collector mesh. Hence, the write beam deflection pattern is traced on the storage surface as a positive charge pattern. Since the insulation of the dielectric material is high enough to prevent any loss of charge for a considerable length of time, the pattern is stored. To view, the stored trace, a flood gun is used when the write gun is turned off.

The flood gun, biased very near the storage mesh potential, emits a flood of electrons which move towards the collector mesh, since it is biased slightly more positive than the deflection region. The collimator, a conductive coating on the CRT envelope with an applied potential, helps to align the flood electrons so that they approach the storage target perpendicularly.

When the electrons penetrate beyond the collector mesh, they encounter either a positively charged region on the storage surface or a negatively charged region where no trace has been stored.

The positively charged areas allow the electrons to pass through to the post accelerator region and the display target phosphor. The negatively charged region repels the flood electrons back to the collector mesh. Thus the charge pattern on the storage surface appears reproduced on the CRT display phosphor just as though it were being traced with a deflected beam.

Figure 7.28 shows a display of the stored charge pattern on mesh storage.

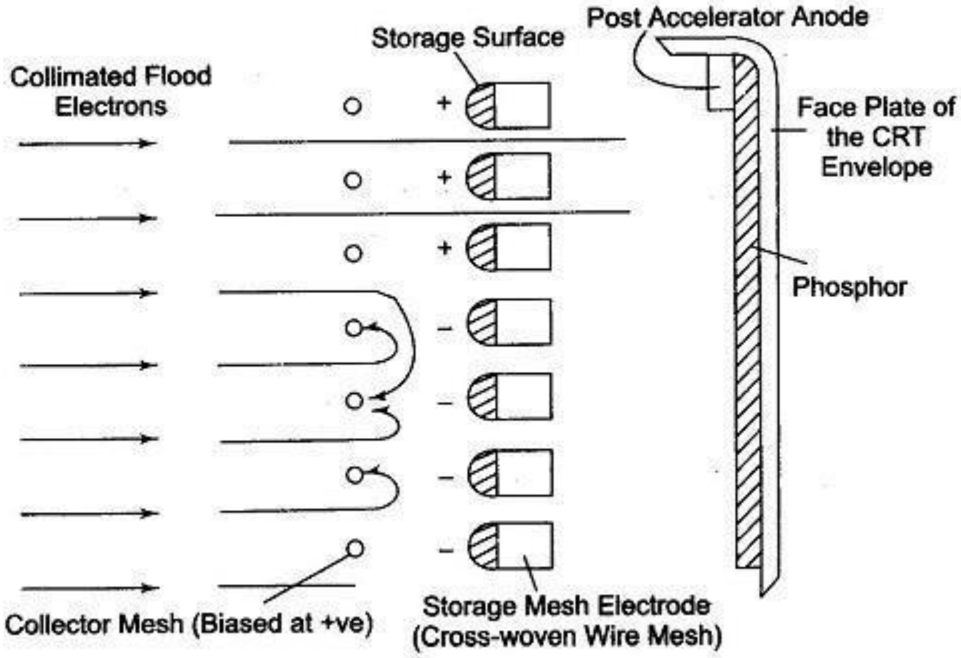


Fig. 7.28 Display of Stored Charged Pattern on a Mesh-storage

Digital Storage Oscilliscope

Digital Storage Oscilliscopes are available in processing and non-processing types. Processing types include built in computing power, which takes advantage of the fact that all data is already in digital form.

The inclusion of interfacing and a microprocessor provides a complete system for information acquisition, analysis and output. Processing capability ranges from simple functions (such as average, area, rms, etc.) to complete Fast Fourier Transform (FFT) spectrum analysis capability.

Non–processing digital scopes are designed as replacements for analog instruments for both storage and non-storage types. Their many desirable features may lead to replace analog scopes entirely (within the Bandwidth range where digitization in feasible).

The basic principle of a digital scope is given in Fig. 7.51. The scope operating controls are designed such that all confusing details are placed on the back side and one appears to be using a conventional scope. However, some digital scope panels are simpler also; most digital scopes provide the facility of switching selectable to analog operation as one of the operating modes.

The basic advantage of digital operation is the storage capability, the stored waveform can be repetitively read out, thus making transients appear repetitively and allowing their convenient display on the scope screen. (The CRT used in Digital Storage Oscilliscope is an ordinary CRT, not a storage type CRT.)

Furthermore, the voltage and time scales of display are easily changed after the waveform has been recorded, which allows expansion (typically to 64 times) of selected portions, to observe greater details.

A cross-hair cursor can be positioned at any desired point on the waveform and the voltage/time values displayed digitally on the screen, and/or readout electrically.

Some scopes use 12 bit converters, giving 0.025% resolution and 0.1% accuracy on voltage and time readings, which are better than the 2-5% of analog scopes.

Split screen capabilities (simultaneously displaying live analog traces and replayed stored ones) enable easy comparison of the two signals.

Pretrigger capability is also a significant advantage. The display of stored data is possible in both amplitude versus time and X- Y modes. In addition to the fast memory readout used for CRT display, a slow readout is possible for producing hard copy with external plotters.

When more memory than the basic amount (typically 4096 points/words) is needed, a magnetic disk accessory allows expansion to 32,000 points.

All Digital Storage Oscilliscope scopes are limited in bandwidth by the speed of their A/D converters. However, 20 MHz digitizing rates available on some scopes yield a 5 MHz bandwidth, which is adequate for most applications.

Consider a single channnel of Fig. 7.51. The analog voltage input signal is digitised in a 10 bit A/D converter with a resolution of 0.1% (1 part in 1024) and frequency response of 25 kHz. The total digital memory storage capacity is 4096 for a single channel, 2048 for two channels each and 1024 for four channels each.

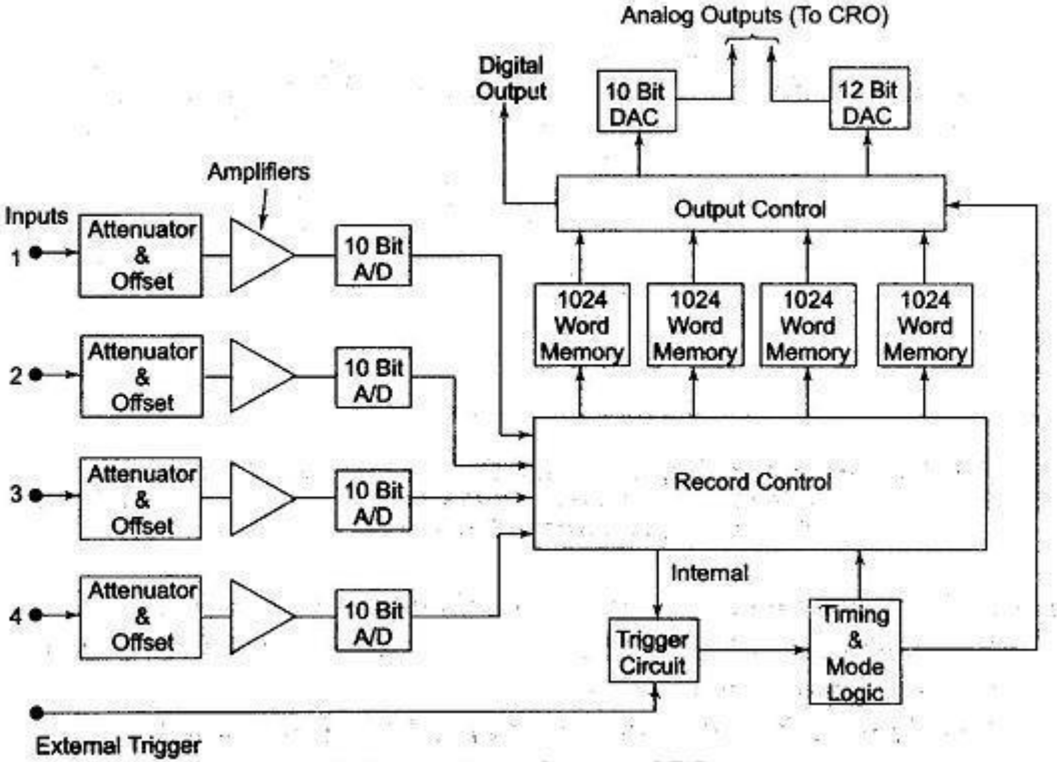


Fig. 7.51 Digital Storage CRO

The analog input voltage is sampled at adjustable rates (up to 100,000 samples per second) and data points are read onto the memory. A maximum of 4096 points are storable in this particular instrument. (Sampling rate and memory size is selected to suit the duration and waveform of the physical event being recorded.)

Once the sampled record of the event is captured in memory, many useful manipulations are possible, since memory can be read out without being erased.

If the memory is read out rapidly and repetitively, an input event which was a single shot transient becomes a repetitive or continuous waveform that can be observed easily on an ordinary scope (not a storage scope). The digital memory also may be read directly (without going through DAC) to, say, a computer where a stored program can manipulate the data in almost any way desired.

Pre-triggering recording allows the input signal preceding the trigger points to be recorded. In ordinary triggering the recording process is started by the rise of the input (or some external triggering) above some preset threshold value.

As in digital recorder, DSO can be set to record continuously (new data coming into the memory pushes out old data, once memory is full), until the trigger signal is received; then the recording is stopped, thus freezing data received prior to the trigger signal in the memory.

An adjustable trigger delay allows operator control of the stop point, so that the trigger may occur near the beginning, middle or end of the stored information.

Digital Storage Oscilliscope Features

1. Sampling rate 20 Mega-samples per second per channel. Max. (simultaneous) capture of both channels.
2. Pre-trigger: 25%, 50%, 75%, for Single Shot, Roll normal.
3. Roll mode: (Continuous and Single Shot with Pre-trigger of 25%, 50%, 75%)
4. Single shot (0.5 p.s Single shot @ 10 pts. /div resolution with pre-trigger 25%, 50%, 75%)
5. Digital Sweep rate: 0.5. µs/cm to 50 sec/cm, (event as long as 8.33 minutes can be captured)
6. Computer built in Interface: (RS 232 Serial port and Centronics Parallel interface).

UNIT - 3
SIGNAL GENERATOR & ANALYZERS

SIGNAL GENERATOR: Fixed And Variable Af Oscillators, Standard Signal Generator, Square Pulse, Random Noise And Sweep Generator- Principles Of Working (Block Diagram Approach)

ANALYZERS: Introduction, Basic Wave Analyzers, Frequency Selective Wave Analyzer, Heterodyne Wave Analyzer, Harmonic Distortion Analyzers, Spectrum Analyzers, And Digital Fourier Analyzer.

INTRODUCTION

A signal generator is an electronic device that generates repeating or non-repeating electronic signals in either the analog or the digital domain. It is generally used in designing, testing, troubleshooting, and repairing electronic or electroacoustic devices, though it often has artistic uses as well

DIFFERENCE BETWEEN A SIGNAL GENERATOR AND AN OSCILLATOR

Signal generators are the sources of electrical signals used for the purpose of testing and Operating different kinds of electrical equipment. A signal generator provides different types of waveforms such as sine, triangular, square, pulse etc., whereas an oscillator provides only sinusoidal signal at the output.

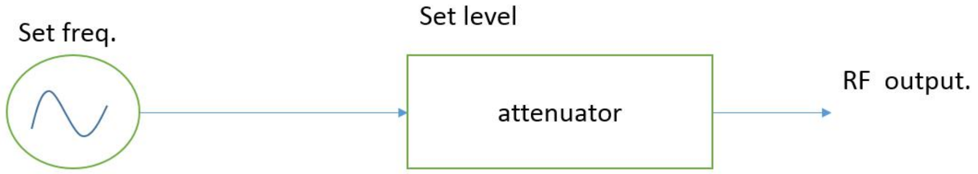
The AF oscillators are divided into two types. They are as follows

1. Fixed frequency AF oscillator

2. Variable frequency AF oscillator.

1. Fixed Frequency AF Oscillator

Many instrument circuits contain oscillator as one of its integral parts to provide output signal within the specified fixed audio frequency range. This specified audio frequency range can be 1 kHz signal or 400 Hz signal. The 1 kHz frequency signal is used to execute a bridge circuit and 400 Hz frequency signal is used for audio testing. A fixed frequency AF oscillator employs an iron core transformer. Due to this a positive feedback is obtained through the inductive coupling placed between the primary winding and secondary winding of the transformer and hence fixed frequency oscillations are generated.



2. Variable Frequency AF Oscillator

It is a general purpose oscillator used in laboratory. It generates oscillations within the entire audio frequency range i.e. From 20 Hz to 20 kHz. This oscillator provides a pure, constant sine wave

output throughout this af range. The examples of variable af oscillators used in laboratory are rc feedback oscillator, beat frequency oscillator.

STANDARD SIGNAL GENERATOR:

A standard signal generator produces known and controllable voltages. It is used as power source for the measurement of gain, signal to noise ratio (S/N), bandwidth, standing wave ratio and other properties. It is extensively used in the testing of radio receivers and transmitters.

The instrument is provided with a means of modulating the carrier frequency, which is indicated by the dial setting on the front panel. The modulation is indicated by a meter. The output signal can be Amplitude Modulated (AM) or Frequency Modulated (FM). Modulation may be done by a sine wave, square wave, triangular wave or a pulse. The elements of a conventional signal generator are shown in Fig. 8.2 (a).

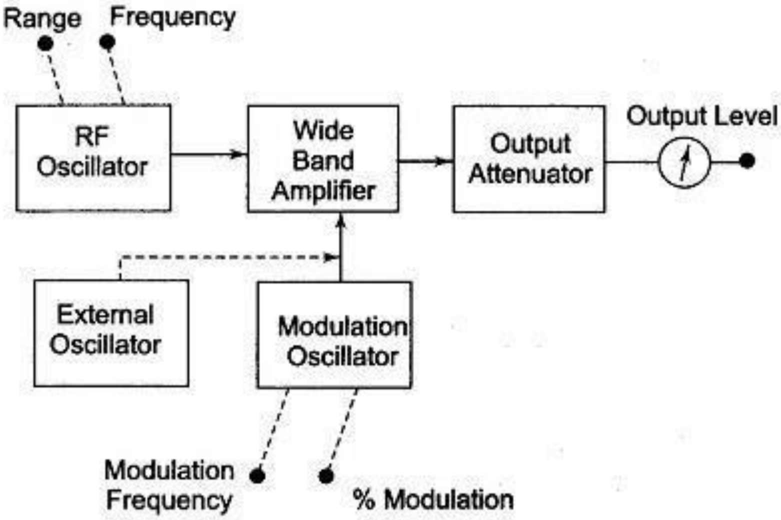


Fig. 8.2 (a) Conventional Standard Signal Generator

The carrier frequency is generated by a very stable RF oscillator using an LC tank circuit, having a constant output over any frequency range. The frequency of oscillations is indicated by the frequency range control and the vernier dial setting. AM is provided by an internal sine wave generator or from an external source.

(Modulation is done in the output amplifier circuit. This amplifier delivers its output, that is, modulation carrier, to an attenuator. The output voltage is read by an output meter and the attenuator output setting.)

Frequency stability is limited by the LC tank circuit design of the master oscillator. Since range switching is usually accomplished by selecting appropriate capacitors, any change in frequency range upsets the circuit design to some extent and the instrument must be given time to stabilise at the new resonant frequency.

In high frequency oscillators, it is essential to isolate the oscillator circuit from the output circuit. This isolation is necessary, so that changes occurring in the output circuit do not affect the oscillator frequency, amplitude and distortion characteristics. Buffer amplifiers are used for this purpose.

SQUARE AND PULSE GENERATOR BLOCK DIAGRAM (LABORATORY TYPE):

Square and Pulse Generator Block Diagram are used as measuring devices in combination with a CRO. They provide both quantitative and qualitative information of the system under test. They are made use of in transient response testing of amplifiers. The fundamental difference between a pulse generator and a square wave generator is in the duty cycle.

$$\text{Duty cycle} = \frac{\text{pulse width}}{\text{pulse period}}$$

A square wave generator has a 50% duty cycle. 8.9.1

Requirements of a Pulse

The pulse should have minimum distortion, so that any distortion, in the display is solely due to the circuit under test.

The basic characteristics of the pulse are rise time, overshoot, ringing, sag, and undershoot.

The pulse should have sufficient maximum amplitude, if appreciable output power is required by the test circuit, e.g. for magnetic core At the same time, the attenuation range should be adequate to produce small amplitude pulses to prevent over driving of some test circuit.

The range of frequency control of the pulse repetition rate (PRR) should meet the needs of the experiment. For example, a repetition frequency of 100 MHz is required for testing fast circuits. Other generators have a pulse-burst feature which allows a train of pulses rather than a continuous

Some pulse generators can be triggered by an externally applied trigger signal; conversely, pulse generators can be used to produce trigger signals, when this output is passed through a differentiator circuit.

The output impedance of the pulse generator is another important in a fast pulse system, the generator should be matched to the cable and the cable to the test circuit. A mismatch would cause energy to be reflected back to the generator by the test circuit, and this may be re-reflected by the generator, causing distortion of the pulses.

DC coupling of the output circuit is needed, when dc bias level is to be maintained.

The basic circuit for pulse generation is the asymmetrical multi-vibrator. A laboratory type square wave and pulse generator is shown in Fig. 8.6.

The frequency range of the instrument is covered in seven decade steps from 1 Hz to 10 MHz, with a linearly calibrated dial for continuous adjustment on all ranges.

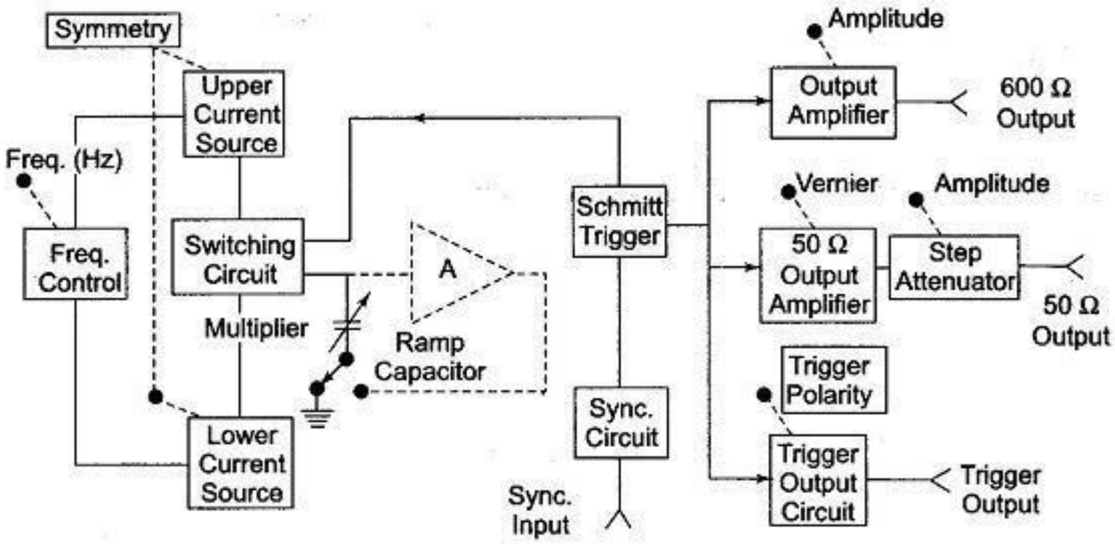


Fig. 8.6 Block Diagram of a Pulse Generator

The duty cycle can be varied from 25 – 75%. Two independent outputs are available, a 50 Q source that supplies pulses with a rise and fall time of 5 ns at 5 V peak amplitude and a 600 Q source which supplies pulses with a rise and fall time of 70 ns at 30 V peak amplitude. The instrument can be operated as a free-running generator, or it can be synchronised with external signals.

The basic generating loop consists of the current sources, the ramp capacitor, the Schmitt trigger and the current switching circuit, as shown in Fig. 8.7.

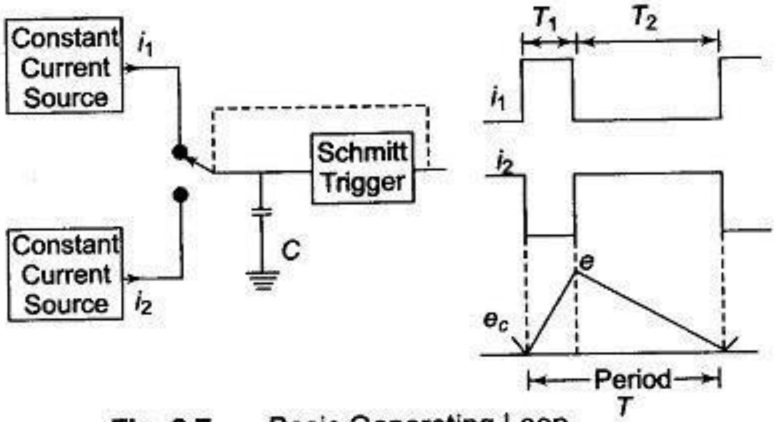


Fig. 8.7 Basic Generating Loop

The upper current source supplies a constant current to the capacitor and the capacitor voltage increases linearly. When the positive slope of the ramp voltage reaches the upper limit set by the internal circuit components, the Schmitt trigger changes state. The trigger circuit output becomes negative and reverses the condition of the current switch. The capacitor discharges linearly, controlled by the lower current source. When the negative ramp reaches a predetermined lower level, the Schmitt trigger switches back to its original state. The entire process is then repeated. The ratio i1/i2 determines the duty cycle, and is controlled by symmetry control. The sum of i1 and i2 determines the frequency. The size of the capacitor is selected by the multiplier switch.

The unit is powered by an internal supply that provides regulated voltages for all stages of the instrument.

Random Noise Generator Block Diagram:

A simplified Random Noise Generator Block Diagram used in the audio frequency range is shown in Fig. 8.8.

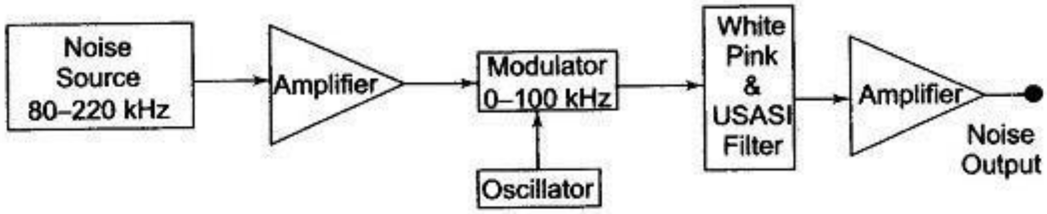


Fig. 8.8 Random Noise Generator

The instrument offers the possibility of using a single measurement to indicate performance over a wide frequency band, instead of many measurements at one frequency at a time. The spectrum of random noise covers all frequencies and is referred to as White noise, i.e. noise having equal power density at all frequencies (an analogy is white light). The power density spectrum tells us how the energy of a signal is distributed in frequency, but it does not specify the signal uniquely, nor does it tell us very much about how the amplitude of the signal varies with time. The spectrum does not specify the signal uniquely because it contains no phase informations.

The method of generating noise is usually to use a semi conductor noise diode, which delivers frequencies in a band roughly extending from 80 — 220 kHz. The output from the noise diode is amplified and heterodyned down to the audio frequency band by means of a balanced symmetrical modulator. The filter arrangement controls the bandwidth and supplies an output signal in three spectrum choices, white noise, pink noise and Usasi noise.

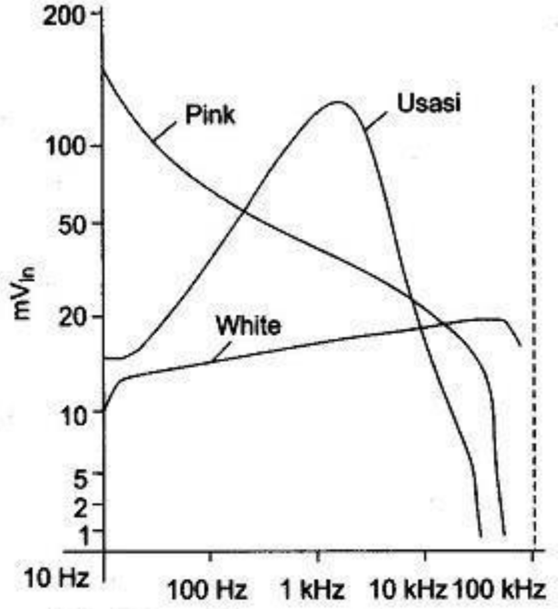


Fig. 8.9 Frequency Response

From Fig. 8.9, it is seen that white noise is flat from 20 Hz to 25 kHz and has an upper cutoff frequency of 50 kHz with a cutoff slope of —12 dbs/ octave.

Pink noise is so called because the lower frequencies have a larger amplitude, similar to red light. Pink noise has a voltage spectrum which is inversely proportional to the square root of frequency and is used in bandwidth analysis.

Usasi noise ranging simulates the energy distribution of speech and music frequencies and is used for testing audio amplifiers and loud speakers.

SWEEP GENERATOR:

Block Diagram of Sweep Generator – It provides a sinusoidal output voltage whose frequency varies smoothly and continuously over an entire frequency band, usually at an audio rate. The process of frequency modulation may be accomplished electronically or mechanically.

It is done electronically by using the modulating voltage to vary the reactance of the oscillator tank circuit component, and mechanically by means of a motor driven capacitor, as provided for in a modern laboratory type signal generator. Figure 8.10 shows a basic block diagram of a sweep generator.

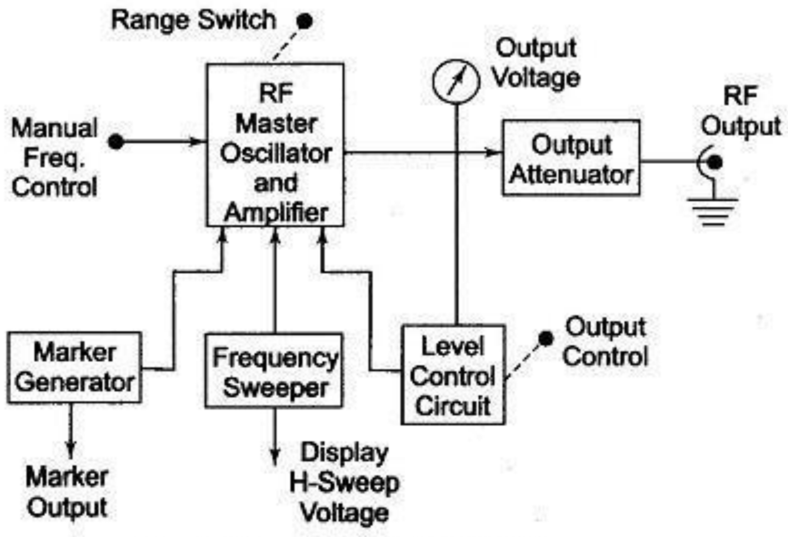


Fig. 8.10 Sweep Generator

The frequency sweeper provides a variable modulating voltage which causes the capacitance of the master oscillator to vary. A representative sweep rate could be of the order of 20 sweeps/second. A manual control allows independent adjustment of the oscillator resonant frequency.

The frequency sweeper provides a varying sweep voltage for synchronisation to drive the horizontal deflection plates of the CRO. Thus the amplitude of the response of a test device will be locked and displayed on the screen.

To identify a frequency interval, a marker generator provides half sinusoidal waveforms at any frequency within the sweep range. The marker voltage can be added to the sweep voltage of the CRO during alternate cycles of the sweep voltage, and appears superimposed on the response curve.

The automatic level control circuit is a closed loop feedback system which monitors the RF level at some point in the measurement system. This circuit holds the power delivered to the load or test circuit constant and independent of frequency and impedance changes. A constant power level prevents any source mismatch and also provides a constant readout calibration with frequency.

Wave Analyzer:

Introduction : It can be shown mathematically that any complex waveform is made up of a fundamental and its harmonics.

It is often desired to measure the amplitude of each harmonic or fundamental individually. This can be performed by instruments called wave analyzers. This is the simplest form of analysis in the frequency domain, and can be performed with a set of tuned filters and a voltmeter. Wave analyzers are also referred to as frequency selective voltmeters, carrier frequency voltmeters, and selective level voltmeters. The instrument is tuned to the frequency of one component whose amplitude is measured.

This instrument is a narrow band superheterodyne receiver, similar to a spectrum analyzer (discussed later). It has a very narrow pass-band. A meter is used for measurement, instead of a CRT. Wave analyzers are used in the low RF range, below 50 MHz and down through the AF range. They provide a very high frequency resolution.

Some wave analyzers have the facility of automatic frequency control, in which the tuning automatically locks to a signal. This makes it possible to measure the amplitude of signals that are drifting in frequency by amounts that would carry them outside the widest pass-band available.

Basic Wave Analyzer

A basic wave analyzer is shown in Fig. 9.1(a). It consists of a primary detector, which is a simple LC circuit. This LC circuit is adjusted for resonance at the frequency of the particular harmonic component to be measured.

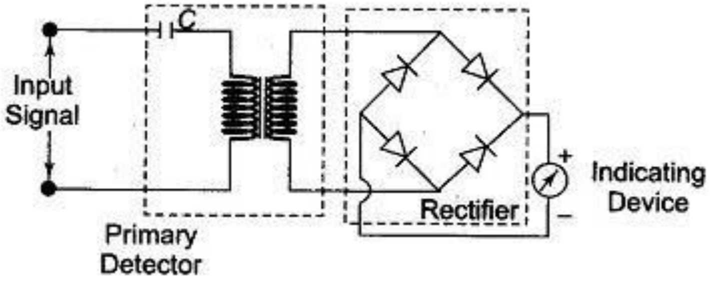


Fig. 9.1 (a) Basic Wave Analyzer

The intermediate stage is a full wave rectifier, to obtain the average value of the input signal. The indicating device is a simple dc voltmeter that is calibrated to read the peak value of the sinusoidal input voltage.

Since the LC circuit is tuned to a single frequency, it passes only the frequency to which it is tuned and rejects all other frequencies. A number of tuned filters, connected to the indicating device through a selector switch, would be required for a useful Wave analyzer.

Heterodyne Wave Analyzer:

Wave analyzers are useful for measurement in the audio frequency range only. For measurements in the RF range and above (MHz range), an ordinary wave analyzer cannot be used. Hence, special types of wave analyzers working on the principle of heterodyning (mixing) are used. These wave analyzers are known as Heterodyne Wave Analyzer.

In this wave analyzer, the input signal to be analyzed is heterodyned with the signal from the internal tunable local oscillator in the mixer stage to produce a higher IF frequency.

By tuning the local oscillator frequency, various signal frequency components can be shifted within the pass-band of the IF amplifier. The output of the IF amplifier is rectified and applied to

the meter circuit.
An instrument that involves the principle of heterodyning is the Heterodyning tuned voltmeter, shown in Fig. 9.3.

The input signal is heterodyned to the known IF by means of a tunable local oscillator. The amplitude of the unknown component is indicated by the VTVM or output meter. The VTVM is calibrated by means of signals of known amplitude..

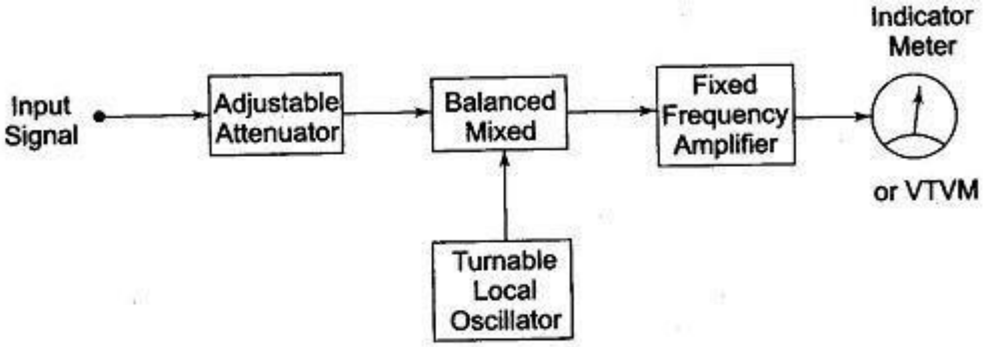


Fig. 9.3 Heterodyne Wave Analyzer

The frequency of the component is identified by the local oscillator frequency, i.e. the local oscillator frequency is varied so that all the components can be identified. The local oscillator can also be calibrated using input signals of known frequency. The fixed frequency amplifier is a multistage amplifier which can be designed conveniently because of its frequency characteristics. This analyzer has good frequency resolution and can measure the entire AF frequency range. With the use of a suitable attenuator, a wide range of voltage amplitudes can be covered. Their disadvantage is the occurrence of spurious cross-modulation products, setting a lower limit to the amplitude that can be measured.

Two types of selective amplifiers find use in Heterodyne wave analyzers. The first type employs a crystal filter, typically having a centre frequency of 50 kHz. By employing two crystals in a band-pass arrangement, it is possible to obtain a relatively flat pass-band over a 4 cycle range. Another type uses a resonant circuit in which the effective Q has been made high and is controlled by negative feedback. The resultant signal is passed through a highly selective 3-section quartz crystal filter and its amplitude measured on a Q-meter.

When a knowledge of the individual amplitudes of the component frequency is desired, a heterodyne wave analyzer is used.

A modified heterodyne wave analyzer is shown in Fig. 9.4. In this analyzer, the attenuator provides the required input signal for heterodyning in the first mixer stage, with the signal from a local oscillator having a frequency of 30 —48 MHz.

The first mixer stage produces an output which is the difference of the local oscillator frequency and the input signal, to produce an IF signal of 30 MHz. This IF frequency is uniformly amplified by the IF amplifier. This amplified IF signal is fed to the second mixer stage, where it is again heterodyned to produce a difference frequency or IF of zero frequency.
The selected component is then passed to the meter amplifier and detector circuit through an

active filter having a controlled band-width. The meter detector output can then be read off on a db- calibrated scale, or may be applied to a secondary device such as a recorder.

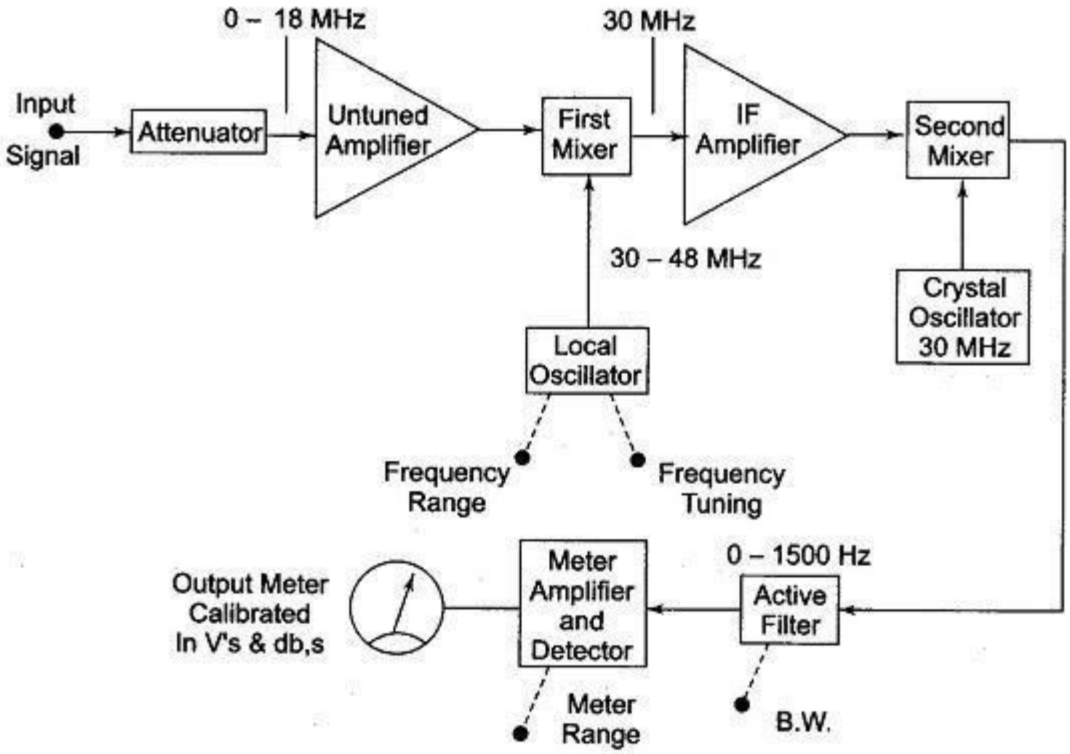


Fig. 9.4 RF Heterodyne Wave Analyzer

This wave analyzer is operated in the RF range of 10 kHz — 18 MHz, with 18 overlapping bands selected by the frequency range control of the local oscillator. The bandwidth, which is controlled by the active filter, can be selected at 200 Hz, 1 kHz and 3 kHz.

Frequency Selective Wave Analyzer:

The Frequency Selective Wave Analyzer consists of a very narrow pass-band filter section which can be tuned to a particular frequency within the audible frequency range (20 Hz — 20 kHz). The block diagram of a wave analyzer is as shown in Fig. 9.1(b).

The complex wave to be analyzed is passed through an adjustable attenuator which serves as a range multiplier and permits a large range of signal amplitudes to be analyzed without loading the amplifier.

The output of the attenuator is then fed to a selective amplifier, which amplifies the selected frequency. The driver amplifier applies the attenuated input signal to a high-Q active filter. This high-Q filter is a low pass filter which allows the frequency which is selected to pass and reject all others. The magnitude of this selected frequency is indicated by the meter and the filter section identifies the frequency of the component. The filter circuit consists of a cascaded RC resonant circuit and amplifiers. For selecting the frequency range, the capacitors generally used are of the closed tolerance polystyrene type and the resistances used are precision potentiometers. The capacitors are used for range changing and the potentiometer is used to change the frequency within the selected pass-band, Hence this wave analyzeris also called a Frequency selective voltmeter.

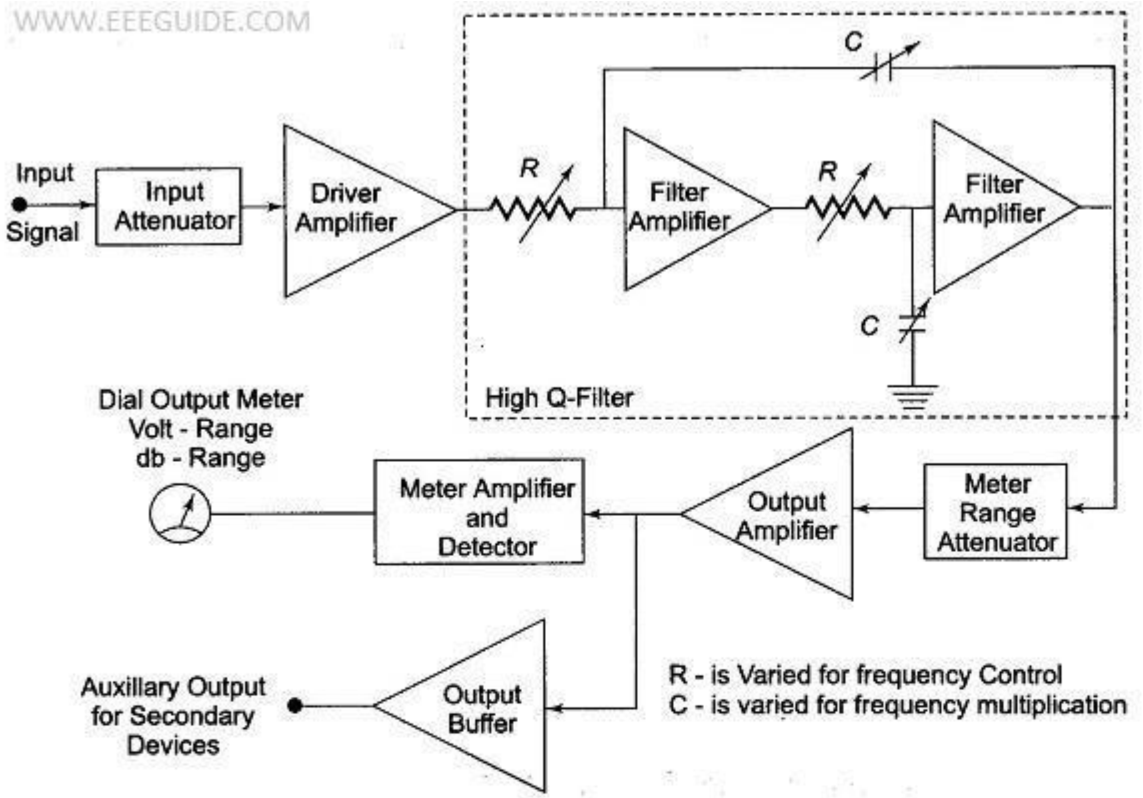


Fig. 9.1 (b) Frequency Selective Wave Analyzer

The complex wave to be analyzed is passed through an adjustable attenuator which serves as a range multiplier and permits a large range of signal amplitudes to be analyzed without loading the amplifier.

The output of the attenuator is then fed to a selective amplifier, which amplifies the selected frequency. The driver amplifier applies the attenuated input signal to a high-Q active filter. This high-Q filter is a low pass filter which allows the frequency which is selected to pass and reject all others. The magnitude of this selected frequency is indicated by the meter and the filter section identifies the frequency of the component. The filter circuit consists of a cascaded RC resonant circuit and amplifiers. For selecting the frequency range, the capacitors generally used are of the closed tolerance polystyrene type and the resistances used are precision potentiometers. The capacitors are used for range changing and the potentiometer is used to change the frequency within the selected pass-band, Hence this wave analyzeris also called a Frequency selective voltmeter.

The entire AF range is covered in decade steps by switching capacitors in the RC section.

The selected signal output from the final amplifier stage is applied to the meter circuit and to an untuned buffer amplifier. The main function of the buffer amplifier is to drive output devices, such as recorders or electronics counters.

The meter has several voltage ranges as well as decibel scales marked on it. It is driven by an average reading rectifier type detector.

The wave analyzer must have extremely low input distortion, undetectable by the analyzer itself. The bandwidth of the instrument is very narrow, typically about 1% of the selective band given by the following response characteristics. (Fig. 9.2).

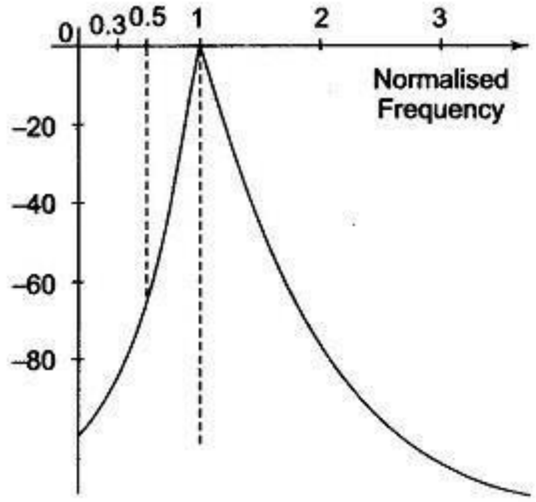


Fig. 9.2 Relative Response in dBs

Harmonic Distortion Analyzer:

Introduction: Harmonic distortion analyzers measure the total harmonic content in the waveforms. It can be shown mathematically that an amplitude distorted sine wave is made up of pure sine wave components, including the fundamental frequency f of the input signal, and harmonic multiples of the fundamental frequency, 2f, 3f, 4f etc.

Harmonic distortion can be quantitatively measured very accurately with a harmonic distortion analyzer, generally called a distortion analyzer.

The total harmonic distortion or factor is given by

$$D = \sqrt{D_2^2 + D_3^2 + D_4^2 \cdots}$$

where D2,D2,D3 … represent the second harmonic, third harmonic, etc. respectively.

The distortion analyzer measures the total harmonic distortion without indicating the amplitude and frequency of each component waves.

Harmonic Distortion Analyzer:

A Harmonic Distortion Analyzer measures the total harmonic power present in the test wave rather than the distortion caused by each component. The simplest method is to suppress the fundamental frequency by means of a high pass filter whose cut off frequency is a little above the fundamental frequency. This high pass allows only the harmonics to pass and the total harmonic distortion can then be measured. Other types of Harmonic Distortion Analyzer based on fundamental suppression are as follows.

1. Resonance Bridge

The bridge shown in Fig. 9.5 is balanced for the fundamental frequency, i.e. L and C are tuned to the fundamental frequency. The bridge is unbalanced for the harmonics, i.e. only harmonic power will be available at the output terminal and can be measured. If the fundamental frequency is changed, the bridge must be balanced again. If L and C are fixed components, then this method is suitable only when the test wave has a fixed frequency. Indicators can be thermocouples or square law VTVMs. This indicates the rms value of all harmonics. When a continuous adjustment of the fundamental frequency is desired, a Wien bridge arrangement is used as shown in Fig. 9.6.

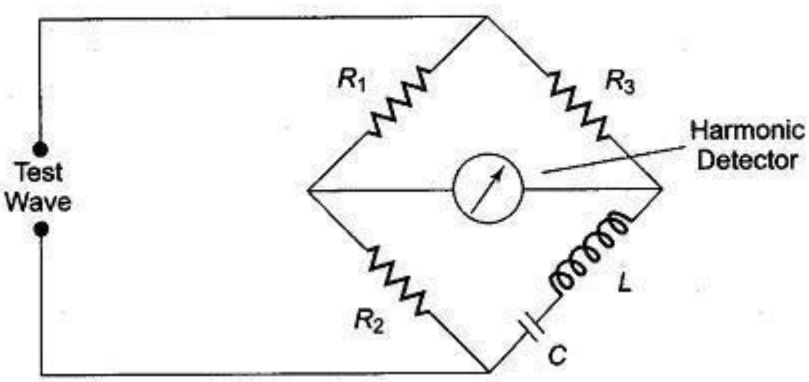


Fig. 9.5 Resonance Bridge

2. Wien's Bridge Method

The bridge is balanced for the fundamental frequency. The fundamental energy is dissipated in the bridge circuit elements. Only the harmonic components reach the output terminals. The harmonic distortion output can then be measured with a meter. For balance at the fundamental frequency, C1,C2,C, R1=R2=R,R3=2R4.

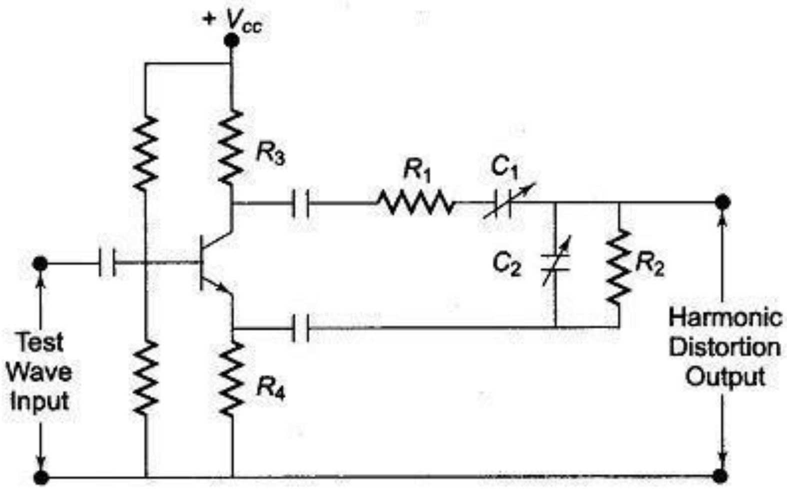


Fig. 9.6 Wien's Bridge Method

3. Bridged T-Network Method

Referring to Fig. 9.7 the, L and C's are tuned to the fundamental frequency, and R is adjusted to bypass fundamental frequency. The tank circuit being tuned to the fundamental frequency, the fundamental energy will circulate in the tank and is bypassed by the resistance. Only harmonic components will reach the output terminals and the distorted output can be measured by the meter. The Q of the resonant circuit must be at least 3-5.

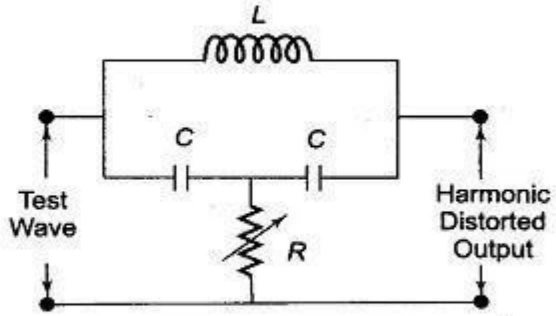


Fig. 9.7 Bridged T-Network Method

One way of using a bridge T-network is given in Fig. 9.8.

The switch S is first connected to point A so that the attenuator is excluded and the bridge T-network is adjusted for full suppression of the fundamental frequency, i.e. minimum output. Minimum output indicates that the bridged T-network is tuned to the fundamental frequency and that the fundamental frequency is fully suppressed.

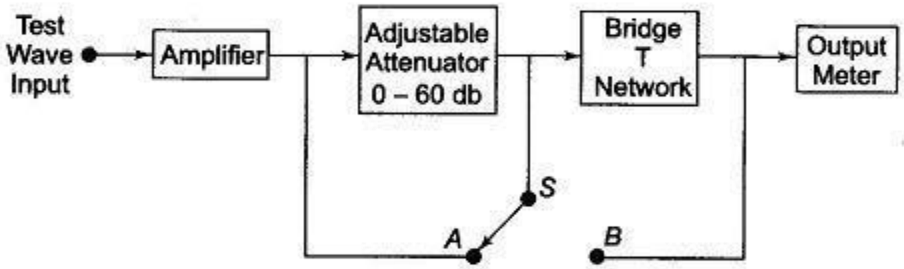


Fig. 9.8 Harmonic Distortion Analyzer Using Bridged T-Network

The switch is next connected to terminal B, i.e. the bridged T-network is excluded. Attenuation is adjusted until the same reading is obtained on the meter. The attenuator reading indicates the total rms distortion. Distortion measurement can also be obtained by means of a wave analyzer, knowing the amplitude and the frequency of each component, the Harmonic Distortion Analyzer can be calculated. However, distortion meters based on fundamental suppression are simpler to design and less expensive than wave analyzers. The disadvantage is that they give only the total distortion and not the amplitude of individual distortion components.

Spectrum Analyzer Block Diagram:

Spectrum Analyzer Block Diagram – The most common way of observing signals is to display them on an oscilloscope, with time as the X-axis (i.e. amplitude of the signal versus time). This is the time domain. It is also useful to display signals in the frequency domain. The instrument providing this frequency domain view is the spectrum analyzer.

A Spectrum Analyzer Block Diagram provides a calibrated graphical display on its CRT, with frequency on the horizontal axis and amplitude (voltage) on the vertical axis.

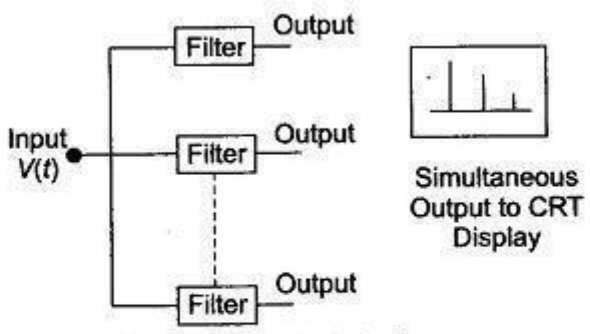
Displayed as vertical lines against these coordinates are sinusoidal components of which the input signal is composed. The height represents the absolute magnitude, and the horizontal location represents the frequency.

These instruments provide a display of the frequency spectrum over a given frequency band. Spectrum analyzers use either a ***parallel filter bank*** or a ***swept frequency*** technique.

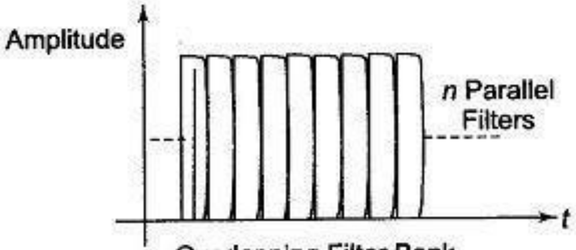
In a ***parallel filter bank*** analyzer, the frequency range is covered by a series of filters whose central frequencies and bandwidth are so selected that they overlap each other, as shown in Fig. 9.9(a).

Typically, an audio analyzer will have 32 of these filters, each covering one third of an octave.

For wide band narrow resolution analysis, particularly at RF or microwave signals, the swept technique is preferred.



Parallel Filter Bank Analyzer



Overlapping Filter Bank

Fig. 9.9 (a) Spectrum Analyzer
(Parallel Filter Bank Analyzer)

Basic Spectrum Analyzer Using Swept Receiver Design

Referring to the block diagram of Fig. 9.9(b), the sawtooth generator provides the sawtooth voltage which drives the horizontal axis element of the scope and this sawtooth voltage is frequency controlled element of the voltage tuned oscillator. As the oscillator sweeps from fmin to fmax of its frequency band at a linear recurring rate, it beats with the frequency component of the input signal and produce an IF, whenever a frequency component is met during its sweep. The frequency component and voltage tuned oscillator frequency beats together to produce a difference frequency, i.e. IF. The IF corresponding to the component is amplified and detected if necessary, and then applied to the vertical plates of the CRO, producing a display of amplitude versus frequency.

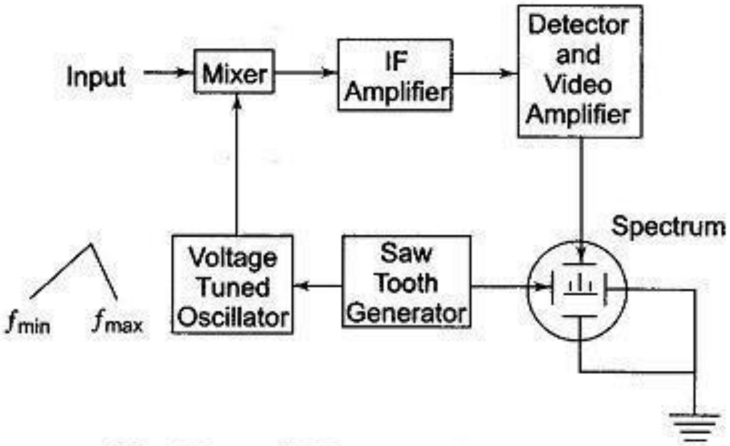


Fig. 9.9 (b) Spectrum Analyzer

The spectrum produced if the input wave is a single toned A.M. is given in Figs 9.10, 9.11, and 9.12.

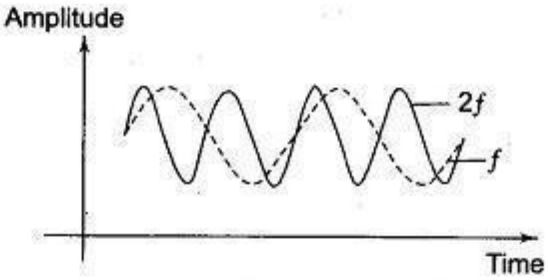


Fig. 9.10 Test Wave Seen on Ordinary CRO

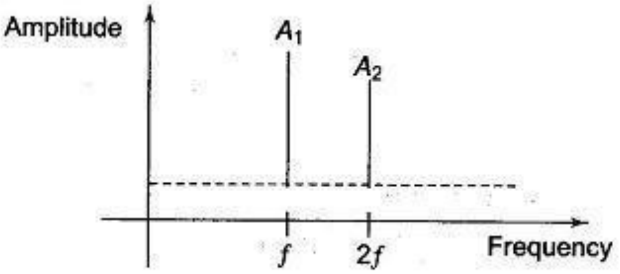


Fig. 9.11 Display on the Spectrum CRO

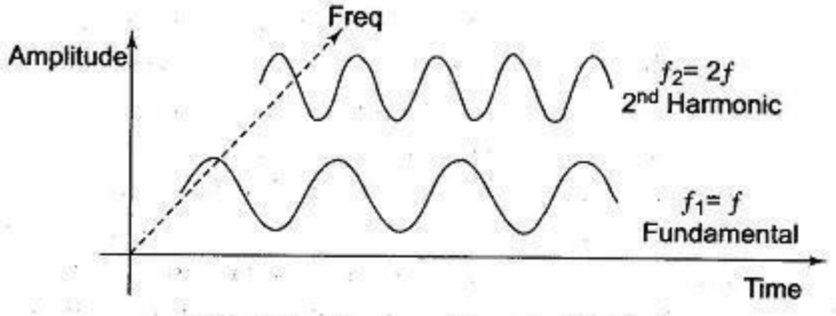


Fig. 9.12 Test Waveform as Seen on X-Axis (Time) and Z-Axis (Frequency)

Spectrum Analyzer Applications

One of the principal applications of spectrum analyzers has been in the study of the RF spectrum produced in microwave instruments. In a microwave instrument, the horizontal axis can display as a wide a range as 2 — 3 GHz for a broad survey and as narrow as 30 kHz, for a highly magnified view of any small portion of the spectrum. Signals at microwave frequency separated by only a few kHz can be seen individually.

The frequency range covered by this instrument is from 1 MHz to 40 GHz. The basic block diagram (Fig. 9.13) is of a spectrum analyzer covering the range 500 kHz to 1 GHz, which is representative of a superheterodyne type.

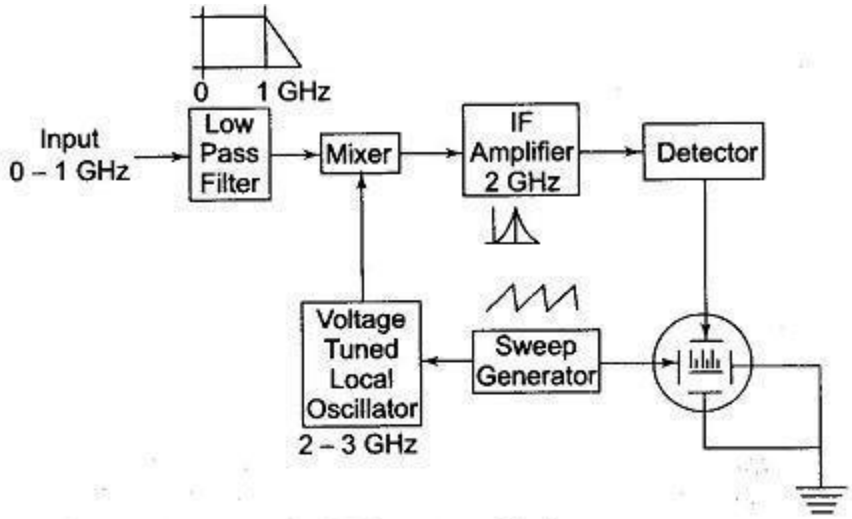


Fig. 9.13 RF Spectrum Analyzer

The input signal is fed into a mixer which is driven by a local oscillator. This oscillator is linearly tunable electrically over the range 2 — 3 GHz. The mixer provides two signals at its output that are proportional in amplitude to the input signal but of frequencies which are the sum and difference of the input signal and local oscillator frequency.

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

From this, it is observed that as the sawtooth signal sweeps, the local oscillator also sweeps linearly from 2 — 3 GHz. The tuning of the spectrum analyzer is a swept receiver, which sweeps linearly from 0 to 1 GHz. The sawtooth scanning signal is also applied to the horizontal plates of the CRT to form the frequency axis. (The Spectrum Analyzer Block Diagram is also sensitive to signals from 4 — 5 GHz referred to as the image frequency of the superheterodyne. A low pass filter with a cutoff frequency above 1 GHz at the input suppresses these spurious signals.) Spectrum analyzers are widely used in radars, oceanography, and bio-medical fields.

Digital Fourier Analyzer:

The basic principle of a Digital Fourier Analyzer is shown in Fig. 9.14. The Digital Fourier Analyzer converts the analogue waveform over time period T into N samples.

The discrete spectral response Sx(kΔf);k=1,2,…,N which is equivalent to simultaneously obtaining the output from N filters having a bandwidth given by Δf=1/T, is obtained by applying a Discrete Fourier Transform (DFT) to the sampled version of the signal. The spectral response is thus given by

$$S_x(k\,\Delta f) = \frac{T}{N}\sum_{n=1}^{N} x(n \cdot \Delta t)\exp\left(\frac{-j2\,\Pi kn}{N}\right)$$

where k=1,2,3,….N.

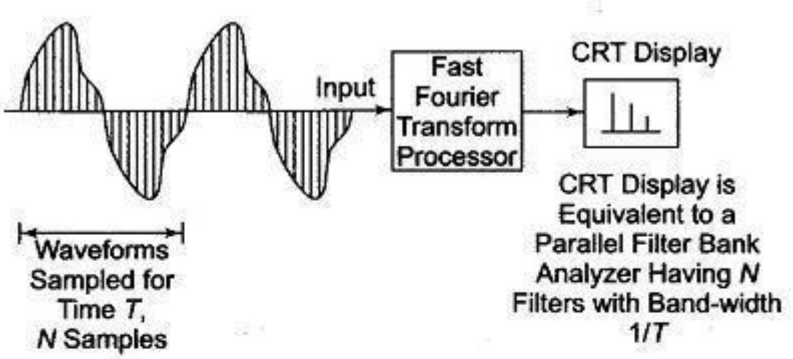


Fig. 9.14 Basic of a Digital Fourier Analyzer

Sx(kΔf) is a complex quantity, which is obtained by operating on all the sample x(n.Δt);n=1,2,3,…,N by the complex factor exp [-j[(2Πkn)/N]].

The discrete inverse transform is given by

$$x(n \cdot \Delta t) = \frac{N}{T}\sum_{n=1}^{N} S_x(k \cdot \Delta f)\exp\left(\frac{j2\,\Pi kn}{N}\right)$$

where n = 1, 2, …, N.

Since Sx(k.Δf); k = 1, 2, …, N is a complex quantity, the DFT provides both amplitude and phase information at a particular point in the spectrum.

The discrete transforms are usually implemented by means of the Fast Fourier Transform (FFT), which is particularly suitable for implementation in a digital computer, since N is constrained to the power of 2, i.e. 210 = 1024.

A digital signal analyzer block diagram is shown in Fig. 9.15. This digital signal analyzer employs an FFT algorithm.

The block diagram is divided into three sections, namely the input section, the control section and the display section.

The input section consists of two identical channels. The input signal is applied to the input amplifier, where it is conditioned and passed through two or more anti-aliasing filters. The cut-off frequencies of these filters are selected with respect to the sampling frequency being used. The 30 kHz filter is used with a sampling rate of 102.4 kHz and the 300 kHz filter with a sampling rate of 1.024 MHz.

To convert the signal into digital form, a 12 bit ADC is used. The output from the ADC is connected to a multiplier and a digital filter.

Depending on the mode of the analyzer to be used, either in Base-band mode (in which the spectrum is displayed from a dc to an upper frequency within the bandwidth of the analyzer) or in the band selectable mode (which allows the full resolution of the analyzer to be focused in a narrow frequency band), the signal is multiplied either by a sine or cosine function.

The processing section of the analyzer provides FFT processing on the input signal (linear or logarithm).

For one channel this can provide the real (magnitude) and imaginary (phase) of the linear spectrum Sx(f) of a time domain signal

$$S_x(f) = F(x(t))$$

where F(x (t)) is the Fourier transform of x(t). The autospectrum Gxx(f) which contains no phase information is obtained from Sx(f) as where Sx (f)* indicates the complex conjugate of Sx (f).

$$G_{xx}(f) = S_x(f)\, S_x(f)^*$$

The Power Spectral Density (PSD) is obtained by normalizing the function Gxx(f) to a bandwidth of 1 Hz, which represents the power in a bandwidth of 1 Hz centered around the frequency f

The Inverse Fourier Transform of Gxx(f) is given by

$$R_{xx}(\tau) = F^{-1}(G_{xx}(f))$$
$$R_{xx}(\tau) = F^{-1}(S_x(f)\,S_x(f))^*$$

writing the above equation in terms of the time domain characteristics of the signal x(t), its autocorrelation function is defined as

$$R_{xx}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_0^T x(t)\,x(t+\tau)\,dt$$

By the use of two channels, the combined properties of the two signals can be obtained. The cross- power spectrum of the two signals x(t) and y(t) can be computed as

$$G_{yx}(f) = S_y(t)\,S_x(t)^*$$

where Sy(t) is the linear spectrum of y(t) and Sx(t)* is the complex conjugate spectrum of x(t).

If x (t) represents the input to a system and y(t) the output of the system, then its transfer function H(f), which contains both amplitude and phase information can be obtained by computing

$$H(f) = \frac{\overline{G_{yx}(f)}}{\overline{G_{xx}(f)}}$$

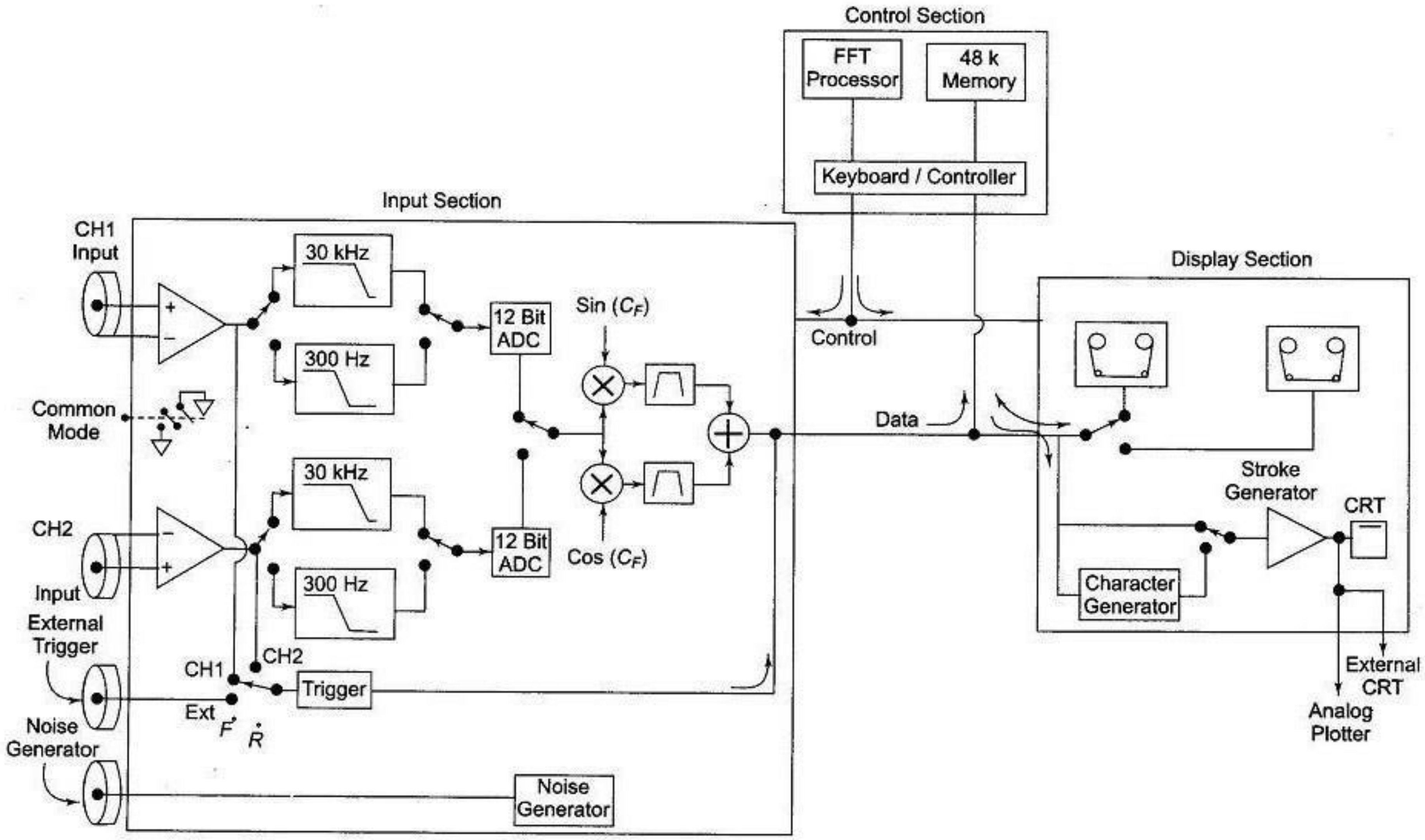


Fig. 9.15 Block Diagram of a Digital Signal Analyzer

UNIT IV

REVIEW OF DC BRIDGES

4.1 Fundamental Concept of Bridges Circuit

In DC measurement circuits, the circuit configuration known as a way to measure unknown values of resistance.

To review, the bridge circuit works as a pair of two across the same source voltage, with a them to indicate a condition of "balance" at zero volts:

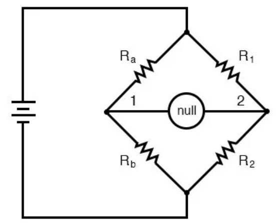


Figure 4.1 : Basic schematic diagram of standard bridges

Any one of the four resistors in the above bridge can be the resistor of unknown value, and its value can be determined by a ratio o resistances are known to a precise degree. When the bridge is in a balanced condition (zero voltage as indicated by the null detector), the ratio works out to be this:

$R_1/R_2= R_3/R_4$ or $R_1R_4=R_3R_2$

One of the advantages of using a bridge circuit to measure resistance is that the voltage of the power source is irrelevant. Practically speaking, the higher the supply voltage, the easier it is to detect a condition of imbalance between the four resistors thus the more sensitive it will be. A greater supply voltage leads to the possibility of increased measurement precision. However, there will be no fundamental error introduced as a result of a lesser or greater power supply voltage unlike other types of resistance measurement schemes.

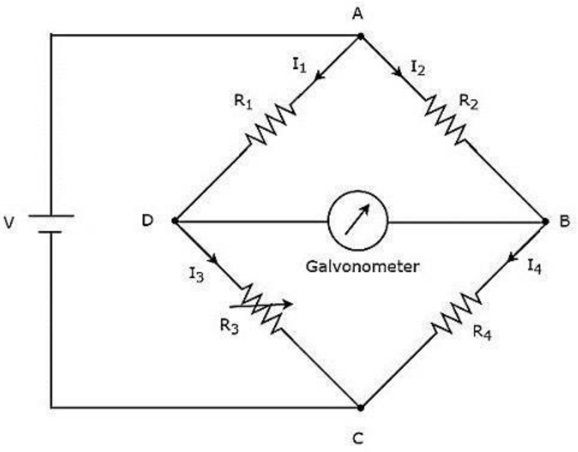
4.2 Principle of DC Bridges

4.2.1 Type of DC Bridges

1. Wheatstone Bridges
2. Kelvin Bridges

WHEATSTONE BRIDGE

- Wheatstone’s bridge is a simple DC bridge, which is mainly having four arms. These four arms form a rhombus or square shape and each arm consists of one resistor.
- To find the value of unknown resistance, we need the galvanometer and DC voltage source. Hence, one of these two are placed in one diagonal of Wheatstone’s bridge and the other one is placed in another diagonal of Wheatstone’s bridge.
- Wheatstone’s bridge is used to measure the value of medium resistance. The **circuit diagram** of Wheatstone’s bridge is shown in below figure.
- •In above circuit, the arms AB, BC, CD and DA together form a **rhombus** or square shape. They consist of resistors *R*2, *R*4, *R*3 and *R*1 respectively. Let the current flowing through these resistor arms
- is *I*2, *I*4, *I*3 and *I*1 respectively and the directions of these currents are shown in the figure.
- •The diagonal arms DB and AC consists of galvanometer and DC voltage source of V volts respectively. Here, the resistor, *R*3 is a standard variable resistor and the resistor, *R*4 is an unknown resistor. We can **balance the bridge**, by varying the resistance value of resistor, *R*3.
- •The above bridge circuit is balanced when no current flows through the diagonal arm, DB. That means, there is **no deflection** in the galvanometer, when the bridge is balanced.
- •The bridge will be balanced, when the following **two conditions** are satisfied.



$VAD=VAB$

$\Rightarrow I1R1=I2R2$ Equation 1

The voltage across arm DC is equal to the voltage across arm BC. i.e.,

$VDC=VBC$

$\Rightarrow I3R3=I4R4$ Equation 2

Take the ratio of Equation 1 and Equation 2.

$I1R1I3R3=I2R2I4R4$ Equation 3

Substitute, $I1=I3$
and $I2=I4$

$I3R1I3R3=I4R2I4R4$

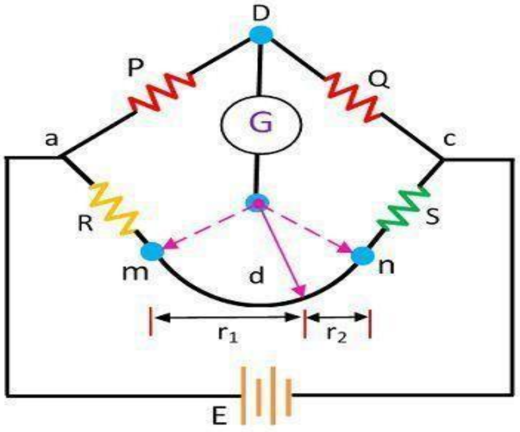
$\Rightarrow R1R3=R2R4$

$\Rightarrow R4=R2R3R1$

By substituting the known values of resistors R1, R2 and R3 in above equation, we will get the value of resistor,R4

KELVIN BRIDGE

- **Definition:** The Kelvin bridge or Thompson bridge is used for measuring the unknown resistances having a value less than 1Ω. It is the modified form of the Wheatstone Bridge.
- Wheatstone bridge use for measuring the resistance from a few ohms to several kilo-ohms. **But error occurs in the result when it is used for measuring the low resistance**. This is the reason because of which the Wheatstone bridge is modified, and the Kelvin bridge obtains. The Kelvin bridge is suitable for measuring the low resistance.



Prinicple of Kelvin's Bridge

Circuit Globe

- The **r** is the resistance of the contacts that connect the **unknown resistance R** to the **standard resistance S**. The **'m'** and **'n'** show the range between which the galvanometer is connected for obtaining a null point.
- When the galvanometer is connected to point 'm', the lead resistance r is added to the standard resistance S. Thereby the very low indication obtains for unknown resistance R. And if the galvanometer is connected to point n then the r adds to the R, and hence the high value of unknown resistance is obtained. Thus, at point n and m either very high or very low value of unknown resistance is obtained.
- So, instead of connecting the galvanometer from point, m and n we chose any intermediate point say d where the resistance of lead r is divided into two equal parts, i.e., r_1 and r_2

The presence of r_1 causes no error in the measurement of unknown resistance.

$$\frac{r_1}{r_2} = \frac{P}{Q} \dots\dots\dots equ(1)$$

$$\frac{r_1}{r_1 + r_2} = \frac{P}{P + Q}$$

$$r_1 = \frac{P}{P + Q}.r$$

$$R + r_1 = \frac{P}{Q}.(S + r_2)$$

$$R + \frac{P}{P + Q}.r = \frac{P}{Q}\left(S + \frac{Q}{P + Q}r\right)$$

From equation (1), we get

$$R = \frac{P}{Q}.S$$

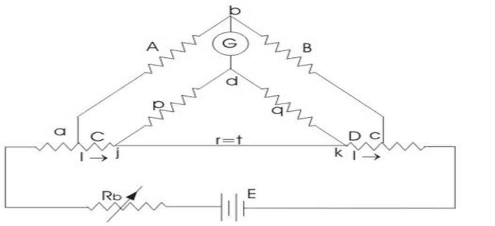
$$r_1 + r_2 = r$$

$$r_2 = \frac{Q}{P + Q}.r$$

as

- The above equation shows that if the galvanometer connects at point d then the resistance of lead will not affect their results.
- The above mention process is practically not possible to implement. For obtaining the desired result, the actual resistance of exact ratio connects between the point m and n and the galvanometer connects at the junction of the resistor.

Kelvin Double Bridge



$$\text{Hence, } E = \frac{A}{A+B} \times F$$

$$\Rightarrow F = I \times \left(C + D + \frac{p+q}{p+q+t} \times t\right)$$

$$\text{Hence, } G \text{ i.e. (voltage drop between a and d)} = I \times \left(C + \frac{p \times t}{p+q+t}\right)$$

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

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

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

Why it is called double bridge? It is because it incorporates the second set of ratio arms as shown below:

In this the ratio arms p and q are used to connect the galvanometer at the correct point between j and k to remove the effect of connecting lead of electrical resistance t.

Under balance condition voltage drop between a and b (i.e. E) is equal to F (voltage drop between a and c)

For zero galvanometer deflection, E = F

Again we reach the same result – t has no effect.

However equation (2) is useful as it gives error when:

ERRORS AND PRECAUTIONS IN USING BRIDGES

ERRORS IN BRIDGES:

Stray conductance effects, due to imperfect insulation. Mutual inductance effects due to magnetic coupling between various components of the bridge.

Stray capacitance effects, due to electrostatic fields between conductors at different potentials.

Residuals in components for example the presence of small magnitudes of series inductance or shunt capacitance in nonreactive resistors

PRECAUTIONS FOR REDUCING ERRORS:

The following precautions may be taken to avoid errors :

High quality components must be used for the elements of the bridge.

The layout of the bridge must be made to avoid interaction of the bridge arms.

The sensitivity of the bridge must be more.

The bridge components and other pieces must be mounted on insulation stands to prevent stray conductance effects.

Presence of large conducting masses near the bridge arms must be avoided to prevent eddy current effects.

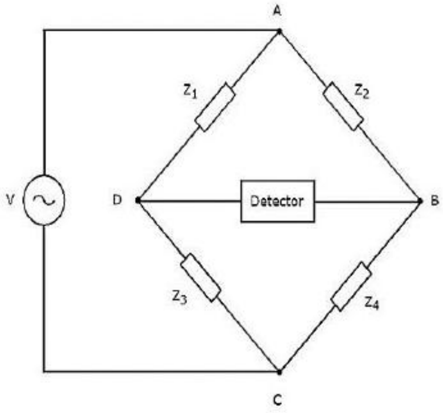
Residual error can be avoided by identifying the nature, evaluating them and compensating them.

Wave filters that eliminate the unwanted harmonics from the source or tuned detectors in place of headphones may be used to avoid the difficulty of frequency and wave form errors.

AC BRIDGES

•If the bridge circuit can be operated with only AC voltage signal, then it is said to be AC bridge circuit or simply AC bridge. AC bridges are used to measure the value of unknown inductance, capacitance and frequency.

•The circuit diagram of AC bridge looks like as shown in below figure.



•The circuit diagram of AC bridge is similar to that of DC bridge. The above AC bridge has **four arms** and each arm consists of some impedance. That means, each arm will be having either single or combination of passive elements such as resistor, inductor and capacitor.

•The above AC bridge circuit can be excited with an **AC voltage source** by placing it in one diagonal. A detector is placed in other diagonal of AC bridge. It shows some deflection as long as the bridge is unbalanced.

•The above AC bridge circuit can be excited with an **AC voltage source** by placing it in one diagonal. A detector is placed in other diagonal of AC bridge. It shows some deflection as long as the bridge is unbalanced.

•Vary the impedance value of variable impedance until the detector shows null (zero) deflection. Now, the above AC bridge is said to be a balanced one. So, we can find the value of **unknown impedance** by using balanced condition

•Following are the two AC bridges, which can be used to measure inductance.

•Maxwell’s Bridge

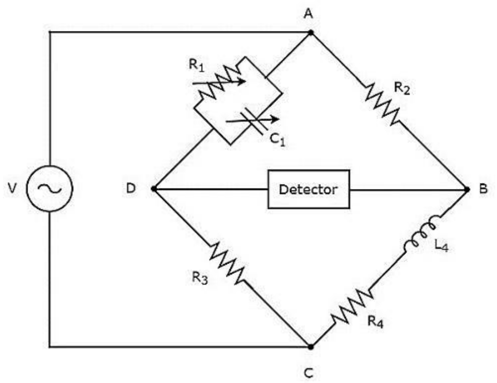
•Hay’s Bridge

Maxwell's Bridge

Maxwell’s bridge is an AC bridge having four arms, which are connected in the form of a rhombus or **square shape**. Two arms of this bridge consist of a single resistor, one arm consists of a series combination of resistor and inductor & the other arm consists of a parallel combination of resistor and capacitor.

An AC detector and AC voltage source are used to find the value of unknown impedance. Hence, one of these two are placed in one diagonal of Maxwell’s bridge and the other one is placed in other diagonal of Maxwell’s bridge.

Maxwell’s bridge is used to measure the value of medium inductance. The **circuit diagram** of Maxwell’s bridge is shown in the below figure



•In above circuit, the arms AB, BC, CD and DA together form a rhombus or square shape. The arms AB and CD consist of resistors,

R2 and R3

• respectively. The arm, BC consists of a series combination of resistor, R4 and inductor, L4

•. The arm, DA consists of a parallel combination of resistor, R1 and capacitor, C1

•Let, Z1,Z2,Z3 and Z4 are the impedances of arms DA, AB, CD and BC respectively. The values of these impedances will be

•Z1=R1(1jωC1)R1+1jωC1

•⇒Z1=R11+jωR1C1

•Z2=R2

•Z3=R3

•Z4=R4+jωL4

•Substitute these impedance values in the following balancing condition of AC bridge.

Z4=Z2Z3Z1

R4+jωL4=R2R3(R11+jωR1C1)

$\Rightarrow R4+j\omega L4=R2R3(1+j\omega R1C1)R1$

$\Rightarrow R4+j\omega L4=R2R3R1+j\omega R1C1R2R3R1$

$\Rightarrow R4+j\omega L4=R2R3R1+j\omega C1R2R3$

By comparing the respective real and imaginary terms of above equation, we will get

$R4=R2R3R1$ Equation 1

$L4=C1R2R3$ Equation 2

By substituting the values of resistors R1, R2 and R3 in Equation 1, we will get the value of resistor, R4 Similarly, by substituting the value of capacitor, C1 and the values of resistors, R2 and R3 in Equation 2, we will get the value of inductor, L4

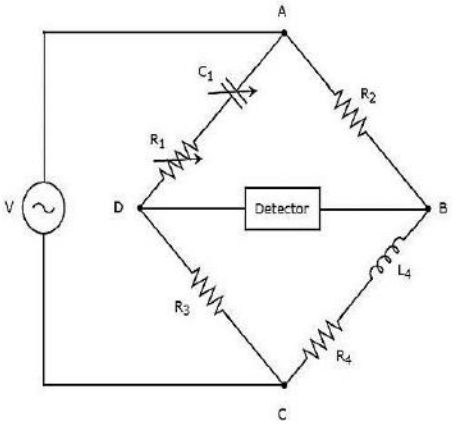
The advantage of Maxwell's bridge is that both the values of resistor, R4 and an inductor, L4 are independent of the value of frequency.

HAY'S BRIDGE

Hay's bridge is a modified version of Maxwell's bridge, which we get by modifying the arm, which consists of a parallel combination of resistor and capacitor into the arm, which consists of a series combination of resistor and capacitor in Maxwell's bridge.

Hay's bridge is used to measure the value of high inductance.

The **circuit diagram** of Hay's bridge is shown in the below figure.



In above circuit, the arms AB, BC, CD and DA together form a rhombus or square shape. The arms, AB and CD consist of resistors, R2 and R3 respectively. The arm, BC consists of a series combination of resistor, R4 and inductor, L4 The arm, DA consists of a series combination of resistor, R1 and capacitor, C1

$Z1=R1+1j\omega C1$

$\Rightarrow Z1=1+j\omega R1C1j\omega C1$ $Z2=R2$ $Z3=R3$

$Z4=R4+j\omega L4$ Substitute these impedance values in the following balancing condition of AC bridge.

$Z4=Z2Z3Z1$

$R4+j\omega L4=R2R3(1+j\omega R1C1j\omega C1)$ $R4+j\omega L4=R2R3j\omega C1(1+j\omega R1C1)$

Multiply the numerator and denominator of right hand side term of above equation with $1-j\omega R1C1$

$\Rightarrow R4+j\omega L4=R2R3j\omega C1(1+j\omega R1C1)\times(1-j\omega R1C1)(1-j\omega R1C1)$

$\Rightarrow R4+j\omega L4=\omega 2C12R1R2R3+j\omega R2R3C1(1+\omega 2R12C12)$

By comparing the respective real and imaginary terms of above equation, we will get

$R4=\omega 2C12R1R2R3(1+\omega 2R12C12)$ Equation 3

$L4=R2R3C1(1+\omega 2R12C12)$ Equation 4

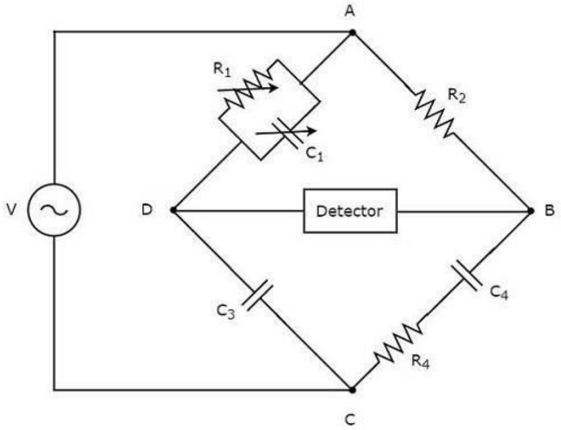
By substituting the values of R1,R2,R3,C1 and ω in Equation 3 and Equation 4, we will get the values of resistor, R4 and inductor, L4

SCHERING BRIDGE

Schering bridge is an AC bridge having four arms, which are connected in the form of a rhombus or **square shape**, whose one arm consists of a single resistor, one arm consists of a series combination of resistor and capacitor, one arm consists of a single capacitor & the other arm consists of a parallel combination of resistor and capacitor.

The AC detector and AC voltage source are also used to find the value of unknown impedance, hence one of them is placed in one diagonal of Schering bridge and the other one is placed in other diagonal of Schering bridge.

Schering bridge is used to measure the value of capacitance. The **circuit diagram** of Schering bridge is shown in the below figure.



In above circuit, the arms AB, BC, CD and DA together form a rhombus or square shape. The arm AB consists of a resistor, R2 . The arm BC consists of a series combination of resistor, R4 and capacitor, C4
. The arm CD consists of a capacitor, C3
. The arm DA consists of a parallel combination of resistor, R1 and capacitor, C1
Let, Z1, Z2 ,Z3 and Z4 are the impedances of arms DA, AB, CD and BC respectively. The values of these impedances will be

$Z1=R1(1j\omega C1)R1+1j\omega C1$

$\Rightarrow Z1=R11+j\omega R1C1$

$Z2=R2$

$Z3=1j\omega C3$

$Z4=R4+1j\omega C4$

$\Rightarrow Z4=1+j\omega R4C4j\omega C4$

Substitute these impedance values in the following balancing condition of AC bridge.

$Z4=Z2Z3Z1$

1+jωR4C4jωC4=R2(1jωC3)R11+jωR1C1
⇒1+jωR4C4jωC4=R2(1+jωR1C1)jωR1C3
⇒1+jωR4C4C4=R2(1+jωR1C1)R1C3
⇒1C4+jωR4=R2R1C3+jωC1R2C3

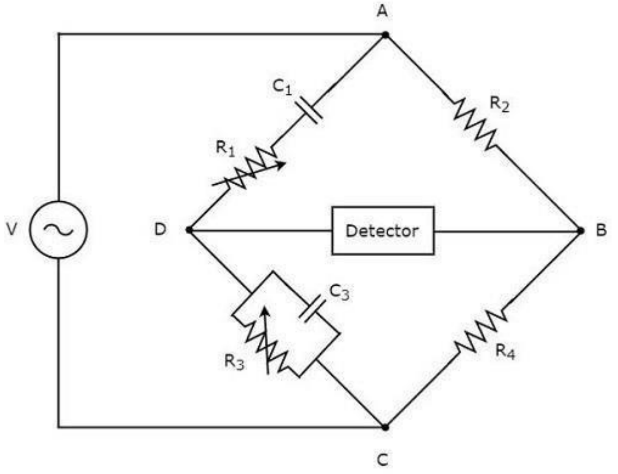
By comparing the respective real and imaginary terms of above equation, we will get
C4=R1C3R2 Equation 1 R4=C1R2C3
Equation 2

By substituting the values of R1,R2 and C3 in Equation 1, we will get the value of capacitor, C4. Similarly, by substituting the values of R2,C1 and C3 in Equation 2, we will get the value of resistor, R4

The advantage of Schering bridge is that both the values of resistor, R4 and capacitor, C4 are independent of the value of frequency.

WIEN'S BRIDGE

Wien's bridge is an AC bridge having four arms, which are connected in the form of a rhombus or square shape. Amongtwo arms consist of a single resistor, one arm consists of a parallel combination of resistor and capacitor & the other arm consists of a series combination of resistor and capacitor.



The AC detector and AC voltage source are also required in order to find the value of frequency. Hence, one of these two are placed in one diagonal of Wien's bridge and the other one is placed in other diagonal of Wien's bridge.

The **circuit diagram** of Wien's bridge is shown in the below figure.

In above circuit, the arms AB, BC, CD and DA together form a rhombus or square shape. The arms, AB and BC consist of resistors, R2 and R4 respectively. The arm, CD consists of a parallel combination of resistor, R3 and capacitor, C3. The arm, DA consists of a series combination of resistor, R1 and capacitor, C1 Let, Z1,Z2,Z3 and Z4 are the impedances of arms DA, AB, CD and BC respectively. The values of these impedances will be

Z1=R1+1jω
C1
⇒Z1=1+jωR
1C1jωC1
Z2=R2
Z3=R3(1jωC3)R3+1jωC3
⇒Z3=R
31+jω
R3C3
Z4=R4

Substitute these impedance values in the following balancing condition of AC bridge.

Z1Z4=Z2Z3
(1+jωR1C1jωC1)R4=R2(R31+jωR3C3)
⇒(1+jωR1C1)(1+jωR3C3)R4=jωC1R2R3
⇒(1+jωR3C3+jωR1C1−ω2R1R3C1C3)R4=jωC1R2R3
⇒R4(ω2R1R3C1C3)+jωR4(R3C3+R1C1)=jωC1R2R3

Equate the respective real terms of above equation.

R4(1−ω2R1R3C1C3)=0
⇒1−ω2R1R3C1C3=0
⇒1=ω2R1R3C1C3
ω=1R1R3C1C3√

Substitute, ω=2πf
.
⇒2πf=1R1R3C1C3−−−−−−−−−√
⇒f=12πR1R3C1C3√

We can find the value of frequency,
F of AC voltage source by substituting the values of R1,R3,C1 and C3 in above equation.

If R1=R3=R and C1=C3=C, then we can find the value of frequency, f of AC voltage source by using the following formula.

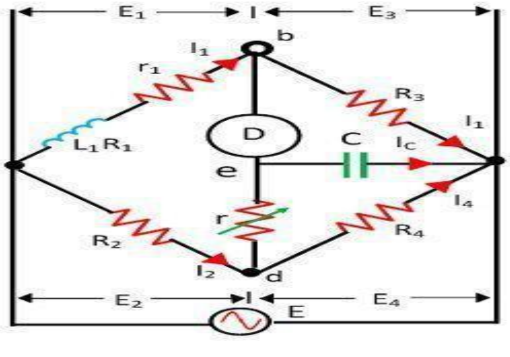
f=12πRC

The Wein's bridge is mainly used for finding the frequency value of AF range.

Definition: The **Anderson's bridge** gives the **accurate measurement** of **self-inductance** of the circuit. The bridge is the **advanced form** of **Maxwell's inductance capacitance bridge.** In Anderson bridge, the **unknown inductance** is compared with the **standard fixed capacitance** which is connected between the two arms of the bridge.

CONSTRUCTIONS OF ANDERSON'S BRIDGE

The bridge has fours arms ab, bc, cd, and ad. The arm ab consists unknown inductance along with the resistance. And the other three arms consist the purely resistive arms connected in series with the circuit.



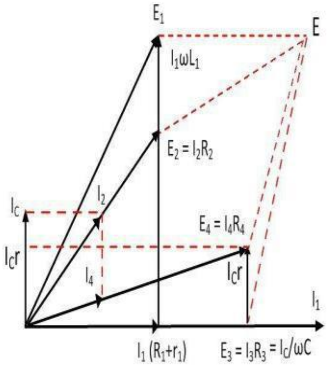
Anderson's Bridge

Circuit Globe

The static capacitor and the variable resistor are connected in series and placed in parallel with the **cd** arm. The voltage source is applied to the terminal a and c.

Phasor Diagram of Anderson's Bridge

The phasor diagram of the Anderson bridge is shown in the figure below. The current **I_1** and the **E_3** are in phase and represented on the horizontal axis. When the bridge is in balance condition the voltage across the arm **bc** and **ec** are equal.



Anderson's Bridge

Circuit Globe

The current enters into the bridge is divided into the two parts **I_1** and **I_2**. The **I_1** is entered into the arm **ab** and causes the voltage drop **$I_1(R_1+R)$** which is in phase with the **I_1**. As the bridge is in the balanced condition, the same current is passed through the arms bc and **ec**

The voltage drop **E_4** is equal to the sum of the **$I_C/\omega C$** and the **I_Cr**. The current **I_4** and the voltage **E_4** are in the same phase and representing on the same line of the phasor diagram. The sum of the current **I_C** and **I_4** will give rise to the current **I_2** in the arm **ad.** When the bridge is at balance condition the emf across the arm **ab** and the point **a, d** and **e** are equal. The phasor sum of the voltage across the arms **ac** and **de** will give rise the voltage drops across the arm **ab**.

The V1 is also obtained by adding the I1(R1+r1) with the voltage drop ωI1L1 in the arm AB. The phasor sum of the E1 and E3 or E2 and E4 will give the supply voltage.

Theory of Anderson Bridge

Let, L1 – unknown inductance having a resistance R1.R2, R3, R4

– known non-inductive resistance C4 – standard capacitor At balance Condition,

$$I_1 = I_3 \; and \; I_2 = I_C + I_4$$

$$I_1 R_3 = I_C \times \frac{1}{j\omega C}$$

$$I_C = I_1 \omega C R_3$$

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_1 j\omega C R_3 r$$

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_2 R_2$$

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_1 j\omega C R_3 r$$

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_2 R_2$$

$$I_1(R_3 + j\omega R_3 R_4 + j\omega C R_3 r) = I_2 R_4$$

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_1(\frac{R_1 R_2}{R_2} + \frac{j\omega C R_3 r R_2}{R_4} + j\omega C R_3 R_2)$$

$$R_1 = \frac{R_1 R_3}{R_4} - r_1$$

$$L_1 = C \frac{R_3}{R_4}[4(R_4 + R_2) + R_2 R_4]$$

Advantages of Anderson Bridge

The following are the advantages of the Anderson's Bridge. The balance point is easily obtained on the Anderson bridge as compared to Maxwell's inductance capacitance bridge.

The bridge uses fixed capacitor because of which accurate reading is obtained.

The bridge measures the accurate capacitances in terms of inductances.

Disadvantages of Anderson Bridge

The main disadvantages of Anderson's bridge are as follow. The circuit has more arms which make it more complex as compared to Maxwell's bridge. The equation of the bridge is also more complex.

The bridge has an additional junction which arises the difficulty in shielding the bridge.

OTHERAC BRIDGES

In previous chapter, we discussed about two AC bridges which can be used to measure inductance. In this chapter, let us discuss about the following two AC bridges.

Schering Bridge

Wien's Bridge

These two bridges can be used to measure capacitance and frequency respectively

SCHERING BRIDGE

Schering bridge is an AC bridge having four arms, which are connected in the form of a rhombus or square shape, whose one arm consists of a single resistor, one arm consists of a series combination of resistor and capacitor, one arm consists of a single capacitor & the other arm consists of a parallel combination of resistor and capacitor.

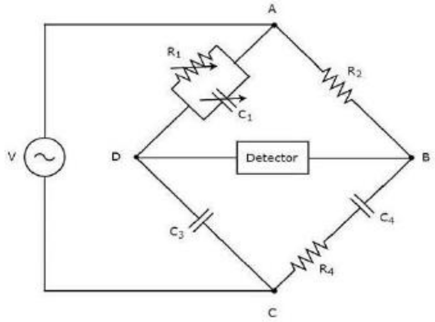
•The AC detector and AC voltage source are also used to find the value of unknown impedance, hence one of them is placed in one diagonal of Schering bridge and the other one is placed in other diagonal of Schering bridge.

Schering bridge is used to measure the value of capacitance. The circuit diagram of Schering bridge is shown in the below figure.

•In above circuit, the arms AB, BC, CD and DA together form a rhombus or square shape. The arm

•AB consists of a resistor, R_2 . The arm BC consists of a series combination of resistor,R_4 andcapacitor,C_4 . The arm CD consists of a capacitor,C_3 . The arm DA consists of a parallel combination of resistor,R_1 and capacitor,C_1.

Let,Z_1 ,Z_2, Z_3,and Z_4 are the impedances of arms DA, AB, CD and BC respectively. The values of these impedances will be



Z 1= RR11jωC(+ 1jωC11-1)

⇒ Z1 = 1+R1jωR1C1

Z2 = R 2

Z3 = jωC1 3

Z4 = R4 + 1jωC4

⇒ Z 4 = $1+j\omega R_{j\omega C}4_4C4$

By substituting the values of R_1,R_2 andC_3 in Equation 1, we will get the value of capacitor,C4 .

Similarly, by substituting the values of R_2,C_1 and C_3 in Equation 2, we will get the value of resistor, R_4 .

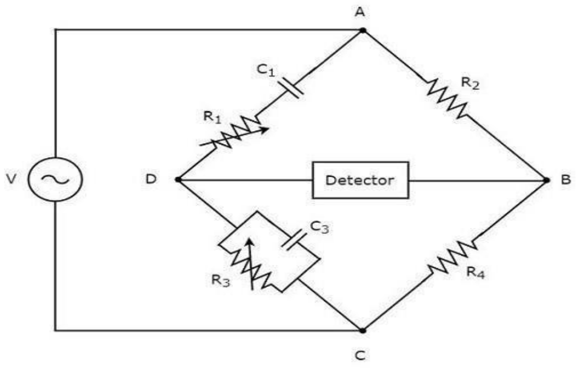
The advantage of Schering bridge is that both the values of resistor, R_4 and capacitor, independent of the value of frequency.

WIEN'S BRIDGE

Wien's bridge is an AC bridge having four arms, which are connected in the form of a rhombus or square shape. Amongtwo arms consist of a single resistor, one arm consists of a parallel combination of resistor and capacitor & the other arm consists of a series combination of resistor and capacitor.

The AC detector and AC voltage source are also required in order to find the value of frequency. Hence, one of these two are placed in one diagonal of Wien's bridge and the other one is placed in other diagonal of Wien's bridge.

The circuit diagram of Wien's bridge is shown in the below figure.



In above circuit, the arms AB, BC, CD and DA together form a rhombus or square shape. The arms,
AB and BC consist of resistors, R_2 and R_4 respectively. The arm, CD consists of a parallel combination of resistor, R_3 and
capacitor, C_3 . The arm, DA consists of a series combination of resistor ,R_1 and capacitor, C_1 .
Let, Z_1,Z_2,Z_3 and $Z_4$are the impedances of arms DA, AB, CD and BC respectively.

The values of these impedances will be

$Z1 = R1 + j\omega C \underline{1}\,1$ $\underline{1+j\omega R\ 1C1}$ $\Rightarrow Z\ 1=$ $j\omega C1$

$Z2 = R\ 2$ $Z3 = \underline{R}\ 3^{3}\underline{(}+j\omega C\underline{1}j\omega C\ _{1}3\underline{)}_{3}\ R$

$$\Rightarrow Z\ ^{3}= \frac{R3}{1+j\omega R\ C3}\quad 3$$

$Z4 = R4$

Substitute these impedance values in the following balancing condition of AC bridge.

$Z1Z4 = Z2Z3$

$\underline{(1^{+}j\omega R\ C1\ )1\ }R\ 4R\ (2\ \cancel{1+}jR\omega R\cancel{)}3_{3}C_{3}\ j\omega C_{1}$

$\Rightarrow (1+j\omega R\ 1C1)\ (1+j\omega R\ 3C3)\ R\ 4 = j\omega C1R\ 2R\ 3$

$\Rightarrow (1+j\omega R_3C_3+j\omega R_1C_1-\omega^2R_1R_3C_1C_3)R_4 = j\omega C_1R_2R_3$

$\Rightarrow R4(\omega 2R1R3C1C3)+j\omega R4(R3C3+R1C1) = j\omega C1R2R3$

Equate the respective real terms of above equation. $R\ 4(1-\omega 2R\ 1R\ 3C1C3)=0$

Q METER

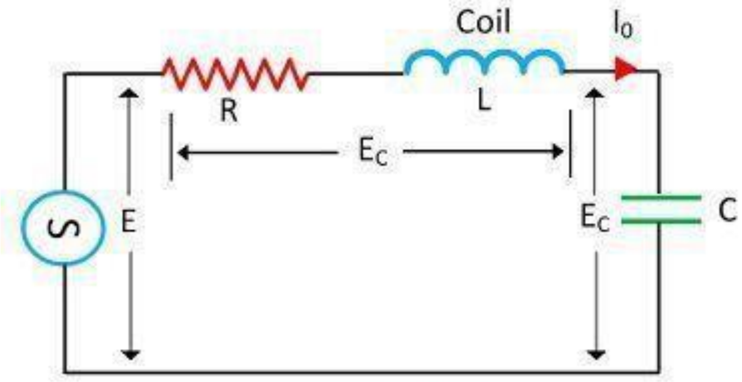
•Definition: The instrument which measures the storage factor or quality factor of the electrical circuit at radio frequencies, such type of device is known as the Q-meter. The quality factor is one of the parameters of the oscillatory system, which shows the relation between the storage and dissipated energy.

•The Q meter measures the quality factor of the circuit which shows the total energy dissipated by it. It also explains the properties of the coil and capacitor. The Q meter uses in a laboratory for testing the radio frequency of the coils.

Working Principle of Q meter

•The Q meter works on series resonant. The resonance is the condition exists in the circuit when their inductance and capacitance reactance are of equal magnitude. They induce energy which is oscillating between the electric and magnetic field of the capacitor and inductor respectively.

•The Q-meter is based on the characteristic of the resistance, inductance and capacitance of the resonant series circuit. The figure below shows a coil of resistance, inductance and capacitance connected in series with the circuit



Resonant RLC Series Circuit

Circuit Globe

At resonant frequency f_0,

$$X_C = X_L$$

The value of capacitance reactance is

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

At inductive reactance,

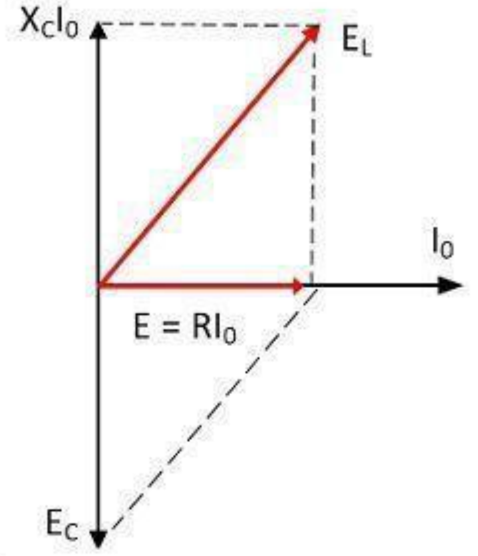
$$X_L = \frac{1}{2}\pi f_0 L = \frac{1}{\omega_0 L}$$

At the resonant frequency,

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

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

and current at resonance becomes



Phasor Diagram

Circuit Globe

$$E_C = I_0 X_C = I_0 X_L = I_0 \omega_0 L$$

$$E = I_0 r$$

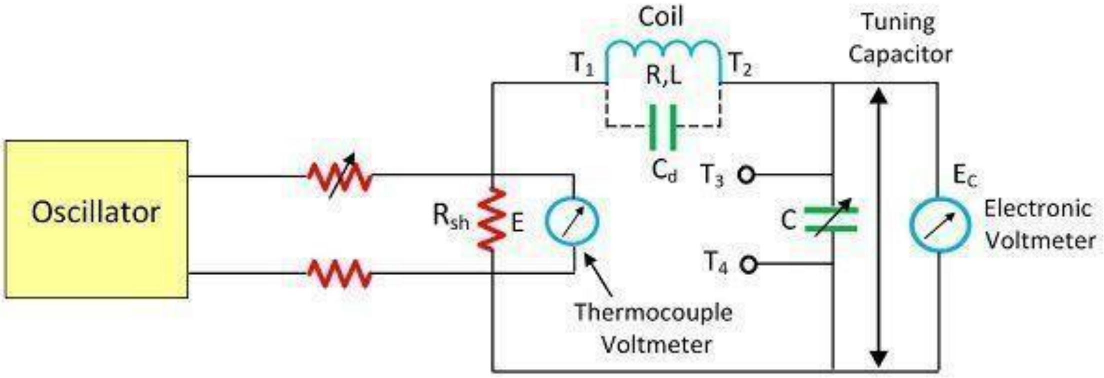
$$\frac{E_C}{E} = \frac{I_0 \omega_0 L}{I_0 R} = \frac{\omega_0 L}{R} = Q$$

$$E_0 = QE$$

The above equation shows that the input voltage E is Q times the voltage appears across the capacitor. The voltmeter is calibrated for finding the value of Q factor

Applications of the Q-meter

1. Measurement of Q – The circuit used for measurement of Q is shown in the figure.



Circuit of Q meter

Circuit Globe

The oscillator and tuning capacitor adjust to the desired frequency for obtaining the maximum value of E_0. Under this condition, the value of the quality factor is expressed as

$$Q_{max} = \frac{\omega_0 L}{R}$$

$$Q_{max} = \frac{\omega_0 L}{R}$$

$$Q_{true} = Q_{meas}\left(1 + \frac{R_{sh}}{R}\right)$$

The value of the quality factor is obtained by the voltmeter which is connected across the capacitor. The measured value is the Q factor of the whole circuit and not only of the coil. Thus, errors occur in the reading because of the shunt resistance and distributed capacitance.

$$Q_{true} = Q_{meas}\left(1 + \frac{C_d}{C}\right)$$

The above equations show that the measured value of the Q is smaller than the true value.

2. **Measurement of Inductance –** The inductance is measured by the equation shown below.

$$L = {}^{1}\!/_{4\pi^2 f_0^2 C}$$

The value of f0 & C is required for calculating the value of inductance.

$$R = \frac{\omega_0 L}{Q_{true}}$$

3. **Measurement of Effective resistance** – The equation computes the value of effective resistance

$$f_1 = \frac{1}{2\pi\sqrt{L(C_1 + C_d)}}$$

$$f_2 = \frac{1}{2\pi\sqrt{L(C_2 + C_d)}}$$

$$f_2 = 2f_1$$

$$\frac{1}{2\pi\sqrt{L(C_2 + C_d)}} = 2 \times \frac{1}{2\pi\sqrt{L(C_1 + C_d)}}$$

4. **Measurement of Self-Capacitance** – The self-capacitance is determined by measuring the two capacitance at different frequencies. The capacitor is adjusted to the high value, and the circuit is resonated by adjusting the oscillator frequency. The resonance of the circuit is determined by the Q meter.

$$C_d = \frac{C_1 - 4C_2}{3}$$

5. **Measurement of Bandwidth – T**he equation below calculates the bandwidth

$$Q_{max} = \frac{\omega_0 L}{R}$$

6. **Measurement of Capacitance** – The capacitance is determined by connecting the dummy coil across the terminal T1 and T2. Let the capacitor under test is connected across the terminal T3 and T4. The circuit is again resonated by varying the value of tuning capacitor C2. The value of testing capacitance is determined by subtracting the C1 and C2.

UNIT V

TRANSDUCERS

Transducer is a device that converts energy in one form of energy to another form of energy. This converts non-electrical quantity into electrical quantity.

A transducer is defined as a device that receives energy from one system and transmits it to another, often in a different form.

Broadly defined, the transducer is a device capable of being actuated by an energising input from one or more transmission media and in turn generating a related signal to one or more transmission systems. It provides a usable output in response to a specified input measurand, which may be a physical or mechanical quantity, property, or conditions. The energy transmitted by these systems may be electrical, mechanical or acoustical.

The nature of electrical output from the transducer depends on the basic principle involved in the design. The output may be analog, digital or frequency modulated.

Basically, there are two types of transducers, electrical, and mechanical.

Transducer is a device that converts energy in one form of energy to another form of energy. This converts non-electrical quantity into electrical quantity.

A transducer is defined as a device that receives energy from one system and transmits it to another, often in a different form.

Broadly defined, the transducer is a device capable of being actuated by an energising input from one or more transmission media and in turn generating a related signal to one or more transmission systems. It provides a usable output in response to a specified input measurand, which may be a physical or mechanical quantity, property, or conditions. The energy transmitted by these systems may be electrical, mechanical or acoustical.

The nature of electrical output from the transducer depends on the basic principle involved in the design. The output may be analog, digital or frequency modulated.

Basically, there are two types of transducers, electrical, and mechanical.

Electrical Transducer Definition

An electrical transducer is a sensing device by which the physical, mechanical or optical quantity to be measured is transformed directly by a suitable mechanism into an electrical voltage/current proportional to the input measurand.

An electrical transducer must have the following parameters:

Electrical Transducer Definition

An electrical transducer is a sensing device by which the physical, mechanical or optical quantity to be measured is transformed directly by a suitable mechanism into an electrical voltage/current proportional to the input measurand.

An electrical transducer must have the following parameters:

1. Linearity: The relationship between a physical parameter and the resulting electrical signal must be linear.
2. Sensitivity: This is defined as the electrical output per unit change in the physical parameter

(for example V/°C for a temperature sensor). High sensitivity is generally desirable for a transducer.

3. Dynamic Range: The operating range of the transducer should be wide, to permit its use under a wide range of measurement conditions.
4. Repeatability: The input/output relationship for a transducer should be predictable over a long period of time. This ensures reliability of
5. Physical Size: The Electrical Transducer Definition must have minimal weight and volume, so that its presence in the measurement system does not disturb the existing conditions.

Advantages of Electrical Transducer

The main advantages of electrical transducer (conversion of physical quantity into electrical quantities) are as follows:

1. Electrical amplification and attenuation can be easily done.
2. Mass-inertia effects are minimised.
3. Effects of friction are minimised.
4. The output can be indicated and recorded remotely at a distance from the sensing medium.
5. The output can be modified to meet the requirements of the indicating or controlling units. The signal magnitude can be related in terms of the voltage current. (The analog signal information can be converted in to pulse or frequency information. Since output can be modified, modulated or amplified at will, the output signal can be easily used for recording on any suitable multichannel recording device.)
6. The signal can be conditioned or mixed to obtain any combination with outputs of similar transducers or control signals.

7. The electrical or electronic system can be controlled with a very small power level.
8. The electrical output can be easily used, transmitted and processed for the purpose of measurement.

Electrical transducer can be broadly classified into two major categories,

Classification of transducers

- **Primary and Secondary Transducers**
- **Analog and Digital Transducers**
- **Active and Passive Transducers**
- **Transducers and Inverse Transducers**

Primary and Secondary Transducers

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

Example: The thermistor senses the temperature directly and causes the change in resistance with the change in temperature.

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

For example, in case of pressure measurement, bourdon tube is a primary sensor which converts pressure first into displacement, and then the displacement is converted into an output voltage by an LVDT.

Analog and Digital Transducers

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

Digital transducer converts input signal into the output signal of the form of pulse e.g. it gives discrete output.

Transducers and Inverse Transducers

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

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

An inverse transducer is a device that converts an electrical quantity into a non-electrical quantity.

Example: piezoelectric oscillator

Active and Passive Transducers

An active transducer generates an electrical signal directly in response to the physical parameter and does not require an external power source for its operation. Active transducers are self generating devices, which operate under energy conversion principle and generate an equivalent output signal (for example from pressure to charge or temperature to electrical potential).

Typical example of active transducers are piezo electric sensors (for generation of charge corresponding to pressure) and photo voltaic cells (for generation of voltage in response to illumination).

Passive transducer operate under energy controlling principles, which makes it necessary to use an external electrical source with them. They depend upon the change in an electrical parameter (R, L and C).

Typical example are strain gauges (for resistance change in response to pressure), and thermistors (for resistance change corresponding to temperature variations).

Electrical transducer is used mostly to measure non-electrical quantities. For this purpose a detector or sensing element is used, which converts the physical quantity into a displacement. This displacement actuates an electric transducer, which acts as a secondary transducer and gives an output that is electrical in nature. This electrical quantity is measured by the standardmethod used for electrical measurement. The electrical signals may be current, voltage, or frequency; their production is based on R, L and C effects.

A transducer which converts a non-electrical quantity into an analog electrical signal may be considered as consisting of two parts, the sensing element, and the transduction element.

The sensing or detector element is that part of a transducer which responds to a physical phenomenon or to a change in a physical phenomenon. The response of the sensing element must be closely related to the physical phenomenon.

The transduction element transforms the output of a sensing element to an electrical output. This, in a way, acts as a secondary transducer.

Transducers may be further classified into different categories depending upon the principle employed by their transduction elements to convert physical phenomena into output electrical signals.

Selecting a Transducer

The transducer or sensor has to be physically compatible with its intended application. The following should be considered while selecting a transducer.

1. Operating range: Chosen to maintain range requirements and good
2. Sensitivity: Chosen to allow sufficient output.
3. Frequency response and resonant frequency: Flat over the entire desired range.

4. Environmental compatibility: Temperature range, corrosive fluids, pressure, shocks, interaction, size and mounting restrictions.
5. Minimum sensitivity: To expected stimulus, other than the measurand.
6. Accuracy: Repeatability and calibration errors as well as errors expected due to sensitivity to other stimuli.
7. Usage and ruggedness: Ruggedness, both of mechanical and electrical intensities versus size and weight.
8. Electrical parameters: Length and type of cable required, signal to noise ratio when combined with amplifiers, and frequency response limitations.

Resistive Transducer

Resistive Transducers are those in which the resistance changes due to a change in some physical phenomenon. The change in the value of the resistance with a change in the length of the conductor can be used to measure displacement.

Strain gauges work on the principle that the resistance of a conductor or semiconductor changes when strained. This can be used for the measurement of displacement, force and pressure.

The resistivity of materials changes with changes in temperature. This property can be used for the measurement of temperature.

Potentiometer(Displacement Transducer)

A resistive potentiometer (pot) consists of a resistance element provided with a sliding contact, called a wiper. The motion of the sliding contact may betranslatory or rotational. Some have a combination of both, with resistive elements in the form of a helix, as shown in Fig. 13.1(c). They are known as helipots.

Translatory resistive elements, as shown in Fig. 13.1(a), are linear (straight) devices. Rotational resistive devices are circular and are used for the measurement of angular displacement, as shown in Fig. 13.1(b).

Helical resistive elements are multi turn rotational devices which can be used for the measurement of either translatory or rotational motion. A potentiometer is a passive transducer since it requires an external power source for its operation.

Advantage of Potentiometers

1. They are inexpensive.
2. Simple to operate and are very useful for applications where the requirements are not particularly severe.
3. They are useful for the measurement of large amplitudes of displacement.
4. Electrical efficiency is very high, and they provide sufficient output to allow control operations.

Disadvantages of Potentiometers

1. When using a linear potentiometer, a large force is required to move the sliding contacts.
2. The sliding contacts can wear out, become misaligned and generate noise.

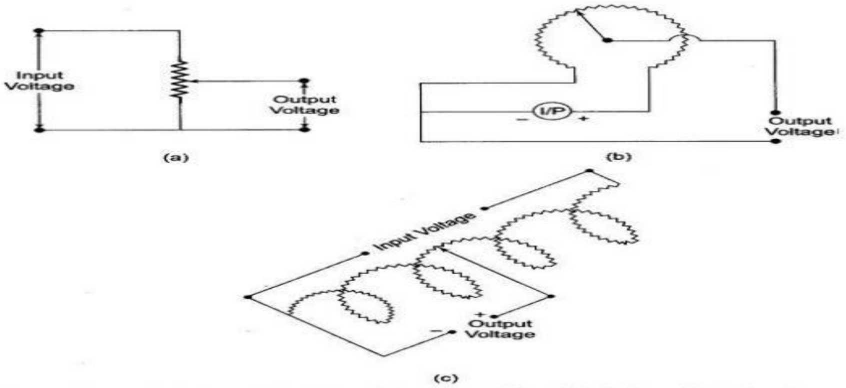


Fig. 13.1 (a) Translatory Type (b) Rotational Type (c) Helipot (Rotational)

STRAIN GAUGES

The strain gauge is an example of a passive transducer that uses electric resistance variation in wires to sense the strain produced by a force on wires. It is a very versatile detector and transducer for measuring weight, pressure, mechanical force, or displacement.

The construction of a bonded strain gauge (see figure) shows a fine wire element looped back and forth on a mounting plate, which is usually cemented to the member undergoing stress. A

tensile stress tends to elongate the wire and thereby increase its length and decrease its cross-sectional area.

Bonded type strain gauges are three types, namely

1. Wire Strain Gauges
2. Foil Strain Gauge
3. Semiconductor Strain Gauge

1. Wire Strain Gauges:

Wire Strain Gauges has three types namely,

1. Grid type
2. Rossette type
3. Torque type

4. Helical type

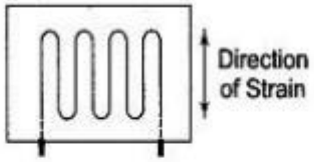


Fig. 13.6 Grid Type Strain Gauge

The grid arrangement of the wire element in a bonded strain gauge creates a problem not encountered in the use of unbonded strain gauges. To be useful as a strain gauge, the wire element must measure strain along one axis. Therefore complete and accurate analysis of strain in a rigid member is impossible, unless the direction and magnitude of stress are known.

The measuring axis of a strain gauge is its longitudinal axis, which is parallel to the wire element, as shown in Fig. 13.6.

When a strain occurs in the member being measured, along the transverse axis of the gauge, it also affects the strain being measured parallel to the longitudinal axis. This introduces an error in the response of the gauge.
In most applications, some degree of strain is present along the transverse axis and the transverse sensitivity must be considered in the final gauge output. Transverse sensitivity cannot be completely eliminated, and in highly accurate measurements the
resultant gauge error must be compensated for.
If the axis of the strain in a component is unknown, Strain Gauge Transducer Types may be used to determine the exact direction. The standard procedure is to place several gauges at a point on the member's surface, with known angles between them. The magnitude of strain in each individual gauge is measured, and used in the geometrical determination of the strain in the member.

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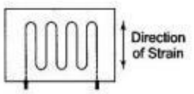


Fig. 13.6 Grid Type Strain Gauge

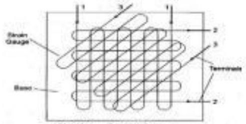


Fig. 13.7 Rosette Gauge

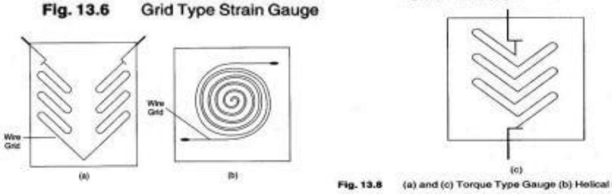


Fig. 13.8 (a) and (c) Torque Type Gauge (b) Helical Gauge

When a strain occurs in the member being measured, along the transverse axis of the gauge, it also affects the strain being measured parallel to the longitudinal axis. This introduces an error in the response of the gauge.

In most applications, some degree of strain is present along the transverse axis and the transverse sensitivity must be considered in the final gauge output. Transverse sensitivity cannot be completely eliminated, and in highly accurate measurements the resultant gauge error must be compensated for.

If the axis of the strain in a component is unknown, Strain Gauge Transducer Types may be used to determine the exact direction. The standard procedure is to place several gauges at a point on the member’s surface, with known angles between them. The magnitude of strain in each individual gauge is measured, and used in the geometrical determination of the strain in the member.

Foil Strain Gauge

This class of strain gauges is an extension of the resistance wire strain gauge. The strain is sensed with the help of a metal foil. The metals and alloys used for the foil and wire are nichrome, constantan (Ni + Cu), isoelastic (Ni + Cr + Mo), nickel and platinum.

Foil gauges have a much greater dissipation capacity than wire wound gauges, on account of their larger surface area for the same volume. For this reason, they can be used for a higher operating temperature range. Also, the large surface area of foil gauges leads to better bonding.

Foil type Strain Gauge Transducer Types have similar characteristics to wire strain gauges. Their gauge factors are typically the same.

The advantage of foil type Strain Gauge Transducer Types is that they can be fabricated on a large scale, and in any shape. The foil can also be etched on a carrier.

Etched foil gauge construction consists of first bonding a layer of strain sensitive material to a thin sheet of paper or bakelite. The portion of the metal to be used as the wire element is covered with appropriate masking material, and an etching solution is applied to the unit. The solution removes that portion of the metal which is not masked, leaving the desired grid structure intact.

This method of construction enables etched foil strain gauges to be made thinner than comparable wire units, as shown in Fig. 13.9. This characteristic, together with a greater degree of flexibility, allows the etched foil to be mounted in more remote and restricted places and on a wide range of curved surfaces. The resistance value of commercially available foil gauges is between 50 and 1000 Ω

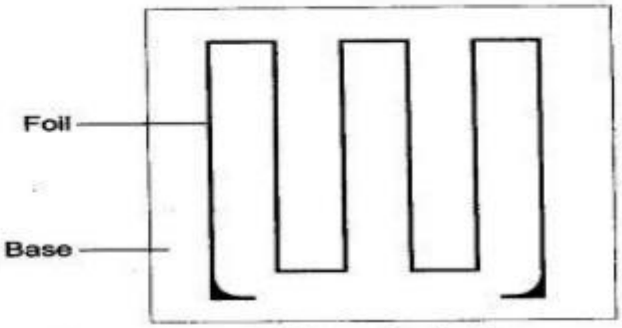


Fig. 13.9 Foil Type Strain Gauge

Semiconductor Strain Gauge

To have a high sensitivity, a high value of gauge factor is desirable. A high gauge factor means relatively higher change in resistance, which can be easily measured with a good degree of accuracy.

Semiconductor strain gauges are used when a very high gauge factor is required. They have a gauge factor 50 times as high as wire strain gauges. The resistance of the semiconductor changes with change in applied strain.

Semiconductor strain gauges depend for their action upon the piezo resistive effect, i.e. change in value of the resistance due to change in resistivity, unlike metallic gauges where change in resistance is mainly due to the change in dimension when strained. Semiconductor materials such as germanium and silicon are used as resistive materials.

A typical strain gauge consists of a strain material and leads that are placed in a protective box, as shown in Fig. 13.10. Semiconductor wafer or filaments which have a thickness of 0.05 mm are used. They are bonded on suitable insulating substrates, such as Teflon.

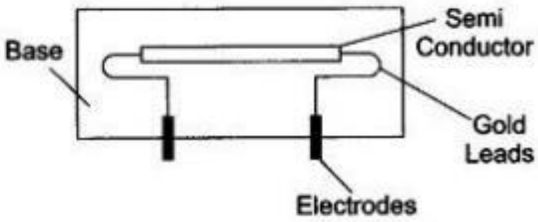


Fig. 13.10 Semiconductor Strain Gauge

Gold leads are generally used for making contacts. These strain gauges can be fabricated along with an IC Op Amp which can act as a pressure sensitive transducer. The large gauge factor is accompanied by a thermal rate of change of resistance approximately 50 times higher than that for resistive gauges. Hence, a semiconductor strain gauge is as stable as the metallic type, but has a much higher output.

Simple temperature compensation methods can be applied to semiconductor strain gauges, so that small values of strain, that is micro strains, can also be measured.

Advantages of Semiconductor Strain Gauge

1. Semiconductor strain gauges have a high gauge factor of about + 130. This allows measurement of very small strains, of the order of 0.01 micro
2. Hysteresis characteristics of semiconductor strain gauges are excellent, e. less than 0.05%.
3. Life in excess of 10 x 106 operations and a frequency response of 1012 HZ.
4. Semiconductor strain gauges can be very small in size, ranging in length from 0.7 to 7.0 mm.

Disadvantages of Semiconductor Strain Gauge

1. They are very sensitive to changes in temperature.
2. Linearity of semiconductor strain gauges is poor.
3. They are more expensive.

Temperature Transducers

- Resistance Temperature Detectors (RTD)
- Thermocouples
- Thermistor

Resistance Temperature Detector (RTD)

Detectors of wire resistance temperature common employ platinum, nickel or resistance wire elements, whose resistance variation with temperature has high intrinsic accuracy. They are available in many configurations and size and as shielded or open units for both immersion and surface applications.

The relationship between temperature and resistance of conductors can be calculated from the equation:

$$R = R_0(1+\alpha\Delta T)$$

where

R = the resistance of the conductor at temperature t (^{0}C)
R_0 = the resistance at the reference temperature, usually 20^{0}C

α = the temperature coefficient of resistance

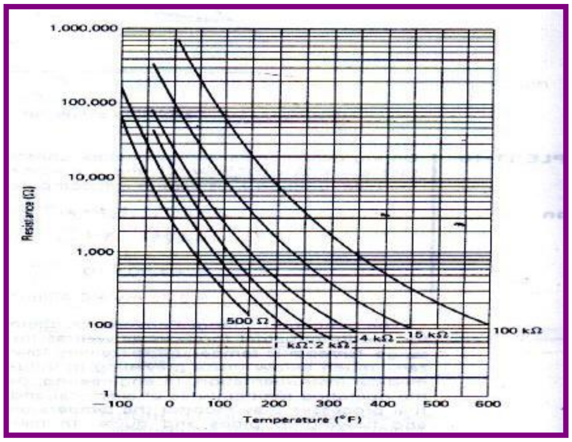
ΔT = the difference between the operating and the reference temperature

Thermistor

A thermistor is a semiconductor made by sintering mixtures of metallic oxide, such as oxides of manganese, nickel, cobalt, copper and uranium.

Termistors have negative temperature coefficient (NTC). That is, their resistance decreases as their temperature rises.

Types of thermistor	Resistance
Disc	1 to 1MΩ
Washer	1 to 50kΩ
Rod	high resistance



This figure shows resistance versus temperature for a family thermistor. The resistance value marked at the bottom end of each curve is a value at 25^{0}C

The resistance decreases as their temperature rises-NTC

Advantages of thermistor

- Small size and low cost
- Fast response over narrow temperature range
- Good sensitivity in Negative Temperature Coefficient (NTC) region

- Cold junction compensation not required due to dependence of resistance on absolute temperature.
- Contact and lead resistance problems not encountered due to large resistance

Limitations of thermistor

- Non linearity in resistance vs temperature characteristics
- Unsuitable for wide temperature range
- Very low excitation current to avoids self heating
- Need of shielded power lines, filters, etc due to high resistance

Thermocouples

It consists of two wires of different metals are joined together at one end, a temperature difference between this end and the other end of wires produces a voltage between the wires. The magnitude of this voltage depends on the materials used for the wires and the amount of temperature difference between the joined ends and the other ends.

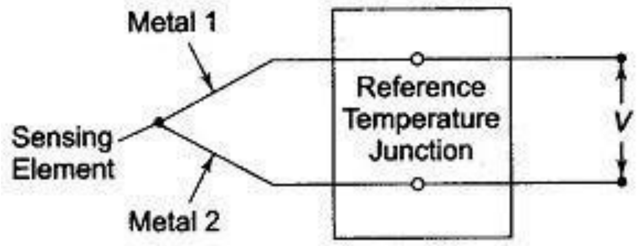


Fig. 13.41 Basic Thermocouple Connection

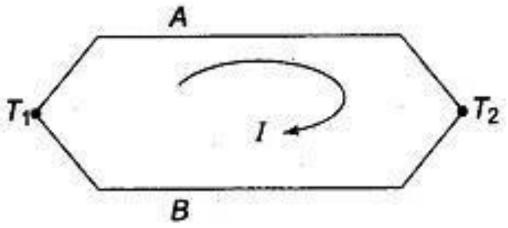


Fig. 13.42 Current through Two dissimilar Metals

A current will circulate around a loop made up of two dissimilar metal when the two junctions are at different temperatures. When this circuit is opened, a voltage appears that is proportional to the observed seeback current. The Thomson and Peltier emfs originate from the fact that, within conductors, the density of free charge carriers (electrons and holes) increases with temperature.

- If the temperature of one end of a conductor is raised above that of the other end, excess electrons from the hot end will diffuse to the cold end. This results in an induced voltage, the **Thomson effect**, that makes the hot end positive with respect to the cold end.

Conductors made up of different materials have different free-carriers densities even when at the same temperature. When two dissimilar conductors are joined, electrons will diffuse across the junction from the conductor with higher electron density. When this happens the conductor losing electrons acquire a positive voltage with respect to the other conductor. This voltage is called the **Peltier emf.**

- When the junction is heated a voltage is generated, this is known as seeback effect. The seeback voltage is linearly proportional for small changes in temperature.
- The magnitude of this voltage depends on the material used for the wires and the amount of temperature difference between the joined ends and the other ends. The junction of the wires of the Thermocouple Circuit is called the **sensing junction.**
- The temperature at this end of the Thermocouple Circuit wire is a reference temperature, this function is known as the reference, also called as the cold junction.
- When the reference end is terminated by a meter or a recording device, the meter indication will be proportional to the temperature difference between the hot junction and the reference junction.
- The magnitude of the thermal emf depends on the wire materials used and in the temperature difference between the junctions.
- Thermal emfs for some common thermocouple materials.

The thermocouple (TC) is a temperature transducer that develops an emf that is a function of the temperature difference between its hot and cold junctions.

- **Type 'E'** Thermocouple units use Chromel alloy as the positive electrode and constantan alloy as the negative electrode.
- **Type 'S'** Thermocouple produces the least output voltage but can be used over greatest temperature range.
- **Type 'T'** uses copper and constantan.

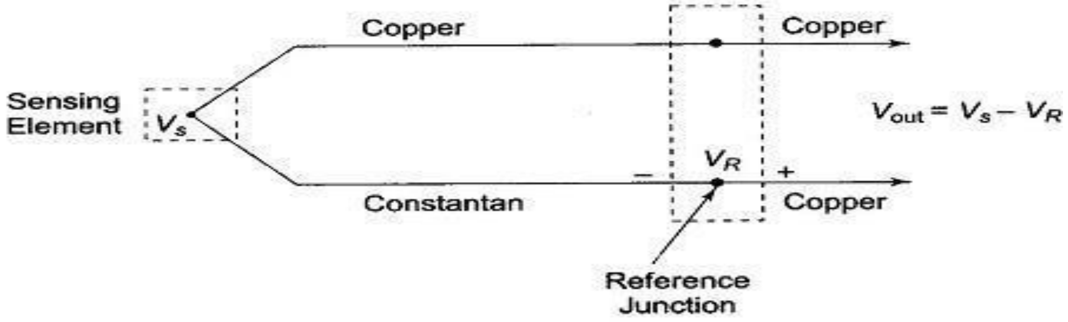


Fig. 13.44 A Type T Thermocouple with Reference Junction

The emf of the thermocouple: $E = c(T_1 - T_2) + k(T_1^2 - T_2^2)$

Where

c and k = constant of the thermocouple materials

T_1 = The temperature of the "hot" junction

T_2 = The temperature of the "cold" or "reference" junction

Advantages of Thermocouple

- It has rugged construction.
- It has a temperature range from —270 °C-2700 °C.
- Using extension leads and compensating cables, long distances transmission for temperature measurement is possible.
- Bridge circuits are not required for temperature measurement.
- Comparatively cheaper in cost.
- Calibration checks can be easily performed.
- Thermocouples offer good reproducibility.
- Speed of response is high compared to the filled system thermometer.
- Measurement accuracy is quite good.

Disadvantages of Thermocouple

- Cold junction and other compensation is essential for accurate
- They exhibit non-linearity in the emf versus temperature characteristics.

- To avoid stray electrical signal pickup, proper separation of extension leads from thermocouple wire is essential.
- Stray voltage pick-ups are possible.
- In many applications, the signals need to be amplified.

Capacitive Transducer

The capacitance of a parallel plate capacitor is given by

$$C = \frac{kA\varepsilon_0}{d}(Farads)$$

where

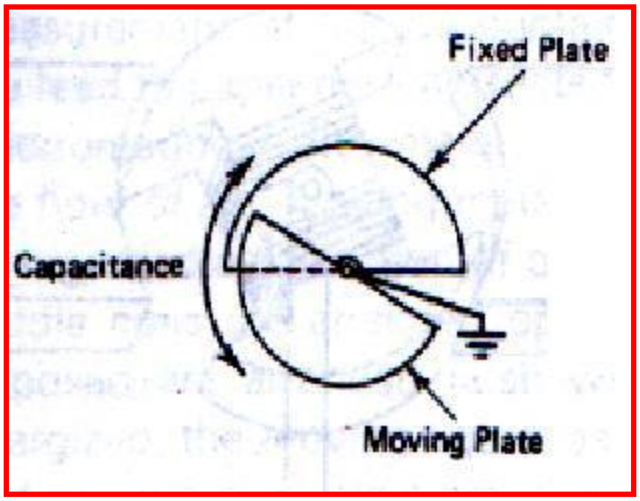
k = dielectric constant

A = the area of the plate, in m^2

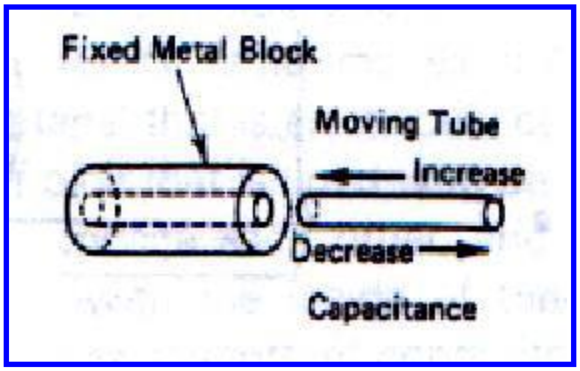
ε_o = 8.854×10^{-12} F/m

d = the plate placing in m

The capacitance of this unit proportional to the amount of the fixed plate that is covered, that shaded by moving plate. This type of transducer will give sign proportional to curvilinear displacement or angular velocity.



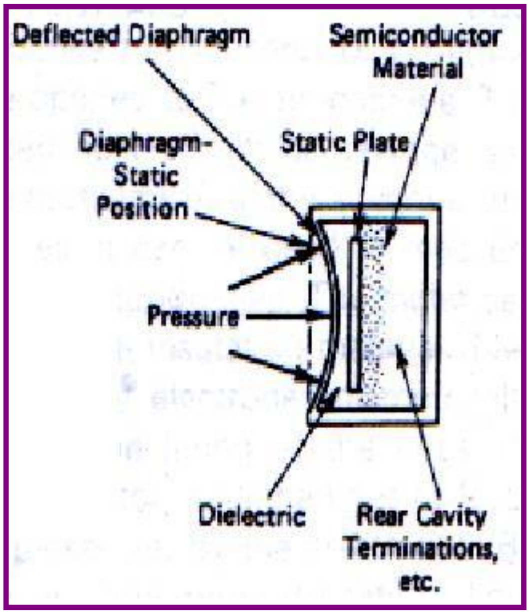
It consists of a fixed cylinder and a moving cylinder. These pieces are configured so the moving piece fits inside the fixed piece but insulated from it.



Capacitive Pressure Transducer

A transducer that varies the spacing between surfaces. The dielectric is either air or vacuum.

Often used as Capacitance microphones.



Inductive Transducer

Inductive transducers may be either of the self generating or passive type. The self generating type utilises the basic electrical generator principle, i.e, a motion between a conductor and magnetic field induces a voltage in the conductor (generator action). This relative motion between the field and the conductor is supplied by changes in the measurand.

An inductive electromechanical transducer is a device that converts physical motion (position change) into a change in inductance. Transducers of variable inductance type work upon one of the following principles:

1. Variation of self inductance and Variation of mutual inductance

Inductive transducers are mainly used for the measurement of displacement. The displacement to be measured is arranged to cause variation in any of three variables

- *Number of turns*
- **Geometric configuration**
- *Permeability of the magnetic material*

$$L = \frac{e}{di/dt} = \frac{N^2}{R} \qquad (13.10)$$

Change in Self Inductance with Numbers of Turns

The output may be caused by a change in the number of turns. Figures 13.14(a) and (b) are transducers used for, the measurement of displacement of linear and angular movement respectively.

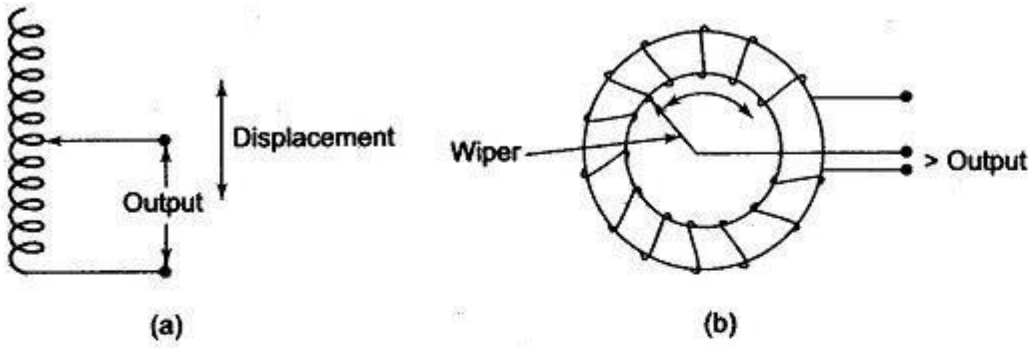


Fig. 13.14 (a) Linear Inductive Transducer (Using Air Core) (b) Angular Inductive Transducer (Using Ferrite Core)

Transducer Working on the Principle of Change in Self Inductance with Change in Permeability

Figure 13.15 shows an Inductive Transducer Definition which works on the principle of the variation of permeability causing a change in self inductance. The iron core is surrounded by a winding. If the iron core is inside the winding, its permeability is increased, and so is the inductance. When the iron core is moved out of the winding, the permeability decreases, resulting in a reduction of the self inductance of the coil. This transducer can be used for measuring displacement.

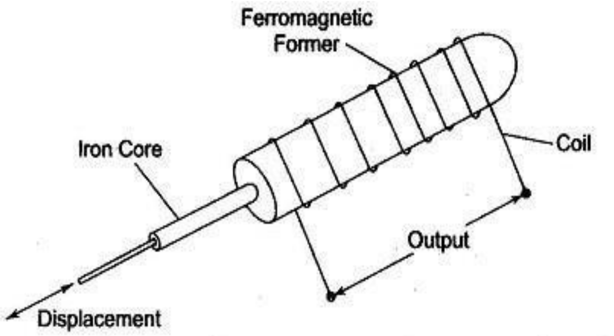


Fig. 13.15 Inductive Transducer Working on the Principle of Variation of Permeability

Variable Reluctance Type Transducer

A transducer of the variable type consists of a coil wound on a ferromagnetic core. The displacement which is to be measured is applied to a ferromagnetic target. The target does not have any physical contact with the core on which it is mounted. The core and the target are separated by an air gap, as shown in Fig. 13.16(a)

The reluctance of the magnetic path is determined by the size of the air gap. The inductance of the coil depends upon the reluctance of the magnetic circuits. The self inductance of the coil is given by

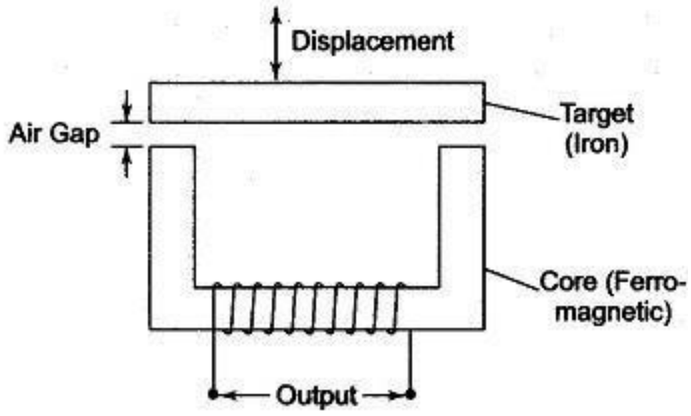


Fig. 13.16(a) Variable Reluctance Transducer

$$L = \frac{N^2}{R_i + R_g} \tag{13.11}$$

where N = number of turns

R_i = reluctance of iron parts

R_g = reluctance of air gap

But reluctance of the air gap is given by

$$R_g = \frac{l_g}{\mu_o \times A_g} \tag{13.13}$$

Where

l_g = length of the air gap

A_g = area of the flux path through air

μ_o = permeability

R_g is proportional to l_g, as μ_o and A_g are constants.

Hence L is proportional to l/lg, i.e. the self inductance of the coil is inversely proportional to the length of the air gap.

Differential Output Transducer

- The inductance of one part increases from L to L + ΔL, while that of the other part decreases from L to L — ΔL. The change is measured as the difference of the two, resulting in an output of 2 ΔL instead of ΔL, when one winding is used. This increases the sensitivity and also eliminates error.

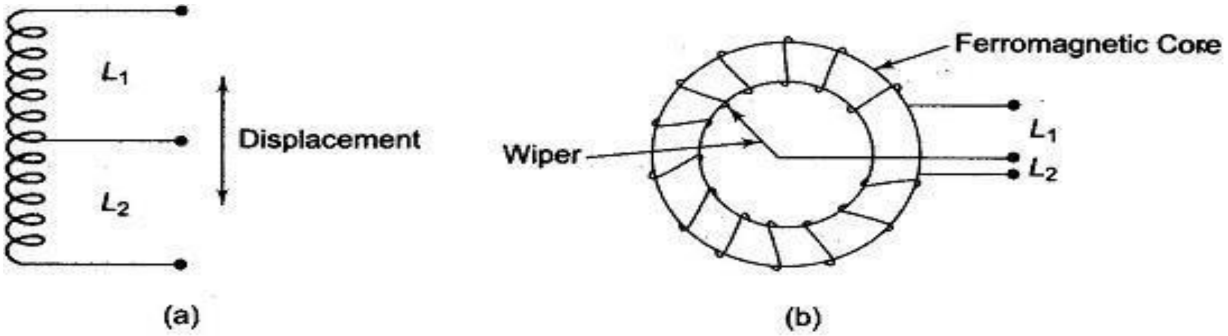


Fig. 13.17 (a) Linear Differential Output Transducer
(b) Angular Differential Output Transducer

Linear Variable Differential Transducer *(LVDT)*

- The differential transformer is a passive inductive transformer. It is also known as a Linear Variable Differential Transducer (LVDT).

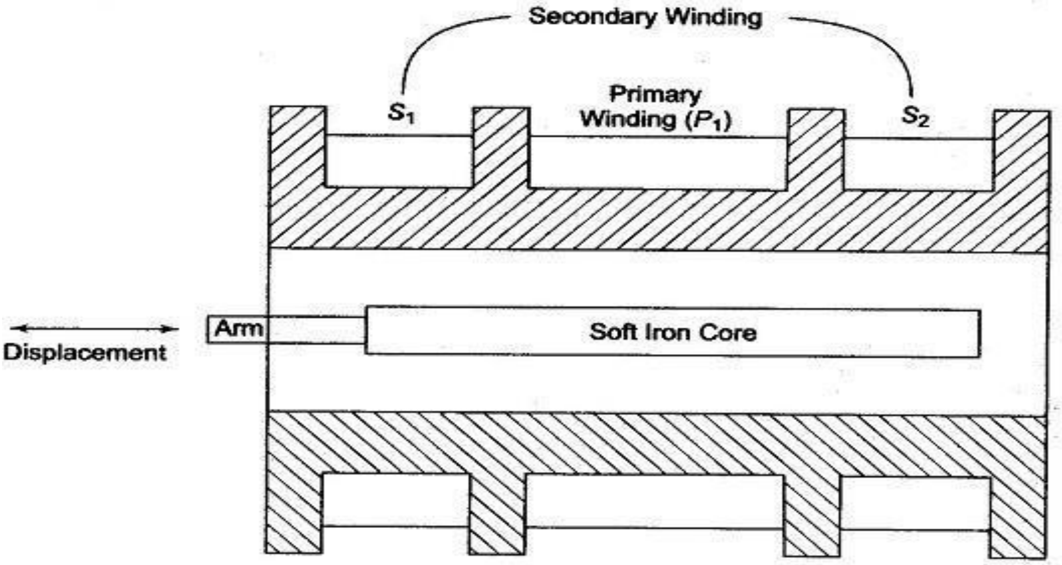
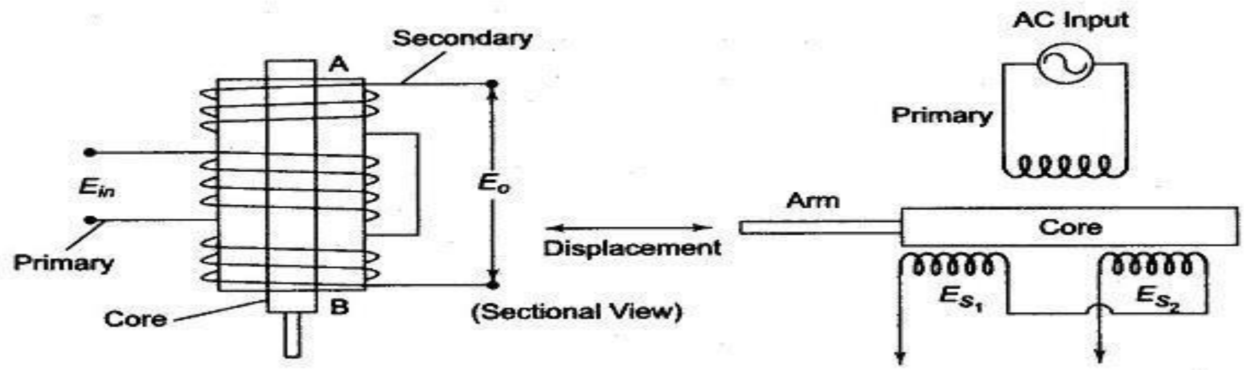


Fig. 13.19 Construction of a Linear Variable Differential Transducer (LVDT)

- The transformer consists of a single primary winding P_1 and two secondary windings S_1 and S_2 wound on a hollow cylindrical former. The secondary windings have an equal number of turns and are identically placed on either side of the primary windings. The primary winding is connected to an ac source.

- An movable soft iron core slides within the hollow former and therefore affects the magnetic coupling between the primary and the two secondaries. The displacement to be measured is applied to an arm attached to the soft iron core.
- When the core is in its normal (null) position, equal voltages are induced in the two secondary windings. The frequency of the ac applied to the primary winding ranges from 50 Hz to 20 kHz.
- The output voltage of the secondary windings S_1 is E_{s1} and that of secondary winding S_2 is E_{s2}.
- In order to convert the output from S_1 to S_2 into a single voltage signal, the two secondaries S_1 and S_2 are connected in series opposition,

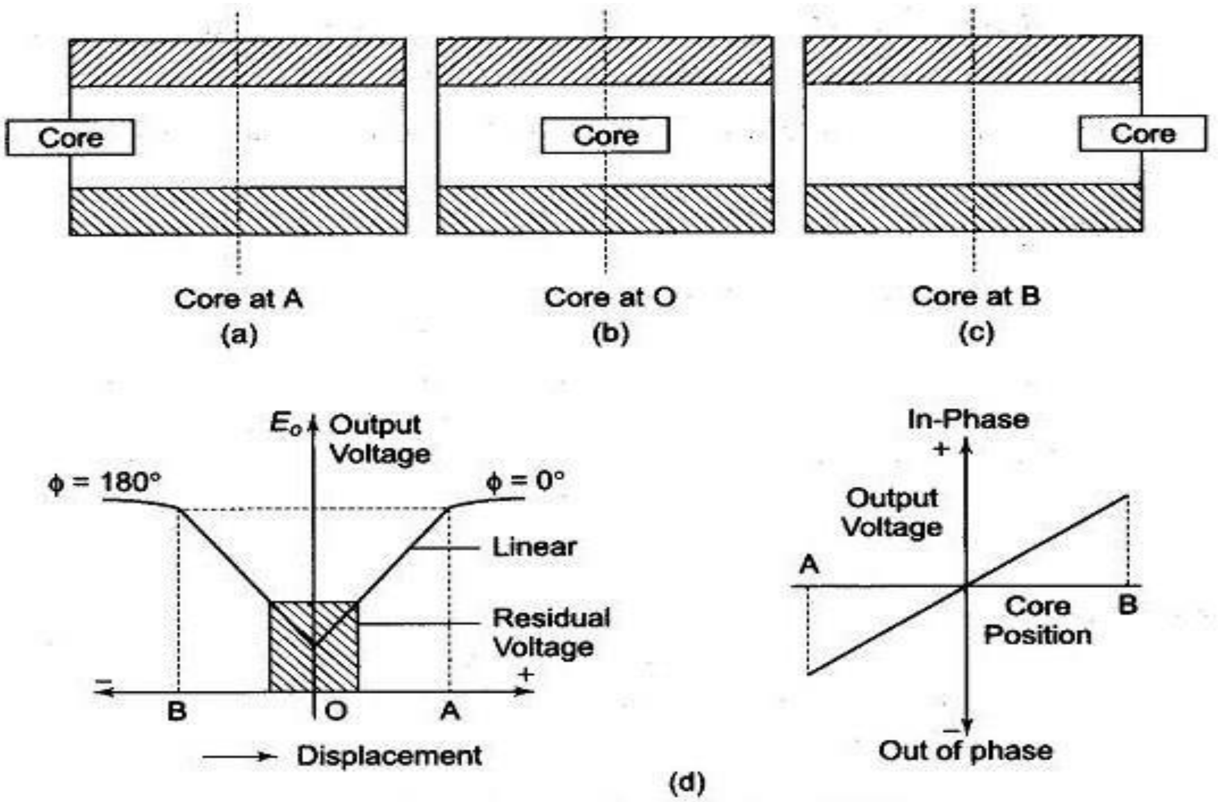


(a) Construction (b) Basic Circuit

Fig. 13.20 Secondary Winding Connected for Differential Output

- Hence the output voltage of the transducer is the difference of the two voltages. Therefore the differential output voltage $E_o = E_{s1} \sim E_{s2}$.
- When the core is at its normal position, the flux linking with both secondary windings is equal, and hence equal emfs are induced in them. Hence, at null position $E_{s1} = E_{s2}$. Since the output voltage of the transducer is the difference of the two voltages, the output voltage E_o is zero at null position.
- Now, if the core is moved to the left of the null position, more flux links with winding S_1 and less with winding S_2. Hence, output voltage E_{s1} of the secondary winding S_1 is greater than E_{s2} . The magnitude of the output voltage of the secondary is then $E_{s1} - E_{s2}$, in phase with E_{s1} (the output voltage of secondary winding S_1).

- Similarly, if the core is moved to the right of the null position, the flux linking with winding S_2 becomes greater than that linked with winding S_1. This results in E_{s2} becoming larger than E_{s1}. The output voltage in this case is $E_o = E_{s2} — E_{s1}$ and is in phase with E_{s2}.



Core at A
(a)

Core at O
(b)

Core at B
(c)

(d)

Fig. 13.21 (a), (b), (c) Various Core Position of LVDT
(d) Variation of Output Voltage vs Displacement

Advantages

- **Linearity:** The output voltage of this transducer is practically linear for displacements upto 5 mm (a linearity of 0.05% is available in commercial LVDTs).

- **Infinite resolution:** The change in output voltage is stepless. The effective resolution depends more on the test equipment than on the

- **High output:** It gives a high output (therefore there is frequently no need for intermediate amplification devices).

- **High sensitivity:** The transducer possesses a sensitivity as high as 40 V/mm.

- **Ruggedness:** These transducers can usually tolerate a high degree of vibration and shock.

- **Less friction:** There are no sliding contacts.

- **Low hysteresis:** This transducer has a low hysteresis, hence repeatability is excellent under all conditions.
- **Low power:** consumption Most LVDTs consume less than 1 W

Disadvantages

- Large displacements are required for appreciable differential output.
- They are sensitive to stray magnetic fields (but shielding is possible).
- The receiving instrument must be selected to operate on ac signals, or ademodulator network must be used if a dc output is required.
- The dynamic response is limited mechanically by the mass of the core and electrically by the applied voltage.
- Temperature also affects the transducer.

Piezoelectric Transducer

- A Symmetrical crystalline materials such as Quartz, Rochelle salt and Barium titanate produce an emfwhen they are placed under stress. This property is used in Piezoelectric Transducer Working Principle, where a crystal is placed between a solid base and the force-summing member.

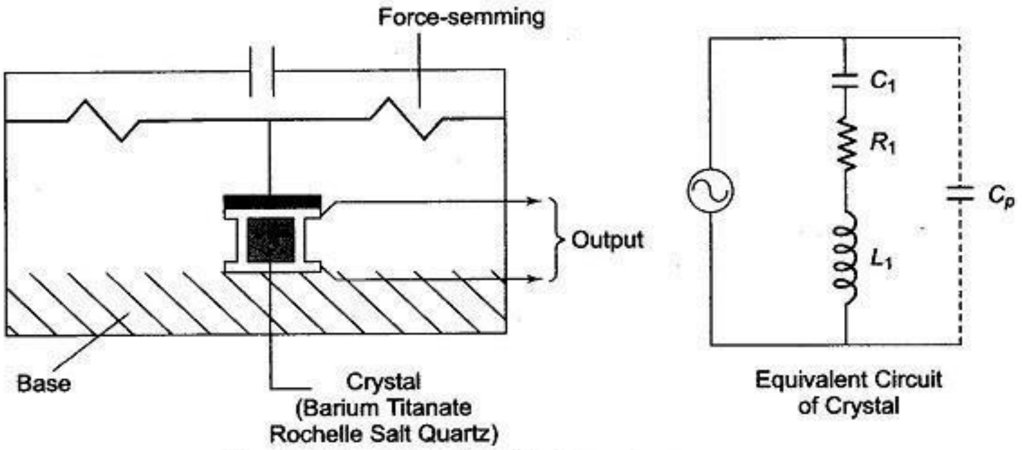


Fig. 13.31 Piezo Electric Transducer

- For a Piezoelectrical Transducer element under pressure, part of the energy is, converted to an electric potential that appears on opposite faces of the element, analogous to a charge on the plates of a capacitor. The rest of the applied energy is converted to mechanical energy, analogous to a compressed spring. When the pressure is removed, it returns to its original shape and loses its electric charge.

From these relationships, the following formulas have been derived for the coupling coefficient K

$$K = \frac{\text{Mechanical energy converted to electrical energy}}{\text{Applied mechanical energy}}$$

or

$$K = \frac{\text{Electrical energy converted to mechanical energy}}{\text{Applied electrical energy}}$$

- An alternating voltage applied to a crystal causes it to vibrate at its natural resonance frequency. Since the frequency is a very stable quantity, Piezoelectrical Transducer crystals are principally used in HF accelerometers.
- The principal disadvantage is that voltage will be generated as long as the pressure applied to the piezo electric element changes.

Synchros

wherein a change in the inductance of a sensing element is produced by a pressure change Pressure Inductive Transducer.A Synchro can be an angular position transducer working on Pressure Inductive Transducer principle, wherein a variable coupling between primary and secondary winding is obtained by changing the relative orientation of the windings.A Synchro appears like an AC motor consisting of a rotor and a stator.They have a rotor with one or three windings capable of revolving inside a fixed stator. There are two common types of rotors, the salientpole and the wound rotor.

- The stator has a 3-phase winding with the windings of the 3-phase displaced by 120°. The synchro may be viewed as a variable coupling transformer.

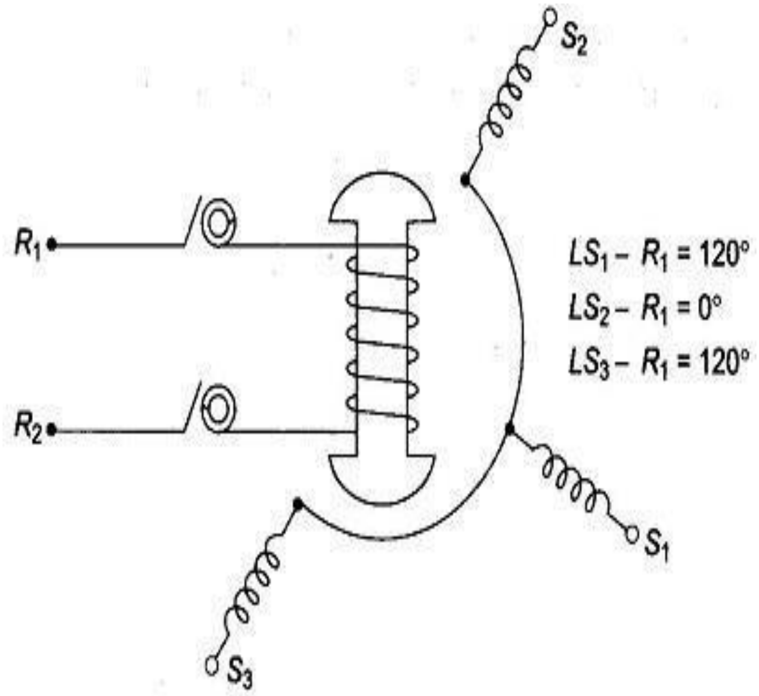


Fig. 13.23 Basic Synchro

- The rotor is energized by an ac voltage and coupling between rotor and stator windings varies as a trigonometric or linear function of the rotor position.

A Synchro system formed by interconnection of the devices called the Synchro transmitter and Synchro control transmitter is perhaps the most widely used error detector in feedback control system. It measures and compares two angular displacements and its output voltage is approximately linear with angular displacement.

When an ac excitation voltage is applied to the rotor, the resultant current produces a magnetic field and by transformer action induces voltages in the stator coils.

The effective voltage induced in any stator coil depends upon the angular position of the coil axis with respect to the rotor axis.

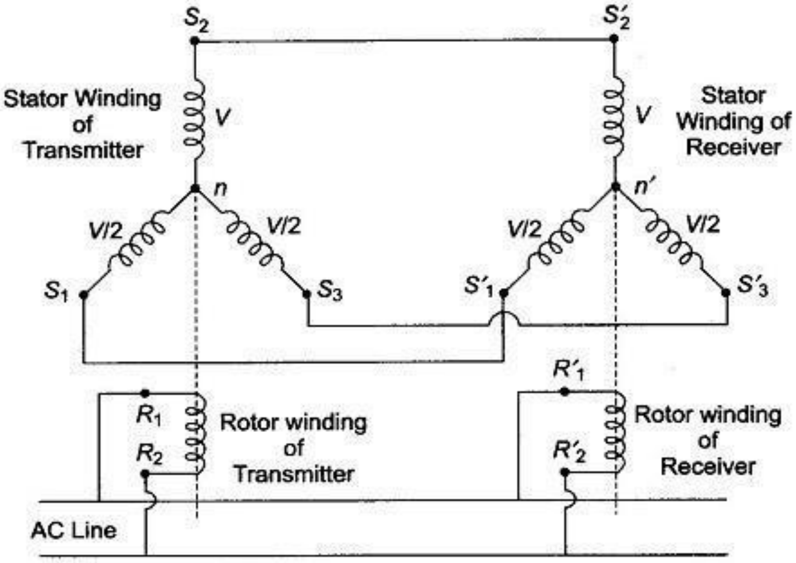
Suppose the voltage is V, the coupling between S_1 and S_2 of the stator and primary (rotor) winding is a cosine function. In general if the rotor is excited by 50 Hz ac, also called reference voltage, the voltage induced in any stator winding will be proportional to the cosine of the angle between the rotor axis and the stator axis.

For example, if a reference voltage V sin ωt excites the rotor of a synchro (R_1— R_2), the stator terminals will have a voltage of the following form:

These voltages are known as Synchro format voltages.

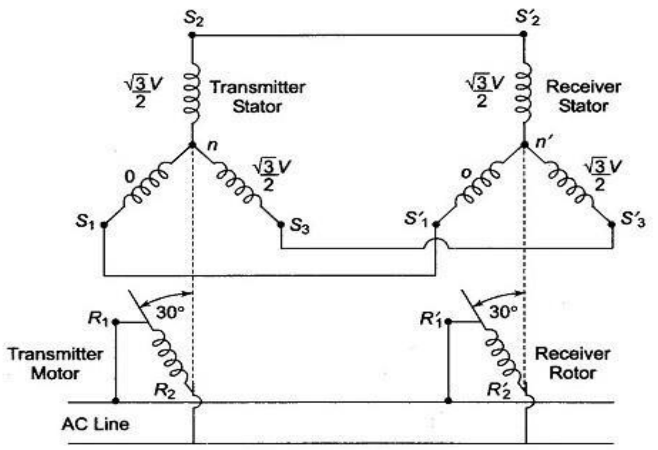
$$V(S_1 - S_2) = V \sin \omega t \sin \theta$$
$$V(S_1 - S_2) = V \sin \omega t (\sin \theta + 120°)$$
$$V(S_2 - S_3) = V \sin \omega t (\sin \theta + 240°)$$

- These voltages are known as Synchro format voltages.



(a)

(a) Torque Transmission Using Synchro Trans



(b)

Fig. 13.24 (b) Follow Up Conditions of Transmitter-Receiver System

A Synchro system formed by interconnection of the devices called the Synchro transmitter and Synchro control transmitter is perhaps the most widely used error detector in feedback control system. It measures and compares two angular displacements and its output voltage is approximately linear with angular displacement.

The conventional Synchro transmitter (TX) uses a salient pole rotor with sleeved slot. When an ac excitation voltage is applied to the rotor, the resultant current produces a magnetic field and by transformer action induces voltages in the stator coils. The effective voltage induced in any stator coil depends upon the angular position of the coil axis with respect to the rotor axis (when the coil voltage is known, the induced voltage at any angular displacement can be determined).

Initially winding S_2 of the stator of transmitter is positioned for maximum coupling with the rotor winding as shown in Fig. 13.24(a). Suppose the voltage is V, the coupling between S_1 and S_2 of the stator and primary (rotor) winding is a cosine function. In general if the rotor is excited by 50 Hz ac, also called reference voltage, the voltage induced in any stator winding will be proportional to the cosine of the angle between the rotor axis and the stator axis. The voltages induced across any pair of stator terminals (S_1— S_2, S_I — S_3, or S_2 —S_3) will be sum or difference, depending on the phase of the voltage measured across the coils.

For example, if a reference voltage V sin ωt excites the rotor of a synchro (R_1— R_2), the stator terminals will have a voltage of the following form:

$$V(S_1 - S_2) = V \sin \omega t \sin \theta$$
$$V(S_1 - S_2) = V \sin \omega t \ (\sin \theta + 120°)$$
$$V(S_2 - S_3) = V \sin \omega t \ (\sin \theta + 240°)$$

where θ is the shaft angle.

These voltages are known as Synchro format voltages.

Therefore, the effective voltages in these windings are proportional to cos 60° or they are V/2 each. So long as the rotors of the transmitter and receiver remains in this position, no current will flow between the stator windings because of the voltage balance.

When the rotor of the transmitter is moved to a new position, the voltage balance is disturbed or changed. Assuming that the rotor of the transmitter is moved through 30° as shown in Fig. 13.24(b), the stator winding voltages of the transmitter will be changed to 0,√3/2 V and √3/2 V respectively.

Hence, a voltage imbalance occurs between the stator windings of the transmitter and receiver. This voltage imbalance between the windings causes current to flow between the windings producing a torque that tends to rotate the rotor of the receiver to a new position where the voltage balance is again restored. This balance is restored only if the receiver turns through the same angle as the transmitter and also the direction of rotation is the same as that of the transmitter. Hence a Synchro can be used to determine the magnitude and direction of angular displacement.

Magnetostrictive Transducer

- Magnetostrictive materials transducer converts magnetic energy to mechanical energy and vice versa. As a magnetostrictive material is magnetized, it strains; that is it exhibits a change in length per unit length.

- Conversely, if an external force produces a strain in a magnetostrictive material, the material's magnetic state will change. This bi-directional coupling between the magnetic and mechanical states of a magnetostrictive material provides a transduction capability that is used for both actuation and sensing devices.

Magnetostriction is an inherent material property that will not degrade with time.

Hot Wire Anemometer

Basic Principle:

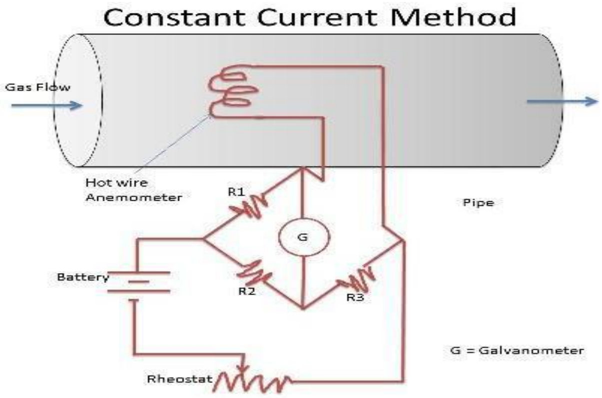
- When an electrically heated wire is placed in a flowing gas stream, heat is transferred from the wire to the gas and hence the temperature of the wire reduces, and due to this, the resistance of the wire also changes. This change in resistance of the wire becomes a measure of flow rate.
- There are two methods of measuring flow rate using a anemometer bridge combination namely:

Constant current method

- Constant temperature method

Constant current method

- The bridge arrangement along with the anemometer has been shown in diagram. The anemometer is kept in the flowing gas stream to measure flow rate.



- A constant current is passed through the sensing wire. That is, the voltage across the bridge circuit is kept constant, that is, not varied.

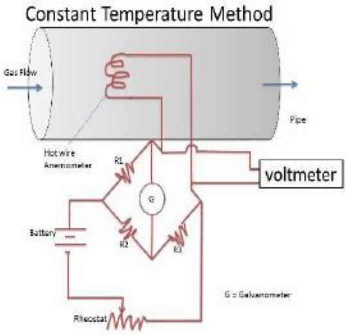
- Due to the gas flow, heat transfer takes place from the sensing wire to the flowing gas and hence the temperature of the sensing wire reduces causing a change in the resistance of the sensing wire. (this change in resistance becomes a measure of flow rate).

- Due to this, the galvanometer which was initially at zero position deflects and this deflection of the galvanometer becomes a measure of flow rate of the gas when calibrated.

Constant temperature method

- The bridge arrangement along with the anemometer has been shown in diagram. The anemometer is kept in the flowing gas stream to measure flow rate.

- A current is initially passed through the wire.



- Due to the gas flow, heat transfer takes place from the sensing wire to the flowing gas and this tends to change the temperature and hence the resistance of the wire.

- The principle in this method is to maintain the temperature and resistance of the sensing wire at a constant level. Therefore, the current through the sensing wire is increased to bring the sensing wire to have its initial resistance and temperature.

- The electrical current required in bringing back the resistance and hence the temperature of the wire to its initial condition becomes a measure of flow rate of the gas when calibrated.