ELECTRONIC MEASUREMENT & MEASURING INSTRUMENTS
SYLLABUS

Module-I (12 Hours)

Basics of Measurements: Accuracy, Precision, resolution, reliability, repeatability, validity, Errors and their analysis, Standards of measurement.

Bridge Measurement: DC bridges- wheatstone bridge, AC bridges – Kelvin, Hay, Maxwell, Schering and Wien bridges, Wagner ground Connection.

Electronic Instruments for Measuring Basic Parameters: Amplified DC meter, AC Voltmeter, True- RMS responding Voltmeter, Electronic multi-meter, Digital voltmeter, Vector Voltmeter.

Module-II (12 Hours)

Oscilloscopes: Cathode Ray Tube, Vertical and Horizontal Deflection Systems, Delay lines, Probes and Transducers, Specification of an Oscilloscope. Oscilloscope measurement Techniques, Special Oscilloscopes – Storage Oscilloscope, Sampling Oscilloscope.

Signal Generators: Sine wave generator, Frequency – Synthesized Signal Generator, Sweep frequency Generator. Pulse and square wave generators. Function Generators.

Module-III (10 Hours)

Signal Analysis: Wave Analyzer, Spectrum Analyzer.

Frequency Counters: Simple Frequency Counter; Measurement errors; extending frequency range of counters

Transducers: Types, Strain Gages, Displacement Transducers.

Module-IV (6 Hours)

Digital Data Acquisition System: Interfacing transducers to Electronics Control and Measuring System. Instrumentation Amplifier, Isolation Amplifier. An Introduction to Computer-Controlled Test Systems.IEEE-488 GPIB Bus

Text Books:

1. Modern Electronics Instrumentation & Measurement Techniques, by Albert D.Helstrick and William D.Cooper, Pearson Education. Selected portion from Ch.1, 5-13.

2. Elements of Electronics Instrumentation and Measurement-3rd Edition by Joshph J.Carr.Pearson Education. Selected portion from Ch.1,2,4,7,8,9,13,14,18,23 and 25.

Reference Books :

3. Electronics Instruments and Instrumentation Technology – Anand, PHI

4. Doebelin, E.O., Measurement systems, McGraw Hill, Fourth edition, Singapore, 1990.

MODULE –I

Chapter 1.   Basics of Measurements

1.   Introduction

A *measuring system* exists to provide information about the physical value of some variable being measured. In simple cases, the system can consist of only a single unit that gives an output reading or signal according to the magnitude of the unknown variable applied to it. However, in more complex measurement situations, a measuring system consists of several separate elements as shown in Figure 1.1.

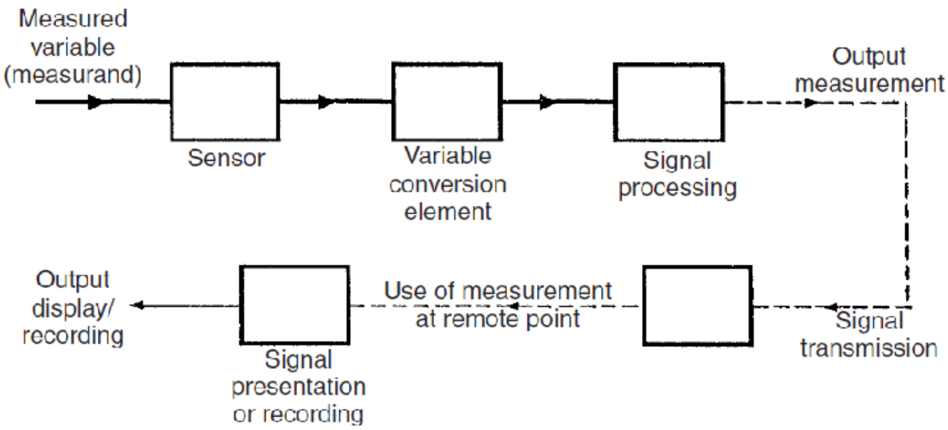

Fig 1.1: Elements of A measuring system

These components might be contained within one or more boxes, and the boxes holding individual measureme nt elements might be either close together or physically separate. The term *measuring instrument* is commonly used to describe a measurement system.

The static characteristics of an instrument are, in general, considered for instruments which are used to measure an unvarying process condition. All the static performance characteristics are obtained by one form or another of a process called calibration. There are a number of related definitions (or characteristics), which are described below, such as accuracy% precision, repeatability, resolution, errors, sensitivity, etc.

- **Instrument:** A device or mechanism used to determine the present value of the quantity under measurement.
- **Measurement:** The process of determining the amount, degree, or capacity by comparison (direct or indirect) with the accepted standards of the system units being used.
- **Accuracy**: The degree of exactness (closeness) of a measurement compared to the expected (desired) value.
- **Resolution:** The smallest change in a measured variable to which an instrument will respond.

- **Precision**: A measure of the consistency or repeatability of measurements, i.e. successive readings does not differ. (Precision is the consistency of the instrument output for a given value of input).
- **Expected value**: The design value, i.e. the most probable value that calculations indicate one should expect to measure.
- **Error:** The deviation of the true value from the desired value.
- **Sensitivity**: The ratio of the change in output (response) of the instrument to a change of input or measured variable.

1.1 Accuracy

The *accuracy* of an instrument is a measure of how close the output reading of the instrument is to the correct value. In practice, it is more usual to quote the *inaccuracy* figure rather than the accuracy figure for an instrument. Inaccuracy is the extent to which a reading might be wrong, and is often quoted as a percentage of the full-scale (f.s.) reading of an instrument. If, for example, a pressure gauge of range 0–10 bar has a quoted inaccuracy of š1.0% f.s. (š1% of full-scale reading), then the maximum error to be expected in any reading is 0.1 bar. This means that when the instrument is reading 1.0 bar, the possible error is 10% of this value. For this reason, it is an important system design rule that instruments are chosen such that their range is appropriate to the spread of values being measured, in order that the best possible accuracy is maintained in instrument readings. Thus, if we were measuring pressures with expected values between 0 and 1 bar, we would not use an instrument with a range of 0–10 bar. The term *measurement uncertainty* is frequently used in place of inaccuracy.

1.2 Precision/repeatability/reproducibility

Precision is a term that describes an instrument's degree of freedom from random errors. If a large number of readings are taken of the same quantity by a high precision instrument, then the spread of readings will be very small. Precision is often, though incorrectly, confused with accuracy. High precision does not imply anything about measurement accuracy. A high precision instrument may have a low accuracy. Low accuracy measurements from a high precision instrument are normally caused by a bias in the measurements, which is removable by recalibration.

The terms repeatability and reproducibility mean approximately the same but are applied in different contexts as given below. *Repeatability* describes the closeness of output readings when the same input is applied repetitively over a short period of time, with the same measurement conditions, same instrument and observer, same location and same conditions of use maintained throughout.

Reproducibility describes the closeness of output readings for the same input when there are changes in the method of measurement, observer, measuring instrument, location, conditions of use and time of measurement. Both terms thus describe the spread of output readings for the same input. This spread is referred to as repeatability if the measurement conditions are constant and as reproducibility if the measurement conditions vary.

The degree of repeatability or reproducibility in measurements from an instrument is an alternative way of expressing its precision. Figure 1.2 illustrates this more clearly. The figure shows the results of tests on three industrial robots that were programmed to place components at a particular point on a table. The target point was at the centre of the concentric circles shown, and the black dots represent the points where each robot actually deposited components at each attempt. Both the accuracy and precision of Robot 1 are shown to be low in this trial. Robot 2 consistently puts the component down at approximately the same place but this is the wrong point. Therefore, it has high precision but low accuracy. Finally, Robot 3 has both high precision and high accuracy, because it consistently places the component at the correct target position.

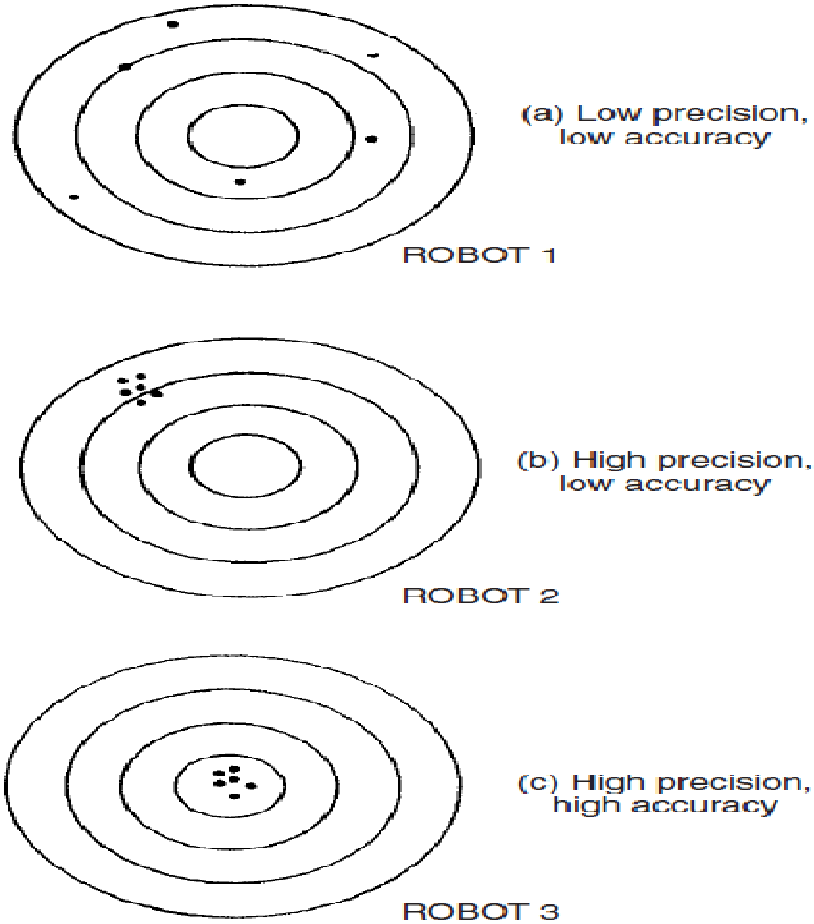

Fig 1. 2 Comparison of accuracy and precision.

1.3 Tolerance

Tolerance is a term that is closely related to accuracy and defines the maximum error that is to be expected in some value. Whilst it is not, strictly speaking, a static characteristic of measuring instruments, it is mentioned here because the accuracy of some instruments is sometimes quoted as a tolerance figure. When used correctly, tolerance describes the maximum deviation of a manufactured component from some specified value. For instance, crankshafts are machined with a diameter tolerance quoted as so many microns, and electric circuit components such as resistors have tolerances of perhaps 5%. One resistor chosen at random from a batch having a nominal value 1000W and tolerance 5% might have an actual value anywhere between 950W and 1050 W.

1.4 Range or span

The *range* or *span* of an instrument defines the minimum and maximum values of a quantity that the instrument is designed to measure.

1.5 Linearity

It is normally desirable that the output reading of an instrument is linearly proportional to the quantity being measured. The Xs marked on Fig. 1.3 show a plot of the typical output readings of an instrument when a sequence of input quantities are applied to it. Normal procedure is to draw a good fit straight line through the Xs, as shown in Fig.1.3. The non-linearity is then defined as the maximum deviation of any of the output readings marked X from this straight line. Non-linearity is usually expressed as a percentage of full-scale reading.

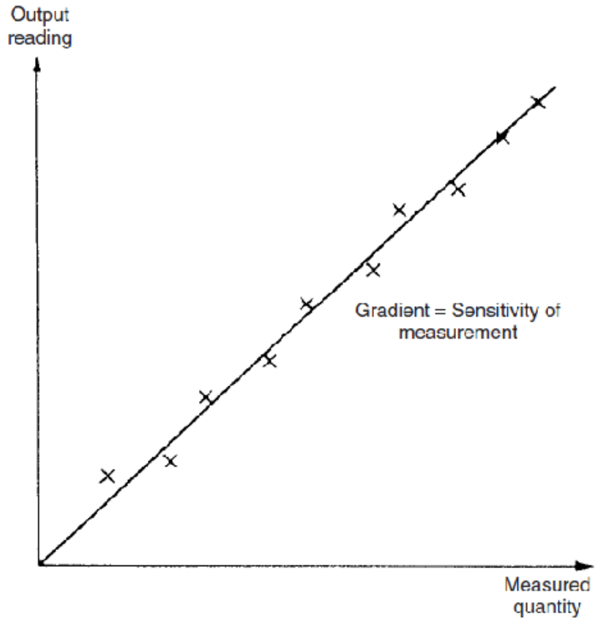

Fig. 1.3 Instrument output characteristic

1.6 Sensitivity of measurement

The sensitivity of measurement is a measure of the change in instrument output that occurs when the quantity being measured changes by a given amount. Thus, sensitivity is the ratio:

$$\frac{\text{scale deflection}}{\text{value of measurand producing deflection}}$$

The sensitivity of measurement is therefore the slope of the straight line drawn on Fig.1.3. If, for example, a pressure of 2 bar produces a deflection of 10 degrees in a pressure transducer, the sensitivity of the instrument is 5 degrees/bar (assuming that the deflection is zero with zero pressure applied).

Example1.1

The following resistance values of a platinum resistance thermometer were measured at a range of temperatures. Determine the measurement sensitivity of the instrument in ohms/^{o}C.

Resistance (Ω)	*Temperature* (°C)
307	200
314	230
321	260
328	290

Solution:-
If these values are plotted on a graph, the straight-line relationship between resistance change and temperature change is obvious.
For a change in temperature of 30 ^{o}C, the change in resistance is 7Ω. Hence the measurement sensitivity = 7/30 =0.233 Ω / ^{o}C.

1.7 Threshold

If the input to an instrument is gradually increased from zero, the input will have to each a certain minimum level before the change in the instrument output reading is of a large enough magnitude to be detectable. This minimum level of input is known as the *threshold* of the instrument. Manufacturers vary in the way that they specify threshold for instruments. Some quote absolute values, whereas others quote threshold is a percentage of full-scale readings. As an illustration, a car speedometer typically has a threshold of about 15 km/h. This means that, if the vehicle starts from rest and accelerates, no output reading is observed on the speedometer until the speed reaches 5 km/h.

1.8 Resolution

When an instrument is showing a particular output reading, there is a lower limit on the magnitude of the change in the input measured quantity that produces an observable change in the instrument output. Like threshold, *resolution* is sometimes specified as an absolute value and sometimes as a percentage of f.s. deflection. One of the major factors influencing the resolution of an instrument is how finely its output scale is divided into subdivisions. Using a car speedometer as an example again, this has subdivisions of typically 20 km/h. This means that when the needle is between the scale markings, we cannot estimate speed more accurately than to the nearest 5 km/h. This figure of 5 km/h thus represents the resolution of the instrument.

1.9 Sensitivity to disturbance

All calibrations and specifications of an instrument are only valid under controlled conditions of temperature, pressure etc. These standard ambient conditions are usually defined in the instrument specification. As variations occur in the ambient temperature etc., certain static instrument characteristics change, and the *sensitivity to disturbance* is a measure of the magnitude of this change. Such environmental changes affect instruments in two main ways, known as *zero drift* and *sensitivity drift*.
Zero drift is sometimes known by the alternative term, *bias*. *Zero drift* or *bias* describes the effect where the zero reading of an instrument is modified by a change in ambient conditions. This causes a constant error that exists over the full range of measurement of the instrument.

Zero drift is normally removable by calibration. In the case of the bathroom scale just described, a thumbwheel is usually provided that can be turned until the reading is zero with the scales unloaded, thus removing the bias. Zero drift is also commonly found in instruments like voltmeters that are affected by ambient temperature changes. Typical units by which such zero drift is measured are volts/ °C. This is often called the *zero drift coefficient* related to temperature changes.

If the characteristic of an instrument is sensitive to several environmental parameters, then it will have several zero drift coefficients, one for each environmental parameter. A typical change in the output characteristic of a pressure gauge subject to zero drift is shown in Fig. 1.4(a).

Sensitivity drift (also known as *scale factor drift*) defines the amount by which an instrument's sensitivity of measurement varies as ambient conditions change. It is quantified by sensitivity drift coefficients that define how much drift there is for a unit change in each environmental parameter that the instrument characteristics are sensitive to. Many components within an instrument are affected by environmental fluctuations, such as temperature changes: for instance, the modulus of elasticity of a spring is temperature dependent. Fig. 1.4 (b) shows what effect sensitivity drift can have on the output characteristic of an instrument. Sensitivity drift is measured in units of the form (angular degree/bar)/ ° C. If an instrument suffers both zero drift and sensitivity drift at the same time, then the typical modification of the output characteristic is shown in Fig. 1.4 (c).

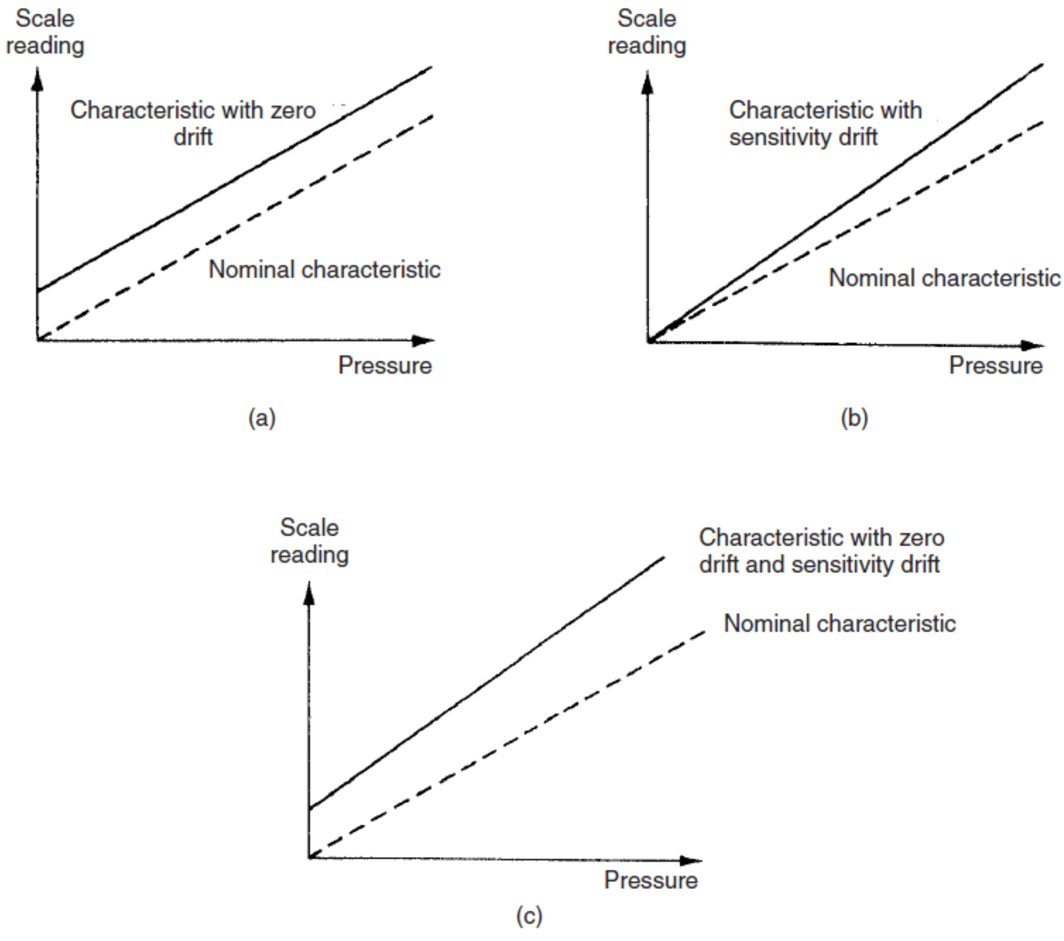

Fig. 1.4: Effect of disturbance (a) zero drift, (b)sensitivity drift, (c) zero drift plus sensitivity drift

Example 1.2

A spring balance is calibrated in an environment at a temperature of 20° C and has the following deflection/load characteristic.

Load (kg)	0	1	2	3
Deflection (mm)	0	20	40	60

It is then used in an environment at a temperature of 30° C and the following deflection/ load characteristic is measured.

Load (kg):	0	1	2	3
Deflection (mm)	5	27	49	71

Determine the zero drift and sensitivity drift per ° C change in ambient temperature.

Solution

At 20°C, deflection/load characteristic is a straight line. Sensitivity = 20 mm/kg.
At 30°C, deflection/load characteristic is still a straight line. Sensitivity = 22 mm/kg.
Bias (zero drift) = 5mm (the no-load deflection)
Sensitivity drift = 2 mm/kg
Zero drift/°C =5/10= 0.5 mm/°C
Sensitivity drift/°C = 2/10 = 0.2 (mm per kg)/°C

1.10 Hysteresis effects s

Fig.1.5 illustrates the output characteristic of an instrument that exhibits *hysteresis*. If the input measured quantity to the instrument is steadily increased from a negative value, the output reading varies in the manner shown in curve (a). If the input variable is then steadily decreased, the output varies in the manner shown in curve (b). The non-coincidence between these loading and unloading curves is known as *hysteresis*. Two quantities are defined, *maximum input hysteresis* and *maximum output hysteresis*, as shown in Fig.1.5. These are normally expressed as a percentage of the full-scale input or output reading respectively.

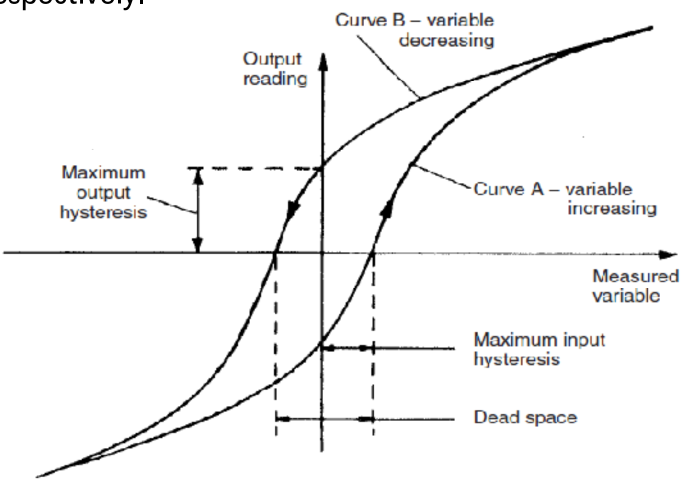

Fig.1.5 Instrument characteristic with hysteresis.

Hysteresis is most commonly found in instruments that contain springs, such as the passive pressure gauge and the Prony brake. It is also evident when friction forces in a system have different magnitudes depending on the direction of movement, such as in the pendulum-scale mass-measuring device. Hysteresis can also occur in instruments that contain electrical windings formed round an iron core, due to magnetic hysteresis in the iron. This occurs in devices like the variable inductance displacement transducer, the LVDT and the rotary differential transformer.

1.11 Dead space

Dead space is defined as the range of different input values over which there is no change in output value. Any instrument that exhibits hysteresis also displays dead space, as marked on Fig.1.5. Some instruments that do not suffer from any significant hysteresis can still exhibit a dead space in their output characteristics, however. Backlash in gears is a typical cause of dead space. Backlash is commonly experienced in gearsets used to convert between translational and rotational motion.

2. STATIC ERROR

The static error of a measuring instrument is the numerical difference between the true value of a quantity and its value as obtained by measurement, i.e. repeated measurement of the same quantity give different indications.

Static errors are categorized as gross errors or human errors, systematic errors and Random errors.

2.1.Gross Errors

This error is mainly due to human mistakes in reading or in using instruments or errors in recording observations. Errors may also occur due to incorrect adjustments of instruments and computational mistakes. These errors cannot be treated mathematically. The complete elimination of gross errors is not possible, but one can minimize them. Some errors are easily detected while others may be elusive. One of the basic gross errors that occur frequently is the improper use of an Instrument the error can be minimized by taking proper care in reading and recording the measurement parameter. In general, indicating instruments change ambient conditions to some extent when connected into a complete circuit.

2.2. Systematic Errors

These errors occur due to shortcomings of, the instrument, such as defective or worn parts, or ageing or effects of the environment on the instrument. These errors are sometimes referred to as bias, and they influence all measurements of a quantity alike. A constant uniform deviation of the operation of an instrument is known as a systematic error.

There are basically three types of systematic errors (i) Instrumental, (ii) Environmental, and (iii) Observational

(i) Instrumental Errors

Instrumental errors are inherent in measuring instruments, because of their mechanical structure. For example, in the D'Arsonval movement friction in the bearings of various moving components, irregular spring tensions, stretching of the spring or reduction in tension due to improper handling or over loading of the instrument. Instrumental errors can be avoided by

(a) Selecting a suitable instrument for the particular measurement applications.
(b) Applying correction factors after determining the amount of instrumental error.
(c) Calibrating the instrument against a standard.

(ii) Environmental Errors

Environmental errors are due to conditions external to the measuring device, including conditions in the area surrounding the instrument, such as the effects of change in temperature, humidity, barometric pressure or of magnetic or electrostatic fields.

These errors can also be avoided by (i) air conditioning, (ii) hermetically sealing certain components in the instruments, and (iii) using magnetic shields.

(iii) Observational Errors

Observational errors are errors introduced by the observer. The most common error is the parallax error introduced in reading a meter scale, and the error of estimation when obtaining a reading from a meter scale These errors are caused by the habits of individual observers. For example, an observer may always introduce an error by consistently holding his head too far to the left while reading a needle and scale reading. In general, systematic errors can also be subdivided into static and dynamic errors.

Static errors are caused by limitations of the measuring device or the physical laws governing its behavior. Dynamic errors are caused by the instrument not responding fast enough to follow the changes in a measured variable

2.3. ERROR IN MEASUREMENT

Measurement is the process of comparing an unknown quantity with an accepted standard quantity. It involves connecting a measuring instrument into the system under consideration and observing the resulting response on the instrument. The measurement thus obtained is a quantitative measure of the so-called "true value" (since it is very difficult to define the true value, the term "expected value" is used). Any measurement is affected by many variables; therefore the results rarely reflect the expected value. For example, connecting a measuring instrument into the circuit under consideration always disturbs (changes) the circuit, causing the measurement to differ from the expected value. Some factors that affect the measurements are related to the measuring instruments themselves.

Other factors are related to the person using the instrument. The degree to which a measurement nears the expected value is expressed in terms of the error of measurement. Error may be expressed either as absolute or as percentage of error.

Absolute error may be defined as the difference between the expected value of the variable and the measured value of the variable, or

$$e = Y_n - X_n$$

Where, e=absolute errors;
Y_n=expected value;
X_n=measured value;

Therefore %error = (absolute value/expected value)*100=(e/Yn)*100

Therefore %error= $\left(\frac{Y_n - X_n}{Y_n}\right) * 100$

It is more frequently expressed as an accuracy rather than error.

Therefore A=1-$mod\left(\frac{Y_n - X_n}{Y_n}\right)$

Where A is the relative accuracy

Accuracy is a=100%-%error

a=A*100% (where a=%accuracy)

2.4 Random (indeterminate) errors:

Those due to causes that cannot be directly established because of random variations in the parameter or the system of measurement. Hence, we have no control over them. Their random nature causes both high and low values to average out. Multiple trials help to minimize their effects. We deal with them using statistics.

3. Statistical analysis of errors

A statistical analysis of measurement data is common practice because it allows an analytical determination of the uncertainty of the final test result. The outcome of a certain measurement method may be predicted on the basis of sample data without having detailed information on all the disturbing factors. To make statistical methods and interpretations meaningful, a large number of measurements are usually required. Also, systematic errors should be small compared with residual or random errors, because statistical treatment of data cannot remove a fixed bias contained in all the measurements.

3.1 Arithmetic Mean

The most probable value of a measured variable is the arithmetic mean of the number of readings taken. The best approximation will be made when the number of readings of the same quantity is very large. Theoretically, an infinite number of readings would give the best result although in practice only a finite number of measurements can be made. The arithmetic mean is given by:

$$x = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n} = \frac{\sum x}{n}$$

where $\bar{x}$ = arithmetic mean, $x_1 \ldots x_n$ = readings taken, and n = number of readings.

Example 3:--

A set of independent current measurements was taken by six observers and recorded as 12.8 mA, 12.2 mA, 12.5 mA, 13.1 mA, 12.9 mA, and 12.4 mA. Calculate the arithmetic mean.

$$\bar{x} = \frac{12.8 + 12.2 + 12.5 + 13.1 + 12.9 + 12.4}{6} = 12.65mA$$

3.2 Deviation from the Mean

In addition to knowing the mean value of a series of measurements, it is often informative to have some idea of their range about the mean. Deviation is the departure of a given reading from the arithmetic mean of the group of readings. If the deviation of the first reading x_1 is called d_1, and thatof the second reading, x_2 is called d_2 and so on, then the deviations from the mean can be expressed as

$d_1 = x_1 - \bar{x}$; $d_2 = x_2 - \bar{x}$; ...; $d_n = x_n - \bar{x}$

Table 1. Deviations around mean

d_1 = 12.8 - 12.65 = 0.15 mA
d_2 = 12.2 - 12.65 = -0.45 mA
d_3 = 12.5 - 12.65 = -0.15 mA
d_4 = 13.1 - 12.65 = 0.45 mA
d_5 = 12.9 - 12.65 = 0.25 mA
d_6 = 12.4 - 12.65 = -0.25 mA

The deviation from the mean may have a positive or a negative value and that the algebraic sum of all the deviations must be zero. The computation of deviations for the previous example is given in Table 1.

3.3 Average Deviation

The average deviation is an indication of the precision at the instruments used in making the measurements. Highly precise instruments will yield a low average deviation between readings. By definition average deviation is the sum of the absolute values of the deviations divided by the number of readings. The absolute value of the deviation is the value without respect to sign. Average deviation may be expressed as

$$D = \frac{|d_1| + |d_2| + |d_3| + \cdots + |d_n|}{n} = \frac{\sum d}{n}$$

Example

The average deviation for the data given in the above example:

$$D = \frac{0.15 + 0.45 + 0.15 + 0.45 - 0.25 + 0.25}{6} = 0.283mA$$

3.4 Standard Deviation

The range is an important measurement. It indicates figures at the top and bottom around the average value. The findings farthest away from the average may be removed from the data set without affecting generality. However, it does not give much indication of the spread of observations about the mean. This is where the standard deviation comes in. In statistical analysis of random errors, the root-mean-square deviation or standard deviation is a very valuable aid. By definition, the standard deviation σ of a finite number of data is the square root of the sum of all the individual deviations squared, divided by the number of readings minus one. Expressed mathematically:

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \cdots + d_n^2}{n-1}} = \sqrt{\frac{\sum d_i^2}{n-1}}$$

Another expression for essentially the same quantity is the variance or mean square deviation, which is the same as the standard deviation except that the square root is not extracted. Therefore *variance (V) = mean square deviation =* σ^2

The variance is a convenient quantity to use in many computations because variances are additive. The standard deviation however, has the advantage of being of the same units as the variable making it easy to compare magnitudes. Most scientific results are now stated in terms of standard deviation.

3.5.Probability of Errors

3.5.1. *Normal Distribution of Errors*

A practical point to note is that, whether the calculation is done on the whole “population” of data oron a sample drawn from it, the population itself should at least approximately fall into a so called “normal (or Gaussian)” distribution. For example, 50 readings of voltage were taken at small time intervals and recorded to the nearest 0.1 V. The nominal value of the measured graphically in the form of a block diagram or histogram in which the number of observations is plotted against each observed voltage reading. The histogram and the table data are given in Fig1.6. The figure shows that the largest number of readings (19) occurs at the central value of 100.0 V while the other readings are placed more or less symmetrically on either side of the central value. If more readings were taken at smaller increments, say 200 readings at 0.05-V intervals, the distribution of observations would remain approximately symmetrical about the central value and the shape of the histogram would be about the same as before. With more and more data taken at smaller and smaller increments, the contour of the histogram would finally become a smooth curve as indicated by the dashed line in the figure. This bell shaped curve is known as a Gaussian curve. The sharper and narrower the curve, the more definitely an observer may state that the most probable value of the true reading is the central value or mean reading.
For unbiased experiments all observations include small disturbing effects, called random errors. Random errors undergo a Normal (Gaussian) law of distribution shown in Fig. 1.7 . They can be positive or negative and there is equal probability of positive and negative random errors. The error distribution curve indicates that:

- Small errors are more probable than large errors.
- Large errors are very improbable.
- There is an equal probability of plus and minus errors so that the probability of a given error will be symmetrical about the zero value.

Tabulation of Voltage Readings	
Voltage reading (volts)	# of reading
99.7	1
99.8	4
99.9	12
100.0	19
100.1	10
100.2	3
100.3	1

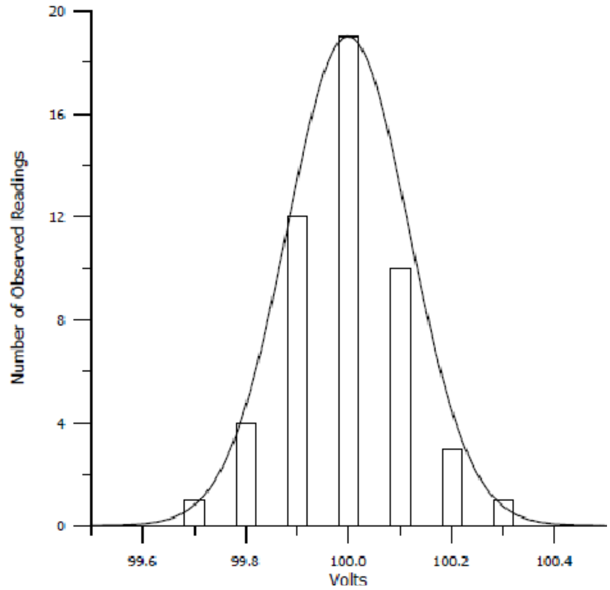

***Fig. 1.6** Distribution of 50 voltage readings*

$$\text{Probability of error} = \frac{1}{\sqrt{2\pi\sigma}}\exp\left(-\frac{x^2}{2\sigma}\right)$$

Area Under the Probability Curve	
Deviation $\pm\sigma$	Fraction of total area
0.6745	0.5000
1.0	0.6828
2.0	0.9546
3.0	0.9972

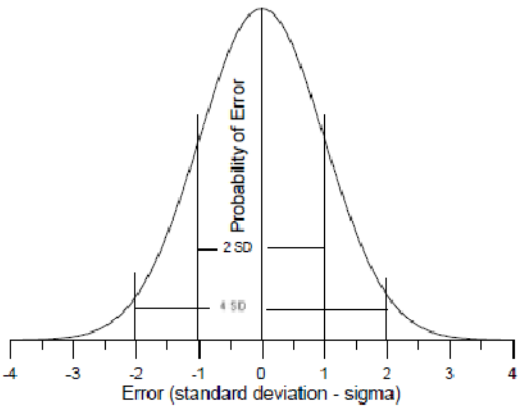

***Fig. 1.7** Error distribution curve for* Normal (Gaussian) law of distribution

The error distribution curve in Fig. 1.7 is based on the Normal (Gaussian) law and shows a symmetrical distribution of errors. This normal curve may be regarded as the limiting form of the histogram in which the most probable value of the true voltage is the mean value of 100.0V. Table 2 lists the readings, deviations and deviation squares of readings from the mean value.

Table 2 Deviations in readings

Reading, x	Deviation	
	d	d^2
101.	-0.1	0.01
101.7	0.4	0.16
101.3	0.0	0.00
101.0	-0.3	0.09
101.5	0.2	0.04
101.3	0.0	0.00
101.2	-0.1	0.01
101.4	0.1	0.01
101.3	0.0	0.00
101.1	-0.2	0.04
$\Sigma x=1013.0$	$\Sigma\|d\|=1.4$	$\Sigma d^2=0.36$

The reason why the standard deviation is such a useful measure of the scatter of the observations is illustrated in the figure. If the observations follow a "normal" distribution, a range covered by one standard deviation above the mean and one standard deviation below it (i.e. $x \pm 1$ SD) includes about 68% of the observations. A range of 2 standard deviations above and below ($x \pm 2$ SD) covers about 95% of the observations. A range of 3 standard deviations above and below ($x \pm 3$ SD) covers about 99.72% of the observations.

3.6 Range of a Variable

If we know the mean and standard deviation of a set of observations, we can obtain some usefull information by simple arithmetic. By putting 1, 2, or 3 standard deviations above and below the mean we can estimate the ranges that would be expected to include about 68%, 95% and 99.7% of observations. Ranges for ± SD and ± 2 SD are indicated by vertical lines. The table in the inset (next to the figure) indicates the fraction of the total area included within a given standard deviation range. Acceptable range of possible values is called the confidence interval. Suppose we measure the resistance of a resistor as (2.65 ± 0.04) kΩ. The value indicated by the color code is 2.7 kΩ. Do the two values agree? Rule of thumb: if the measurements are within 2 SD, they agree with each other. Hence, ± 2 SD around the mean value is called the range of the variable.

3.7 Probable Error

The table also shows that half of the cases are included in the deviation limits of $\pm 0.6745\sigma$. The quantity *r* is called the *probable error* and is defined as

$$\textit{probable error } r = \pm 0.6745\sigma$$

This value is *probable* in the sense that there is an even chance that any one observation will have a random error no greater than ±r. Probable error has been used in experimental work to some extent in the past, but standard deviation is more convenient in statistical work and is given preference.

Example

Ten measurements of the resistance of a resistor gave 101.2 Ω, 101.7 Ω, 101.3 Ω, 101.0 Ω, 101.5 Ω, 101.3 Ω, 101.2 Ω, 101.4 Ω, 101.3 Ω, and 101.1 Ω. Assume that only random errors are present. Calculate the arithmetic mean, the standard deviation of the readings, and the probable error.

SOLUTION: With a large number of readings a simple tabulation of data is very convenient and avoids confusion and mistakes.

$$\text{Arithmetic mean, } \bar{x} = \frac{\sum x}{n} = \frac{1013.0}{10} = 101.3\ \Omega$$

$$\text{Standard deviation, } \sigma = \sqrt{\frac{d^2}{n-1}} = \sqrt{\frac{0.36}{9}} = 0.2\ \Omega$$

Probable error = 0.6745 σ = 0.6745 x 0.2 = 0.1349 Ω

4. MEASUREMENT STANDARDS

4.1 Standard Classifications

Electrical measurement standards are precise resistors, capacitors, inductors, voltage sources, and current sources, which can be used for comparison purposes when measuring electrical quantities. For example, resistance can be accurately measured by means of a Wheatstone bridge which uses a standard resistor. Similarly, standard capacitors and inductors may be employed in bridge (or other) methods to accurately measure capacitance and inductance.

Measurement standards are classified in four levels:

- international standards,
- primary standards,
- secondary standards, and
- working standards.

International standards are defined by international agreements, and are maintained at the International Bureau of Weights and Measures in France. These are as accurate as it is scientifically possible to achieve. They may be used for comparison with primary standards, but are otherwise unavailable for any application.

Primary standards are maintained at institutions in various countries around the world, such as the National Bureau of Standards in Washington. They are also constructed for the greatest possible accuracy, and their main function is checking the accuracy of secondary standards.

Secondary standards are employed in industry as references for calibrating high-accuracy equipment and components, and for verifying the accuracy of working standards. Secondary standards are periodically checked at the institutions that maintain primary standards.

Working standards are the standard resistors, capacitors, and inductors usually found in a measurements laboratory. Working standard resistors are usually constructed of manganin or a similar material, which has a very low temperature coefficient. They are normally available in resistance values ranging from 0.01 to 1 M , with typical accuracies of ±0.01% to ±0.1%. A working standard capacitor could be air dielectric type, or it might be constructed of silvered mica. Available capacitance values are 0.001 F to 1 F with a typical accuracy of ±0.02%. Working standard inductors are available in values ranging from 100 H to 10 H with typical accuracies of ±0.1%. Calibrators provide standard voltages and currents for calibrating voltmeters and ammeters.

4.2 IEEE Standards

Standards published by the Institute of Electrical and Electronic Engineers (IEEE) are not the kind of measurement standards discussed above. Instead, for example, they are standards for electrical hardware, for the controls on instrument front panels, for test and measuring procedures, and for electrical installations in particular situations. Standard device and logic graphic symbols for use on schematics are also listed. For instrumentation systems, a very important IEEE standard is standard hardware for interfacing instruments to computers for monitoring and control purposes. Detailed information about IEEE standards is available on the internet.

Chapter2: Bridge Measurement

2.1 DC bridges

1. Whetstone's bridge

Whetstone's bridge is the most accurate method available for measuring resistances and is popular for laboratory use. The circuit diagram of a Wheatstone bridge is given in Fig2.1. The source of emf and switch is connected to points *A* and S, while a sensitive current indicating meter, the galvanometer, is connected to points C and D. The galvanometer is a sensitive micro ammeter a zero center scale. When there is no current through the meter, the galvanometer pointer rests at 0, i.e. mid scale. Current in one direction causes the points deflect on one side and current in the opposite direction to the other side. When SW_1 is closed, current flows and divides into the two arms at point A i.e. I_1 and I_2. The bridge is balanced when there is no current through the galvanometer, or when the potential difference at points *C* and *D* is equal, i.e. the potential across the galvanometer is zero. For the galvanometer current to be zero, the following conditions should be satisfied

$$\frac{E \times R_1}{R_1 + R_3} = \frac{E \times R_2}{R_2 + R_4}$$

$$R_1 \times (R_2 + R_4) = (R_1 - R_3) \times R_2$$

$$R_1\, R_2 - R\, R_4 = R_1\, R_2 + R_3\, R_2$$

$$R_4 = \frac{R_2\, R_3}{R_1}$$

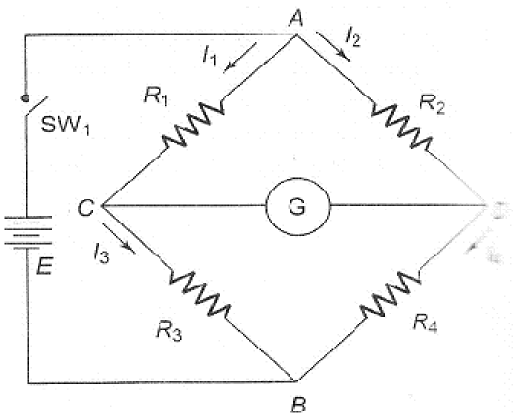

Fig. 2.1 Whetstone's bridge

This is the equation for the bridge to be balanced. In a practical Whetstone's bridge, at least one of the resistance is made adjustable, to permit balancing. When the bridge is balanced, the unknown resistance (normally connected at R4) may be determined from the setting of the adjustable resistor, which is called a standard resistor because it is a precision device having very small tolerance. Hence

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

2 Kelvin bridge

A **Kelvin bridge** (also called a **Kelvin double bridge** and some countries **Thomson bridge**) is a measuring instrument invented by William Thomson, 1st Baron Kelvin. It is used to measuring very low resistances (typically less than 1/10 of an ohm)

Its operation is similar to the Wheatstone bridge except for the presence of additional resistors. These additional low value resistors and the internal configuration of the bridge are arranged to substantially reduce measurement errors introduced by voltage drops in the high current (low resistance) arm of the bridge.

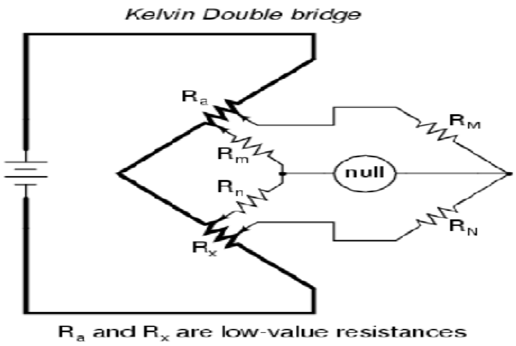

Fig 2.2 Kelvin bridge

When the null detector indicates zero voltage, we know that the bridge is balanced and that the ratios R_a/R_x and R_M/R_N are mathematically equal to each other. Knowing the values of R_a, R_M, and R_N therefore provides us with the necessary data to solve for R_x . . . almost.

We can manage the stray voltage drops between R_a and R_x by sizing the two new resistors so that their ratio from upper to lower is the same ratio as the two ratio arms on the other side of the null detector. This is why these resistors were labeled R_m and R_n in the original Kelvin Double bridge schematic: to signify their proportionality with R_M and R_N:

With ratio R_m/R_n set equal to ratio R_M/R_N, rheostat arm resistor R_a is adjusted until the null detector indicates balance, and then we can say that R_a/R_x is equal to R_M/R_N, or simply find R_x by the following equation:

$$R_x = R_a \frac{R_N}{R_M}$$

The actual balance equation of the Kelvin Double bridge is as follows (R_{wire} is the resistance of the thick, connecting wire between the low-resistance standard R_a and the test resistance R_x):

$$\frac{R_x}{R_a} = \frac{R_N}{R_M} + \frac{R_{wire}}{R_a}\left(\frac{R_m}{R_m + R_n + R_{wire}}\right)\left(\frac{R_N}{R_M} - \frac{R_n}{R_m}\right)$$

So long as the ratio between R_M and R_N is equal to the ratio between R_m and R_n, the balance equation is no more complex than that of a regular Wheatstone bridge, with R_x/R_a equal to R_N/R_M, because the last term in the equation will be zero, canceling the effects of all resistances except R_x, R_a, R_M, and R_N.

In many Kelvin Double bridge circuits, $R_M=R_m$ and $R_N=R_n$. However, the lower the resistances of R_m and R_n, the more sensitive the null detector will be, because there is less resistance in series with it. Increased detector sensitivity is good, because it allows smaller imbalances to be detected, and thus a finer degree of bridge balance to be attained. Therefore, some high-precision Kelvin Double bridges use R_m and R_n values as low as 1/100 of their ratio arm counterparts (R_M and R_N, respectively). Unfortunately, though, the lower the values of R_m and R_n, the more current they will carry, which will increase the effect of any junction resistances present where R_m and R_n connect to the ends of R_a and R_x. As you can see, high instrument accuracy demands that *all* error-producing factors be taken into account, and often the best that can be achieved is a compromise minimizing two or more different kinds of errors.

2.2. AC bridge

Impedances at AF or RF are commonly determined by means of an ac Wheatstone bridge. The diagram of an ac bridge is given in Fig2.3. This bridge is similar to a dc bridge, except that the bridge arms are impedances. The bridge is excited by an ac source rather than dc and the galvanometer is replaced by a detector, such as a pair of headphones, for detecting ac. When the bridge is balanced

$$\frac{Z_1}{Z_3} = \frac{Z_2}{Z_4}$$

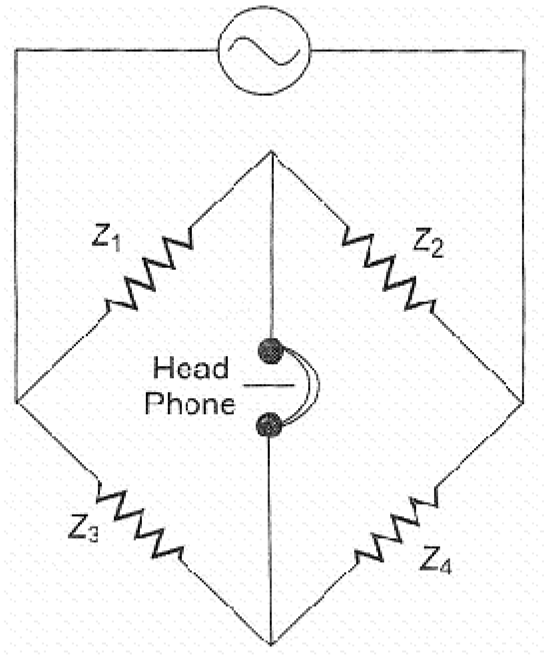

Fig. 2.3 AC Whetstone's bridge

Where Z1, Z2, Z3 and Z4 are the impedances of the arms, and are vector complex quantities that possess phase angles. It is thus necessary to adjust both the magnitude and phase angles of the impedance arms to achieve balance, i.e. the bridge must be balanced for both the reactance and the resistive component

1. Maxwell's bridge

Maxwell's bridge shown in Fig. 2.4, measures an unknown inductance in of standard arm offers the advantage of compactness and easy shielding. The capacitor is almost a loss-less component. One arm has a resistance R_x in parallel with C_u and hence it is easier to write the balance equation using the admittance of arm 1 instead of the impedance.
The general equation for bridge balance is

$$Z_x = \frac{Z_2 Z_3}{Z_1} = Z_2 Z_3 Y_1$$

$Z_1 = R_1$ in parallel with C_1 i.e. $Y_1 = \frac{1}{Z}$

$$Y_1 = \frac{1}{R_1} + j\omega C_1$$

$$Z_2 = R_2$$

$$Z_3 = R_3$$

$Z_x = R_x$ in series with $L_x = R_x + j\omega L_x$

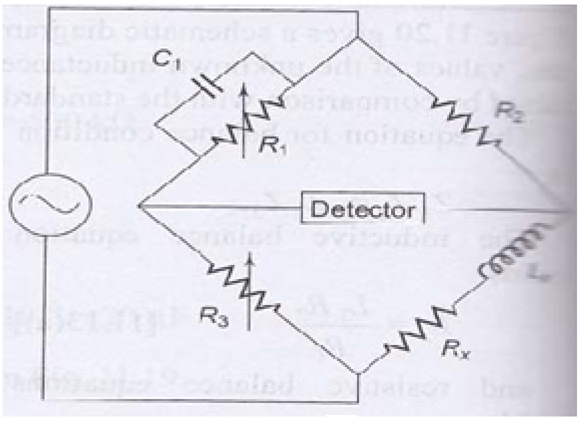

Fig. 2.4 Maxwell's bridge

From equation of Z_x we get

$$R_x + j\omega L_x = R_2 R_3 \left(\frac{1}{R_1} + j\omega C_1\right)$$

$$R_x + j\omega L_x = \frac{R_2 R_3}{R_1} + j\omega C_1 R_2 R_3$$

Equating real terms and imaginary terms we have

$$R_x = \frac{R_2 R_3}{R_1} \text{ and } L_x = C_1 R_2 R_3$$

Also

$$Q = \frac{\omega L_x}{R_x} = \frac{\omega C_1 R_2 R_3 \times R_1}{R_2 R_3} = \omega C_1 R_1$$

Maxwell's bridge is limited to the measurement of low Q values (1 -10).The measurement is independent of the excitation frequency. The scale of the resistance can be calibrated to read inductance directly.
The Maxwell bridge using a fixed capacitor has the disadvantage that there an interaction between the resistance and reactance balances. This can be avoids: by varying the capacitances, instead of R_2 and ft, to obtain a reactance balance. However, the bridge can be made to read directly in Q.
The bridge is particularly suited for inductances measurements, since comparison on with a capacitor is more ideal than with another inductance. Commercial bridges measure from 1 – 1000H. With ± 2% error. (If the Q is very becomes excessively large and it is impractical to obtain a satisfactory variable standard resistance in the range of values required).

2. Wien’s Bridge

Wien Bridge shown in Fig. 2.5 has a series *RC* combination in one and a parallel combination in the adjoining arm. Wien's bridge in its basic form is designed to measure f r e qu ency. It can also be used for the instrument of an unknown capacitor with great accuracy.

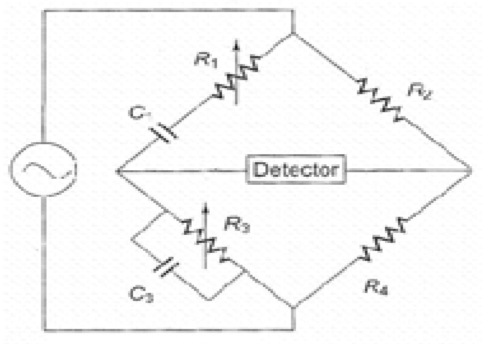

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Fig. 2.5 Wien Bridge

The *impedance* of one arm is

$$Z_1 = R_1 - j/\omega C_1$$

The admittance of the parallelarm is

$$Y_3 = 1/R_3 + j\,\omega\,C_3$$

Using the bridge balance equation,we have

$$Z_1\,Z_4 = Z_2\,Z_3$$

Therefore

$$Z_1\,Z_4 = Z_2/Y_3,\ \text{i.e. } Z_2 = Z_1\,Z_4\,Y_3$$

$$R_2 = R_4\left(R_1 - \frac{j}{\omega C_1}\right)\left(\frac{1}{R_3} + j\omega C_3\right)$$

$$R_2 = \frac{R_1 R_4}{R_3} - \frac{j R_4}{\omega C_1 R_3} + j\,\omega\,C_3\,R_1\,R_4 + \frac{C_3 R_4}{C_1}$$

$$R_2 = \left(\frac{R_1 R_4}{R_3} + \frac{C_3 R_4}{C_1}\right) - j\left(\frac{R_4}{\omega C_1 R_3} - \omega C_3 R_1 R_4\right)$$

Equating the real and imaginary terms we have

$$R_2 = \frac{R_1 R_4}{R_3} + \frac{C_3 R_4}{C_1} \quad \text{and} \quad \frac{R_4}{\omega C_1 R_3} - \omega\,C_3\,R_1\,R_4 = 0$$

Therefore

$$\frac{R_2}{R_4} = \frac{R_1}{R_3} + \frac{C_3}{C_1}$$

............(i)

And

$$\frac{1}{\omega C_1 R_3} = \omega\,C_3\,R_1$$

............(ii)

$$\omega^2 = \frac{1}{C_1 R_1 R_3 C_3}$$

$$\omega = \frac{1}{\sqrt{C_1 R_1 C_3 R_3}}$$

$$\omega = 2\pi f$$

$$f = \frac{1}{2\pi \sqrt{C_1 R_1 C_3 R_3}} \quad \text{...........(iii)}$$

The two conditions (i)&(ii), for bridge balance result in an expression determining the required resistance ratio R_2/R_4 and another express determining the frequency of the applied voltage. If we satisfyEq. (i) an also excite the bridge with the frequency of Eq. (iii), the bridge will be balanced.

In most Wien bridge circuits, the components are chosen such that $R_1 = R_3 = R$ and $C_1 = C_3 = C$. Equation (i) therefore reduces to $R_2/R_4 = 2$ *at* Eq. (iii) to $f = 1/2\pi RC$, which is the general equation for the frequency of bridge circuit.

The bridge is used for measuring frequency in the audio range. Resistances R_1 and R_3 can be ganged together to have identical values. Capacitors C_1 and C_3 are normally of fixed values The audio range is normally divided into 20 - 200 - 2 k - 20 kHz range In this case, the resistances can be used for range changing and capacitors, and C_3 for fine frequency control within the range. The bridge can also be use for measuring capacitances. In that case, the frequency of operation must be known.

The bridge is also used in a harmonic distortion analyzer, as a Notch filter, an in audio frequency and radio frequency oscillators as a frequency determine element.

An accuracy of 0.5% - 1% can be readily obtained using this bridge. Because it is frequency sensitive, it is difficult to balance unless the waveform of the applied voltage is purely sinusoidal.

3. The Hay Bridge

The Hay Bridge, shown in Fig 2.6 differs from Maxwell's bridge by having a resistance R_1 in series with a standard capacitor C_1 instead of a parallel. For large phase angles, R_1 needs to be low; therefore, this bridge is more convenient for measuring high Q coils. For Q=10, the error is ± 1 %, and for Q = 30, the is ± 0.1%. Hence Hay's bridge is preferred for coils with a high Q, and Ma bridge for coils with a low Q.

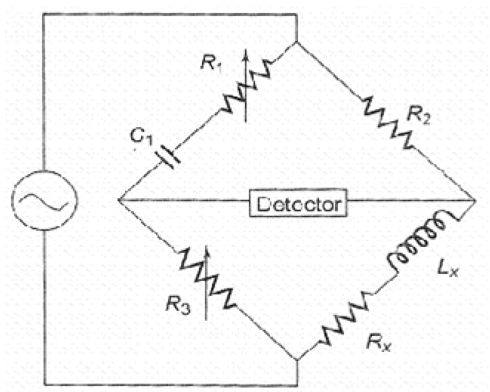

Fig 2.6 The Hay Bridge

At balance,

$$Z_1 Z_x = Z_2 Z_3,$$

Where

$$Z_1 = R_1 - j/\omega C_1$$

$$Z_2 = R_2$$

$$Z_3 = R_3$$

$$Z_x = R_x + j\omega L_x$$

Substituting the values at balance

$$\left(R_1 - \frac{j}{\omega c_1}\right)(R_x + j\omega L_x) = R_2 R_3$$

$$R_1 R_x + \frac{L_x}{C_1} - \frac{j R_x}{\omega C_1} + j\omega L_x R_1 = R_2 R_3$$

Equating the real and imaginary terms

$$R_1 R_x + \frac{L_x}{C_1} = R_2 R_3$$

$$\frac{R_x}{\omega C_1} = \omega L_x R_1$$

Solving for *Lx* and *Rx* we have ,

$$R_x = \omega^2 L_x C_1 R_1$$

Substituting for *Rx* in equation

$$R_1 (\omega^2 R_1 C_1 L_x) + \frac{L_x}{C_1} = R_2 R_3$$

$$\omega^2 R_1^2 C_1 L_x + \frac{L_x}{C_1} = R_2 R_3$$

Multiply both sides by C1 we get

$$\omega^2 R_1^2 C_1^2 L_x + L_x = R_2 R_3 C_1$$

Therefore,

$$L_x = \frac{R_2 R_3 C_1}{1 + \omega^2 R_1^2 C_1^2}$$

Substituting for *Lx* in it's eq. we get

$$R_x = \frac{\omega^2 C_1^2 R_1 R_2 R_3}{1 + \omega^2 R_1^2 C_1^2}$$

The term ω appears in the expression for both LX and RX. This indicates that the bridge is frequency sensitive. Hay Bridge is also used in the measurement of incremental inductance. The inductance balance equation depends on the losses of the inductor (or Q) and also on the operating frequency. An inconvenient feature of this bridge is that the equation giving the balance condition for inductance, contains the multiplier 1/ (1 + 1/Q2). The inductance balance thus depends on its Q and frequency. Therefore

$$I_1 = I_3 = \frac{E}{R_1 + R_3}$$

$$I_2 = I_4 = \frac{E}{R_2 + R_4}$$

$$L_x = \frac{R_2 R_3 C_1}{1 + (1/Q)^2}$$

For a value of Q greater than 10, the term L/Q2 will be smaller than 1/100 and can be therefore neglected. Therefore LX = R2 R3 C1 which is the same as Maxwell's equation. But for inductors with a Q less than 10, the 1/Q2 term cannot be neglected. Hence this bridge is not suited for measurements of coils having Q less than 10. A commercial bridge measure from 1µH - 100 H with ± 2% error.

4. Schering bridge

The Schering bridge is used extensively for the measurement of capacitance, particularly for insulators with a phase angle of nearly 90°. In the standard arm of the bridge, a high-quality mica capacitor for general measurements and an air capacitor for insulator measurements are used. The circuit is shown in Fig. .

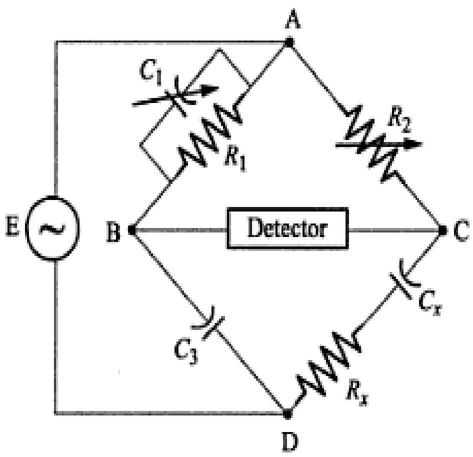

Figure Schering bridge for the measurement of capacitance

At balance,

$$Z_x = \frac{Z_2 Z_3}{Z_1}$$

$$R_x + \frac{1}{j\omega C_x} = \frac{1}{j\omega C_3}\frac{\left(\frac{-R_2}{R_1}\right)}{1 + j\omega C_1 R_1}$$

$$R_x - \frac{-j}{\omega C_x} = \frac{-j}{j\omega C_3}\left\{\frac{R_2}{R_1}(1 + j\omega C_1 R_1)\right\}$$

$$R_x - \frac{-j}{\omega C_x} = \frac{R_2}{R_3}\frac{1}{\omega C_3} + \frac{C_1 R_2}{C_3}$$

$$R_x = R_2 \frac{C_1}{C_3}$$

$$\boxed{C_x = C_3 \frac{R_1}{R_2}}$$

R_x is the series resistance associated with the capacitor C_x.

Dissipation factor, Δ;

$$\boxed{D = \frac{R_x}{X_c}\omega C_x R_x}$$

Power factor, PF;

$$\boxed{PF = \frac{R_x}{Z_x}}$$

The dissipation factor gives the indication of how close the phase angle is to 90°.

Phasor Diagram for a Schering Bridge

1. In arm AB, R_1 and C_1 are in parallel. Therefore, as per convention, voltage V_{AB} is taken as reference. V_{AB} and I_{R_1} are to be in phase. I_{C_1} leads V_{AB} by 90°
2. At balance, $I_{AB} = I_{BD}$; V_{BD} lags with respect to I_{BD} (or $= I_{AB}$) by 90°.
3. At balance, $V_{AB} = V_{AC}$; I_{AC} will be in phase with V_{AC}
4. At balance, $I_{AC} = I_{CD}$; I_{AC} and V_{R_X} will be in phase. V_{C_X} lags I_{C_X} by 90°.
5. Total voltage 'V' is the vector sum of V_{AB} and V_{BD}.
6. Total current I is the vector sum of I_{AB} and I_{AC}.

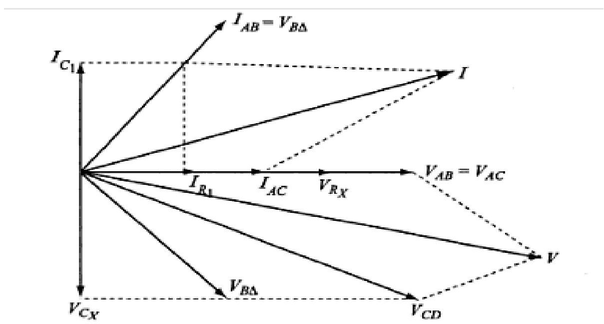

Figure Phasor diagram for a Schering bridge

Wagner ground connection

One of the most widely used method for eliminating some of the effects of stray capacitance in bridge circuit is Wagner ground connection. It removes the capacitance between detector terminal and ground.

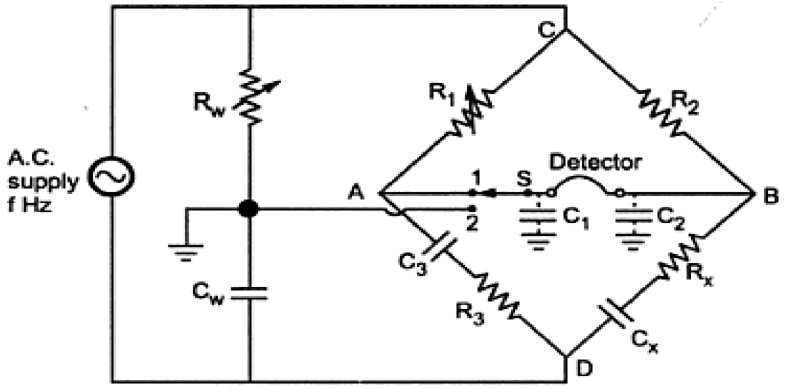

Fig. **Wagner ground connection**

The circuit is a capacitance bridge where C_1 and C_2 represent the stray capacitances. The Wagner's connection is the use of separate arm consisting of the resistance R_w and the capacitance C_w across the terminals C and D, forming a potential divider. This arm is also called **guarding arm**. The procedure for the adjustment is as follows :

The switch S is connected in series with the detector. The switch is connected to position 1 and R_1 is then adjusted to get null response i.e. minimum sound in headphones.

The switch is then thrown to position 2, which connects the detector to the Wagner ground point. The resistance R_w of the Wagner connection is now adjusted to get the minimum sound.

The switch is again thrown back to position 1. There is some imbalance present now. The resistances R_1 and R_3 are then adjusted to get minimum sound.

This procedure is repeated till a null is obtained on both the switch positions 1 and 2. This null obtained at both the positions indicates that the points 1 and 2 are at the same potential. But the point 2 is at the ground potential due to Wagner ground connection. Hence points 1 and 2 are at the ground potential. Thus the stray capacitances C_1 and C_2 are effectively short circuited. Thus they have no effect on the normal bridge balancing.

There are capacitances existing from points C and D to ground but the addition of the Wagner ground connection eliminates them as current through these capacitances will enter through Wagner ground connection.

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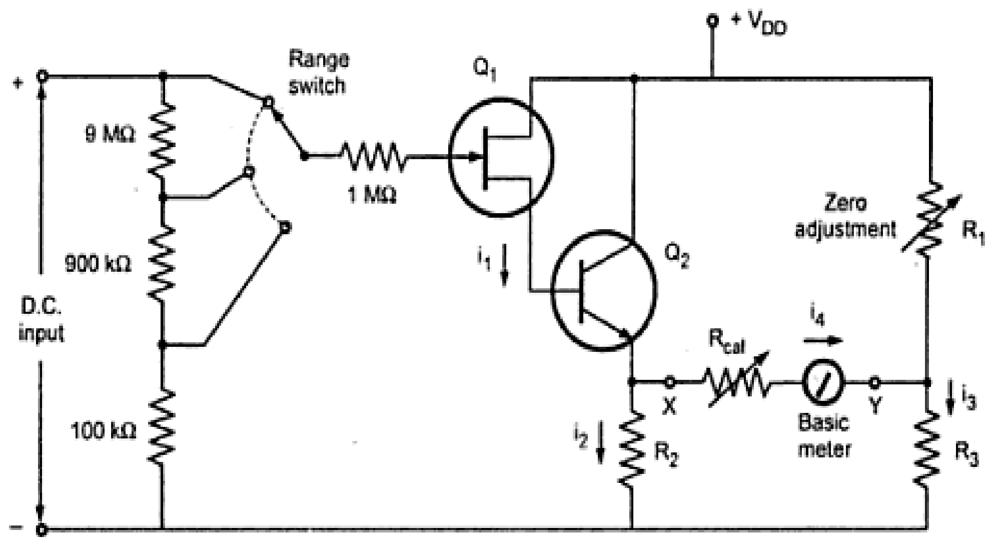
2. **Electronic Measurements and Instrumentation** by A.V.Bakshi U.A.Bakshi - 2008

Chapter 3: Electronic Instruments for Measuring Basic Parameters

1. Amplified DC meter

To measure the low voltage signals, an amplifier is used in the electronic voltmeters. A d.c. amplifier with one or more stages is used in d.c. electronic voltmeter before the basic PMMC meter. The high input impedance can be achieved using FET at the input. Such a d.c. electronic voltmeter with d.c. coupled amplifier and FET at the input side is shown in the Fig.



The bipolar junction transistor Q_2 alongwith the resistors forms a balanced bridge circuit. The FET Q_1 acts as a source follower, which provides high input impedance. Due to this, the meter circuit can be effectively isolated from the circuit under measurement.

Key Point: *The input impedance of FET is greater than 10 MΩ.*

The bridge balance is obtained by zero adjustment resistor such that for zero input, the pointer shows zero. The bias on Q_2 is such that $i_2 = i_3$ when the input is zero. Under such condition, potential of point X i.e. V_x and potential of point Y i.e. V_y is same. No current flows through the meter i.e. $i_4 = 0$ for zero input.

When the input voltage is applied, the bias on Q_2 increases. This causes V_x to increase hence proportional current i_4 flows through the meter. Thus the deflection of the meter is proportional to the input voltage, within the dynamic range of the amplifier.

The value of the input which causes maximum meter deflection is the basic range of the meter. This is generally the lowest range on the range switch in nonamplified models. High ranges can be obtained by using an input attenuator. The input attenuator is a calibrated front panel control in the form of resistance voltage divider. The full scale voltage appears across the divider hence the voltage at each tap is a increasing lower fraction of the full input voltage.

Advantages

1) High input impedance to isolate meter from the measurement circuit.
2) The amount of power drawn is very low from circuit under measurement so no loading effect.
3) The sensitivity is very high as much as 100 times the normal PMMC voltmeter.
4) The gain of the d.c. amplifier allows the voltmeter to be used for the measurement of voltages in the mV range.
5) The overload cannot damage the meter because amplifier saturates and limits the current through the meter.

Chopper stabilized circuit

If the voltages in the range of μV are desired to be measured then the d.c. amplifier requires very high gain of the order of 10^5 to 10^6. This is possible by using op-amp which can give such a high gain. But alongwith the high gain, it gives problems due to temperatue drifts of offset currents, offset voltages and the bias currents. Any fluctuations in supply voltage or variation in the `Q' characteristics (quiescent point) due to rise in temperature causes change in the zero setting i.e. bridge balance gets adversely affected. This drift in steady state condition of d.c. amplifier causes the change in deflection and thus gives an impression as if input is changed. The drift problem limits the minimum voltage that can be measured. To avoid these drift problems, the chopper type d.c. amplifier voltmeter is used.

The Fig. shows the basic block diagram of the chopper type voltmeter, which explains its principle of operation.

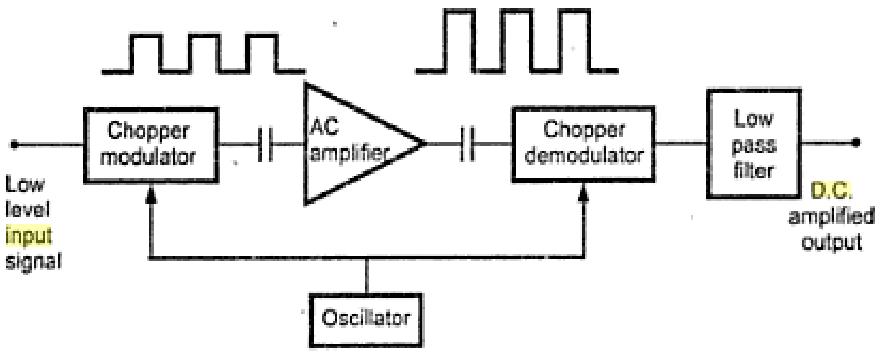


Fig. Chopper type voltmeter

The basic principle of such voltmeter is that the d.c. input is first converted into an a.c. voltage. This is then amplified by an a.c. amplifier. And finally it is converted back into a d.c. voltage proportional to the original input voltage.

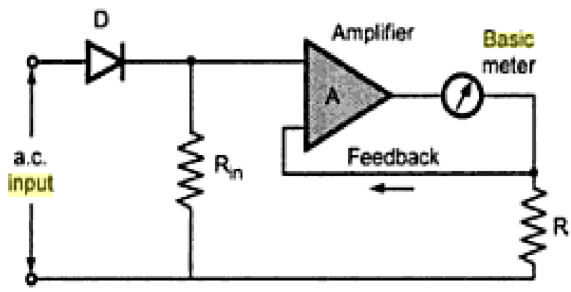
AC voltmeter using rectifier

A.C. voltmeters can be designed in two ways :

i) First rectifying the a.c. signal and then amplifying.

ii) First amplifying the a.c. signal and then rectifying.

First Rectifying and then Amplifying A.C. Signal



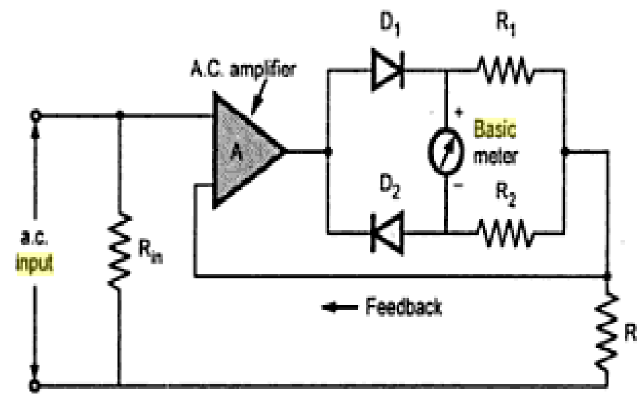
A.C. voltmeter with first rectification

In this arrangement simple diode rectifier circuit precedes the amplifier and the meter. This is shown in the Fig.

The a.c. input voltage if first rectified using the diode D. This rectified signal is then applied to the amplifier of gain A. The amplified signal is then given to the basic PMMC meter to obtain the deflection.

This approach ideally requires a d.c. amplifier with zero drift characteristics and a d.c. meter movement with high sensitivity. The resistance R_{in} indicates input resistance of the meter.

First Amplifying and then Rectifying A.C. Signal



A.C. voltmeter with first amplification

In this approach, the a.c. input signal which is a small signal is amplified first and then rectified after the sufficient amplification. The a.c. signal is applied to an amplifier and hence amplifier is necessarily an a.c. amplifier. This type of approach is shown in the Fig.

The a.c. amplifier requires a high open loop gain and the large amount of negative feedback to overcome the nonlinearity of the rectifier diodes.

The amplifier output is then applied to full wave rectifier consisting of diodes D_1 and D_2.

Basic Rectifier Type A.C. Voltmeter

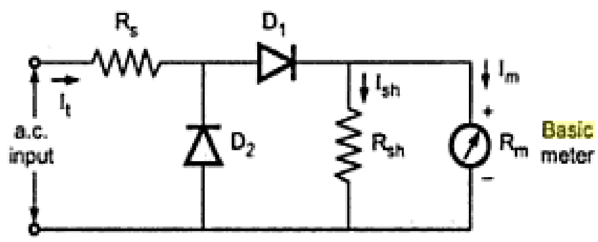


Fig. Basic rectifier type a.c. voltmeter

A general rectifier type a.c. voltmeter is shown in the Fig.

The diodes D_1 and D_2 are used for the rectifier circuit. The diodes show the nonlinear behaviour for the low currents hence to increase the current through diode D_1, the meter is shunted with a resistance R_{sh}. This ensures high current through diode and its linear behaviour.

When the a.c. input is applied, for the positive half cycle, the diode D_1 conducts and causes the meter deflection proportional to the average value of that half cycle.

In the negative cycle, the diode D_2 conducts and D_1 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 the meter indicates the average value of the input.

A.C. Voltmeter using Half Wave Rectifier

The a.c. voltmeter using half wave rectifier is achieved by introducing a diode in a basic d.c. voltmeter. This is shown in the Fig. 1.10.

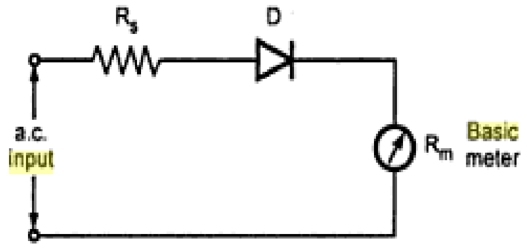


Fig. A.C. voltmeter using half wave rectifier.

The diode D conducts only during positive half cycle. Let us compare the sensitivities of d.c. and a.c. voltmeters.

The sensitivity of d.c. voltmeter is,

$$\boxed{S_{d.c.} = \frac{1}{I_{fsd}}}$$

Let I_{fsd} be 1 mA, hence the sensitivity becomes 1 kΩ/volt. The series resistance R_s is 10 kΩ hence the 10 V d.c. input would cause exactly the full scale deflection, when connected with proper polarity.

Let purely sinusoidal input of 10 V r.m.s. is applied.

$$\therefore \quad E_{r.m.s.} = 10 \text{ V}$$

$$\therefore \quad E_p = \text{Peak value} = \sqrt{2}\, E_{r.m.s.}$$

$$= 14.14 \text{ V}$$

Now the rectified d.c. is pulsating d.c. hence meter will deflect proportional to the average value.

$$\therefore \quad E_{av} = 0.636\, E_p = 8.99 \text{ V}$$

But the diode conducts only for half cycle and meter movement is bypassed for another cycle. Hence it responds to half the average value of the a.c. input.

$$\therefore \qquad E_{av} = \frac{8.99}{2} \approx 4.5 \text{ V}$$

Thus pointer will deflect for full scale if 10 V d.c. is applied and 4.5 V when 10 V r.m.s. sinusoidal input is applied.

Key Point: *Thus the a.c. voltmeter is less sensitive than d.c. voltmeter.*

$$\therefore \qquad \boxed{E_{dc} = 0.45 \; E_{r.m.s.}}$$

Thus the value of series multiplier can be obtained for a.c. voltmeters as,

$$R_s = \frac{E_{dc}}{I_{dc}} - R_m$$

$$\therefore \qquad \boxed{R_s = \frac{0.45 E_{r.m.s.}}{I_{dc}} - R_m}$$

Where I_{dc} is the full scale deflection current.

A.C. Voltmeter using Full Wave Rectifier

The a.c. voltmeter using full wave rectifier is achieved by using bridge rectifier consisting of four diodes, as shown in the Fig.

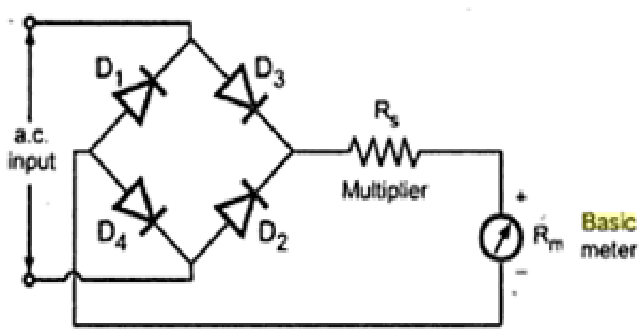


Fig. A.C. voltmeter using full wave rectifier

Let 10 V r.m.s. purely sinusoidal input be applied.

$$\therefore \quad E_{r.m.s.} = 10 \text{ V}$$

$$\therefore \quad E_p = 14.14 \text{ V}$$

Thus
$$E_{av} = 0.636\, E_p = 8.99 \text{ V} \approx 9 \text{ V}$$

Now this meter uses full wave rectifier and hence the average value of output over a cycle is same as average of the input over a cycle i.e. 9 V.

Thus, the 10 V r.m.s. voltage is equal to 9 V d.c. for full scale deflection. Thus the pointer will deflect to 90 % of full scale.

$$\boxed{\text{Sensitivity (a.c.)} = 0.9 \times \text{Sensitivity (d.c.) for full wave}}$$

The multiplier resistance can be obatined as,

$$\boxed{R_s = \frac{E_{dc}}{I_{dc}} - R_m = \frac{0.9\, E_{r.m.s.}}{I_{dc}} - R_m}$$

True r.m.s responding voltmeter

The r.m.s. value means root-mean-square value . As mentioned earlier it is obtained by squaring the input signal and then calculating square root of its average value. The r.m.s. value is also called **effective value**. It compares the heating effect produced by a.c. and d.c.

The true r.m.s. responding voltmeter produces a meter deflection by sensing the heating power of the waveform. This heating power is proportional to the square of the input r.m.s. value. The measurement of heating power is achieved by the use of thermocouple. The input voltage to be measured is applied to the heater. The heating effect of the heater is sensed by a thermocouple attached to the heater. The thermocouple generates the corresponding voltage. The a.c. input is amplified and then given to the heater element to achieve enough heating so that thermocouple can generate enough level of voltage to cause meter deflection.

Key Point: *The output voltage is proportional to the r.m.s. value of the a.c. input.*

For a thermocouple,
$$\text{Power} = \frac{E^2_{r.m.s.}}{R_{heater}}$$

$$\therefore \quad E_0 \propto \text{heat} \propto \text{power}$$

$$\boxed{E_o = \frac{KE^2_{r.m.s.}}{R_{heater}}}$$

Where E_{rms} = r.m.s. value of the a.c. input

E_o = Output voltage of thermocouple

K = Constant of proportionality

The value of K depends on the distance between the heater and the thermocouple and also on the materials used in the heater and the thermocouple.

The main difficulty in such a meter is the nonlinear characteristics of a thermocouple. In some instruments this difficulty is ovecome by placing two thermocouples in the same thermal environment. The effect of the nonlinear behaviour of the input thermocouple is cancelled by similar nonlinear effect caused by thermocouple in the feedback path. The input thermocouple is called measuring thermocouple while the thermocouple in the feedback path is called **balancing thermocouple**. The true r.m.s responding voltmeter using two thermocouples is shown in the Fig.

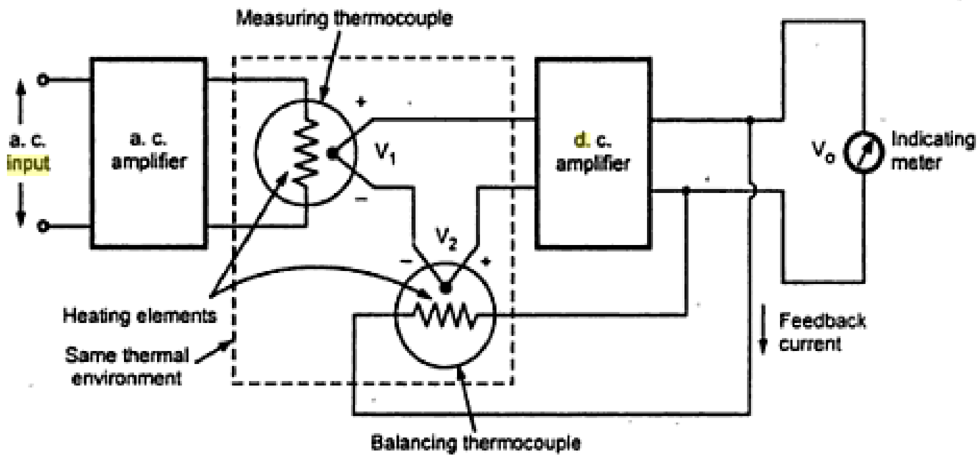


Fig. True r.m.s. responding voltmeter

The two thermocouples balancing and measuring, forms a balanced bridge in the input circuit of the d.c. amplifier.

When the a.c. input is applied, the measuring thermocouple produces the voltage V_1 which upsets the balance of the bridge. The d.c. amplifier amplifies the unbalanced voltage. This amplified voltage is feedback to the balancing thermocouple, which heats the heater element to produce V_2 such that the balance of the bridge is re-established.

Thus the d.c. feedback current is the current which is producing same heating effect as that of a.c. input current i.e. the d.c. current is nothing but the r.m.s. value of the input current. The meter deflection is thus proportional to r.m.s or effective value of the a.c. input.

Advantages

1) The nonlinear behaviour is avoided by using two thermocouples placed in same thermal environment.

2) The true r.m.s. value measured is independent of the waveform of the a.c. input, if the peak amplitude of a.c. input is within the dynamic range of the a.c. amplifier.

3) Sensitivities in the millivolt region are possible. The voltages throughout a range of 100 μV to 300 V within a frequency range of 10 Hz to 10 MHz can be measured, with good instruments.

However the response of thermocouples is slow hence the overall response of the meter is sluggish. Similarly the crest factor puts the limitation on the meter reading in case of highly nonlinear waveforms. The meter cost is high compared to average and peak responding meters.

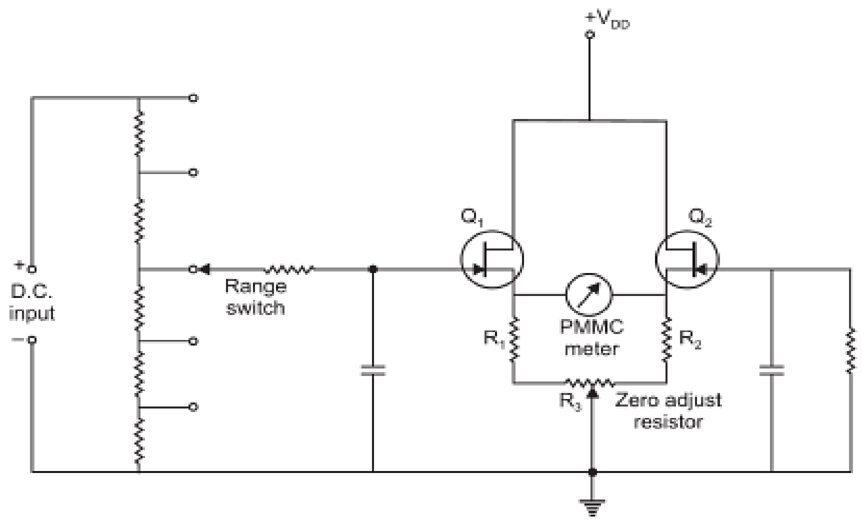
A typical laboratory type r.m.s. responding voltmeter provides the accurate r.m.s. reading of complex waveforms having a crest factor (ratio of maximum to r.m.s. value) of 10/1.

Electronic multimeter

The solid-state electronic multimeter or VOM (Voltage-Ohm Meter) is one of the most versatile general-purpose shop instruments *capable of measuring D.C. and A.C. voltages as well as current and resistance.*

An electronic multimeter generally consists of the following *elements* :

1. Balanced-bridge D.C. amplifier and indicating meter.
2. Input attenuator or Range switch...*To limit the magnitude of the input voltage to the desired value.*
3. Rectifier section... *To convert an A.C. input voltage to a proportional D.C. value.*



Q_1, Q_2 = FETs ; R_1, R_2 = Source resistors, R_3 = Zero adjust resistor.

Fig. Balanced-bridge D.C. amplifier with input attenuator and indicating meter.

4. Internal battery and additional circuitry... *To provide the capability of resistance measurement.*
5. "Function switch" ... *To select the various measurement functions of the instrument such as voltage, current or resistance.*

The instrument is also usually provided with a built-in power supply for operation on A.C. mains and, in most cases, one or more batteries for operation as *portable test instrument*.

Fig. shows the schematic diagram of a balanced-bridge D.C. amplifier using field effect-transistors (FETs). (This circuit also applies to a bridge amplifier with ordinary bipolar transistors (BJTs) :

— Q_1 and Q_2 are the two *FETs*; these should be reasonably well matched for current gain to ensure thermal stability of the circuit.

— The two *FETs*, Q_1 and Q_2 constitute the *upper* arms of a bridge circuit, whereas, source resistors R_1 and R_2, together with "*Zero*" adjust resistor R_3 form the *lower* bridge arms.

— The PMMC meter is connected between the source terminals of the FETs, representing two opposite corners of the bridge.

DIGITAL VOLTMETER

It is a device used for measuring the magnitude of DC voltages. AC voltages can be measured after rectification and conversion to DC forms. DC/AC currents can be measured by passing them through a known resistance (internally or externally connected) and determining the voltage developed across the resistance (*V=IxR*).
The result of the measurement is displayed on a digital readout in numeric form as in the case of the counters. Most DVMs use the principle of time period measurement. Hence, the voltage is converted into a time interval "*t*" first. No frequency division is involved. Input range selection automatically changes the position of the decimal point on the display. The unit of measure is also highlighted in most devices to simplify the reading and annotation.
The DVM has several advantages over the analog type voltmeters as:

- **Input range: from ±1.000 000 V to ±1,000.000 V with automatic range selection.**
- **Absolute accuracy: as high as ±0.005% of the reading.**
- **Stability**
- **Resolution: 1 part in 10^6 (1 µV can be read in 1 V range).**
- **Input impedance: R_i=10 MΩ; input capacitance C_i =40 pF.**
- **Calibration: internal standard derived from a stabilized reference voltage source.**
- **Output signals: measured voltage is available as a BCD (binary coded decimal) code and can be send to computers or printers.**

Ramp Type DVM

It uses a linear ramp technique or staircase ramp technique. The staircase ramp technique is simpler than the linear ramp technique. Let us discuss both the techniques.

Linear Ramp Technique

The basic principle of such measurement is based on the measurement of the time taken by a linear ramp to rise from 0 V to the level of the input voltage or to decrease from the level of the input voltage to zero. This time is measured with the help of electronic time interval counter and the count is displayed in the numeric form with the help of a digital display.

Basically it consists of a linear ramp which is positive going or negative going. The range of the ramp is ± 12 V while the base range is ± 10 V. The conversion from a voltage to a time interval is shown in the Fig.

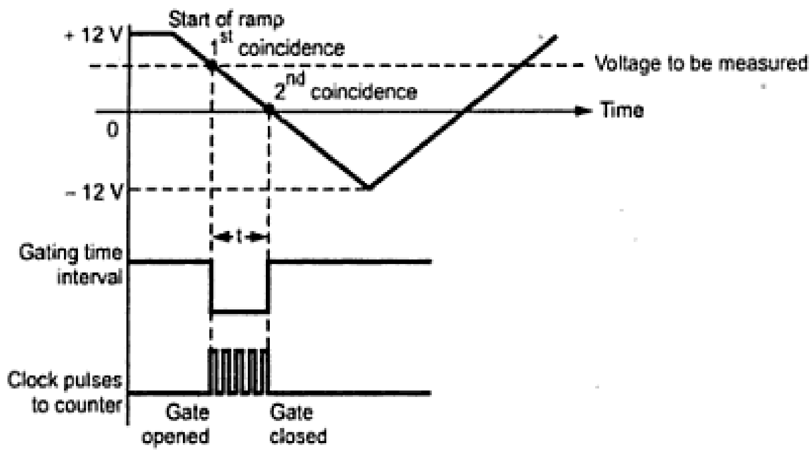


Fig. Voltage to time conversion

At the start of measurement, a ramp voltage is initiated which is continuously compared with the input voltage. When these two voltages are same, the comparator generates a pulse which opens a gate i.e. the input comparator generates a start pulse. The

ramp continues to decrease and finally reaches to 0 V or ground potential. This is sensed by the second comparator or ground comparator. At exactly 0 V, this comparator produces a stop pulse which closes the gate. The number of clock pulses are measured by the counter. Thus the time duration for which the gate is opened, is proportional to the input voltage. In the time interval between start and stop pulses, the gate remains open and the oscillator circuit drives the counter. The magnitude of the count indicates the magnitude of the input voltage, which is displayed by the display. The block diagram of linear ramp DVM is shown in the Fig.

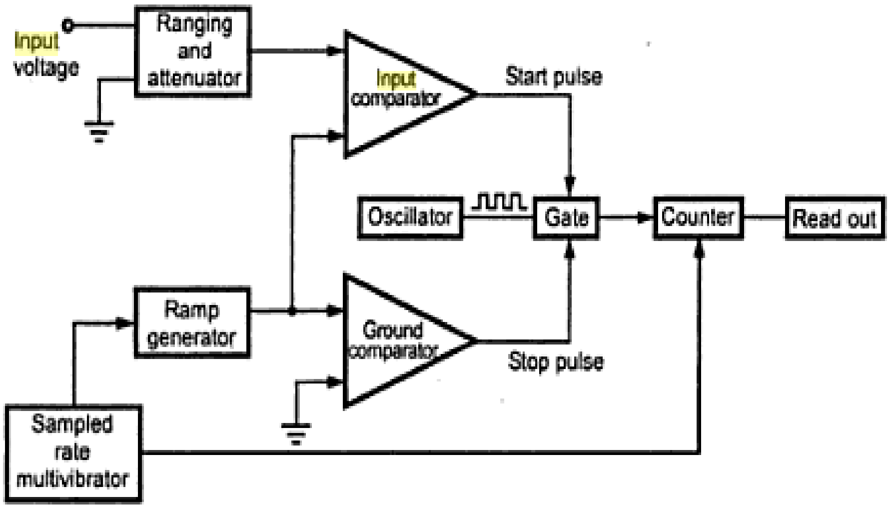


Fig. Linear ramp type DVM

Properly attenuated input signal is applied as one input to the input comparator. The ramp generator generates the proper linear ramp signal which is applied to both the comparators. Initially the logic circuit sends a reset signal to the counter and the readout.

The comparators are designed in such a way that when both the input signals of comparator are equal then only the comparator changes its state. The input comparator is used to send the start pulse while the ground comparator is used to send the stop pulse.

When the input and ramp are applied to the input comparator, and at the point when negative going ramp becomes equal to input voltages the comparator sends start pulse, due to which gate opens. The oscillator drives the counter. The counter starts counting the pulses received from the oscillator. Now the same ramp is applied to the ground comparator and it is decreasing. Thus when ramp becomes zero, both the inputs of ground comparator becomes zero (grounded) i.e. equal and it sends a stop pulse to the gate due to which gate gets closed. Thus the counter stops receiving the pulses from the local oscillator. A definite number of pulses will be counted by the counter, during the start and stop pulses which is measure of the input voltage. This is displayed by the digital readout.

The sample rate multivibrator determines the rate at which the measurement cycles are initiated. The oscillation of this multivibrator is usually adjusted by a front panel control named **rate,** from few cycles per second to as high as 1000 or more cycles per second. The typical value is 5 measuring cycles/second with an accuracy of ± 0.005 % of the reading. The sample rate provides an initiating pulse to the ramp generator to start its next ramp voltage. At the same time, a reset pulse is also generated which resets the counter to the zero state.

The **advantages** of this technique are :

i) The circuit is easy to design.

ii) The cost is low.

iii) The output pulse can be transferred over long feeder lines without loss of information.

iv) The input signal is converted to time, which is easy to digitize.

v) By adding external logic, the polarity of the input also can be displayed.

vi) The resolution of the readout is directly proportional to the frequency of the local oscillator. So adjusting the frequency of the local oscillator, better resolution can be obtained.

The **disadvantages** of this technique are :

i) The ramp requires excellent characteristics regarding its linearity.

ii) The accuracy depends on slope of the ramp and stability of the local oscillator.

Stair Case Ramp Technique

In this type of DVM, instead of linear ramp, the staircase ramp is used. The staircase ramp is generated by the digital to analog converter. The block diagam of staircase ramp type DVM is shown in the Fig. 3.15.

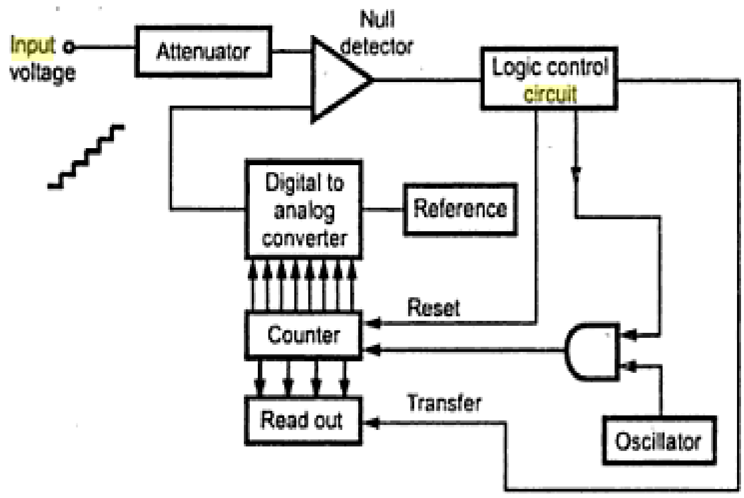


Fig. Staircase ramp type DVM

counter information is transferred to the readout. The readout shows the digital result of the count.

The **advantages** of this technique are :

i) The greater accuracy is obtained than the linear ramp technique.

ii) The overall design is more simple hence economical.

The technique of using staircase ramp is also called **null balance technique**. The input voltage is properly attenuated and is applied to a null detector. The another input to null detector is the staircase ramp generated by digital to analog converter. The ramp is continuously compared with the input signal.

Initially the logical control circuit sends a reset signal. This signal resets the counter. The digital to analog converter is also resetted by same signal.

At the start of the measurement, the logic control circuit sends a starting pulse which opens the gate. The counter starts counting the pulses generated by the local oscillator.

The output of counter is given to the digital to analog converter which generates the ramp signal. At every count there is an incremental change in the ramp generated. Thus the staircase ramp is generated at the output of the digital to analog converter. This is given as the second input of the null detector. The increase in ramp continues till it achieves the voltage equal to input voltage.

When the two voltages are equal, the null detector generates a signal which in turn initiates the logic control circuit. Thus logic control circuit sends a stop pulse, which closes the gate and the counter stops counting.

At the same time, the logic control circuit generates a transfer signal due to which the

iii) The input impedance of the digital to analog converter is high when the compensation is reached.

The **disadvantages** of this technique are :

i) Though accuracy is higher than linear ramp, it is dependent on the accuracy of digital to analog converter and its internal reference.

ii) The speed is limited upto 10 readings per second.

The staircase ramp type DVM is also called **counter type** DVM. After the discussion of the non-integrating type of DVMs, let us see the operation and features of integrating type of DVMs.

Dual-Slope Integration Type DVM

The ramp type DVM (single slope) is very simple yet has several drawbacks. The major limitation is the sensitivity of the output to system components and clock. The dual slope techniques eliminate the sensitivities and hence the mostly implemented approach in DVMs. The operation of the integrator and its output waveform are shown in Figure
TC,max=(2N – 1)x clock period

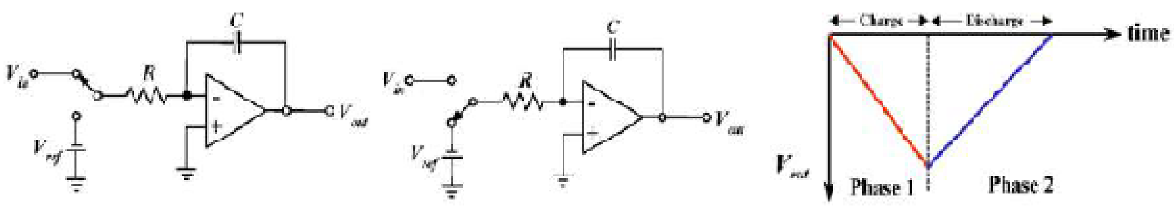


Figure .The integrator in dual-slope type DVM and its output

The integrator works in two phases as charging and discharging. In phase-1, the switch connects the input of the integrator to the unknown input voltage (*Vin*) for a predetermined time *T* and the integrator capacitor *C* charges through the input resistor *R*. The output at the end of the charging time *T* is (assuming that *VC(0) = 0*);

$$V_{out1} = \frac{V_{in}T}{RC}.$$

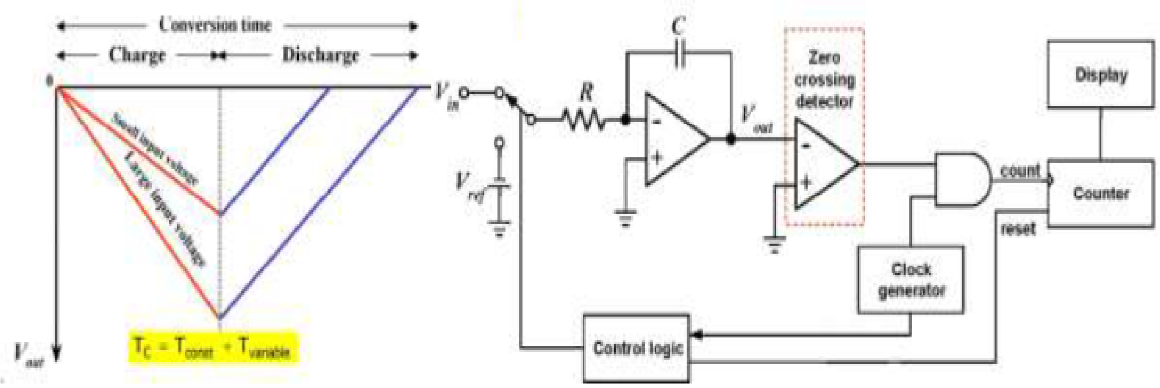
. In phase-2, the switch toggles to thesecond position that connects the input to the reference voltage *Vref* and the capacitor dischargesuntil the output voltage goes to zero as;

$$V_{out} = \frac{V_{ref}T_x}{RC} + V_{out1}$$

. The value of *Tx* at which *Vout* becomes zero is;

$$T_x = \frac{V_{in}T}{V_{ref}}.$$

The block diagram and integrator waveforms for the dual-slope DVM are shown in Figure . The figure illustrates the effects of the input voltage on charging and discharging phases of the converter. The total conversion time is the sum of the charging and discharging times. Yet, only the discharging time is used for the measurement and it is independent of the system components *R* and *C*, and the clock frequency.



Example

A dual slope A/D has *R*= 100 kΩ and *C*= 0.01 µF . The reference voltage is 10 volts and the fixed integration time is 10ms. Find the conversion time for a 6.8 volt input.

$$T_x = \frac{V_{in}T}{V_{ref}} = \frac{6.8V * 10ms}{10V} = 6.8ms;$$

, the total conversion time is then 10 ms + 6.8 ms = 16.8 ms

Successive Approximation Type DVM

In this approach, the input voltage is compared to the internally generated voltage. It is the most common A/D conversion for general applications. The conversion time is fixed (not depend on the signal amplitude as in the previous cases) and relatively fast, that is; *TC = N x clock period,* where *N* is the number of bits.

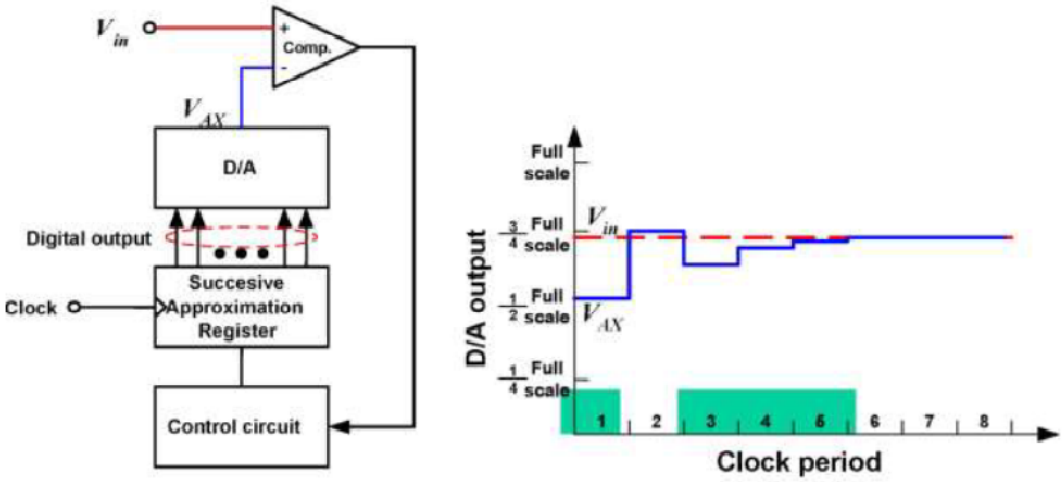


Figure- Block diagram and output waveform of the conversion unit of the successive aproximation type DVM

The block diagram and a sample output waveform of the conversion section are shown in Figure. The block diagram looks like the one given in Figure for the staircase type DVM except that the counter has been replaced by a successive approximation register. The register is set to the middle of the dynamic range at the beginning and the set value increases or decreases successively until the output voltage of the D/A converter approaches the input voltage with a difference smaller than the resolution of the converter. The operation of the successive approximation type D/A converter is illustrated in the following examples.

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Vector voltmeter

The vector voltmeter is basically a new type of amplitude and phase measuring device. It uses two samplers to sample the two waves whose amplitudes and relative phase are to be measured. It measures the voltages at two different points in the circuit and also measures the phase difference between these voltages at these two points.

In this voltmeter, two RF signals of same fundamental frequency (1 MHz to GHz) are converted to two IF signals. The amplitudes, waveforms and the phase relations of IF signals are same as that of RF signals. Thus, the fundamental components of the IF signals have the same amplitude and phase relationships as the fundamental components of the RF signals. These fundamental components are filtered from the IF signals and are measured by a voltmeter and a phase meter.

The block diagram of the vector voltmeter is shown in the Fig. .

The instrument consists of four sections :

i) Two RF to IF converters

ii) Automatic phase control circuit

iii) Phase meter circuit

iv) Voltmeter circuit

The channel A and B are the two RF to IF converters. The RF signals are applied to sampling gates. The sampling pulse generator controls the opening and closing of the gates. The RF to IF converters and phase control circuit section produce two 20 kHz sine waves with the same amplitudes and the same phase relationship as that of the same amplitudes and the same phase relationship as that of the fundamental components of the RF signals applied to the channels A and B. The tuned amplifier extracts the 20 kHz fundamental component from these sine waves.

The pulse control unit generates the sampling pulses for both the RF to IF converters. The sampling pulse rate is controlled by voltage tuned oscillator for which the tuning voltage is supplied by the automatic phase control unit. This section locks the IF signal of channel A to a 20 kHz reference oscillator. Due to this, the section is also called **phase locked section.**

The tuned amplifier passes only 20 kHz fundamental component of the IF signal of each channel. Thus the output of each tuned amplifier maintains the original phase relationship with respect to the signal in the other channel and also its correct amplitude relationship.

These two filtered signals are then connected to the voltmeter circuit by a front panel switch marked channel A and channel B. The appropriate meter range is decided by the input attenuator. This attenuator is also a front panel control marked amplitude range. It is basically a d.c. voltmeter and it consists of input attenuator, feedback amplifier having fixed gain, the rectifier and filtering arrangement and a d.c. voltmeter for the indication. The d.c. voltmeter gives the reading of the voltage corresponding to the channel A and channel B.

To determine the phase difference, there exists a phase meter circuit. The signals from channel A and B are applied to the amplifier and the limiter circuit. Due to this the signals are amplified and limited i.e. clipped. This produces a square wave signal at the output of each amplifier and limiter circuit. These square waves are then applied to the phase shifting network.

The circuit in upper part i.e. channel A shifts the phase of the square wave by + 60° while the circuit in lower part i.e. channel B shifts the phase by – 120° . The phase shifts are achieved by using capacitive networks and inverting, non-inverting amplifiers. The shifted square wave signals are then applied to trigger amplifers.

These trigger amplifiers convert the square wave signals to the positive spikes with very fast rise times. These spikes are used to trigger the bistable multivibrator.

The signal from channel A is connected to set input of the multivibrator while the signal from channel B is connected to the reset input of the multivibrator.

Now if the phase shift between the two signals is zero then the trigger pulses are + 60° − (− 120°) i.e. 180° out of phase due to phase shift circuitry. Hence in such a case the bistable multivibrator produces a square wave which is symmetrical about zero.

Thus if there exists a phase shift between the two signals, the bistable multivibrator produces asymmetrical square wave. Such asymmetrical signal is used to control the current switch which is transistorized switch. The conduction of the transistorized switch is during the negative portion of the square wave. This switch connects the constant current supply to the phase meter. When phase shift is 0°, then the current from constant current source is so adjusted that the meter reading is 0°. Depending upon the asymmetric nature of the square wave, current by current source varies and causes the appropriate reading of the phase difference, on the meter.

The main limitation of the meter is when the shift at the input side is 180° then the square wave produced by the bistable multivibrator causes either zero current or maximum current as in such a case square wave no longer remains square but collapse into either positive or negative d.c. voltage. These maximum deviations from the centre reading of 0° are marked on the meters as +180° and −180°. The phase range can be selected by a front panel switch that places a shunt across the phase meter and changes its sensitivity.

Features of Vector Voltmeter

1) The vector voltmeters cover a 1000 to 1 frequency range accommodating inputs from few microvolts upto about 1 V without input attenuation. Thus it gives broad frequency range.
2) They allow voltage ratios to be measured over a 70 to 80 dB range within a few tenths of a decibel.
3) The phase to be measured to an accuracy of about 1°.
4) Due to self locking feature, there is automatic tuning of the local oscillator in each frequency range.
5) Easy to operate, as simple as normal voltmeters.

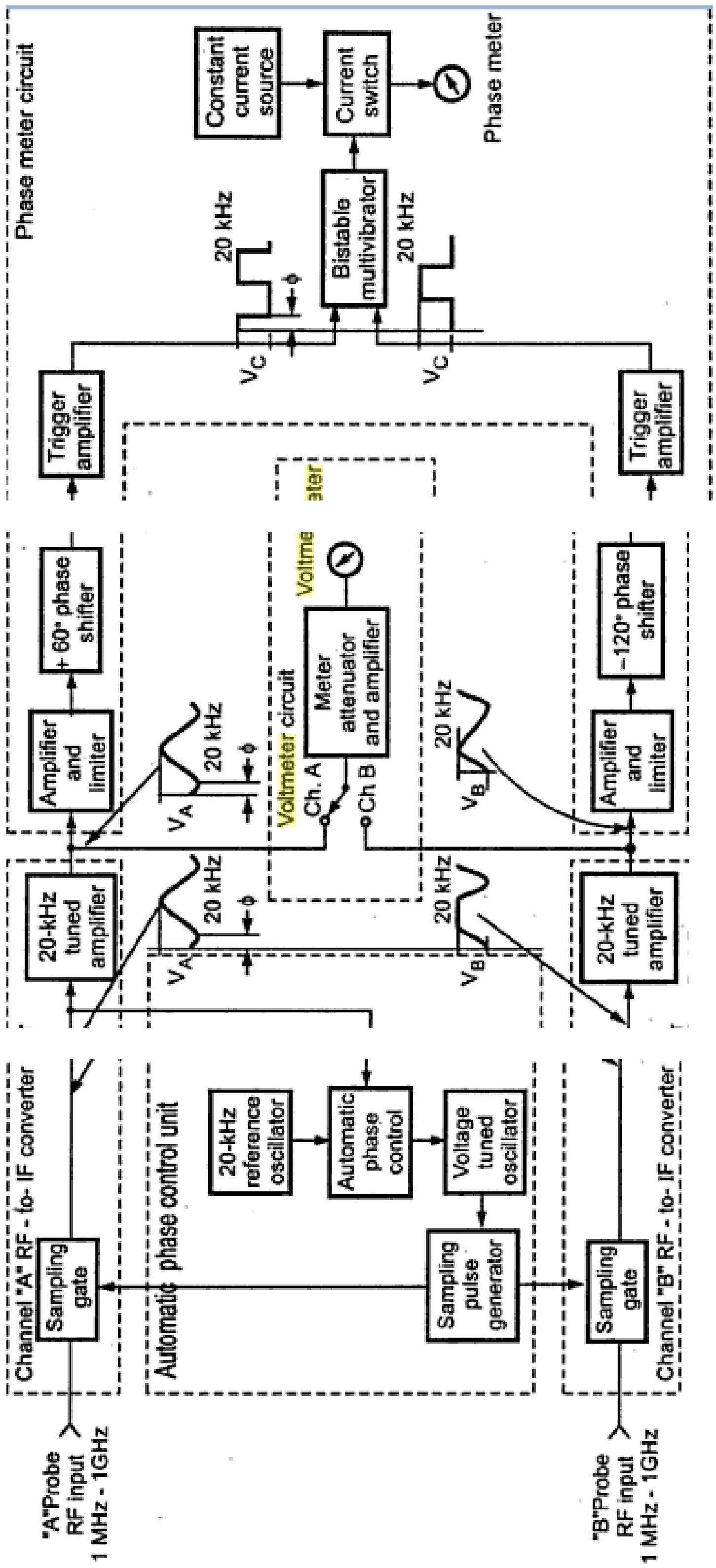

Fig . Block diagram of vector voltmeter

Ref.:Electronic Measurements and Instrumentation byA.V.Bakshi U.A.Bakshi – 2008