LECTURE NOTES

On

Electrical & Electronics Measurement

(PCEE4204)

3^{rd} Semester ETC Engineering

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Module-1

Accuracy and precision are defined in terms of systematic and random errors. The more common definition associates accuracy with systematic errors and precision with random errors. Another definition, advanced by ISO, associates *trueness* with systematic errors and precision with random errors, and defines accuracy as the combination of both trueness and precision.

In the fields of science, engineering, industry, and statistics, the accuracy of a measurement system is the degree of closeness of measurements of a quantity to that quantity's actual (true) value.[1] The precision of a measurement system, related to reproducibility and repeatability, is the degree to which repeated measurements under unchanged conditions show the same results.[1][2] Although the two words precision and accuracy can be synonymous in colloquial use, they are deliberately contrasted in the context of the scientific method.

A measurement system can be accurate but not precise, precise but not accurate, neither, or both. For example, if anexperiment contains a systematic error, then increasing the sample size generally increases precision but does not improve accuracy. The result would be a consistent yet inaccurate string of results from the flawed experiment. Eliminating the systematic error improves accuracy but does not change precision.

A measurement system is considered *valid* if it is both *accurate* and *precise*. Related terms include *bias* (non-random or directed effects caused by a factor or factors unrelated to the independent variable) and *error* (random variability).

The terminology is also applied to indirect measurements—that is, values obtained by a computational procedure from observed data.

In addition to accuracy and precision, measurements may also have a measurement resolution, which is the smallest change in the underlying physical quantity that produces a response in the measurement.

In numerical analysis, accuracy is also the nearness of a calculation to the true value; while precision is the resolution of the representation, typically defined by the number of decimal or binary digits.

Accuracy is also used as a statistical measure of how well a binary classification test correctly identifies or excludes a condition.

That is, the accuracy is the proportion of true results (both true positives and true negatives) in the population. To make the context clear by the semantics, it is often referred to as the "Rand Accuracy". It is a parameter of the test.

$$\text{accuracy} = \frac{\text{number of true positives} + \text{number of true n}}{\text{number of true positives} + \text{false positives} + \text{false negati}}$$

On the other hand, precision or positive predictive value is defined as the proportion of the true positives against all the positive results (both true positives and false positives)

$$\text{precision} = \frac{\text{number of true positives}}{\text{number of true positives} + \text{false positives}}$$

An accuracy of 100% means that the measured values are exactly the same as the given values.

Also see Sensitivity and specificity.

Accuracy may be determined from Sensitivity and Specificity, provided Prevalence is known, using the equation:

$$\text{accuracy} = (\text{sensitivity})(\text{prevalence}) + (\text{specificity})(1 - \text{prevalence})$$

The accuracy paradox for predictive analytics states that predictive models with a given level of accuracy may have greater predictive power than models with higher accuracy. It may be better to avoid the accuracy metric in favor of other metrics such as precision and recall.[*citation needed*] In situations where the minority class is more important, F-measuremay be more appropriate, especially in situations with very skewed class imbalance.

Another useful performance measure is the *balanced accuracy* which avoids inflated performance estimates on imbalanced datasets. It is defined as the arithmetic mean of sensitivity and specificity, or the average accuracy obtained on either class:

$$\text{balanced accuracy} = \frac{\text{sensitivity} + \text{specificity}}{2}$$
$$= \frac{0.5 * \text{true positives}}{\text{true positives} + \text{false negatives}} + \frac{0.5 * \text{true negatives}}{\text{true negatives} + \text{false positives}}$$

If the classifier performs equally well on either class, this term reduces to the conventional accuracy (i.e., the number of correct predictions divided by the total number of predictions). In contrast, if the conventional accuracy is above chance *only* because the classifier takes advantage of an imbalanced test set, then the balanced accuracy, as appropriate, will drop to chance.[5] A closely related chance corrected measure is:

$$\text{Informedness} = \text{sensitivity} + \text{specificity} - 1 = 2 * \text{balanced accuracy}$$
[6]

A direct approach to debiasing and renormalizing Accuracy is Cohen's kappa, whilst Informedness has been shown to be a Kappa-family debiased renormalization of Recall.[7]Informedness and Kappa have the advantage that chance level is defined to be 0, and they have the form of a probability. Informedness has the stronger property that it is the probability that an informed decision is made (rather than a guess), when positive. When negative this is still true for the absolutely value of Informedness, but the information has been used to force an incorrect response

Error Analysis and Significant Figures

Errors using inadequate data are much less than those using no data at all.

C. Babbage]

No measurement of a physical quantity can be entirely accurate. It is important to know, therefore, just how much the measured value is likely to deviate from the unknown, true, value of the quantity. The art of estimating these deviations should probably be called uncertainty analysis, but for historical reasons is referred to as error analysis. This document contains brief discussions about how errors are reported, the kinds of errors that can occur, how to estimate random errors, and how to carry error estimates into calculated results. We are not, and will not be, concerned with the “percent error” exercises common in high school, where the student is content with calculating the deviation from some allegedly authoritative number.

You might also be interested in our tutorial on using figures (Graphs).

Significant figures

Whenever you make a measurement, the number of meaningful digits that you write down implies the error in the measurement. For example if you say that the length of an object is 0.428 m, you imply an uncertainty of about 0.001 m. To record this measurement as either 0.4 or 0.42819667 would imply that you only know it to 0.1 m in the first case or to 0.00000001 m in the second. You should only report as many significant figures as are consistent with the estimated error. The quantity 0.428 m is said to have three significant figures, that is, three digits that make sense in terms of the measurement. Notice that this has nothing to do with the "number of decimal places". The same measurement in centimeters would be 42.8 cm and still be a three significant figure number. The accepted convention is that only one uncertain digit is to be reported for a measurement. In the example if the estimated error is 0.02 m you would report a result of 0.43 ± 0.02 m, not 0.428 ± 0.02 m.

Students frequently are confused about when to count a zero as a significant figure. The rule is: If the zero has a non-zero digit anywhere to its left, then the zero is significant, otherwise it is not. For example 5.00 has 3 significant figures; the number 0.0005 has only one significant figure, and 1.0005 has 5 significant figures. A number like 300 is not well defined. Rather one should write 3×10^2, one significant figure, or 3.00×10^2, 3 significant figures.

Absolute and relative errors

The absolute error in a measured quantity is the uncertainty in the quantity and has the same units as the quantity itself. For example if you know a length is 0.428 m ± 0.002 m, the 0.002 m is an absolute error. The relative error (also called the fractional error) is obtained by dividing the absolute error in the quantity by the quantity itself. The relative error is usually more significant than the absolute error. For example a 1 mm error in the diameter of a skate wheel is probably more serious than a 1 mm error in a truck tire. Note that relative errors are dimensionless. When reporting relative errors it is usual to multiply the fractional error by 100 and report it as a percentage.

Systematic errors

Systematic errors arise from a flaw in the measurement scheme which is repeated each time a measurement is made. If you do the same thing wrong each time you make the measurement, your measurement will differ systematically (that is, in the same direction each time) from the correct result. Some sources of systematic error are:

- Errors in the calibration of the measuring instruments.
- Incorrect measuring technique: For example, one might make an incorrect scale reading because of parallax error.
- Bias of the experimenter. The experimenter might consistently read an instrument incorrectly, or might let knowledge of the expected value of a result influence the measurements.

It is clear that systematic errors do not average to zero if you average many measurements. If a systematic error is discovered, a correction can be made to the data for this error. If you measure a voltage with a meter that later turns out to have a 0.2 V offset, you can correct the originally determined voltages by this amount and eliminate the error. Although random errors can be handled more or less routinely, there is no prescribed way to find systematic errors. One must simply sit down and think about all of the possible sources of error in a given measurement, and then do small experiments to see if these sources are active. The goal of a good experiment is to reduce the systematic errors to a value smaller than the random errors. For example a meter stick should have been manufactured such that the millimeter markings are positioned much more accurately than one millimeter. mistake or blunder - a procedural error that should be avoided by careful attention [Taylor, 3]. These are illegitimate errors and can generally be corrected by carefully repeating the operations [Bevington, 2].

discrepancy - a significant difference between two measured values of the same quantity [Taylor, 17; Bevington, 5]. (*Neither of these references clearly defines what is meant by a "significant difference," but the implication is that the difference between the measured values is clearly greater than the combined experimental uncertainty*.)

relative error [VIM 3.12] - error of measurement divided by a true value of the measurand [ISO, 34]. (*Relative error is often reported as a percentage. The relative or "percent error" could be 0% if the measured result happens to coincide with the expected value, but such a statement suggests that somehow a perfect measurement was made. Therefore, a statement of the uncertainty is also necessary to properly convey the quality of the measurement*.)

significant figures - all digits between and including the first non-zero digit from the left, through the last digit [Bevington, 4]. (*e.g. 0.05070 has 4 significant figures*.)

decimal places � the number of digits to the right of the decimal point. (*This term is not explicitly defined in any of the examined references*.)

standard error (standard deviation of the mean) � the sample standard deviation divided by the square root of the number of data points: SE or SDM $= \frac{\sigma}{\sqrt{n}}$ where $\sigma^2 = \sum_i \frac{(x_i - \bar{x})^2}{n-1}$ is the sample variance [Taylor, 102].

(*The ISO Guide and most statistics books use the letter s to represent the sample standard deviation and s (sigma) to represent the standard deviation of the population; however, s is commonly used in reference to the sample standard deviation in error analysis discussions, i.e. x ± 2s)*

margin of error - range of uncertainty. Public opinion polls generally use *margin of error* to indicate a 95% confidence interval, corresponding to an uncertainty range of $x \pm 2s$ [Taylor, 14].

coverage factor, k � numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty. Note: k is typically in the range 2 to 3 [ISO, 3; Fluke 20-6].

(e.g. If the combined standard uncertainty is $u_c = 0.3$ and a coverage factor of $k = 2$ is used, then the expanded uncertainty is $U_c = ku_c = 0.6$)

law of propagation of uncertainty - the uncertainty s_z of a quantity $z = f(w_1, w_2,$ �, $w_N)$ that depends on N input quantities w_1, w_2, �, w_N is found from

$$\sigma_z^2 = \sum_{i=1}^{N}\left(\frac{\partial f}{\partial w_i}\right)^2 \sigma_i^2 + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{\partial f}{\partial w_i}\frac{\partial f}{\partial w_j}\,\sigma_i\,\sigma_j\,\rho_{ij}$$

where s_i^2 is the variance of w_i and r_{ij} is the correlation coefficient of the covariance of w_i and w_j. If the input quantities are independent (as is often the case), then the covariance is zero and the second term of the above equation vanishes. The above equation is traditionally called the "general law of error propagation," but this equation actually shows how the uncertainties (not the errors) of the input quantities combine

Random errors

Random errors arise from the fluctuations that are most easily observed by making multiple trials of a given measurement. For example, if you were to measure the period of a pendulum many times with a stop watch, you would find that your measurements were not always the same. The main source of these fluctuations would probably be the difficulty of judging exactly when the pendulum came to a given point in its motion, and in starting and stopping the stop watch at the time that you judge. Since you would not get the same value of the period each time that you try to measure it, your result is obviously uncertain. There are several common sources of such random uncertainties in the type of experiments that you are likely to perform:

- Uncontrollable fluctuations in initial conditions in the measurements. Such fluctuations are the main reason why, no matter how skilled the player, no individual can toss a basketball from the free throw line through the hoop each and every time, guaranteed. Small variations in launch conditions or air motion cause the trajectory to vary and the ball misses the hoop.
- Limitations imposed by the precision of your measuring apparatus, and the uncertainty in interpolating between the smallest divisions. The precision simply means the smallest amount that can be measured directly. A typical meter stick is subdivided into millimeters and its precision is thus one millimeter.
- Lack of precise definition of the quantity being measured. The length of a table in the laboratory is not well defined after it has suffered years of use. You would find different lengths if you measured at different points on the table. Another possibility is that the quantity being measured also depends on an uncontrolled variable. (The temperature of the object for example).

- Sometimes the quantity you measure is well defined but is subject to inherent random fluctuations. Such fluctuations may be of a quantum nature or arise from the fact that the values of the quantity being measured are determined by the statistical behavior of a large number of particles. Another example is AC noise causing the needle of a voltmeter to fluctuate.

No matter what the source of the uncertainty, to be labeled "random" an uncertainty must have the property that the fluctuations from some "true" value are equally likely to be positive or negative. This fact gives us a key for understanding what to do about random errors. You could make a large number of measurements, and average the result. If the uncertainties are really equally likely to be positive or negative, you would expect that the average of a large number of measurements would be very near to the correct value of the quantity measured, since positive and negative fluctuations would tend to cancel each other

UNIT 1 STANDARD OF MEASUREMENT Measurements

Structure

1.11 Key Words

1.12 Answers to SAQs

1.1 INTRODUCTION

In order that the investigators in different parts of the country and different parts of

world may compare the results of their experiments on a consistent basis, it is necessary

to establish certain standard units of length, weight, time, temperature and electrical,

quantities. The National Bureau of Standards has the primary responsibility for

maintaining these standard in the United States. In India, Indian Standard Institute (ISI),

New Delhi has taken the responsibility for maintaining all the standard measurements.

To monitor the standard of measurements, the same Institute issues instructions to put

ISI mark on measuring instruments and items so that these may be compared with

non-standard ones.

In the measurement system, the quantity to be measured, in the direct method, is

compared directly against a standard of same kind of quantity. The magnitude of

quantity being measured is expressed in terms of a chosen unit for the standard and a

numerical multiplier. A length can be measured in terms of meter and a numerical

constant. Thus, a 10 meter length means a length ten times greater than a meter. Thus, by the means of standard, it is possible to provide means of establishing and maintaining the

magnitudes of the various units. The simplest kind of standard is a physical object

having desired property. This standard can be used as a basis of comparison.

Objectives

After studying this unit, you should be able to

 understand the importance of standard in the measurement systems,

 explain the sources and causes of errors in the measurements, and

 perform the analysis of experimental data to find the accuracy, precision

and the general validity of the experimental results.6

Metrology and

Instrumentation 1.2 STANDARDS OF MEASUREMENTS AND THEIR

CLASSIFICATION

The standards of measurements are very useful for calibration of measuring instruments.

They help in minimizing the error in the measurement systems. On the basis of the

accuracy of measurement the standards can be classified as primary standards and

secondary standards.

1.2.1 Primary Standard

A primary standard quantity will have only one value and it is fixed. An instrument

which is used to measure the value of primary standard quantity is called primary standard instrument. It gives the accurate value of the quantity being measured. No precalibration

is required for this instrument. It is used to calibrate the instruments having

less accuracy. By comparing the readings of the two instruments, the accuracy of the

second instrument can be determined.

1.2.2 Secondary Standard

The value of the secondary standard quantity is less accurate than primary standard one.

It is obtained by comparing with primary standard. For measurement of a quantity using

secondary standard instrument, pre-calibration is required. Without calibration, the result

given by this instrument is meaningless. Calibration of a secondary standard is made by

comparing the results with a primary standard instrument or with an instrument having

high accuracy or with a known input source. In practical fields, secondary standard

instruments and devices are widely used. Using calibration charts, the error in the

measurement of these devices can be reduced.

1.3 STANDARD UNIT OF LENGTH

The meter is considered as one of the fundamental unit upon which, through appropriate

conversion factors, the English system of length is based. The SI unit of length in metre.

The standard metre is defined as the length of a platinum-iridium bar maintained at very accurate conditions at the International Bureau of Weights and Measures at Sevres, near

Paris, France. All other metres had to be calibrated against the metre. The conversion

factor for length for English and Metric systems in the United States is fixed by law as

1 meter = 39.37 inches

Secondary standard of length is maintained at the National Bureau of Standards for

calibration purposes. In 1960, the general conference on weights and measures defined

the standard meter in terms of the wavelength of the orange-red light of a krypton-86

lamp. The standard meter is thus

1 meter = 1,650,763.73 wavelengths of orange-red light of Krypton-86

In 1982, the definition of the meter was changed to the distance light travels in

1/299,792,458ths of a second. For the measurement, light from a helium-neon laser

illuminates iodine which fluoresences at a highly stable frequency.

In CGS system, the fundamental unit of length is centimeter. Its conversion factors for

other system are already mentioned above. The derived units for length are as follows :

1 m = 100 cm

1 km = 105

cm = 1000 m

1 mm = 10^{-3} m = 10^{-1}

cm

1 centimeter = 10 2 m

1 decimeter = 10 1 m

1 decameter = 10 m

1 hectometer = 102 m.

We also have some other units, which are frequently used for short and large lengths.7

Standard of

Measurements

They are :

1 Fermi = 1 f = 10– 15 m

1 Angstrom = 1

o

A

= 10– 10 m

1 light year

15 9.46 10 m

(distance that light travels in 1 year)

Note : Velocity of light is

8

3 10 m/s .

1.4 STANDARD UNIT OF WEIGHT

The kilogram is considered as fundamental unit upon which, through appropriate

conversion factors, the English system of mass is based. The SI unit of mass is kilogram.

The standard kilogram is defined in terms of platinum-iridium mass maintained at very

accurate conditions at the International Bureau of Weights and Measures in Sevres,

France.

The conversion factors for the English and Metric systems in the United States are fixed

by law is

1 pound-mass = 453.59237 grams

= 0.45359237 kilogram

Secondary standard of mass is maintained at the National Bureau of Standards for

calibration purpose. In MKS and SI systems, fundamental unit of mass is kilogram,

whereas in CGS system, the unit for the same is gram. The conversion factors for the

above units and units derived from them are as follows :

1 kilogram = 1000 grams; 1 gram = 10^{-3}

kilogram

1 hectogram = 100 grams = 10^{-1}

kilogram

1 decagram = 10 grams = 10^{-2}

kilogram

1 milligram = 0.001 gram = 10^{-6}

kilogram

1.5 STANDARD UNIT OF TIME

The standard units of time are established in terms of known frequencies of oscillation of

certain devices. One of the simpliest devices is a pendulum. A torsional vibration system

may also be used as a standard of frequency. The torsional system is widely used in

clocks and watches. Ordinary 50 HZ line voltage may be used as a frequency standard

under certain circumstances. An electric clocks uses this frequency as a standard because

it operates from a synchronous electric motor whose speed depend on line frequency. A

turning fork is a suitable frequency source, as are piezo-electric crystals. Electronic

oscillator may also be designed to serve as very precise frequency sources. The SI unit of

time is second.

The fundamental unit of time, the second, has been defined in the past as 864001of a mean solar day. The solar day is measured as the time interval between successive transits of the sun across a meridian of the earth. The time interval varies with location of the earth and time of the year, however, the mean solar day for one year is constant.The solar year is the time required for the earth to make one revolution around the sun.The mean solar year is 365 days 5 hr 48 min 48 s.

1.6 STANDARD UNIT OF TEMPERATURE

An absolute temperature scale was proposed by Lord Kelvin in 1854 and forms the basis for thermodynamic calculations. This absolute scale is so defined that particular meaning is given to the second law of thermodynamics when this temperature scale is used.

The International Practical Temperature Scale of 1968 furnishes an experimental basis for a temperature scale which approximates as closely as possible the absolute thermodynamic temperature scale. In the International Scale, 11 primary points are

established as given in Table 1.1. Secondary fixed points are also established as given in

Table 1.2. In addition to the fixed points, precise points are also established for

interpolating between these points.

Table 1.1 : Primary Points for the International

Practical Temperature Scale of 1968

Point Normal Pressure = 14.6959 psia

= 1.0132 □ 105 Pa

Temperature

oC F

Triple point equilibrium hydrogen □ 259.34 □ 434.81

Boiling point equilibrium hydrogen at 25/76 normal pressure □ 256.108 □ 428.99

Normal boiling point (1 atm) of equilibrium hydrogen □ 252.87 □ 423.17

Normal boiling point of Neon □ 246.048 □ 410.89

Triple point of oxygen □ 218.789 □ 361.82

Normal boiling point oxygen □ 182.962 □ 297.33

Triple point of water 0.01 32.018

Normal boiling point of water 100 212.00

Normal freezing point of Zinc 419.58 787.24

Normal freezing point of silver 961.93 1763.47

Normal freezing point of gold 1064.43 1947.97

Table 1.2 : Secondary Fixed Points for the International Practical

Standard of Measurements

More recently, the International Temperature Scale of 1990 (ITS-90) has been adopted. The fixed points for ITS-90 that are differ only slightly from IPTS-68. For ITS-90, a platinum resistance thermometer is used for interpolation between the triple point of hydrogen and the solid equilibrium for silver, while above, the silver point black body radiation is used for interpolation.

Derived Units

The units of all other physical quantities can be expressed in terms of these base units. For example, we can express the unit of speed in metre per second, the unit of density in kilogram per cubic metre. Let us consider another physical quantity like force. From Newton’s second law of motion, force can be defined as the product of mass and acceleration. We can therefore take the unit of force as 1 kilogram □ 1 metre/second2

. We call this by the name, Newton for convenience.The unit of energy is Newton-metre. We call this by the name Joule. The unit of

power is Joule per second. We call it Watt.

The conversion factor for various units are

1 H.P = 746 watt (J/s)

1 H.P = 550 ft-1b/sec.

1 H.P = 75 kg-m/sec.

1.7 STANDARD UNIT OF LUMINOUS INTENSITY

OF A SOURCE OF LIGHT

Candela is the SI unit of luminous intensity of a source of light in a specified direction.

The candela is the luminous intensity of a black body of surface area 1/60,000 m2

placed

at the temperature of freezing platinum and at a pressure of 101, 325 N/m2

, in the

direction perpendicular to its surface. Now candela is redefined as the luminous intensity

in a given direction of a source that emits monochromatic radiation of frequency

540 □ 1012 Hz and that has a radiant intensity in that direction of 1/683 watt per

steradian. (SI unit of solid angle).

1.8 STANDARD UNIT OF AMOUNT OF SUBSTANCE

The mole (mol) is the SI unit of amount of substance.

One mole is the amount of substance of a system that contains as many elementary

entities as there are atoms in 0.012 kg of carbon – 12.

1.9 STANDARD UNITS OF ELECTRICAL

QUANTITIES

The International conference on electrical units in London in 1908 confirmed the

absolute system units adopted by the British Association Committee on Electrical

Measurement in 1863. This conference decided to specify some material standard which

can be produced in isolated laboratories and used as International standards. The desired

properties of International standards are that they should have a definite value, be

permanent, and be readily set up anywhere in the world, also that their magnitude should

be within the range at which the most accurate measurements can be done.

The four units – ohm, ampere, volt and watt – established by above specifications were

known as International units. The ohm and ampere are primary standards. Definitions of

International unit are given below.10

Metrology and

Instrumentation

International Ohm

The international ohm is the resistance offered to the passage of an unvarying

electric current at the temperature of melting ice by a column of mercury of

uniform cross-section, 106.300 cm long and having mass of 14.4521 gm

(i.e., about 1 sq. mm in cross-section).

International Ampere

The international ampere is the unvarying current which when passed through a

solution of silver nitrate in water deposits at the rate of 0.0001118 gm per second.

The International Volt and Watt

The international volt and watt defined in terms of International ohm and ampere.

As constructing standards, which did not vary appreciably with time, was difficult

and also as, by 1930, it was clear that the absolute ohm and ampere could be

determined as accurately as the international units. The International committee on

Weights and Measures decided in October, 1946 to abandon the international units and choose January 1, 1948 as the date for putting new units into effect. The

change was made at appropriate time and the absolute system of electrical units is

now in use as the system on which electrical measurements are based.

SAQ 1

(a) Why are standards necessary?

(b) What is the difference between primary and secondary standards?

(c) The Universal gas constant has a value of 1545 ft-lbf/1bm-mol oR. By

applying appropriate conversion factors, obtain its value in SI unit.

(d) Mention the fundamental SI units which are used in mechanical system.

(e) What are the SI unit of the following :

(i) Temperature,

(ii) Current,

(iii) Luminous intensity of light, and

(iv) Amount of substance.

Kelvin double circuit for measurement of low resistances:

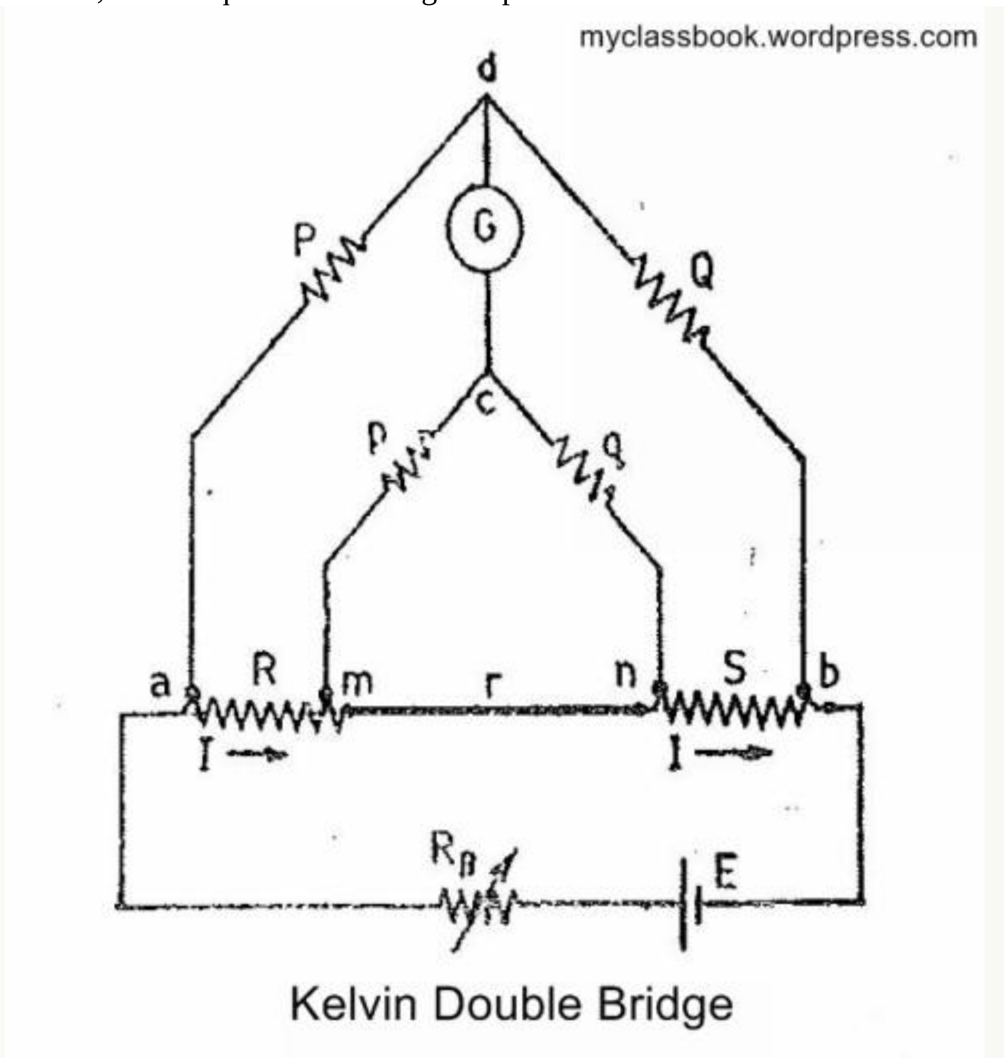
The Kelvin double bridge is the modification of the Wheatstone bridge and provides greatly increased accuracy in measurement of low value resistance.

An understanding of the Kelvin bridge arrangement may be obtained by the study of the difficulties that arise in a Wheatstone bridge on account of the resistance of the leads and the contact resistances while measuring low valued resistance.

The Kelvin double bridge incorporates the idea of a second set of ratio arms-hence the name double bridge-and the use of four terminal resistors for the low resistance arms.

Figure shows the schematic diagram of the Kelvin bridge. The first of ratio arms is P and Q. the second set of ratio arms, p and q is used to connect the galvanometer to a point d at the appropriate potential between points m and n to eliminate effect of connecting lead of resistance r between the unknown resistance, R, and the standard resistance, S.

The ratio p/q is made equal to P/Q. under balance conditions there is no current through the galvanometer, which means that the voltage drop between a and b, Eab is equal to the voltage drop Eamd.



kelvin double bridge

Now the voltage drop between a and b is given by,

$$E_{ab} = \frac{P}{P+Q} E_{ac}$$

Since,

$$E_{ac} = I\left[R + S + \frac{(p+q)r}{p+q+r}\right]$$

Put above value of E_{ac} in E_{ab} , we get,

$$E_{ab} = \frac{P}{P+Q} I\left[R + S + \frac{(p+q)r}{p+q+r}\right]$$

$$E_{amd} = I\left\{R + \frac{p}{p+q}\frac{(p+q)r}{p+q+r}\right\}$$

$$= I\left[R + \frac{pr}{p+q+r}\right]$$

for bridge to be

$$E_{ab} = E_{amd}$$

$$\frac{P}{P+Q} I\left[R + S + \frac{(p+q)r}{p+q+r}\right] = I\left[R + \frac{pr}{p+q+r}\right]$$

$$R = \frac{P}{Q} S + \frac{qr}{p+q+r}\left[\frac{P}{Q} - \frac{p}{q}\right]$$

If

$$\frac{P}{Q} = \frac{p}{q}$$

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

balance

Above equation is the usual working equation for the Kelvin Bridge. It indicates that the resistance of connecting lead, r, has no effect on the measurement, provided that the two sets of ratio arms have equal ratio. The former equation is useful, however, as it shows the error that is introduced in case the ratios are not exactly equal. It indicates that it is desirable to keep r as small as possible in order to minimize the errors in case there is a difference between ratios P/Q and p/q.
solution:

Methods of measuring low, medium and high resistances

<u>Classification of resistances</u>:

Low resistance:
Resistance of the order of 1ohm and under.

Medium resistance:
1ohm to 100 Kilo ohm or 0.1Mohm.

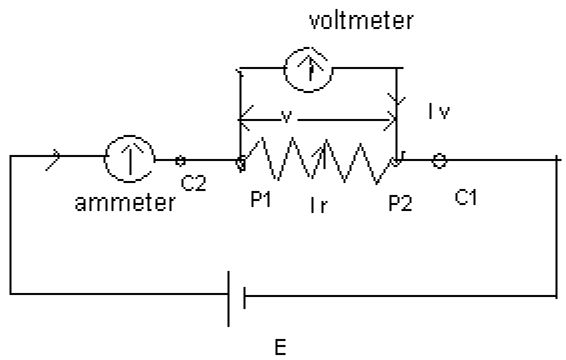
High resistance:
100 k ohm and above.

<u>Low resistance</u>

Introduction:

For low resistance, the contact resistance of 0.002 Ω also causes an error. Therefore, during measurement, the contact resistance should either be eliminated by some means or taken into account.

Construction:



Consists of four terminals:

(i) One pair of terminals c_1c_2 called current terminals, is used to lead current to and from the resistor.

(ii) Other pair p_1p_2 between which voltage drop is measured is called potential terminals.

Results:

- Resistors of low values are measured in terms of resistance between potential terminals.
- It is independent of contact drop.

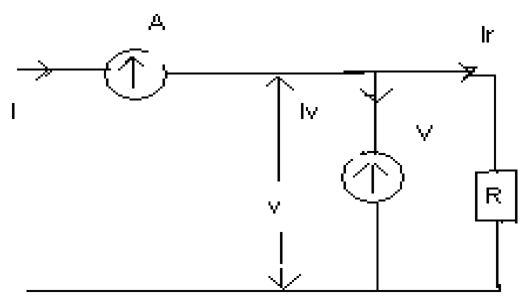
Methods of measuring low resistance:

(i) ammeter voltmeter method
(ii) Kelvin double bridge method
(iii) Potentiometer method

Ammeter voltmeter method

This is very popular method as instruments required for test are usually available in the laboratory.

Connection:



Explanation:

- Voltmeter measures true value of voltage
- Ammeter reads sum of currents through resistance and voltmeter

Let Rv =resistance of voltmeter

Iv =current through the voltmeter = V / Rv

Measured value of resistance = Rm =V/I =V / (Ir+Iv)

=V / (V/R +V/ Rv) =R / (1+ R/Rv)

True value of resoisstance = $R= Rm (1+R/Rv)$

Or, $R=Rm (Rv + R)/ Rv$

Or, $R.Rv = RmRv + Rm R$

Or, $R (Rv-Rm)=RmRv$

Or, $R= RmRv / (Rv-Rm)$

Or, $R = Rm[1/ (1-Rm/Rv)]$

$R=Rm (1+ Rm / Rv)$ ———————— (1)

Thus from above eqn. we can say that measured value is much smaller than the true value.
Again, when $Rv \gg Rm$
Then, Rm / Rv is very small, so neglected.
Now from eqn. (i) above, under such condition, $R=Rm$.
i.e. true value =measured value.
In other words,
The true value of resistance is equal to measured value only if the resistance of voltmeter Rv is infinite.

From eqn (1)

$R=Rm(1+ Rm/Rv)$

Or, $Rm- R = - Rm^2 /Rv$

Relative error, $\varepsilon_r =(Rm-R)/ R =- Rm^2 / (Rv R)$

Since, $Rm \approx R$

Therefore, $\varepsilon_r =- Rm^2 / (Rv R) =- R/ Rv$

i.e. error is very small if value of resistance is very small compared to resistance of voltmeter.

Advantage: easy and simple method.

Disadvantage: (i) not accurate
(ii) use confined to laboratory work.

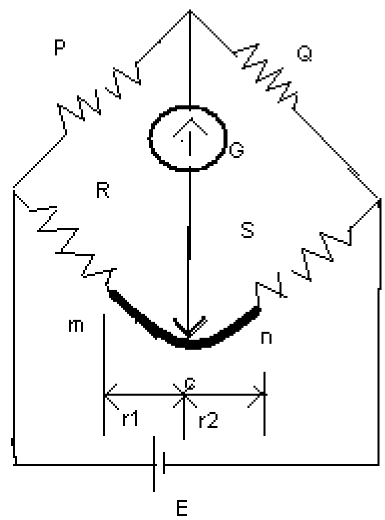
<u>Kelvin double bridge method</u>

Purpose: measures low resistance.

Principle:

It is a modification of Wheatstone bridge taking into account the resistance of leads and contact resistance while measuring low resistance.

Diagram:



Theory:

- When galvanometer is connected to m, the resistance r is connected to S. indicating low resistance.
- When connected to n, then r is added to R, resulting too high a value for R.
- Suppose point c is selected ,which will not give any high or plow value, such that

$r_1 / r_2 = P/Q$ ———————— (1)

Then the presence of r_1 causes no error in the result. Then we have,
$R + r_1 = P(S + r_2)/Q$ ———————— (2)

From (1), $r_1 / r_2 = P/Q$

or, $r_1 /(r_1 + r_2) = P/(P+Q)$

or, $r_1 = P[r_1 + r_2] / (P+Q) = P\,r / (P+Q)$

and $r_2 = Q\,r / (P+Q)$

Now, from (2)
$R + r_1 = P(S + r_2) / Q$

or, $R + Pr / (P+Q) = P[S + Qr / (P+Q)] / Q$

or, $R + Pr / (P+Q) = PS / Q + Pr / (P+Q)$

or, $R = PS/Q$

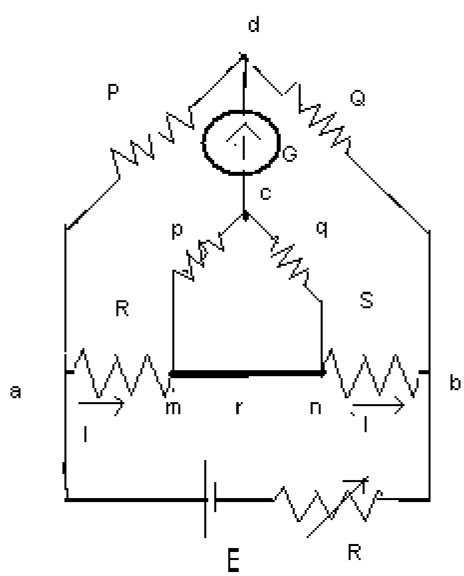
i.e. making the galvanometer connection at c, the resistance of leads does not affect the result.

Practically Kelvin double bridge

It is difficult to find out correct connecting point i.e. c. To overcome this difficulty, it is compensated by connecting two actual resistance units of correct ratio between m and n. The galvanometer is connected to junction of resistors.

This bridge incorporates second set of rated arms. Hence named double bridge.

Diagram:



Construction:

- First ration arm is P and Q.
- Second ratio arm p and q is used to connect the galvanometer to a point c at appropriate potential between points m and n to eliminate the effect of connecting lead of resistance r4 between R and standard resistance S.
- p/q is made equal to P/Q.

Derivation:

At balance point,
$Ead = Eamc$ ——————————————— (1)

Now,

$Ead + P. Eab / [P+Q]$

$Eab = I [R+S+ (p+q)r / (p+q+r)]$

$Eamc = I [R+ px (p+q)r / (p+q)(p+q+r)]$

From (1)
$Px Eab / (P+Q) = I [R+ px (p+q)r / (p+q)(p+q+r)]$

Or, $Px I [R+S+ (p+q)r / (p+q+r)] / (P+Q) = I [R+ px (p+q)r / (p+q)(p+q+r)]$

Or, $R [1- P/(P+Q)]= PS/(P+Q) + [P/(P+Q) – p/(p+q)]x (p+q)r/ (p+q+r)$

Or, $R. Q / (P+Q) = PS/(P+Q) + [P/(P+Q) – p/(p+q)]x (p+q)r/ (p+q+r)$

Dividing both sides by Q /(P+Q),we get

$$R= PS/Q + \frac{(P+Q)}{Q} x [P/(P+Q) – p/(p+q)]x (p+q)r/ (p+q+r)$$

Let second term on the right side of the above eqn =0

Under such condition, we will get R=PS/Q which is same as Wheatstone bridge eqn.
However when second term on right side of eqn is made equal to zero, we get
$P/(P+Q) =p/(p+q)$

Or, $(p+q)/p = (P+Q)/P$

Or, $q/p = Q/P$
Or, $P/Q = p/q$

It means the resistance of connected leads r has no effect on the measurement provided that the two sets of ration arms have equal ratio.

Shortcomings:

(1) Error is introduced in case ratios are not exactly equal.
Remedy:-keep r as small as possible.

(2) Effect of thermo electric emf.
Remedy: True value R is taken as mean of two readings. Second reading is taken by reversing battery connection.

Medium resistance

Methods:

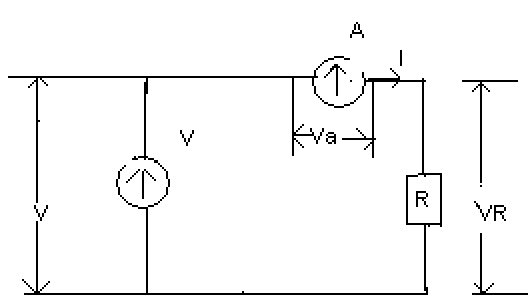
(1) Ammeter voltmeter
(2) Substitution
(3) Wheatstone bridge
(4) Ohmmeter

Ammeter voltmeter method

In this method ammeter reads the true value of the current through the resistance but voltmeter odes not measure the true voltage across the resistance.

Voltmeter reads sum of voltage across ammeter and resistance
Ra=resistance of ammeter
Rm= measured value

Diagram:



Derivation:

Now, $Rm = V/I = (Va+V_R) / I = Va / I + V_{R/} I = Ra + R$

True value of resistance, R =Rm -Ra =Rm - Rm. Ra / Rm
=Rm (1-Ra/Rm)

Or, Rm = R +Ra

Thus measured value is higher than true value.
True value is equal to measured value only if the ammeter resistance Ra is zero.

Relative error, ε_r = (Rm-R) / R =Ra/R

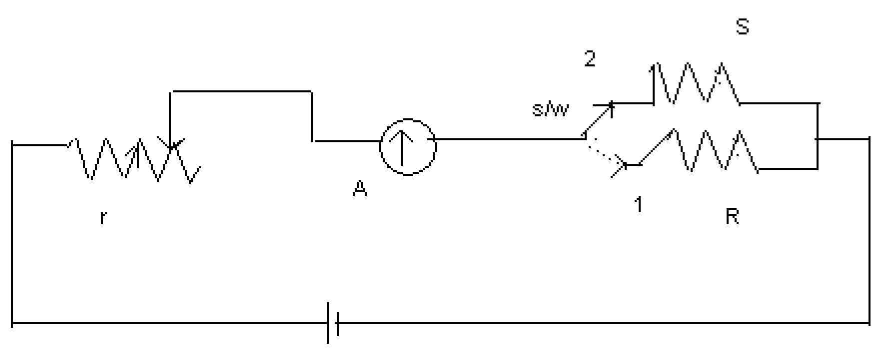
If the value of resistance under measurement is large as compared to internal resistance of ammeter, the error in measurement would be small.

Advantage:
Easy, simple, rough method.

Disadvantage:
- At full scale error may be around 0-1%.
- Errors sometimes considerably high.

Substitution method

Diagram:



A --- Ammeter
r---regulating resistance
S---standard variable resistance
R--- Unknown resistance
S/W ---switch for putting R and S alternatively into circuit.

Procedure:

Case 1: Resistance R in the circuit .

- S/W is set to position 1.
- This brings R into the circuit.
- r is adjusted to give ammeter the chosen scale mark.

Case 2: Resistance S in the circuit.

- Change S/W to position 2.
- This brings S in to the circuit.
- Adjust S to give same chosen scale mark by ammeter.
- The substitution for one resistance by another has left current unaltered.
- The value of S gives the value of R.

Advantage:

- More accurate than ammeter voltmeter method as no error as the case of ammeter voltmeter method.
- Many applications in bridge method.
- Used in high frequency ac measurement.

Disadvantage:

- Accuracy depends upon constancy of battery emf and resistance of circuit(excluding R & S)
- Also depends upon accuracy of measurement of S.

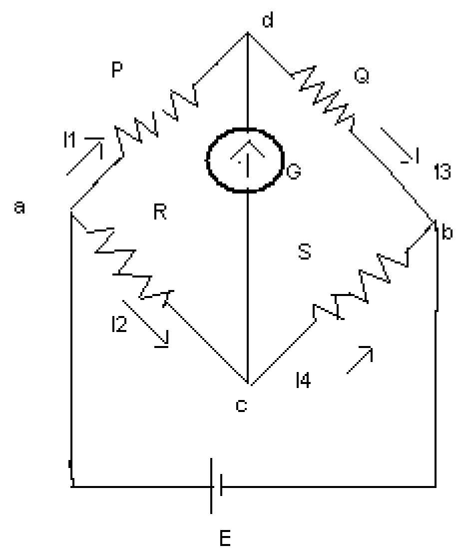
<u>Wheatstone bridge</u>

Purpose: It is an important device tomeasure medium resistance.

Construction:

- Consists of four arms , asource of emf and a null detector(usually a galvanometer)
- Pand Q fixed resistances.
- S is a variable (standard) resistance.
- R is an unknown resistance.

Diagram:



Derivation:

When bridge is balanced-

- No current through galvanometer
- Potential at d is equal to potential at c.

i.e. $I1P = I2\ R$ ———————— (1)

Again $I1=I3= E/(P+Q)$ ———————— (2)

As no current flows through galvanometer

And $I2=I4=E/(R+S)$ ———————— (3)

Putting the value of I1 and I2 from eqn (2) & (3) into eqn (1), we get

$E \times P/(P+Q) = E \times R/(R+S)$

Or, $(P+Q)/P=(R+S)/S$

Or, $1+Q/P = 1+S/R$

Or, $R/S=P/Q$

Or, $R=PS/Q$

Sensitivity:

When the bridge is unbalanced, it is desired to know the galvanometer response. This is achieved by

1. With a specified bridge arrangement, under given unbalance, the galvanometer which shows deflection is selected.
2. Determining the minimum unbalance which can be observed with a given galvanometer.
3. Determining deflection for given unbalance.

Derivation:

Suppose r is changed to $R+\Delta R$, creating an unbalance. With galvanometer branch open-

$E_{ad}=I_1 P = EP/(P+Q)$

Similarly, $E_{ac}=I_2(R+\Delta R) = E(R+\Delta R) / (R+\Delta R+S)$

P.D between points c and d is
$e= E_{ac} - E_{ad}$

$= E\ [\ (R+\Delta R)/(\ R+\Delta R+S) - P/\ (P+Q)]$

Since $P/(P+Q) = R/(R+S)$

We have,
$e= E[\ (R+\Delta R)/(\ R+\Delta R+S) - R/\ (R+S)]$

$$= \frac{ER}{(R+S)}.\ \left[(1+\Delta R/R)/\left(1+\frac{\Delta R}{(R+S)}\right) - 1\right]$$

$$= \frac{ER}{(R+S)}.\ \left[(1+\Delta R/R)\left(1-\frac{\Delta R}{(R+S)}\right) - 1\right]$$

Neglecting square terms of increment i.e. ΔR^2

$$e= \frac{ER}{(R+S)}.\ \left[1-\frac{\Delta R}{(R+S)}+\frac{\Delta R}{R}-\frac{\Delta R^2}{R(R+S)} - 1\right]$$

$$=\frac{ER}{(R+S)}.\ \left[\frac{\Delta R}{R}-\frac{\Delta R^2}{(R+S)}\right]$$

$$= \underline{ER}.\quad x\ \ \underline{\Delta R}\quad [\ \underline{\Delta R}\ x\ \underline{(R+S)}\quad 1]$$

$(R+S) \quad (R+S) \quad R \qquad \Delta R$

$$= \frac{ER.}{(R+S)} \times \frac{\Delta R}{(R+S)} \left[\frac{(R+S)}{R} \quad 1 \right]$$

$$= \frac{ER.}{(R+S)^2} \times \Delta R \times \frac{S}{R}$$

$$= \frac{E \Delta R \, S}{(R+S)^2}$$

Deflection of galvanometer,

$\theta = e. Sv$

Where Sv is the voltage sensitivity of galvanometer

$$\theta = e. Sv = Sv . \frac{E \Delta R \, S}{(R+S)^2} \quad / \quad \Delta R/R$$

$$= \frac{E \, Sv \, S}{(R+S)^2 / R}$$

$$= \frac{E \, Sv}{(R+S)^2 / R S}$$

$$= \frac{E \, Sv}{(R/S+2+ S/R)}$$

Thus sensitivity is maximum when R/S=1

Sensitivity decreases if ration is greater or smaller than unity.

Limitations:

- Use is limited to the measurement of resistances ranging from a few ohms to several mega ohms.
- When high resistance is required to measured ,sensitivity decreases
- Upper limit is extended by increasing emf applied.
- Care to be taken to avoid overheating.
- Inaccuracy arises during measurement of high resistance.

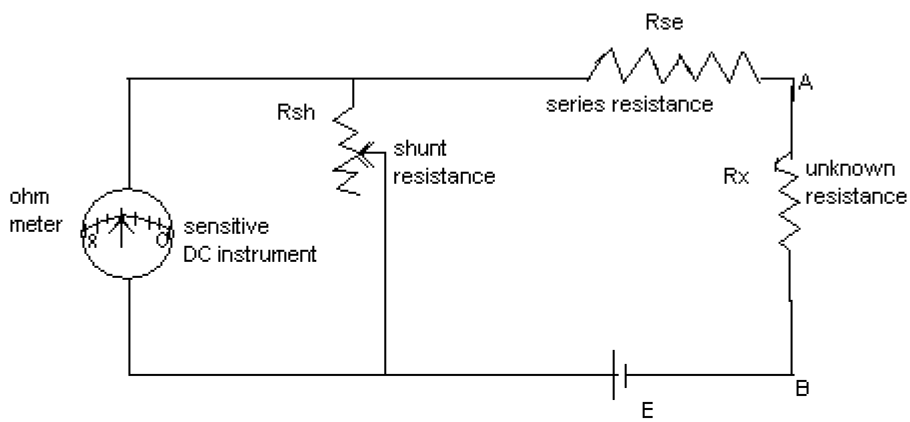
Remedy:

- For high resistance, use mega Ohm Bridge.

- For lower resistance measurement, resistance of connecting leads and contact resistance comes into account
- Lower limit is 1 to 5 ohm.
- For further lower resistance, Kelvin double bridge is suitable.

Ohm meter

Diagram:



Procedure:

- Terminals A and B are shorted together
- Maximum current is adjusted by Rsh to flow through meter which depends upon Rx.
- This corresponds to zero resistance.
- The terminals are left open. No current flows through the circuit. Therefore no movement of pointer. This corresponds to maximum resistance (infinity).
- Based on this, the instrument is calibrated to indicate the resistance.

Types:

Series type ohmmeter
Shunt type ohmmeter
Cross-coil ohmmeter

Advantage: simple, convenient, and fast method.

Disadvantage: accuracy is of low order.

High resistance

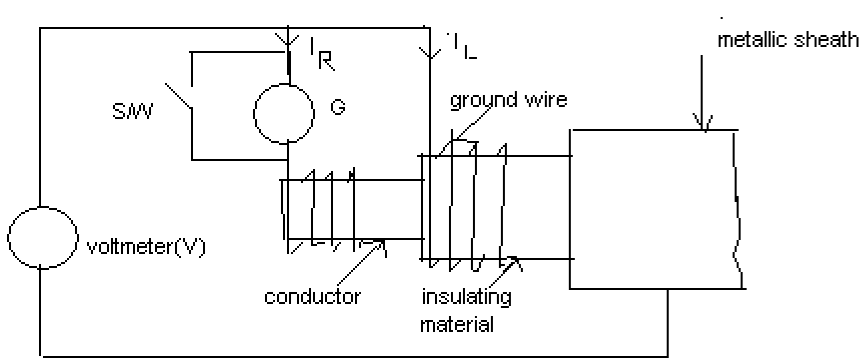
Methods:

- Direct deflection method
- Loss of charge method
- Mega ohm bridge
- Megger

Direct deflection method

Purpose: measurement of high resistance such as insulation resistance of cables.

Diagram:



Explanation:

- Galvanometer G measures current Ir between the conductor and metal sheath.
- Leakage current Il over the insulating material is carried by guard wire wound on the insulation
- Cables without metal sheaths can be tested in a similar way by immersing the cable ends, on which connection are made, in water in a tank.
- The water and tank then form the return path for the current.

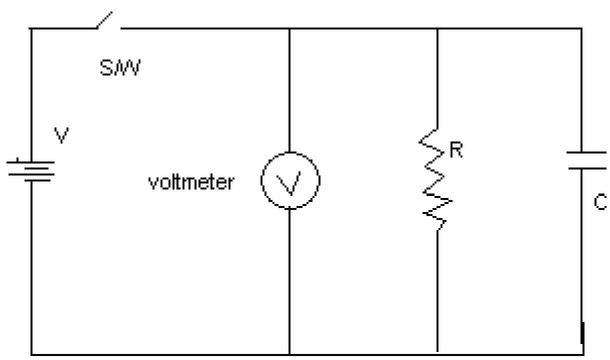
Insulation resistance of cable, $R=V/ I_R$

Requirements:

- A high voltage source500V emf is required.
- A protective series resistance is included
- Galvanometer is short circuited to avoid existence of charging and absorption current.
- The value of protective resistance is subtracted to get true value.

Loss of charge method

Diagram:



Construction:

- R, an unknown resistance is connected in parallel with a capacitor C and electrostatic voltmeter.
- A battery with emf V in parallel with R and C.

Operation:

- Capacitor is charged to suitable voltage by battery.
- Then allowed to discharge through resistance.
- Terminal voltage is observed over a considerable period of time during discharge.
- After application of voltage, Voltage across capacitor at any instant ‘t’

$$v = Ve^{(-t / CR)}$$

or, $V/v = e^{t/CR}$

or, $\log_e V/v = t / CR$

or, $R = t / [C \log_e V/v]$

$= 0.4343\, t / [C \log_{10} V/v]$

Results:

- If R is very large, time for appreciable fall in voltage is very large.
- Care is to be taken while measuring V and v i.e. voltage at beginning and end of time ‘t’
- Error in V/v
- Better results by change in voltage (V-v) directly and calculating R as

$R=0.4343\, t / [C \log_{10} V/(V-e)]$

Where, V-v=e

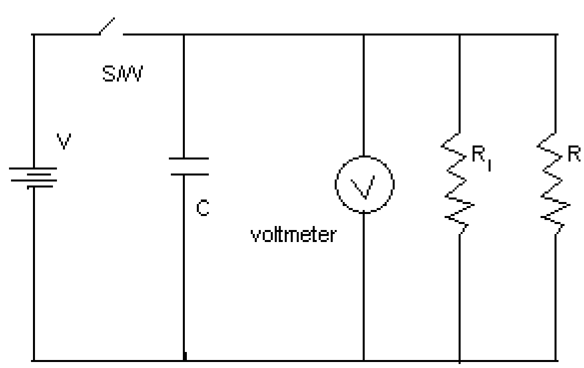
- This method is applicable to high resistance.
- It requires capacitor of high leakage resistance.

Shortcomings:

- True value of R is not measured as Rv , voltmeter resistance and leakage resistance of capacitor considered to be infinite.

Correction:

Two resistances are taken into account.



- First if R’----equivalent resistance of R1 and R

Then discharge eqn gives

$R' = 0.4343\, t / [C \log_{10} V/v]$ ________________ (1)

- Secondly test is repeated with R disconnected, capacitor discharge through R1,.

- R1 is obtained from here is substituted in eqn (1) which gives

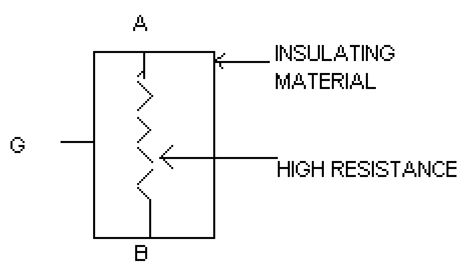
$$\frac{RR1}{R+R1} = 0.4343\, t / [\ C \log_{10} V/v\ ]$$

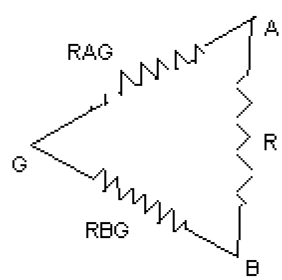
Mega ohm bridge

Introduction:

During measurement of high resistance, the leakage comes into effect over and around the specimen being measured.
The effect of leakage paths is removed by some form of guard circuit.

Concept of guard circuit:





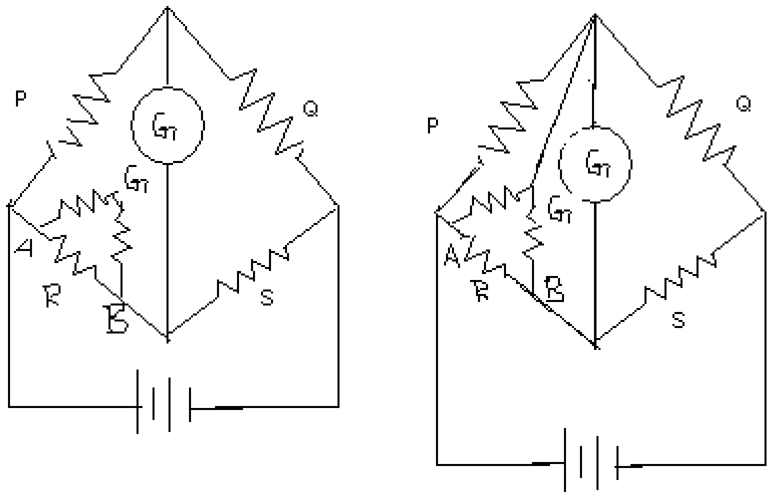
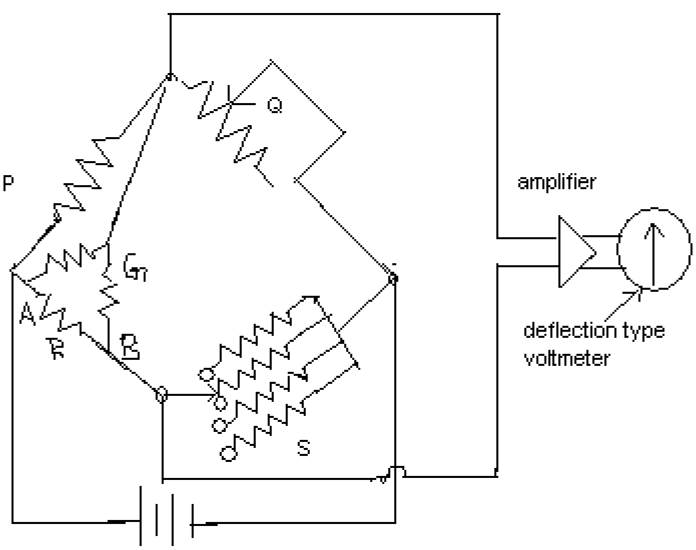


Diagram of mega ohm bridge:



Sensitive null indicating arrangement

Construction:

- Fixed resistance P
- Guard circuit AGB
- Variable resistance Q
- Standard adjustable resistance S
- Amplifier

- Deflection type voltmeter

Explanation:

The bridge is shown in the fig. The unknown resistance is connected across terminals AB with proper guard circuit arrangement.
When the unknown resistance is equal to the standard resistance S, the output given to the amplifier is zero and so the voltmeter which is a null type voltmeter would not deflect. Thus the standard resistance S value is equal to the unknown resistance. The adjustment is done with the help of S.

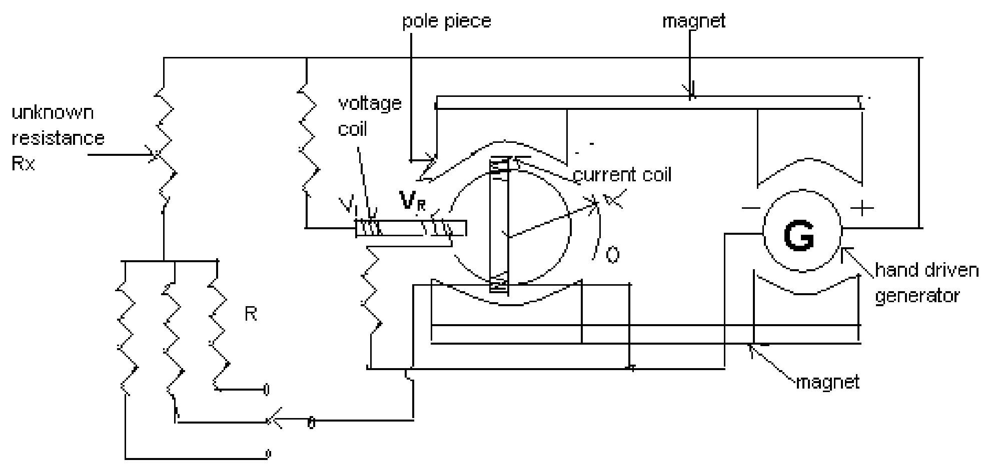
<u>Megger</u>

Purpose: Measures high resistance (insulation resistance)

Construction:

- Hand cranked generator G which generates voltage of 500V,1000V, 2500V.
- A centrifugal clutch is incorporated which slips at predetermined speed so that a constant voltage is applied to insulation under test.
- Current coli similar to PMMMC
- Voltage coil V1, V2.
- Permanent magnet

Diagram:



Explanation:

- When pointer is at ∞ position, voltage coil can exert very little torque.
- Current coil is parallel to PMMC instrument
- Torque exerted by voltage coil increases as it moves into stronger field.
- When maximum, pointer is at zero.
- Current in current coil is very large, scale is at zero.
- At ∞, current is very weak.
- Voltage range can be controlled by a voltage selector switch.

AC bridges

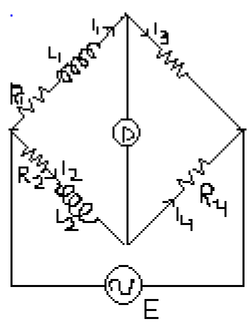
The ac bridge is a natural out growth of the Wheatstone bridge. The four arms is impedance. The battery and galvanometer are replaced by an ac source and a detector sensitive to small alternating potential difference.

Detectors commonly used are:-

Head phones
Vibration galvanometer
Tunable amplifies detector.

Headphones widely used as detectors at frequency of 250 Hz and above up to 3 or 4kHz.
Vibration galvanometer at frequency 5 Hz to 1000 Hz .commonly used below 200 Hz.

General form of AC bridge:-



R1, R2, R3, R4 are non inductive resistances.
L1, L2 are non resistive inductance.

At balance,
Z1Z4=Z2Z3
Or, (R1+jωL1) R4 = (R2 + jωL2) R3

Or, R1R4+ jωL1R4 = R2R3 + jωL2R3

Equating real and imaginary parts,
We get,

R1R4=R2R3
or, R1=R3R2 /R4

And jωL1R4= jωL2R3

Or, $L1 = R3L2/R4$

Thus if L1, R1 are unknown, the above bridge may be used to measure these quantities in terns of R2, R3, R4 and L2.

Conclusion:

- For balance in ac bridge, both magnitude and phase relationship must be satisfied. This requires that real and imaginary terms must be separated which gives two equations which is to be satisfied for balance.
- If abridge is balanced for fundamental frequency, it must be balanced for any harmonics.

Measurement of self inductance

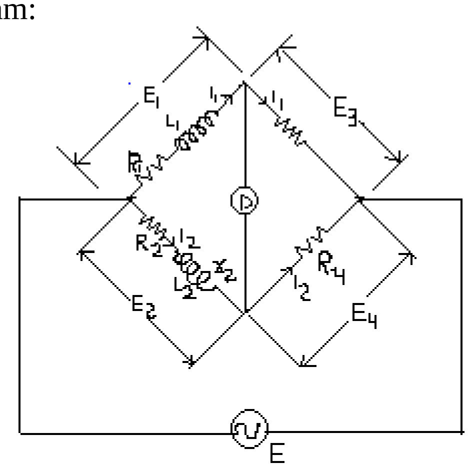
Methods:

- Maxwell's inductance bridge
- Maxwell's inductance capacitance bridge
- Hay bridge
- Anderson's bridge
- Owen bridge

Maxwell's inductance bridge

Purpose: It measures unknown inductance by comparing with a variable standard self inductance.

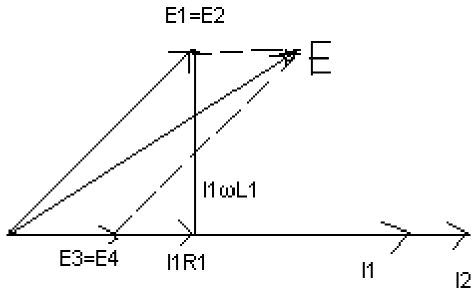
Connection Diagram:



L1 ---- unknown inductance of resistance R1

L2 ---- variable inductance of fixed resistance r2
R2 ---- variable resistance connected in series with inductor L2.
R3, R4 ----- known non inductive resistances.

Phasor diagram:



Balance equation:
At balance:
(R1+jωL1)R4 = R3 [(R2+r2) + jωL2]

Or, R1R4 + jωL1R4= R3(R2+r2) + jωL2R3

Or, R1= R3 (R2+r2)/ R4
And L1= R3L2/R4

Note: In some cases an additional known resistance may have to be inserted in series with unknown coil in order to obtain balance.

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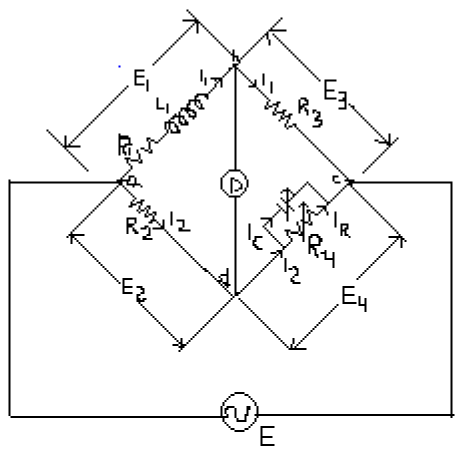
Maxwell's inductance capacitance bridge

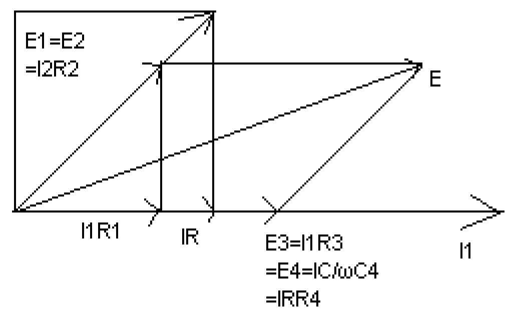
Purpose: In this bridge, inductance is measured by comparison with a standard variable capacitance.

Connection Diagram:



L1=unknown inductance
R1=effective resistance of inductor L1
R2,R3, R4= known non-inductive resistance
C4=variable standard capacitor.

Phasor diagram:



Balance equation: at the point of balance:
$(R1+ j\omega L1)$ [$R4 / (1+ j\omega C4R4) = R2R3$

Or, $R1R4 + j\omega L1R4= R2R3 + j\omega R2R3R4C4$

Equating real and imaginary parts,

$R1R4=R2R3$

Or, $R1 = R2R3/ R4$

And $L1R4= R2R3R4C4$

Or, $L1 = R2R3C4$

And Q factor $= \omega L1/ R1 = \omega R2R3C4/ R1$

$$= \frac{\omega R2R3C4}{\frac{R2R3}{R4}} = \omega R4C4$$

Q factor $= \omega R4C4$

Advantage:

- Balance equations are independent if C4 and R4 are variable.
- Frequency does not effect the calculation of unknown variable.
- Simple expressions for unknown L1 and R1 in terms of known bridge elements.
- Maxwell's inductance-capacitance bridge is very useful for measurement of wide range of inductance at power and audio frequency.

Disadvantage:

- Variable capacitor is expensive and less accurate. So fixed capacitor is sometimes used. In that case balance adjustments are done by-
    1. Varying R2 and R4, which is difficult.
    2. Putting an additional resistance in series with inductance under measurement and varying this resistance and R4.

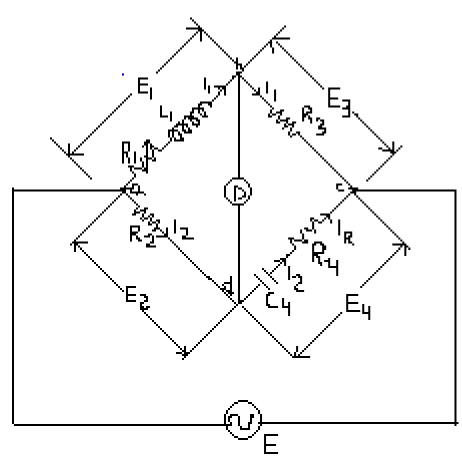
- Limited to measurement of low Q coil (1< Q< 10) also unsuitable for very low Q (Q<1)

Note: Maxwell's bridge is suitable for measurement of only medium Q coils.

Hay Bridge

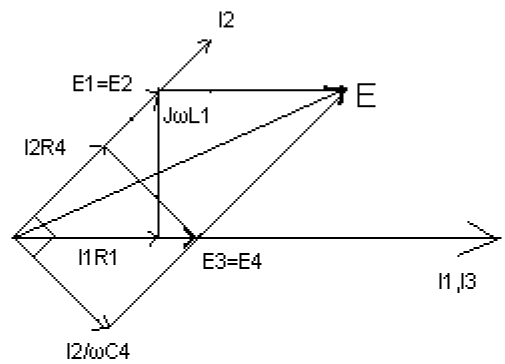
- It is modification of Maxwell's bridge
- Uses resistance in series with standard capacitor.

Connection Diagram:



L1= unknown inductance having a resistance R1
R2, R3, R4 = known non-inductive resistances.
C4=standard capacitor.

Phasor diagram:



Balance equaton:

(R1+ jωL1)(R4- j/ ωC4) = R2R3
Or, R1R4 +L1 + jωL1R4 – jR1/ωC4 = R2R3

Separating real and imaginary parts,

R1R4 +L1/C4 =R2R3 ———————— (1)
And L1=R1/ ω^2R4C4 ———————— (2)

Solving the equations (1) &(2),
We get,
L1=R2R3C4 / [1+ $\omega^2 R_4^2 C_4^2$]

And R1= ω^2 R2R3 R4 C_4^2 / [1+ $\omega^2 R_4^2 C_4^2$]

Q factor of coil, Q= ωL1/ R!= 1/ ωC4R4

Results:

The expression for inductance and capacitance contains frequency terms. So frequency should be known accurately.
Now,
L1=R2R3C4 / [1+ $\omega^2 R_4^2 C_4^2$]
But, Q= 1/ ωC4R4

Therefore,
L1= R2R3C4/ [1+ $(1/Q)^2$]

So for Q> 10, the term $(1/Q)^2$ < 100. Which is neglected.
Therefore, this method is suitable for Q > 10 or higher. Under such cases, L1=R2R3C4.

Advantages:

- Simple expression for inductance of Q>10 and higher.
- Simple expression for Q factor.
- This bridge requires low value resistor for R4 as Q=1/ ωC4R4 for higher Q., R4 is smaller.

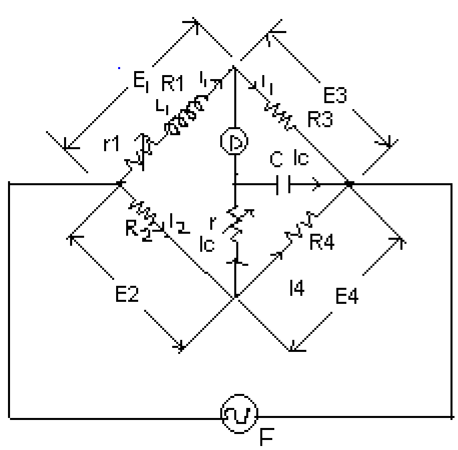
Disadvantage:

Not suitable for measurement of coils having Q < 10.

<u>Anderson's bridge</u>

- Modification of Maxwell's inductance-capacitance bridge
- Inductance measured in terms of a standard capacitance.
- Applicable for precise measurement of self inductance.

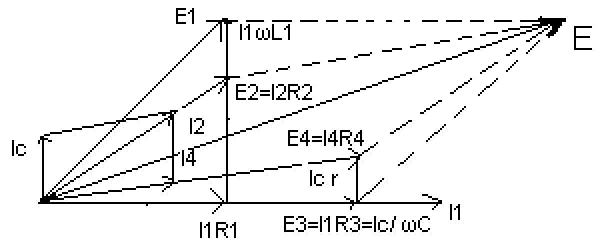
Connection Diagram:



L1=self inductance to be measured
R1=resistance of self inductance
r1= resistance in series with L1
r, R2,R3,R4=known non-inductive resistances

c=fixed –standard capacitor

Phasor diagram:



Balance equation:

At balance, I1=I3 and I2=I4+Ic

Now, I1R3=Icx 1/ jωC

Or, Ic = I1 jωCR3 ———— (1)

Balance equations are,

I1 (R1+r1+ jωL1) =I2R2+Icr ———— (2)

And Ic (r+1/ jωC) = (I2—Ic) R4 ———— (3)

Putting the value of Ic from (1) in (2) and (3), we get,

I1R1+I1r1+ jωI1L1=I2R2 + jωCI1R3r ———— (4)

And jωCI1R3 r + I1R3 = I2R4 – jωC I1R3R4 ———— (5)

From (4),

I1 (R1+r1+ jωL1 – jωC R3 r) = R2I2 ------------------- (6)

And I1 (jωC R3 r +R3 + jωCR3R4) = R4I2 -------------(7)

Dividing (6) by (7), we get

$$\frac{R1+r1+ j\omega L1 - j\omega C\ R3\ r}{j\omega C\ R3\ r + R3 + j\omega CR3R4} = \frac{R2}{R4}$$

Or, R4 (R1 + r1) + j ω R4(L1 --- CR3 r) = R2 R3 + jω C R2 (R3 r +R3R4)

equating real and imaginary parts,

$$R4 (R1+r1) = R2R3$$

Or, $$R1 = \frac{R2R3 - R4r1}{R4} = \frac{R2R3}{R4} \text{ --- } r1$$

Or, $$R1 = \frac{R2R3}{R4} \text{ --- } r1$$

Also, $$j\,\omega\, R4 (L1 \text{ --- } CR3\, r) = j\omega\, C\, R2 (R3\, r + R3R4)$$

Or, $$R4L1 \text{ --- } CR3R4r = CR2R3r + C\, R2R3R4$$

Or, $$L1 = \frac{CR3R4r}{R4} + \frac{CR2R3r}{R4} + CR2R3$$

$$= \frac{C\, R3}{R4} [R4\, r + R2\, r + R2R4]$$

Therefore, $$L1 = \frac{C\, R3}{R4} [R4\, r + R2\, r + R2R4]$$

Conclusion:
From the eqn of 1 and L1, it is clear that adjustment of r1 and r should be done to obtain easy convergence.

Advantage:

- By manipulation of r1 and r ,they become independent and easier to obtain balance for low Q coil than Maxwell's bridge.
- Fixed capacitor I used.
- Also useful for accurate measurement of capacitance in terms of inductance.

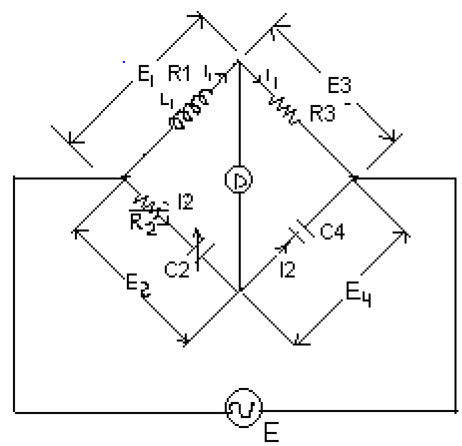
Disadvantage:

- More complex, manipulation and circuits.
- Additional junction point increases difficulty of shielding the bridge.

Owen's bridge

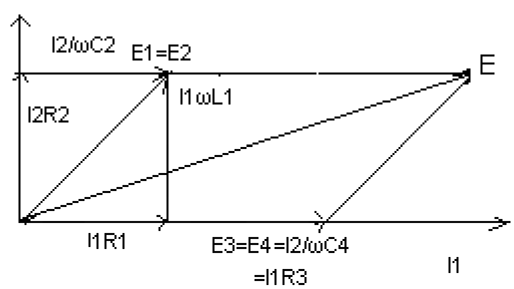
Purpose: measures inductance in terms of capacitance.

Connection Diagram:



L1=unknown self-inductance of resistance R1
R2=variable non inductive resistance
R3=fixed non-inductive resistance
C2=variable standard capacitor
C4=fixed standard capacitor.

Phasor diagram:



Balance equation:
At balance,
(R1 + jωL1) (1/ jωC4) = (R2 + 1 / jωC2) R3

Or, -- jR1/ ωC4 + L1/ C4 = R2R3 – j R3 / ωC2

Equating real and imaginary parts,
L1/ C4 = R2R3

Or, L1= C4R2R3

And,

$R1/ \omega C4 = R3 / \omega C2$

Or, $R1 = R3C4/ C2$

Advantage:

- Convergence to balance condition is much easier as R2 and C2 the variable elements are in same form.
- Balance equations are simple and do not contain any frequency component
- Used over a wide range of measurement of inductance.

Disadvantage:

- Requires a variable capacitor which is expensive
- When Q is high, C2 tends to become rather large.

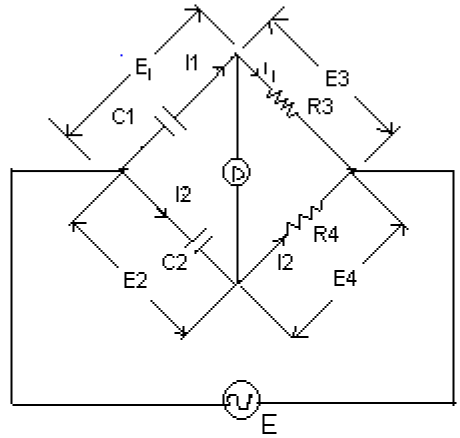
Measurement of capacitance

Methods:
De Sauty's bridge
Schering Bridge

De Sauty 's bridge

Principle: Based on comparing two capacitors

Connection Diagram:



C1= capacitor to be measured
C2=A standard capacitor
R3, R4=non-inductive resistors

At balance,
$(1/\omega C1) \times R4 = (1/\omega C2) \times R3$

Or, $C1 = C2 \times R4 / R3$

The balance is obtained by varying either R3 or R4.

Advantage:
Simple and easy method.

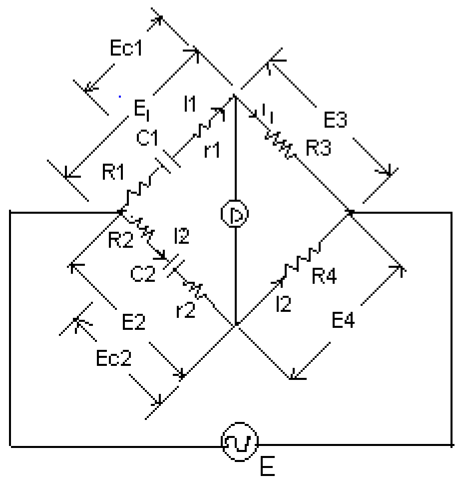
Disadvantage:

- It is impossible to obtain balance if both the capacitors are not free from dielectric loss.

Use: suitable for air capacitor only.
Remedy: to overcome the problem with dielectric loss , the bridge is modified.

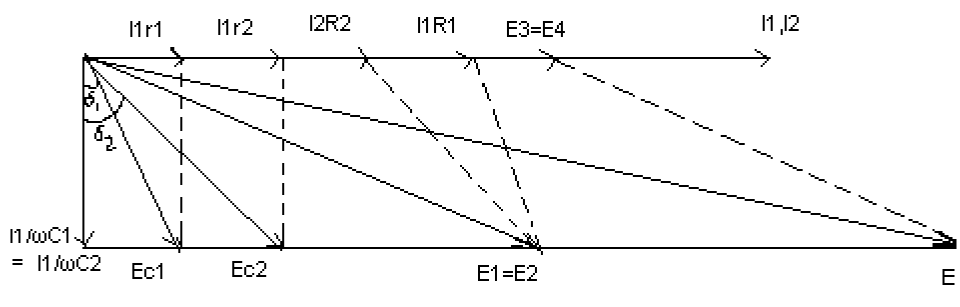
Modified De Sauty's bridge

Connection Diagram:



- R1, R2 are connected in series with C1 and C2 respectively.
- r1, r2 are small resistance representing loss component of the capacitor.

Phasor diagram:



Balance equation;

$(R1+r1+1/ j\omega C1\ ) R4 = (R2 +r2+1/ j\omega C2) R3$

Or, $(R1+r1)R4 - j\, R4/ \omega C1 = (R2+r2)R3 - jR3/ \omega C2$

Equating real and imaginary parts,

$(R1+r1)R4=(R2+r2)R3$-----------(1)
And $R4/ \omega C1 = R3/ \omega C2$

Or, $C1/C2=R4/R3$-----------(2)

Again from (1),

$$R4/R3 = \frac{R2+r2}{R1+r1} \text{-------------(3)}$$

From (1) ,(2),(3),

$$C1/C2 = R4 /R3 = \frac{R2+r2}{R1+r1} \text{-------------(4)}$$

Balance is obtained by varying R1,R2,R3,R4.

$\delta 1$ ----- phase angle of C1

$\delta 2$ ------ phase angle of C2

Dissipation factor for C1=D1=tan $\delta 1 = \omega C1r1$ ------------(5)

Dissipation factor for C2 = D2= tan $\delta 1 = \omega C2r2$ ----------(6)

From (4),

$$C1/C2 = \frac{R2+r2}{R1+r1}$$

Or, C2R2 +C2r2 =C1R1 +C1r1

Or, C2r2 – C1r1 = C1R1 – C2R2

Or, $\omega C2r2 - \omega C1r1 = \omega(C1R1 -- C2R2)$

Or, $D2 - D1 = \omega (C1R1 -- C2R2)$

Again,
C1/C2 = R4/R3

$$\text{Therefore, } D2 - D1 = \omega \left[\frac{C2 .R4. R1}{R3} \text{ -- } C2R2 \right]$$

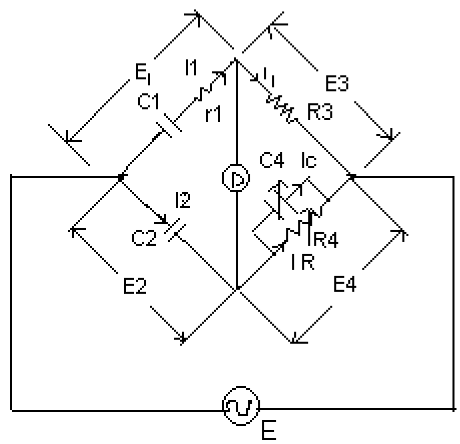
$$= \omega\, C2 \left[\frac{R4. R1}{R3} \text{ -- } R2 \right] \text{---------- (7)}$$

From, (7)
if dissipation factor of one of the capacitor is known, dissipation factor of other can be determined.

Results: does not give accurate results i.e. dissipation factor.

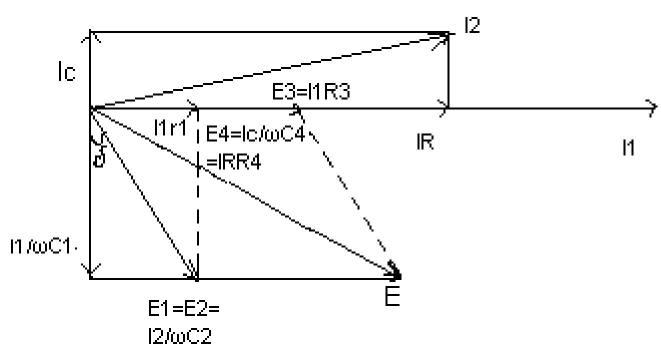
Schering bridge

Connection Diagram:



C1=capacitor to be measured.
R1=a series resistance representing loss in C1.
C2= a standard capacitor. It is an air or gas capacitor and hence loss free.
R3 = a non –inductive resistance.
C4=a variable capacitor.
R4= a variable non non inductive resistance in parallel with C4.

Phasor diagram:



Balance equation:

$$(R1+1/j\omega C1)\left[\frac{R4}{(1+j\omega C4R4)}\right] = 1x\ R3/j\omega C2$$

$$\text{Or, } (r1+1/j\omega C1) \cdot R4 = \frac{R3}{j\omega C2}[1+j\omega C4R4]$$

$$\text{or, } r1\,R4 - j \times R4/\omega C1 = -j \times R3/\omega C2 + \frac{R3R4C4}{C2}$$

Equating real and imaginary parts,

$$r1R4 = \frac{R3R4C4}{C2}$$

Or, $r1 = C4R3/C2$

And $R4/C1 = R3/C2$

Or, $C1 = C2\,R4/R3$

Dissipation factor, $D1 = \tan\delta = \omega C1\,r1 = \omega \cdot \frac{R4}{R3}.C2.\frac{C4}{C2}.R3$

Or, $D1 = \omega C4\,R4$

Balancing is done by adjustment of R2 and C4 with C2,R4 fixed.

Advantage:

- As C1=R4C2/R3 and C2, R4 fixed. The dial of R3 may be calibrated to read capacitor directly.
- In case fixed of frequency fixed, dial of capacitor C4 can be calibrated to read dissipation factor directly as $D1 = \omega C4R4$

Disadvantage:

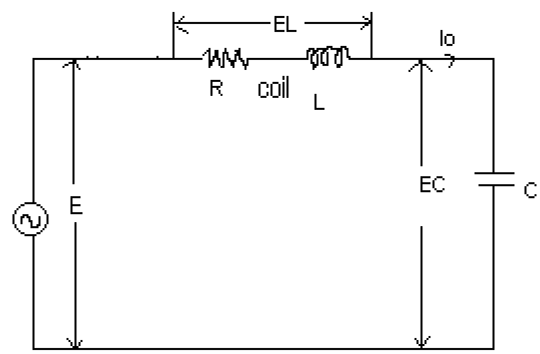
Difficulty in obtaining balance as R3 appears in both equations.

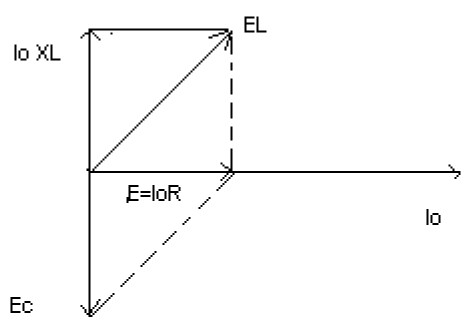
Q meter

- It is an instrument which is designed to measure the value of Q directly. Therefore it can measure the characteristic of coils and capacitors.

Principle of working:

It is based on principle of resonant R,L ,C series circuit.





At resonant frequency f_o ,

$X_c = X_L$, ----------- (1)

$X_c = 1/ 2\pi f_o c = 1/ \omega_o c$

$X_L = 2\pi f_o c = \omega_o L$

From (1),

$1/\omega_o c = \omega_o L$
Or, $\omega_o^2 = 1/LC$

Or, $f_o = \dfrac{1}{2\pi\sqrt{LC}}$

And $I_o = E/R$

Voltage across capacitor, $E_c=I_oX_c=I_oX_L=I_o\,\omega_o\,L$

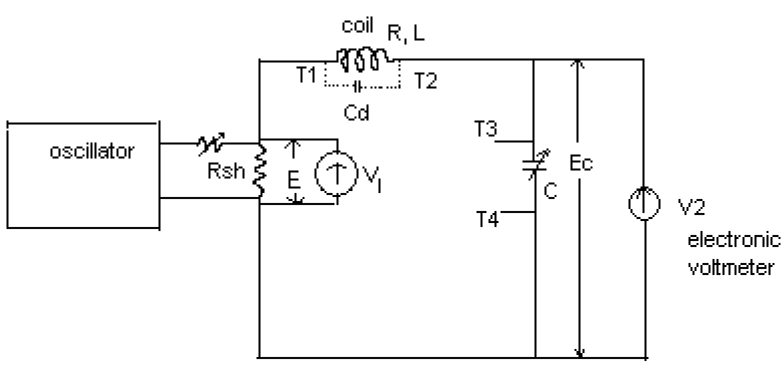
Input voltage, $E=I_oR$

Therefore, $E_c/E= I_o\,\omega_o\,L/\,I_oR = \omega_o\,L/R =Q$.

$E_c =Q\,E$

Thus the input voltage E is magnified by Q times and appears across the capacitor. A voltmeter connected across the capacitor can be calibrated to read the value of Q directly.

Practical circuit:



R_{sh} --- low value shunt resistor.
V1--- thermocouple voltmeter
V2--- electronic voltmeter
T1, T2---terminal across which coil is connected.
C---tuning capacitor.
T3, T4--- terminal across which tuning capacitor is connectd.
C_d—distributed capacitor.

Construction:

The practical circuit consists of a self contained variable frequency RF oscillator. This oscillator injects voltage E into the circuit through small resistance R_{sh}. Voltmeter V1 reads injected voltage. The injected voltage is magnified across capacitor c. this magnified voltage is read by V2.

Therefore, Ec=QE

The voltmeter V2 is calibrated to read Q directly.

Application:

(1) Measurement of Q:

The voltage V2 across capacitor is given by V2=QV1. The voltmeter across capacitor is calibrated to read Q directly.
This Q represents Q of entire circuit. So error exists.
Cause:

- On account of shunt resistance.
- Due to distributed capacitance of the circuit.
-

Correction for shunt resistance:

$$Q_{measured} = \frac{\omega_o L}{R + R_{sh}}$$

$$Q_{true} = \omega_o L/R = \frac{Q_{measured}\,(R+R_{sh})}{R}$$

$$=Q_{measured}\,(1 + R_{sh}/R)$$

Therefore,

$$Q_{measured} = \frac{Q_{true}}{1 + Rsh/R} = Q_{true}\,(1 - R_{sh}/R)$$

Therefore measured value of Q is smaller than true value.

Results:

For low Q coils (high resistance)--- R_{sh}/R is negligible
$Q_{measured} = Q_{true}$.

For high Q coils (low resistance)—
Error caused may be serious.

Correction for distributed capacitance:

It can be shown,
$Q_{true} = Q_{measured}\ (1+C_d / C)$

Thus measured value of Q is less than true value.
(2) Measurement of inductance:
We know,
$f_o = 1/ 2\pi\sqrt{LC}$

$$\text{or,}LC = \frac{1}{4\pi^2 fo^{\ 2}}$$
$$\text{or, } L = \frac{1}{4\pi^2 fo^{\ 2} C}$$

f_o and C are known, L can be calculated easily.

(3) Measurement of effective resistance:
effective resistance ,R=_ωo L /Q_{true}

(4) Measuernent of self capacitance:

Case 1:
1. capacitor is set to high value (C_1)
2. circuit is set to resonance by adjustment of oscillator frequency (f_1)
3. resonance indicated by Q meter
4. $\therefore f_1 = \dfrac{1}{2\pi\sqrt{L(C_1 + C_d)}}$ -----------------(1)

case2:
Frequency is doubled i.e. $f_2=2f_1$-----------(2)
Resonance is obtained by adjustment of tuning capacitor (C2)

$$\therefore f_2 = \frac{1}{2\pi\sqrt{L(C_2 + C_d)}} \text{---------------------(3)}$$

From (1),(2),(3), we get,
$f_2=2f_1$

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

$$or, \frac{1}{c_2 + c_d} = \frac{4}{c_1 + c_d}$$

$$or, c_1 + c_d = 4c_2 + 4c_d$$

$$or, c_d = \frac{c_1 - 4c_2}{3}$$

(5) Measurement of capacitance:

- connect dummy coil across T_1 and T_2
- resonance is set by varying C (let it is C1)
- Insert capacitor under test (C_T) across T3 and T4.
- resonance is set up by varying C (let it is C2)

Therefore capacitor under test, C_T =C1-C2

Measurement of Resistance of Insulating Materials

insulation resistance (IR) test (also commonly known as a Megger) is a spot insulation test which uses an applied DC voltage (typically either 250Vdc, 500Vdc or 1,000Vdc for low voltage equipment <600V and 2,500Vdc and 5,000Vdc for high voltage equipment) to measure insulation resistance in either kΩ, MΩ or GΩ. The measured resistance is intended to indicate the condition of the insulation or dieletric between two conductive parts, where the higher the resistance, the better the condition of the insulation. Ideally, the insulation resistance would be infinite, but as no insulators are perfect, leakage currents through the dielectric will ensure that a finite (though high) resistance value is measured.

Because IR testers are portable, the IR test is often used in the field as the final check of equipment insulation and also to confirm the reliability of the circuit and that there are no leakage currents from unintended faults in the wiring (e.g. a shorted connection would be obvious from the test results).

One of the advantages of the IR test is its non-destructive nature. DC voltages do not cause harmful and/or cumulative effects on insulation materials and provided the voltage is below the breakdown voltage of the insulation, does not deteriorate the insulation. IR test voltages are all well within the safe test voltage for most (if not all) insulation materials.

Contents

[hide]

Test Equipment

IR test set (courtesy ofMegger)

The Megger company were the original manufacturers of IR test equipment over 100 years ago and have become synonymous with insulation resistance testing. Most modern IR testers are digital, portable / handheld units and some have multi-functional capabilities (e.g. built-in continuity testing).

Test Procedure

Firstly ensure that the equipment to be tested and the work area is safe, e.g. equipment is de-energised and disconnected, all the relevant work permits have been approved and all locks / tags in place.

Next, discharge capacitances on the equipment (especially for HV equipment) with static discharge sticks or an IR tester with automatic discharging capabilities.

The leads on the IR tester can then be connected to the conductive parts of the equipment. For example, for a three-core and earth cable, the IR test would be applied between cores (Core 1 to Core 2, Core 1 to Core 3 and Core 2 to Core 3) and between each core and earth. Similarly for three-phase motors, circuit breakrs, switch-disconnectors, etc the IR test can be applied at the equipment terminals (and earth connection).

Note that when applying an IR test to earth, it is good practice to connect the positive pole of the IR tester to earth in order to avoid any polarisation effects on the earth.

Once connected, the IR tester is energised for a typical test duration of 1 minute. The IR test measurements are recorded after 1 minute.

When the IR test is finished, discharge capacitances again for a period of 4-5 times the test duration.

Interpretation of Test Results

The minimum values for IR tests vary depending on the type of equipment and the nominal voltage. They also vary according to international standards. Some standards will define the minimum IR test values for the general electrical installations.

For example, for low voltage installations in the IEC world, IEC 60364-6 [1] Table 6A gives the minimum IR values and also suggests test voltage, i.e.

Nominal Circuit Voltage (Vac)	Test Voltage (Vdc)	Insulation Resistance (MΩ)
Extra low voltage	250	≥ 0.5
Up to 500V	500	≥ 1.0
Above 500V	1,000	≥ 1.0

In the ANSI/NEC world, the standard ANSI/NETA ATS-2009 [2] provides test procedures and acceptance levels for most types of electrical equipment. Table 100.1 provides representative acceptance values for IR test measurements, which should be used in the absence of any other guidance (from the manufacturer or other standards):

Nominal Equipment Voltage (Vac)	Min Test Voltage (Vdc)	Min Insulation Resistance (MΩ)
250	500	25
600	1,000	100
1,000	1,000	100
2,500	1,000	500
5,000	2,500	1,000
8,000	2,500	2,000
15,000	2,500	5,000
25,000	5,000	20,000

34,500 and above	15,000	100,000

NFPA 70B [3] also provides some guidance on insulation resistance testing for different types of equipment.

Factors Affecting Test Results

There are two main factors that will affect IR test results:

Temperature

Electrical resistance has an inverse exponential relationship with temperature, i.e. as temperature increases, resistance will decrease and vice versa. Since the minimum acceptable IR test values are based on a fixed reference temperature (usually 20^oC), the measured IR test values must be corrected to the reference temperature in order to make sense of them.

As a rule of thumb, the resistance halves for every 10^oC increase in temperature (and vice versa). So if the measured IR test value was $2M\Omega$ at 20^oC, then it would be $1M\Omega$ at 30^oC or $4M\Omega$ at 10^oC.

ANSI/NETA ATS-2009 Table 100.14 provides correction factors for IR test measurements taken at temperatures other than 20^oC or 40^oC, which were in turn based on the correction factors in the freely available Megger book "A stitch in time..." [4].

Humidity

The presence (or lack) of moisture can also affect the IR test measurements, the higher the moisture content in the air, the lower the IR test reading. If possible, IR tests should not be carried out in very humid atmospheres (below the dew point). While there are no standard correction factors or guidance for humid conditions, it is good practice to record the relative humidity of each IR test so that they can be used for baseline comparisons in future tests. For example, having past data on the IR test values for dry and humid days will give you a foundation for evaluating future test values

MODULE-II

ELECTRONIC COUNTERS

Frequency Counters

Electronic counters are extensively used for measuring the frequency (number of occurrence of an
event in a given time), time period of an event and time interval between two events. Most digital
voltmeters generate a time-interval related to the level of the input voltage first. Then, they measure
that interval and display it.

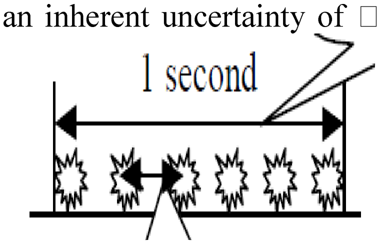
Time and Frequency Measurements

Operational Modes of Counters

Electronic counters are extensively used for measuring the frequency (number of occurrence of an event in a given time), time period of an event and time interval between two events. They display the results directly in digital forms that can be easily read by the user. The counters work in three operational modes as:

□ the frequency,
□ time-period and
□ time-interval.

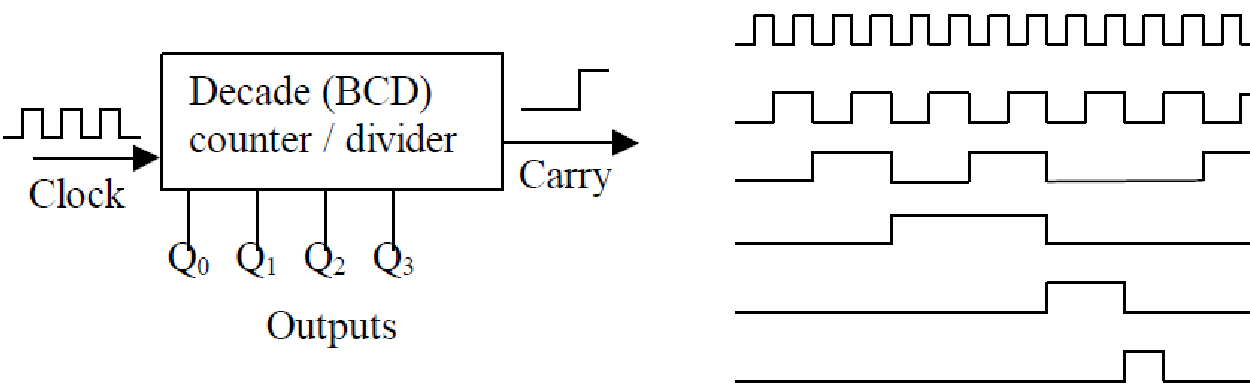
The number of occurrences of event over the time of observation (i.e. 6 events per
second). All digital displays have an inherent uncertainty of □1 digit in the



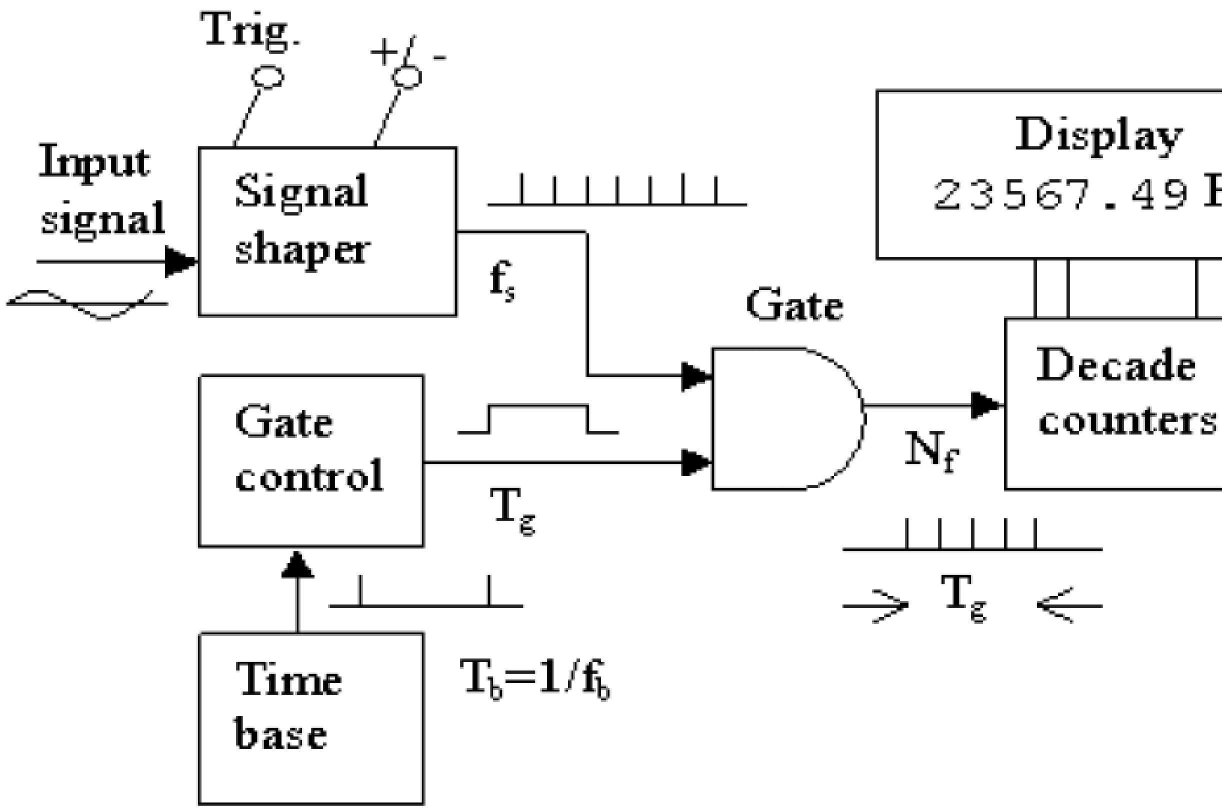
last digit of the
display. If the number displayed is small, this uncertainty causes large reading errors. Therefore, this mode is useful at high frequencies The inverse of the time-period (i.e. one explosion every 100 millisecond). This is useful at low frequencies. Some counters automatically switch to this mode as the low frequency ranges are selected. The period is measured and inverted usually by digital techniques and the displayed result is the frequency. New counters contain microprocessors that perform this operation easily.

Following elements are common in all modes of counters:
The magnitude of the input signal is not important. The periodic input signal is converted into a pulse sequence by the signal shaper, which is composed of a comparator and a pulse generator. Here, AC/DC coupling, trigger level and polarity settings are available as in the case of the oscilloscope. There is no amplitude range selection except a divide by ten (20 dB) attenuator to reduce the amplitude of the input signal to a safe level for high-amplitude inputs.

- All measurements are related to the timing information coming from an internal time-base. Therefore, a very stable time base is an essential element of the counter. Calibration of the time-base circuits may be achieved by using special frequency standards based on tuning forks, crystal oscillators or with NBS (National Broadcasting Society) standard broadcast frequencies.
- A control gate sets the duration of the counting and refresh rate (the frequency of repeating the measurement).
- They mostly use 7-segment light emitting diode (led) or liquid crystal (lcd) type displays. Depending upon the frequency range of operation, there may be six to eight digits displayed. Decimal counters are used to accumulate (count) incoming pulses from the pulse gate and generate a binary coded decimal (BCD) code at the output as illustrated in Figure. The code ranges from 0000 to 1001 corresponding to decimal "0" and "9" incrementing with every input pulse. With the 10th pulse, the code returns to 0000 and the counter provides a carry pulse to the next stage. At the end of the counting session, the code accumulated in the counters is transferred to a digital latch that holds it until the end of the next counting session. Counters are cleared automatically after the data is transferred to the latch. The user can also clear them during initialization. This code stored in the latch is applied to the display through BCD to 7-segment decoders and displayed as decimal numbers. The display also incorporates annotations for the time units (□s, ms, and s) and frequency units (Hz, kHz, and MHz). The time-base and/or gate control switches set the position of the decimal point.



The Counter in Frequency Mode



Block diagram of the counter in frequency mode

Principle of Operation

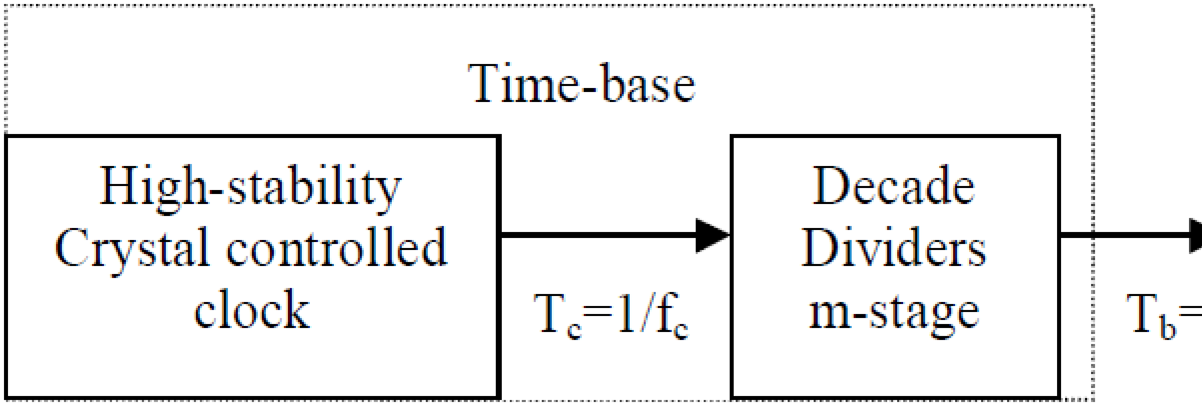
Figure shows the block diagram of a counter set to the frequency mode of operation. The timebase
circuitry provides the start and stop pulses for the pulse gate. The pulses generated from the input signal via the signal shaper are counted. The duration of the gate signal (*Tg*) is equal to the period of the time base signal (*Tb*).

Number of pulses counted N=Tg* fs

f_s being frequency of the input signal. Commonly used values for T_b are 0.1 s, 1 s, and 10 s.

The Time Base

Accuracy of the measurement is directly affected by the uncertainty in gating. Hence, a time-base with high accuracy, precision and long-term stability is essential. This is managed via a high stability clock circuit that runs at frequency *fc*



Block diagram of the time-base

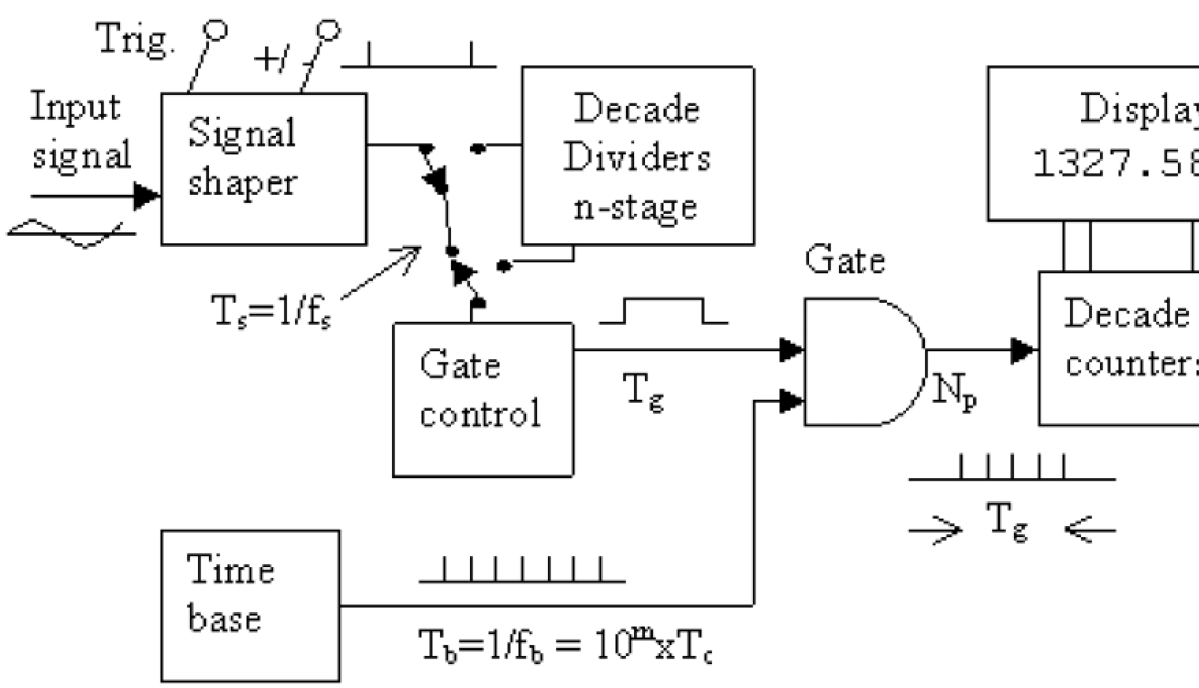
In some counters, the divider ratio is indicated at the time-base selector switch. Finally, the frequency of the input (f_s) is determined from the number displayed (N_f) and time-base setting (10_m) as:

$$f_s = \frac{N_f}{T_b} = \frac{N_f}{10^m} f_c$$

The decimal point automatically moves in between appropriate digits and respective frequency unit is also highlighted
to ease the reading as mentioned above.

The Counter in Time-Period Mode

Principle of Operation



Block diagram of the counter in time-period mode

In the period mode, the input signal provides the gating and the time-base supplies the pulses for counting as shown in Figure . The number of pulses counted:N=fb*Tg.

$$T_s = \frac{N_p}{f_c} \times 10^m$$

Hence, 10m becomes the multiplier in case of the period measurement. Period measurement is preferred to frequency measurement in determining lower frequencies. The read-out logic is designed to automatically positioned the decimal point and display the proper unit.

The Counter in Time-Interval Mode

The phase-angle (shift) between two signals may be determined by measuring the time interval between similar points on the two waveforms. Figure 4.40 illustrates the principle diagram of the measuring set-up. Both inputs contain signal shapers that generate pulses corresponding to the trigger pick-off. One of the pulse controls the starting of the counting while the other one stops the counting. Trigger levels and slopes may be different for both channels. A common-separate switch (Cm / Sep) allows utilization of the same signal for both channels and with different trigger settings; the time between sections of the same waveform can be measured. This is especially important in determining the pulse duration and rise-time of the signal.

HARMONIC DISTORTION ANALYZERS

22·28. Introduction. Another measurement which provides information on the wa of an alternating voltage or current is the harmonic distortion This type of measurement is testing of amplifiers and networks as to what extent they distort the input signal.

A measure of the distortion represented by a particular harmonic is simply the amplitude of harmonic to that of fundamental. Harmonic distortion (HD) is then represente

$$D_2 = \frac{E_2}{E_1},\ D_3 = \frac{E_3}{E_1},\ D_4 = \frac{E_4}{E_1}$$

where D_n (n=2, 3, 4……) represents the distortion of nth harmonic and E_n represents the am of nth harmonic. E_1 is the amplitude of the fundamental.

The total harmonic distortion or distortion factor is defined as

$$D = \sqrt{D_2^2 + D_3^2 + D_4^2 + \ldots\ldots} = \frac{\sqrt{E_2^2 + E_3^2 + E_4^2 \ldots\ldots}}{E_1}$$

Percentage harmonic distortion

$$= \sqrt{D_2^2 + D_3^2 + D_4^2 + \ldots} \times 100 = \frac{\sqrt{E_2^2 + E_3^2 + E_4^2 + \ldots}}{E_1} \times 100$$

The harmonic distortion can be computed from the measurements of wave anal
described earlier. However instruments are available whereby the distortion can b
directly.

22·29. **Distortion Meters.** These instruments operate on the principle of firs
the rms value of the total wave (fundamental plus harmonics) and then removing the f
component by means of a highly selective filter circuit and measuring the rms value of
only. A block diagram of a distortion meter of this type is shown in Fig. 22·23. F
value of the total wave is measured with selector switch in position 1 and the circuit is
that the meter reads 100%. The selector switch is then put to position 2. This cuts

which rejects the fundamental frequency component, and meter reads the rms value of the
only. Thus the meter indicates the precentage distortion directly.

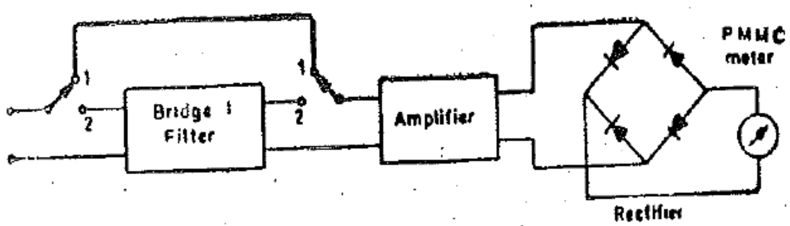


Fig. 22·23. Harmonic distortion meters.

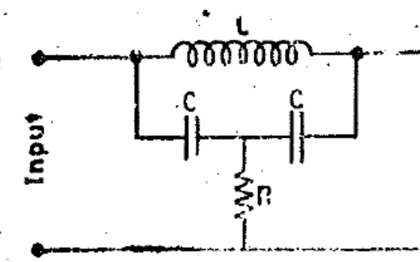


Fig. 22·24. Bridge 'T' Filter circu

A 'T' bridge circuit is commonly employed to reject the fundamental freque
circuit is shown in Fig. 22·24.

It can be shown that if the circuit is tuned to the fundamental frequency of $f_0 = 1/2\pi$
and R is adjusted to satisfy the relation $R = Q_L X_L/4$.

where $Q_L = X_L/R_L$ with R_L = resistance of inductor, the attenuation of fundamental
components is infinite under these conditions.

SPECTRUM ANALYZERS

22·30. Introduction. Spectrum analysis is defined as the study of energy distribu the frequency spectrum of a given electrical signal. The study gives valuable informa bandwidth, effects of different types of modulation and spurious signal generation. The of the above quantities and phenomena are useful in the design and testing of radio frequenc pulse circuitry.

The spectrum analysis is divided into two major categories on account of instr limitations and capabilities. They are : (*i*) Audio frequency (AF) analysis, and (*ii*) Radi (RF) spectrum analysis. The RF spectrum analysis covers a frequency range of 10 MHz and hence is more important, because it includes the vast majority of communication, radar, and industrial instrumentation frequency bands.

The spectrum analyzers are sophisticated instruments which are capable of graphically the amplitude as a function of frequency in a portion of RF spectrum. These find wide applications for measurement of attenuation, FM deviation, and freque in puls

22·30·1. Basic Spectrum Analyzer. The basic spectrum analyzer is designed t graphically, a plot of amplitude versus frequency of a selected portion of the frequency spec study. The modern spectrum analyzer basically consists of a narrow band superheterody and a CRO. The receiver is electronically tuned by varying the frequency of the local

Signal Acquisition in a Spectrum Analyzer

Most spectrum analyzers (including the models in lab) are heterodyne spectrum analyzers (also called scanning spectrum analyzers). A heterodyne analyzer is essentially a radio receiver (a very sensitive and selective reciever). Radio receivers, including those based on the heterodyne , will be covered later in lecture. For now we will provide a simple description of the basic ideas. Given a voltage signal x(t), we need to somehow extract the frequency content out of it. As we know, the digital storage oscilloscope provides one solution as it can calculate the FFT of the signal from stored samples. Another solution would be to pass x(t) through a long series of very narrow bandpass filters, having adjacent passbands, and then plot the amplitudes of the filter outputs. That is, if filter 1 has passband f1 - BW/2 < f < f1 + BW/2, and filter 2 has passband f 2 -BW/2 < f < f2 + BW/2, where f1 + BW/2 = f2 - BW/2, and so on, and if BW (the bandwidth) is small enough, then the filter outputs give us the frequency components X(f1), X(f 2), . . . and so on . This is, of course, not a practical solution. A better solution is suggested by a simple property of Fourier transforms: recall that if we multiply (in the time domain) a signal by a sinusoid, the spectrum of the signal is shifted in frequency by an amount equal to the frequency the sinusoid.

Now instead of a bank of narrow filters, we shall have one narrow filter centered at a fixed frequency, say fI, and we shall scan the signal spectrum across this filter by multiplying x(t) by a sinusoid of varying frequency f0 . See Figure 1. The filter is a narrow bandpass filter at a fixed frequency, fI, (called the intermediate frequency); in a spectrum

analyzer, its bandwidth is selected by the user. The oscillator frequency, f0, is adjustable, as indicated in Figure 1. In an ordinary AM or FM radio, when you tune the receiver you are selecting this frequency so that the signal will pass through the filter; in a spectrum analyzer, this frequency is automatically scanned (repeatedly) over a range, which must be selected so that the frequency component X(f) is shifted to fI and passed by the filter. For example, if we want to view the frequency content of x(t) from f1 to f2 , then we must select f0 to scan from f1 + fI to f2 + fI.

MODULE-III

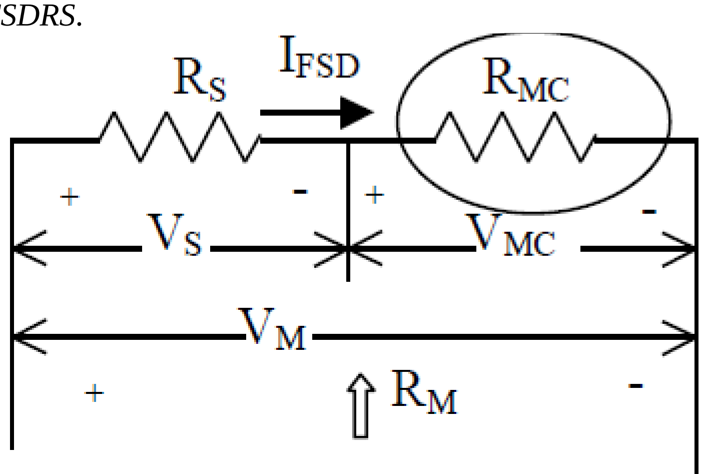
A Basic DC Voltmeter

The moving coil can be used as a voltmeter by adding a series resistance *RS* as illustrated in Figure 4.14. The input voltage is divided between the coil resistance *RMC* and *RS*. Current passing through both resistors is *IMC* which is limited by the full-scale deflection current *IFSD* of the coil. The full-scale input voltage

VM = IFSD(RS+RMC)

The input impedance seen is: *RM = RS + RMC*

However, with *RS>>RMC*, *RM* is approximately equal to *RS* and *VM* □ *IFSDRS*.



Basic DC voltmeter

AC VOLTMETERS

The voltmeter based on the permanent magnet moving coil (PMMC or D'Arsonval) and digital
voltmeter that will be discussed later cannot be directly used to measure the alternating voltages.

When measuring the value of an alternating current signal it is often necessary to convert the signal into a direct current signal of equivalent value (known as the root mean square, RMS value). This process can be quite complex. Most low cost instrumentation and signal converters carry out this conversion by rectifying and filtering the signal into an average value and applying a correction factor. Hence, we can classify the AC voltmeters in two broad categories as the averaging and true RMS types.

Average and RMS Values

The moving coil instrument reads the average of an AC waveform. The average of the current waveform i(t)

$$I_{AV} = \frac{1}{T}\int_0^T I_m \sin\omega t\,dt = 0$$

where T is the period and □ = 2□/T = radial frequency (rad/sec). However, if this current is applied to a resistor R, the instantaneous power on the resistor
p(t) = i2(t)R
The average power over the period T becomes

$$P_{AV} = \frac{R}{T}\int_0^T I_m{}^2 \sin \omega t dt = \frac{I_m{}^2 R}{2}$$

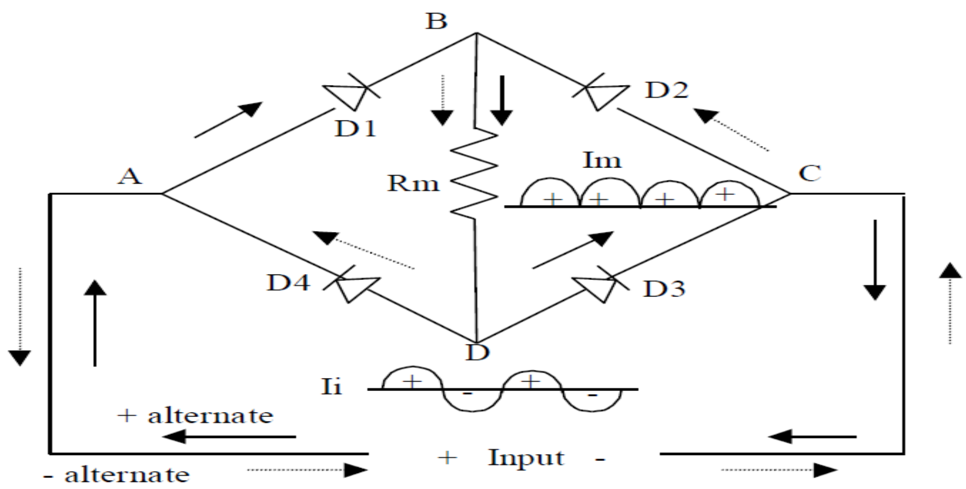
Hence, the average power is equivalent to the power that would be generated by a DC current callethe effective current that

$$I_{eff} = I_{RMS} = \sqrt{\frac{1}{T}\int_0^T i^2(t)dt} = \frac{I_m}{\sqrt{2}} = 0.707 I_m$$

i
Due to squaring, averaging (mean) and square-rooting operations, this is called the "RMS." value of the current and *IRMS* is the true value of the current that we want to measure. The averaging time must be sufficiently long to allow filtering at the lowest frequencies of operation desired. Hence, in electrical terms, the AC RMS value is equivalent to the DC heating value of a particular waveform—voltage or current.

The Full-Wave Rectifier

The half-wave rectifier is used in some voltmeters, but the mostly adapted one uses the full waverectifier shown in Figure 4.23. Here, a bridge-type full-wave rectifier is shown. For the + half cycle the current follows the root ABDC. For the – half cycle root CBDA is used. The current through the meter resistor *Rm* is the absolute value of the input current as shown in the inset. The voltage waveform on the meter resistance *Rm* has the same shape as the current. The average value of the voltage becomes:



$$V_{AV} = \frac{2}{T}\int_0^{T/2} V_m \sin\omega t dt = \frac{2V_m}{\pi} = 0.636V_m$$

VAV is the DC component of the voltage and it is the value read by the moving coil instruments.

Hence, **the inherently measured value (IM) is the average value, while the true value is the RMS value**.

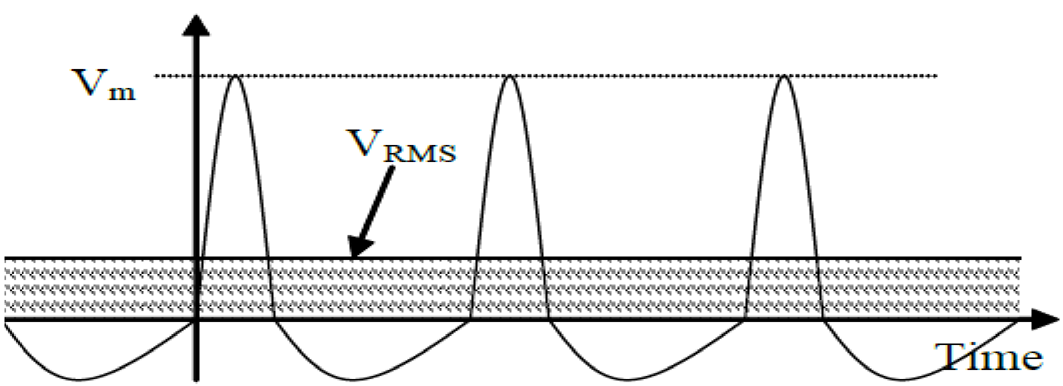
Form Factor

The ratio of the true value to the measured value is called the **form factor or safe factor** *(SF)*. For sinusoidal signals the form factor is *SF = (VRMS/VAV).*

In AC voltmeters, the reading is corrected by a scale factor = safe factor *(SF)* = 1.11.

True RMS Meters

The rectification, averaging and form factor correction approach produces adequate results in most cases. However, a correct conversion or the measurement of non sine wave values, requires a more complex and costly converter, known as a True RMS converter. The characteristics of these meters are defined in terms of the input range, bandwidth (frequency range in which the device operates successfully), accuracy and crest factor. The **crest factor** is a measurement of a waveform, calculated from the peak amplitude of the waveform divided by the RMS value of the waveform

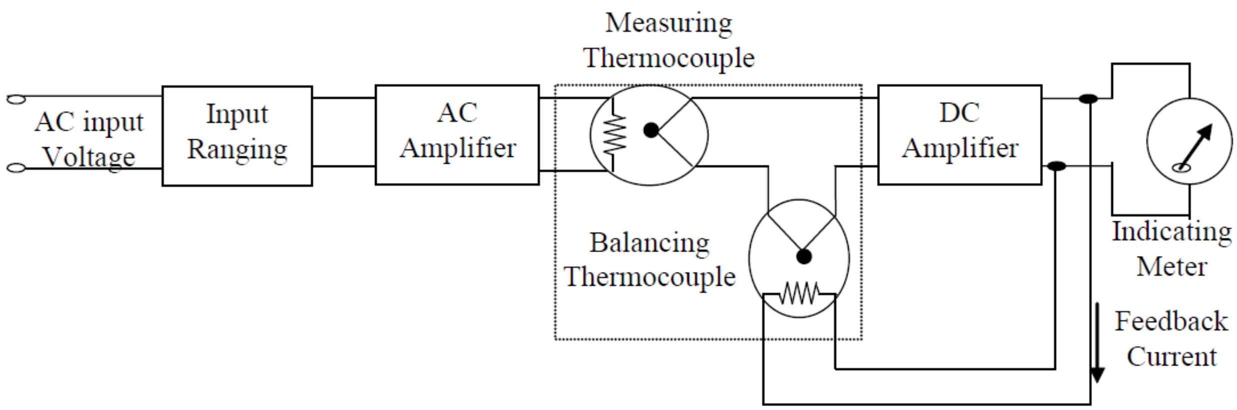


The power dissipated by a resistor R that is exposed to the signal is

$$P = I_{RMS}^2 * R = \frac{V_{RMS}^2}{R}.$$

The AC signal would be applied to a small heating element which was twinned with a thermocouple which could be used in a DC measuring circuit.

The technique is not particularly precise but it will measure any waveform at any frequency. Thermal converters have become quite rare, but as they are inherently simple and cheap they are still used by radio hams and hobbyists, who may remove the thermal element of an old unreliable instrument and incorporate it into a modern design of their own construction.



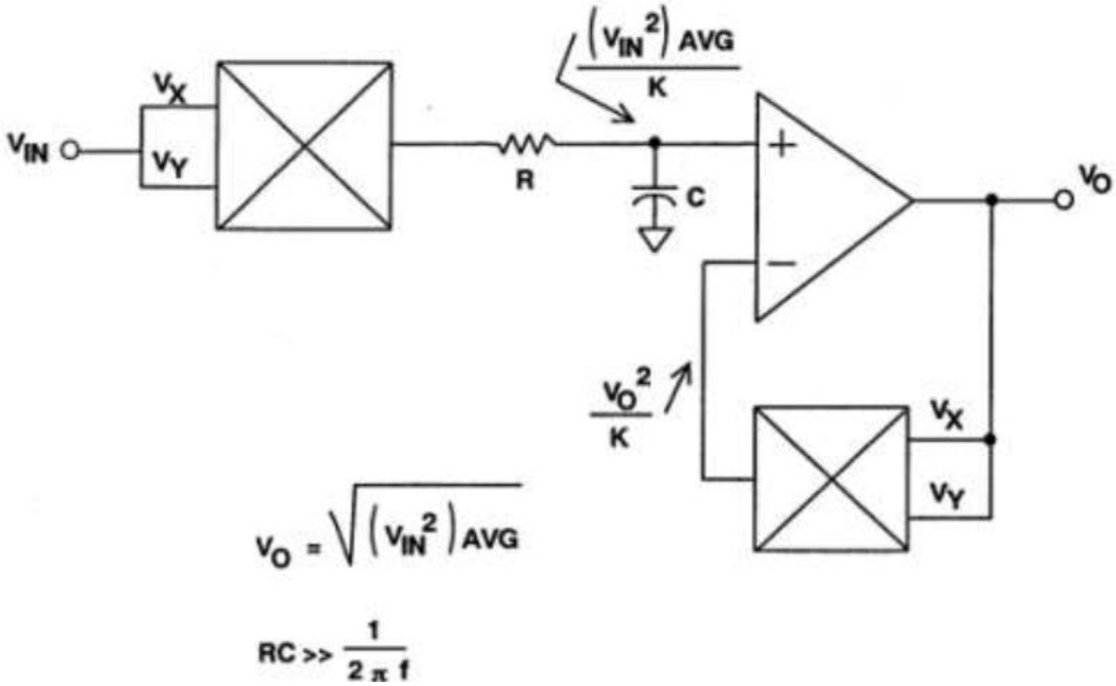
A true RMS type AC voltmeter that uses the thermal converter principle

an analog multiplier in a specific configuration which multiplies the input signal by itself (squares it), averages the result with a capacitor, and then calculates the square root of the value (via a multiplier/squarer circuit in the feedback loop of an operational amplifier), or

 a full-wave precision rectifier circuit to create the absolute value of the input signal, which is fed into a operational amplifier arranged to give an exponential transfer function, then doubled in voltage and fed to a log amplifier as a means of deriving the square-law transfer function, before time-averaging and calculating the square root of the voltage, similar to above,

 or a field-effect transistor may be used to directly create the square-law transfer function, before time-averaging. thermal converters they are subject to bandwidth limitations which makes them unsuitable for most RF work. The circuitry before time averaging is particularly crucial for high frequency performance. The slew rate limitation of the operational amplifier used to create the absolute value (especially at low input signal levels) tends to make the second method the poorest at high frequencies, while the FET method can work close to VHF. Specialist techniques are required to produce sufficiently accurate integrated circuits for complex analog calculations, and very often meters equipped with such circuits offer True RMS conversion as an optional extra with a significant price increase.

The third approach is to use Digital RMS converters. Digital and PC-based oscilloscopes have the waveform being digitized so that the correct RMS value may be calculated directly. Obviously the precision and the bandwidth of the conversion is entirely dependent on the analog to digitalconversion. In most cases, true RMS measurements are made on repetitive waveforms, and under such conditions digital oscilloscopes (and a few sophisticated sampling multimeters) are able to achieve very high bandwidths as they sample at a fraction of the signal frequency to obtain a stroboscopic effect (that will be explained later in section covering the digital storage oscilloscope).



Analog RMS to DC converter

The third approach is to use Digital RMS converters. Digital and PC-based oscilloscopes have the waveform being digitized so that the correct RMS value may be calculated directly. Obviously the precision and the bandwidth of the conversion is entirely dependent on the analog to digital conversion. In most cases, true RMS measurements are made on repetitive waveforms, and under such conditions digital oscilloscopes (and a few sophisticated sampling multimeters) are able to achieve very high bandwidths as they sample at a fraction of the signal frequency to obtain a stroboscopic effect (that will be explained later in section covering the digital storage oscilloscope)

Amplifiers

The amplifier is a device that increases the magnitude of the input voltage (voltage amplifier as in Figure 4.33), current (current amplifier) and power (power amplifier). The ratio of the output to the input (if of the same kind, i.e. both voltage) is called the **gain** if it is greater than 1 and denoted by G. For a voltage amplifier; $G=Vo/VI$

where Vo is the output voltage and VI is the input voltage. The gain is a unitless quantity.

Sometimes the gain is expressed in decibels (dB) as: $GdB = 10\log(Po/PI) = 20\log(Vo/VI)$

where Po is the output power and PI is the input power of the amplifier measured across the same resistor.

If the output is smaller than the input, this is called the **attenuation**. *GdB* is positive for the
gain and negative for the attenuation. For example, a gain of 60 dB indicates that the output is the input multiplied by 1000 while a gain of –20 dB shows that the input is reduced (attenuated) by 10 times by the system.

THE DIGITAL VOLTMETER (DVM)

Use, Advantages and Operation

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

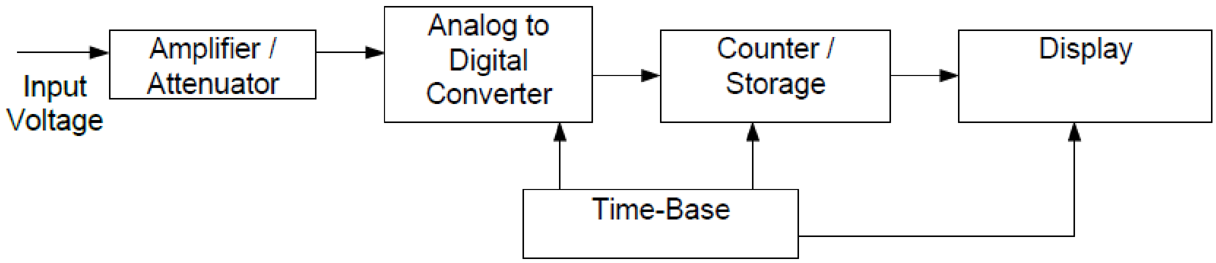
□ Resolution: 1 part in 106 (1 □V can be read in 1 V range).

□ Input impedance: *Ri* □ 10 M□ ; *Ci* □ 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.

It is composed of an amplifier/attenuator, an analog to digital converter, storage, display and timing circuits. There is also a power supply to provide the electrical power to run electronic components. The circuit components except the analog to digital converter circuits are similar to the ones used in electronic counters. The input range selection can be manually switched between ranges to get most accurate reading or it can be auto ranging that switches between ranges automatically for best reading.



A simplified diagram for a digital voltmeter

The Analog to Digital Converter (ADC) – Sample and Hold

The analog to digital converter contains a sample and hold circuit, and conversion circuits. The
sample and hold is composed of an electronic switch and a capacitor. The switch turns on and off at regular intervals. The capacitor charges and assumes the level of the input voltage as the switch is on. It holds the charge (hence the level of the input voltage) as the switch is off. The unity-gain buffer eliminates the loading of the capacitor by proceeding analog to digital converter circuitry.shows a simplified diagram with the input and output waveforms of the circuit.

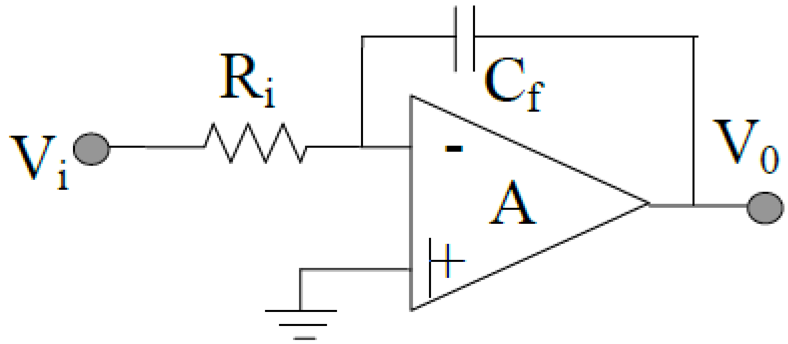
Digitization of Analog Signals

The input of the sample and hold circuit is a continuous time analog signal that can take any value any time. The output is a discrete time signal that can take any value but only at certain times. This signal can't be processed by a digital circuit unless it is converted into a digital code.
The analog input signal is continuous in time and it can take any value at any time. This is converted to a discrete-time signal that can accept any value but at certain times. The next stage is to divide the amplitude range into discrete steps as well by a process called the quantization. The figure exemplifies the principles for a 4-bit converter in which the dynamic range (the maximum peak to peak amplitude that the input signal can attain) is divided into 24 – 1 = 15 steps. A binary code (or binary coded decimal – BCD) is assigned for each level from 0000 to 1111 (1001 for BCD).

Integrating Type Analog to Digital Converters

The Basic Integrator

This type of converters generates a time interval

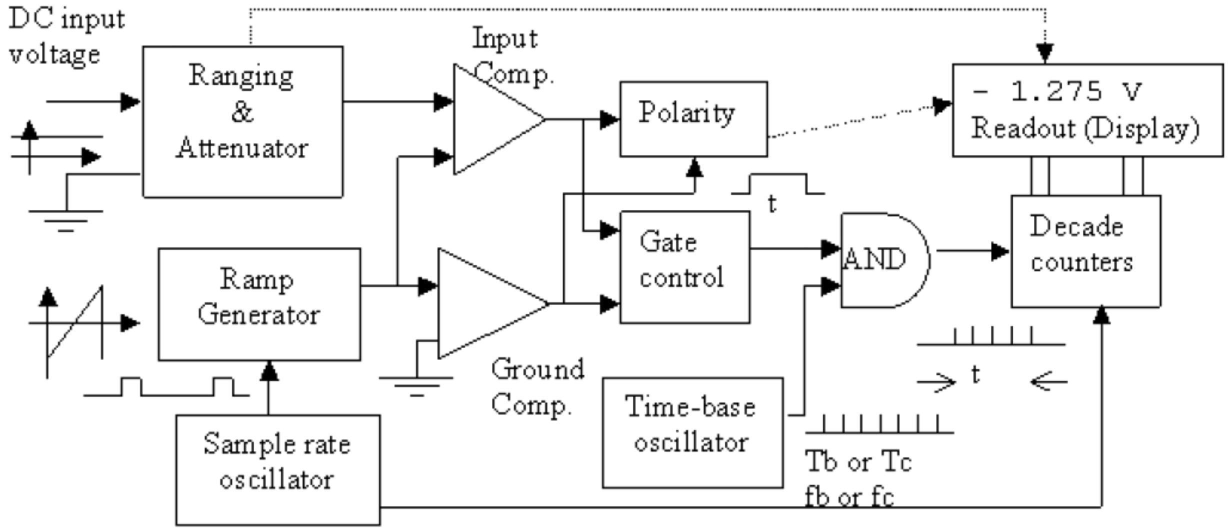


proportional to the input voltage. Then, this interval is measured and displayed using methods that were discussed in the counters section previously. The key circuit element is the integrator that generates an output that is related to the integral of the input. The basic integrator circuit is shown in Figure 4.45. It is similar to the inverting amplifier with the feedback resistor replaced by a capacitor. The input voltage V_i causes a current $I_i = {}^{V_i}/_{R_i}$ to flow through the capacitor C_f that generates an output voltage $V_0 = -\frac{1}{C_f}\int_0^t I_i dt - V_{co}$ since the inverting terminal of the op-amp is at virtual ground provided that the op-amp is not saturated. Hence, the output can be expressed as $V_0 = -\frac{1}{C_f R_i}\int_0^t V_i dt - V_{co}$. V_0 will decrease (or increase if V_i is negative) at a rate of $\frac{V_i}{R_i C_f}$

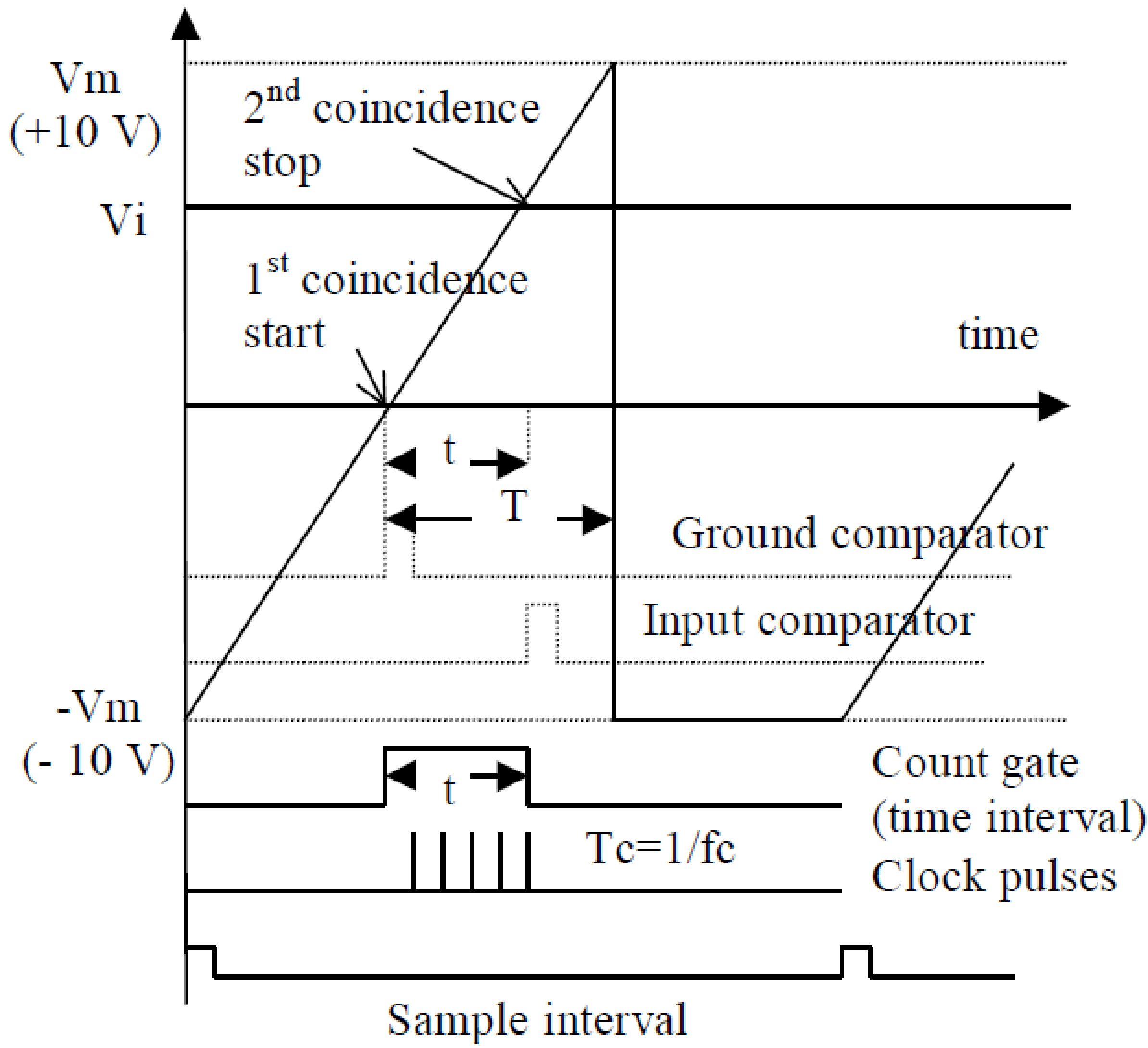
Functional Block Diagram of Ramp Type (Single Slope) DVM

Functional block diagram of a positive ramp type DVM is shown in Figure 4.46 The timing diagram is given in Fig. It has two major sections as the voltage to time conversion unit and time measurement unit. The conversion unit has a ramp generator that operates under the control of the sample rate oscillator, two comparators and a gate control circuitry. The internally generated ramp voltage is applied to two comparators. The first comparator compares the ramp voltage into the input signal and produces a pulse output as the coincidence is achieved (as the ramp voltage becomes larger than the input voltage). The second comparator compares the ramp to the ground voltage (0 volt) and produces an output pulse at the coincidence.

The input voltage to the first comparator must be between □ *Vm*. The ranging and attenuation section scales the DC input voltage so that it will be within the dynamic range. The decimal point in the output display automatically positioned by the ranging circuits.



Simplified block diagram of a single-ramp type digital voltmeter



Timing diagram for a single-ramp digital voltmeter

The outputs of the two comparators derive the gate control circuit that generates and output
pulse that starts with the first coincidence pulse and ends with the second.
Thus, the duration of the pulse "*t*" can be computed from the triangles as

$$\frac{V_i}{V_m} = \frac{t}{T} \Rightarrow t = \frac{T}{V_m} V_i$$

Hence, the voltage to time conversion is done yielding "*t*" to V_i with *T* and V_m constant.

Number of time intervals (clock pulses) counted during this interval become:

$$N = t * f_c = V_i \frac{T * f_c}{V_m}$$

For the ramp voltage with fixed slope and time base that runs at fixed rate (*fc*) *N* is directly proportional to *Vi*. The multiplier *T.fc/Vm* is set to a constant factor of 10. The polarity of the voltage is indicated if it is "-". With no indication, it is understood that the polarity is "+". The polarity is detected by the polarity circuit with the help of comparator pulses. For positive slope ramp type voltmeter, the first coincidence of the ramp is with the ground voltage if the input is positive. With a negative input voltage however, the first coincidence will be with the input voltage. The display stays for sometimes (around three seconds) and then it is refreshed by the sample rate oscillator. A trigger pulse is applied to the ramp generator to initiate a new ramp. Meanwhile a reset (initialize) pulse is applied to the decade counters to clear the previously stored code.

The display indicates the polarity as well as the numbers in decimal and a decimal point. The first digit contains the polarity sign and the number displayed can be only "1" or "0" for most voltmeters. Therefore, this is called "half" digit. Hence, a three and a half digit display can have up to 1999 and a four and a half digit one can go up to 19999.

Q meter:

A **Q meter** is a piece of equipment used in the testing of radio frequency circuits. A Q meter measures Q, the quality factor of a circuit, which expresses how much energy is dissipated per cycle in a non-ideal reactive circuit:

$$Q = 2\pi \times \frac{\text{Peak Energy Stored}}{\text{Energy dissipated per cycle}}.$$

This expression applies to an RF and microwave filter, bandpass LC filter, or any resonator. It also can be applied to an inductor or capacitor at a chosen frequency. For inductors

$$Q = \frac{X_L}{R} = \frac{\omega L}{R}$$

Where XLis the reactance of the inductor, L is the inductance,W is the angular frequency and R is the resistance of the inductor. The resistance represents the loss in the inductor, mainly due to the resistance of the wire.Q meter works on the principle of series resonance. For LC band pass circuits and filters:

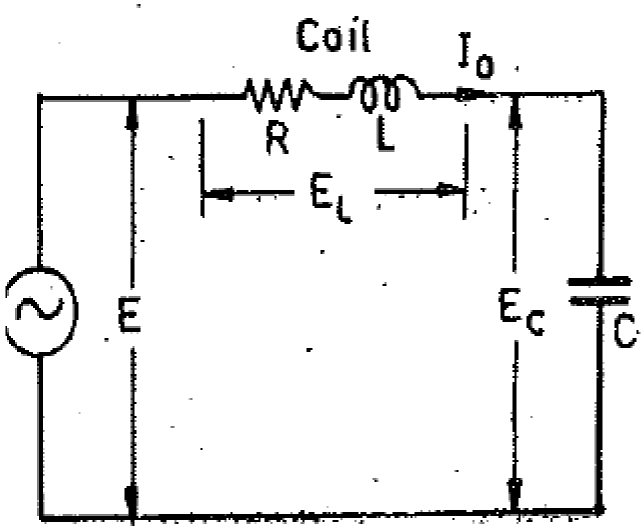
$$Q = \frac{F}{BW}$$

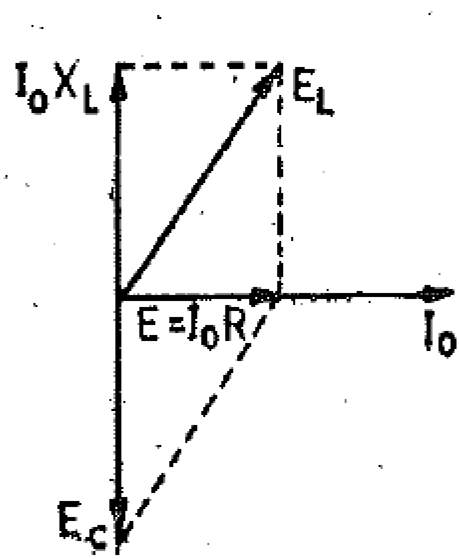
Where F is the resonant frequency (center frequency) and BW is the filter bandwidth. In a band pass filter using an LC resonant circuit, when the loss (resistance) of the inductor increases, its Q is reduced, and so the bandwidth of the filter is increased. In a coaxial cavity filter, there are no inductors and capacitors, but the cavity has an equivalent LC model with losses (resistance) and the Q factor can be applied as well.

OPERATION:

Internally, a minimal Q meter consists of a tuneable RF generator with a very low impedance output and a detector with a very high impedance input. There is usually provision to add a calibrated amount of high Q capacitance across the component under test to allow inductors to be measured in isolation. The generator is effectively placed in series with the tuned circuit formed by the components under test, and having negligible output resistance, does not materially affect the Q factor, while the detector measures the voltage developed across one element (usually the capacitor) and being high impedance in shunt does not affect the Q factor significantly either. The ratio of the developed RF voltage to the applied RF current, coupled with knowledge of the reactive impedance from the resonant frequency, and the source impedance, allows the Q factor to be directly read by scaling the detected voltage.

WORKING PRINCIPLE:





Principle of Working. The working of this useful laboratory i based upon the well-known chara a resonant series R, L, C circuit. F shows a coil of resistance R and i in series with a capacitor C.

At resonant frequency f_0 w

$$X_C = X_L.$$

resonant frequency $f_0 = \dfrac{1}{2\pi\sqrt{LC}}$ and current $I_0 = \dfrac{E}{R}$.

The phasor diagram is shown in Fig. 23·11 (b).

Voltage across capacitor, $E_C = I_0 X_C = I_0 X_L = I_0 \omega_0 L$

Input voltage $E = I_0 R$ $\therefore$ $\dfrac{E_C}{E} = \dfrac{I_0 \omega_0 L}{I_0 R} = \dfrac{\omega_0 L}{R} = Q$

or $$E_C = QE \quad \ldots$$

Thus the input voltage E is magnified Q times.

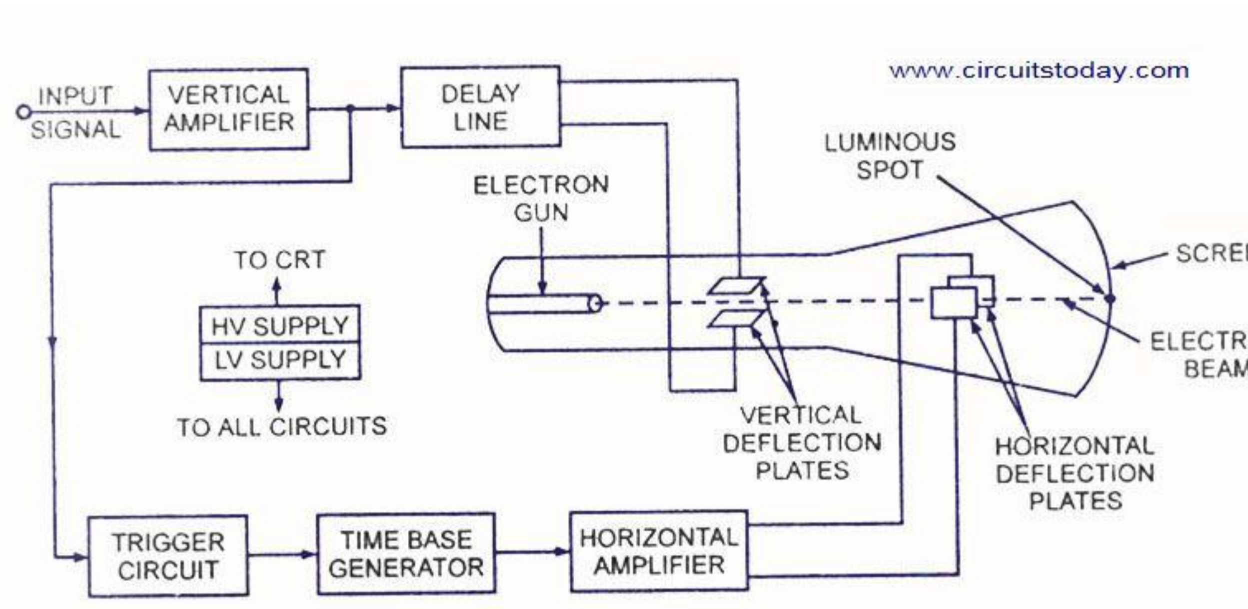
If the input voltage E is kept constant, the voltage appearing across the capacitor is E and a voltmeter connected across the capacitor can be calibrated to read the value of Q direc

<u>MODULE-IV</u>

OSCILLOSCOPE:

In many applications, observing certain voltage waveforms in a circuit plays a crucial role in understanding the operation of the circuit. For that purpose several measurement instruments are used like voltmeter, ammeter, or the oscilloscope. An oscilloscope (sometimes abbreviated as “scope”) is a voltage sensing electronic instrument that is used to visualize certain voltage waveforms. An oscilloscope can display the variation of a voltage waveform in time on the oscilloscope’s screen.

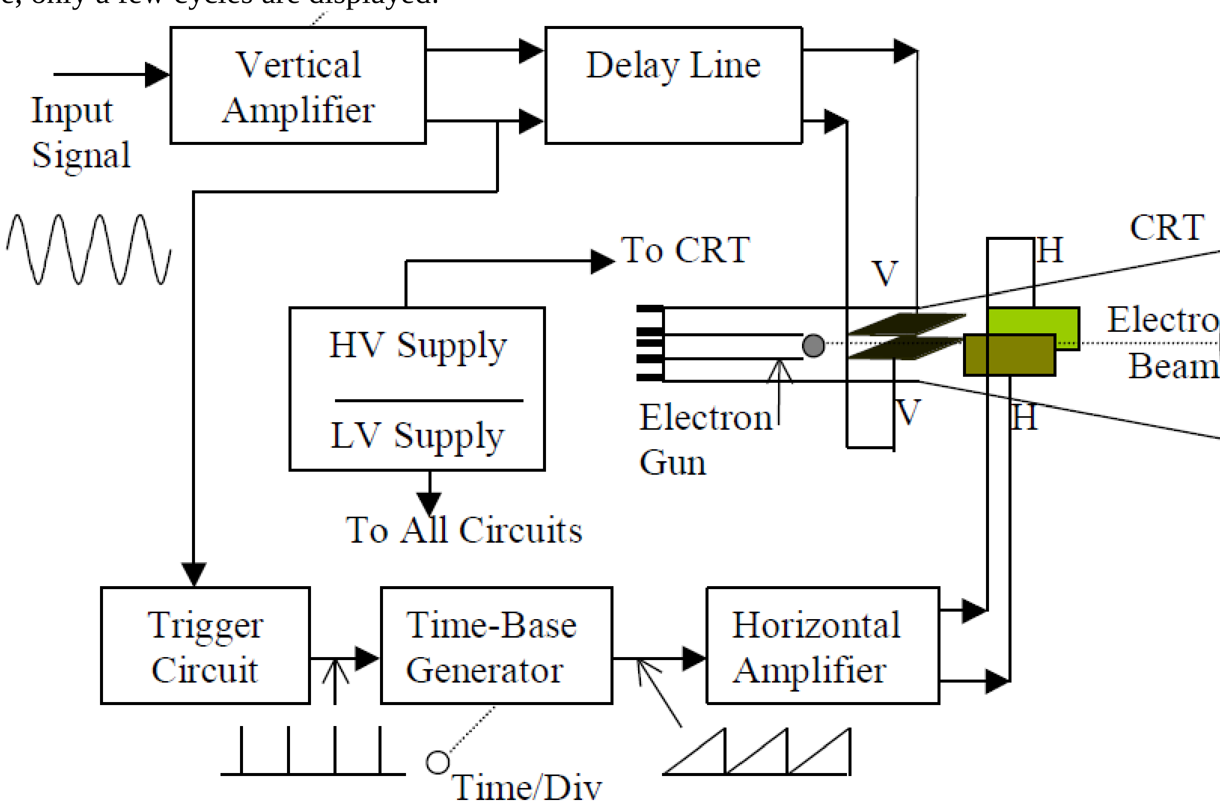
Oscilloscopes also come in analog and digital types. An analog oscilloscope works by directly applying a voltage being measured to an electron beam moving across the oscilloscope screen. The voltage deflects the beam up and down proportionally, tracing the waveform on the screen. This gives an immediate picture of the waveform. In contrast, a digital oscilloscope samples the waveform and uses an analog-to-digital converter (or ADC) to convert the voltage being measured into digital information. It then uses this digital information to reconstruct the waveform on the screen.



Block Diagram of a General Purpose CRO

An oscilloscope measures voltage waves. One *cycle* of a wave is the portion of the wave that repeats. A voltage waveform shows time on the horizontal axis and voltage on the vertical axis. Oscilloscopes are electronic equipment mainly used in displaying and measuring electrical voltage signals. Other physical signals can be displayed through proper sensors. The writing pen in this equipment is the electron beam and writing medium is a special screen that glows when the electron beam strikes on it. The electron beam can be deflected from its straight path using electrical or magnetic fields, hence easily moved across the screen. Eventually a spot of light that can be placed on different locations on the screen under the control of external electrical signals becomes available. For *y-t* recording, the spot travels horizontally across the screen at a constant speed and moves vertically in response to the magnitude of the input signal. Intensity or brightness of thedisplay is sometimes called the *z* axis.

Oscilloscopes can be classified as analog and digital. To better understand the oscilloscope controls, we need to know a little more about how oscilloscopes display a signal. Analog oscilloscopes work somewhat differently than digital oscilloscopes. However, several of the internal systems are similar. Analog oscilloscopes are somewhat simpler in concept and are described below. Front panel of an oscilloscope is shown in Figure 5.3. It has a display screen with a 8 cm by 10 cm grid drawn on it. The display has controls for the intensity (brightness of the trace), focus and astigmatism (sharpness of the trace). On the right hand side there are control sections for vertical, horizontal, and trigger controls and input connectors. The oscilloscope is a versatile instrument that can be used for measuring signal voltages from a few millivolts up to hundreds of volts. Depending on how we set the vertical scale (volts/div control), an *attenuator* reduces the signal voltage or an *amplifier* increases the signal voltage. One *cycle* of a wave is the portion of the wave that repeats. In general
use, only a few cycles are displayed.



Simplified block diagram of an analog oscilloscope

Two signals are needed to deflect the beam on the screen horizontally and vertically. The laboratory oscilloscope is generally used to display signals in time. The signal to be viewed is applied to a vertical (deflection) amplifier that increases the potential of the input signal to a level that will provide a useful deflection of the electron beam.

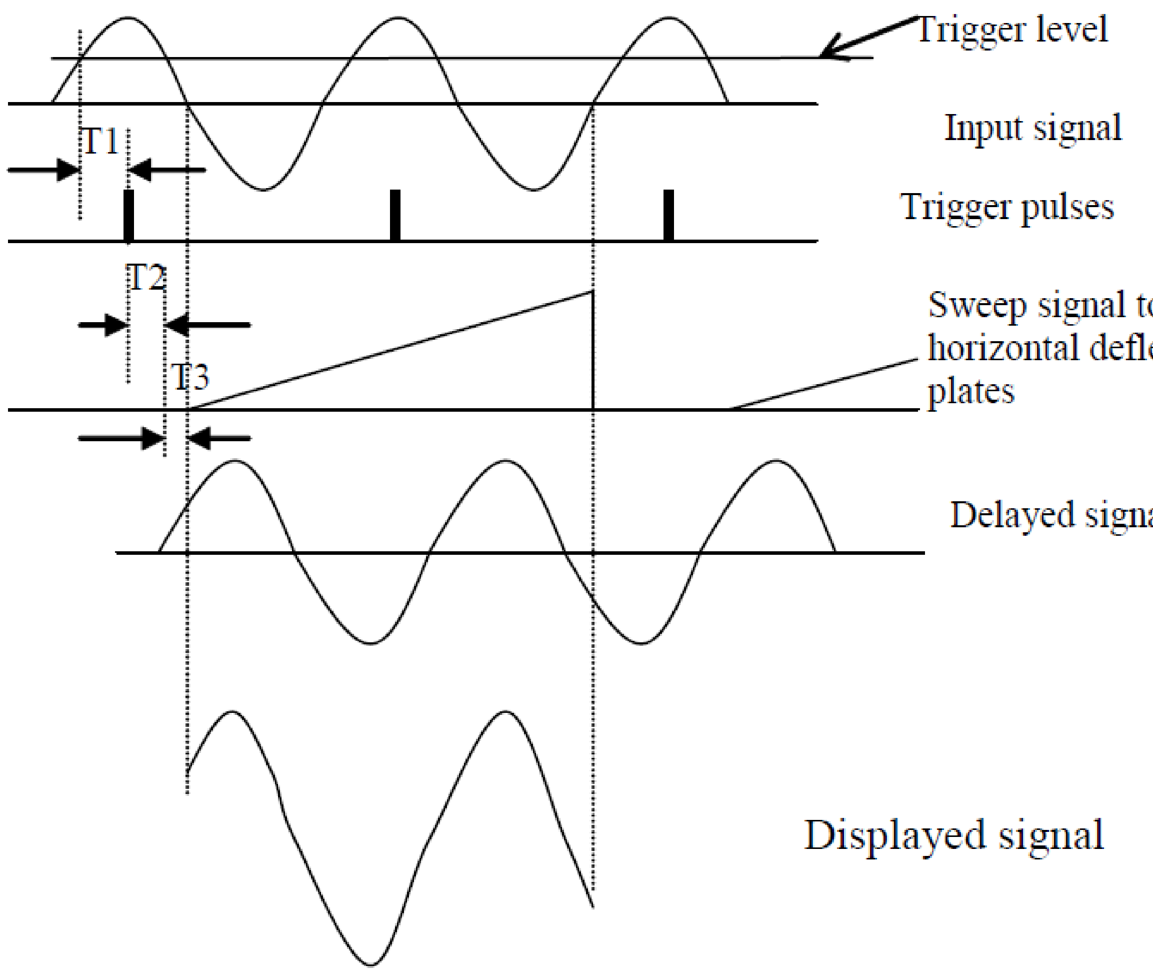
The time-base circuitry generates a voltage to supply the CRT to deflect the spot at a constant time-dependant rate. The voltage waveform is named commonly as the sweep signal and it has the appearance of a repetitive ramp function. A triggering circuit is used to synchronize the horizontal deflection with the vertical input, so that the horizontal deflection starts at the same point of the vertical input signal each time it runs (sweeps). Eventually, the beam moves at a constant time-dependant rate horizontally and the image generated on the screen indicates the time variation of the input signal. Each block in a signal path causes certain time delay. Hence, the beam does not start moving horizontally immediately following the detection of the trigger point. The delay line delays the signal applied to the vertical plates by an amount equal to the time delay for the sweep signal applied to the horizontal deflection plates. Eventually, the vertical signal is displayed on the screen alwaysstarting at the trigger point.

DELAY LINE

The purpose of delay lines in oscilloscopes is to allow observation of the leading edge of the trigger event. In the vertical signal path, before the delay line, there is typically a trigger pick-off which supplies an undelayed copy of the vertical signal to the the trigger and sweep circuitry. Trigger and sweep circuitry need about 60ns to react when presented with the trigger event. Without a delay line, the trigger event would already have come and gone before the scope can trigger and sweep. By sending the input signal through a delay line, the scope will have triggered and begun sweeping by the time the trigger event emerges from the delay line. Thus, the trigger event is drawn on the screen where the operator can see it, photograph it, or record it by other means.

There is an inevitable delay between the application of the input and appearance of the output in all electronic circuit elements. The amount of delay depends upon the element itself and specified by its manufacturer. In the triggered mode of operation, the input signal is applied to the trigger circuit that derives the sawtooth waveform generator. Then, the resultant sawtooth waveform is applied to the horizontal deflection plates via the horizontal amplifier. Hence, there is a time delay (in the order of a few hundred nanosecond) between the coincidence of the input signal with the trigger level signal (trigger pick-off) and starting of the sweep on the display. This delay may not be objectionable at low frequency applications. For example, the period of a 1 kHz sine wave is 1 millisecond. If the delay is 100 nanosecond which is one in a ten thousand of the period. Hence, it will not be effective displaying the signal. However, if we have the frequency as 10 MHz, the period of the signal is 100 nanosecond, which is the same as the delay. A delay line is added between the vertical amplifier and the vertical deflection plates that will delay the application of the input signal to the deflection plates by the amount of time equal to the delay comes from the time-base circuitry.

The delay in trigger circuit is T1, delay in sawtooth generator is T2 and delay in the horizontal amplifier is indicated as T3. The input signal is delayed by the same amount so that the sweeps starts displaying the input signal from the coincidence point.



Function of the delay line

PROBES:

A **test probe** (**test lead**, **test prod**, or **scope probe**) is a physical device used to connect electronic test equipment to a device under test (DUT).

The probes are of three different types :

(*i*) Direct reading probe, (*ii*) circuit isolation probe, and (*iii*) detector probe.

1. Direct Probe. This probe is simplest of all the probes and uses a shielded co-a
It avoids stray pick-ups which may create problems when low level signals are being
It is usually used for low frequency or low impedance circuits. However, in using the shiel
the shunt capacitance of the probe and cable is added to the input impedance and capa
scope and acts to lower the response of the oscilloscope to high impedance and high
circuits.

2. Isolation Probe. Isolation probe is used in order to avoid the undesirable circu
effects of the shielded probe. The isolation of the probe, which is used along with a
voltage divider, decreases the input capacitance and increases the input resistance of the os
This way the loading effects are drastically reduced.

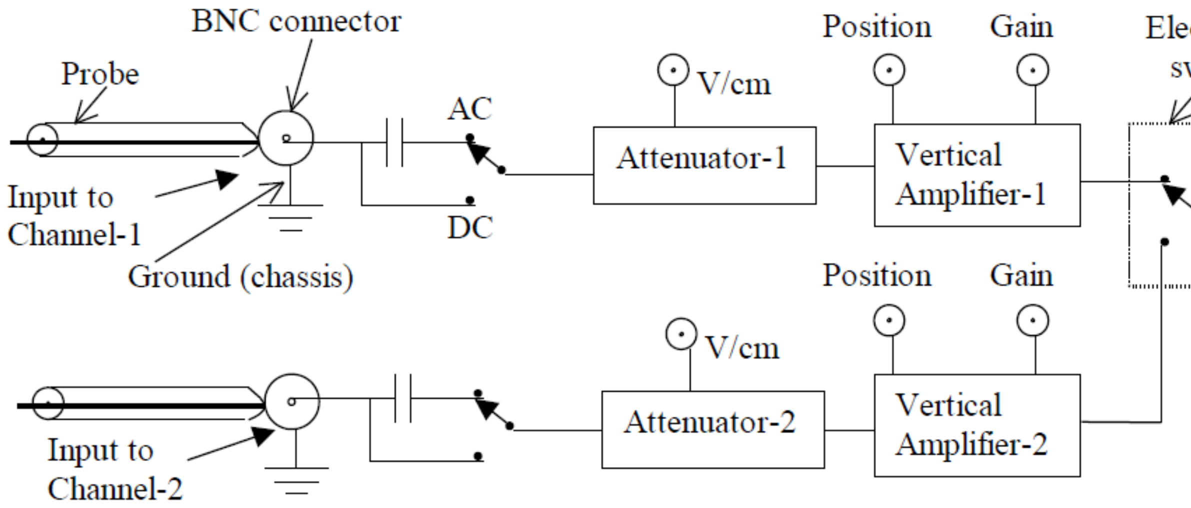
3. Detector probe. When analyzing the response to modulated signals used in co
tion equipment like AM, FM and TV receivers, the detector probe functions to separate
frequency modulation component from the high frequency carrier. The amplitude of the
carrier (which is proportional to the response of the receiver to the much high freque
signal) is displayed on the oscilloscope by rectifying and bypassing action. This p
oscilloscope capable of audio-frequency response to perform signal tracing tests on comm
signals in the range of hundreds of MHz, a range, which is beyond the capabilities of all os
except the highly specialized ones.

MULTI-TRACE OSCILLOSCOPES

Most laboratory oscilloscopes display two more traces simultaneously although they have a single electron gun. Each trace can represent an independent input signal. There are identical input connector, attenuator and amplifier for each input. Outputs of vertical amplifiers are selected oneby- one by an electronic switch and applied to the driver amplifier for the vertical deflection plate assembly as illustrated in Figure 5.18. There are two modes of operation of the electronic switch as chopped and alternate. In the chopped mode, the switch runs at high frequency (around 500 kHz) and calls at each input for a fraction of the total sweep duration. Hence, traces are drawn as short spots of light on the screen. For example, if we have two input signals each at 1 kHz and the sweep rate is 500 kHz, then there are 250 spots across one period of each trace. The illumination of the spot the gap between the spots. Also, the chopping is not synchronous with the sweep leading to the dots appearing at different places along the trajectory for successive sweeps. Hence, the traces

are seen continuous at low frequency applications. Therefore, the chopped mode is useful at low frequencies.

In the second operational mode, the switch remains in one of the chan el throughout the complete sweep duration and it picks the other one in the next sweep. Since switch displays each channel at alternate cycles of the sweep signal, the name alternate mode is used. This is useful at high frequency operations. Some laboratory oscilloscopes incorporate the selection of chopped or alternate mode in the time-base switch. Only one of the input channels is used for the trigger control in both modes. In the alternate mode if channel-1 is selected as the trigger input, it is used even while channel-2 is displayed.



Multi-trace operation using an electronic switch

DIGITAL STORAGE OSCILLOSCOPES (DSO)

Oscilloscopes also come in analog and digital types. An analog oscilloscope works by directly applying a voltage being measured to an electron beam moving across the oscilloscope screen. The voltage deflects the beam up and down proportionally, tracing the waveform on the screen. This gives an immediate picture of the waveform as described in previous sections. In contrast, a digital oscilloscope samples the waveform and uses an analog-to-digital converter (or ADC) to convert the voltage being measured into digital information. It then uses this digital information to reconstruct the waveform on the screen. For many applications either an analog or digital oscilloscope will do. However, each type does possess some unique characteristics making it more or less suitable for specific tasks. People often prefer analog oscilloscopes when it is important to display rapidly varying signals in "real time" (or as they occur). Digital oscilloscopes allow us to capture and view events that may happen only once. They can process the digital waveform data or send the data to a computer
for processing. Also, they can store the digital waveform data for later viewing and printing.

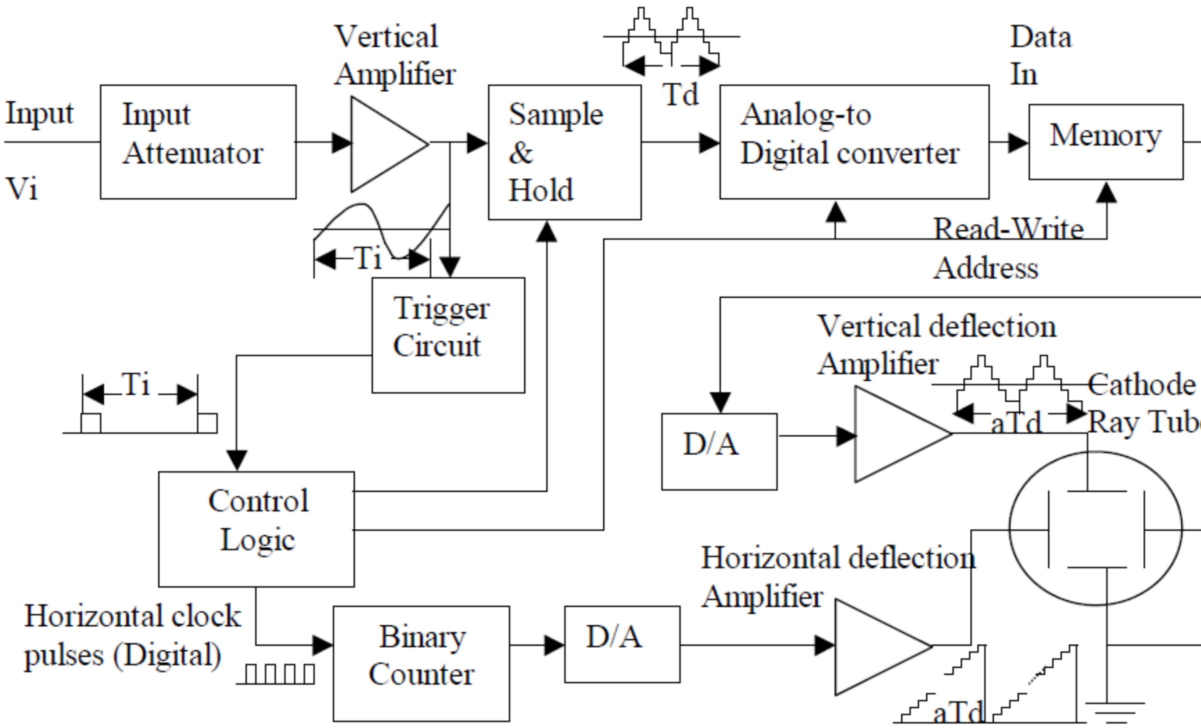
Necessity for DSO and Its Advantages

If an object passes in front of our eyes more than about 24 times a second over the same trajectory, we cannot follow the trace of the object and we will see the trajectory as a continuous line of action. Hence, the trajectory is stored in our physiological system. This principle is used in obtaining a stationary trace needed to study waveforms in conventional oscilloscopes. This is however, is not possible for slowly varying signals and transients that occur once and then disappear. Storage oscilloscopes have been developed for this purpose. Digital storage oscilloscopes came to existence in 1971 and developed a lot since then. They provide a superior method of trace storage. The waveform to be stored is digitized, stored in a digital memory, and retrieved for displayed on the storage oscilloscope. The stored waveform is continuously displayed by repeatedly scanning the stored waveform. The digitized waveform can be further analyzed by either the oscilloscope or by loading the content of the memory into a computer. They can present waveforms before, during and after trigger. They provide markers, called the cursors, to help the user in measurements in annotation (detailing) of the measured values.

Principles of Operation

Principle Diagram Representing Operation of the DSO

A simplified block diagram of a digital storage oscilloscope is shown in fig. The input circuitry of the DSO and probes used for the measurement are the same as the conventional oscilloscopes. The input is attenuated and amplified with the input amplifiers as in any oscilloscope. This is done to the input signal so that the dynamic range of the A/D converter can be utilized maximally. Many DSOs can also operate in a conventional mode, bypassing the digitizing and storing features. The output of the input amplifier drives the trigger circuit that provides signal to the control logic. It is also sampled under the control of the control logic. The sample and hold circuit takes the sample and stores it as a charge on a capacitor. Hence, the value of the signal is kept constant during the analog to digital conversion. The analog to digital converter (A/D) generates a binary code related to the magnitude of the sampled signal. The speed of the A/D converter is important and “flash” converters are mostly used. The binary code from the A/D converter is stored in the memory. The memory consists of a bank of random access memory (RAM) integrated circuits (ICs).

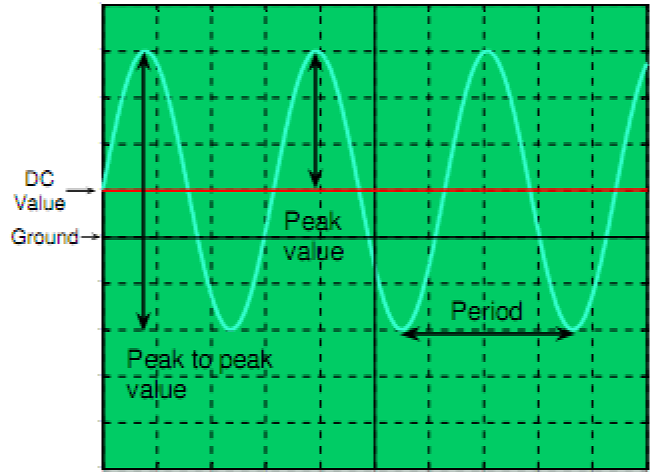


Simplified block diagram of a digital storage oscilloscope (DSO)

Measurement Techniques:

The major concern in observing a signal on the oscilloscope screen is to make voltage and time measurements. These measurements may be helpful in understanding the behavior of a circuit component, or the circuit itself, depending on what you measure. Except for the X-Y mode of operation, the oscilloscope displays the voltage value of the waveform as a function time. The oscilloscope screen is partitioned into the grids, which divides both the horizontal axis(voltage) and the vertical axis(time) into divisions which will be helpful in making the measurements. Obviously one needs to know the time or the voltage values corresponding to each division, in order to make accurate calculations. These values are determined by two variables namely the time/div and the volt/div both of which can be adjusted from the relevant buttons available on the front panel of the oscilloscope . Also note that, the time/div button controls the trace time of the sweep generator, whereas the volt/div button controls the `gain` in the vertical amplifiers in the vertical deflection system.

Typical quantities, which are of primer interest when observing a signal with the scope, are Shown.



Sinusoidal Signal on Oscilloscope Screen.

For the given figure, suppose that the variables volt/div and time/div are set to:

volt/div = 2Volts/div.

time/div = 1millisecond/div

Then the corresponding values shown on the figure are calculated to be;

Peak Value = 6volts

Peak to peak value = 12 Volts

DC Value (Average Value) = 2 Volts

Period = 3 milliseconds

Frequency =1/T =333 Hz.

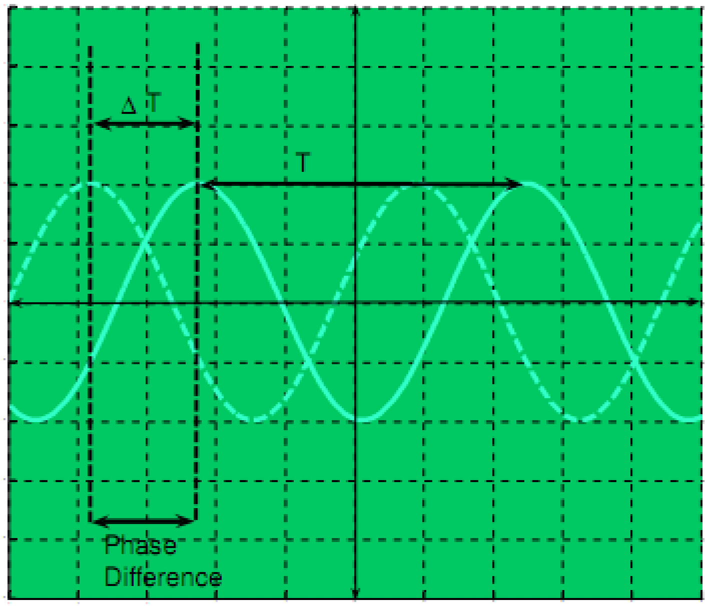
Note that the signal s(t), shown on the oscilloscope screen can be expressed as,

$$\begin{aligned} s(t) &= V_{peak}\sin(2\pi ft) + V_{DC} \\ &= 6\sin(2\pi 333t) + 2 \\ &= 6\sin(666\pi t) + 2\ Volts. \end{aligned}$$

Phase difference:

In some applications, one may need to monitor or compare two or more signals simultaneously. A typical example can be the comparison of the input voltage with the output voltage of a two-port (input and output ports) circuit. If the signals that are being monitored have the same frequency, a time delay may occur between the signals (i.e. one signal may lead the other or vice versa). Two waves that have the same frequency, have a phase difference that is constant (independent of t). When the phase difference(2*pi) is zero, the waves are said to be in phase with each other. Otherwise, they are out of phase with each other. If the phase difference is 180 degrees. , then the two signals are said to be in anti-phase. If the peak amplitudes of two anti-phase waves are equal, their sum is zero at all values of time. The phase difference is expressed in terms of radians or degrees.

In Dual Mode of the oscilloscope the phase difference can be calculated easily as follows.



Del T = horizontal spacing of the peak values (or the zero crossings) of the two signals.

T = horizontal spacing for one period.

Then the phase difference=θ= ΔT/T *360 In degree.