UNIT – 1

Performance characteristics of instruments, Static characteristics; Accuracy, Resolution, Precision, Expected value, Error, Sensitivity. Dynamic Characteristic: speed of response, Fidelity, Lag and Dynamic error. Types of errors in measurement and their analysis, Design of multi-range AC, DC meters (voltmeter & Ammeter) and Ohm meter (series, shunt type) using D'Arsonval movement, True RMS meter.

INTRODUCTION:

Instrumentation is a technology of measurement which serves not only science but all branches of engineering, medicine, and almost every human Endeavour. The knowledge of any parameter largely depends on the measurement. The in-depth knowledge of any parameter can be easily understood by the use of measurement, and further modify captions can also be obtained.

Measuring is basically used to monitor a process or operation, or as well as the controlling process. For example, thermometers, barometers, anemometers are used to indicate the environmental conditions. Similarly, water, gas and electric meters are used to keep track of the quantity of the commodity used, and also special monitoring equipment are used in hospitals.

Whatever may be the nature of application, intelligent selection and use of measuring equipment depends on a broad knowledge of what is available and how the performance of the equipment renders itself for the job to be performed.

But there are some basic measurement techniques and devices that are useful and will continue to be widely used also. There is always a need for improvement and development of new equipment to solve measurement problems.

The major problem encountered with any measuring instrument is the error. Therefore, it is obviously necessary to select the appropriate measuring instrument and measurement method which minimizes error. To avoid errors in any experimental work, careful planning, execution and evaluation of the experiment are essential.

The basic concern of any measurement is that the measuring instrument should not effect the quantity being measured; in practice, this non-interference principle is never strictly obeyed. Null measurements with the use of feedback in an instrument minimize these interference effects.

PERFORMANCE CHARACTERISTICS OF INSTRUMENTS:

A knowledge of the performance characteristics of an instrument is essential for selecting the most suitable instrument for specific measuring jobs. It consists of two basic characteristics—static and dynamic.

STATIC CHARACTERISTICS:

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

1. ***Instrument:*** A device or mechanism used to determine the present value of the quantity under measurement.
2. ***Measurement***: The process of determining the amount, degree, or capacity by comparison (direct or indirect) with the accepted standards of the system units being used.
3. ***Accuracy:*** The degree of exactness (closeness) of a measurement compared to the expected (desired) value.
4. ***Resolution***: The smallest change in a measured variable to which an instrument will respond.
5. ***Precision***: A measure of the consistency or repeatability of measurements, i.e. successive reading do not differ. (Precision is the consistency of the instrument output for a given value of input).
6. ***Expected value:*** The design value, i.e. the most probable value that calculations indicate one should expect to measure.
7. ***Error***: The deviation of the true value from the desired value.
8. ***Sensitivity:*** The ratio of the change in output (response) of the instrument to a change of input or measured variable.

DYNAMIC CHARACTERISTICS:

Instruments rarely respond instantaneously to changes in the measured variables. Instead, they exhibit slowness or sluggishness due to such things as mass, thermal capacitance, fluid capacitance or electric capacitance. In addition to this, pure delay in time is often encountered where the instrument waits for some reaction to take place. Such industrial instruments are nearly always used for measuring quantities that fluctuate with time. Therefore, the dynamic and transient behavior of the instrument is as important as the static behavior. The dynamic behaviour of an instrument is determined by subjecting its primary element (sensing element) to some unknown and predetermined variations in the measured quantity. The three most common variations in the measured quantity are as follows:

1. Step change, in which the primary element is subjected to an instantaneous and finite change in measured variable.
2. Linear change, in which the primary element is following a measured variable, changing linearly with time.
3. Sinusoidal change, in which the primary element follows a measured variable, the magnitude of which changes in accordance with a sinusoidal function of constant amplitude.

The dynamic characteristics of an instrument are

(i) ***Speed of Response:*** It is the rapidity with which an instrument responds to changes in the measured quantity.

(ii***) Fidelity*** :It is the degree to which an instrument indicates the changes in the measured variable without dynamic error (faithful reproduction).

(iii) **Lag**: It is the retardation or delay in the response of an instrument to changes in the measured variable.

(iv) ***Dynamic Error*** :It is the difference between the true value of a quantity changing with time and the value indicated by the instrument, if no static error is assumed.

When measurement problems are concerned with rapidly varying quantities, the dynamic relations between the instruments input and output are generally defined by the use of differential equations.

ERROR IN MEASUREMENT:

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

Some factors that affect the measurements are related to the measuring instruments themselves. Other factors are related to the person using the instrument. The degree to which a measurement nears the expected value is expressed in terms of the error of measurement.

Error may be expressed either as absolute or as percentage of error. Absolute error may be defined as the difference between the expected value of the variable and the measured value of the variable, or

$$e = Y_n - X_n$$

where

e = absolute error
Y_n = expected value
X_n = measured value

Therefore % Error = (Absolute value/ Expected value) * 100
$= (e/ Y_n) * 100$
$= ((Y_n - X_n)/ Y_n)) * 100$

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

Therefore $A = 1 - [((Y_n - X_n)/ Y_n)]$

where A is the relative accuracy.

Accuracy is expressed as % accuracy

$$a = 100\% - \%\ \text{error}$$

$$a = A * 100\ \%$$

where a is the % accuracy

TYPES OF STATIC ERROR

The static error of a measuring instrument is the numerical difference between the true value of a quantity and its value as obtained by measurement, i.e. repeated measurement of the same quantity gives different indications. Static errors are categorized as gross errors or human errors, systematic errors, and random errors.

i) Gross Errors: These errors are mainly due to human mistakes in reading or in using instruments or errors in recording observations. Errors may also occur due to incorrect adjustment of instruments and computational mistakes. These errors cannot be treated mathematically.

The complete elimination of gross errors is not possible, but one can minimize them. Some errors are easily detected while others may be elusive. One of the basic gross errors that occurs frequently is the improper use of an instrument. The error can be minimized by taking proper care in reading and recording the measurement parameter.

In general, indicating instruments change ambient conditions to some extent when connected into a complete circuit

ii) Systematic Errors: These errors occur due to shortcomings of the instrument, such as defective or worn parts, or ageing or effects of the environment on the instrument.

These errors are sometimes referred to as bias, and they influence all measurements of a quantity alike. A constant uniform deviation of the operation of an instrument is known as a systematic error. There are basically three types of systematic errors—(i) Instrumental, (ii) Environmental, and (iii) Observational.

a. Instrumental Errors: Instrumental errors are inherent in measuring instruments, because of their mechanical structure. For example, in the D'Arsonval movement, friction in the bearings of various moving components, irregular spring tensions, stretching of the spring, or reduction in tension due to improper handling or overloading of the instrument.

Instrumental errors can be avoided by

1. selecting a suitable instrument for the particular measurement applications
2. applying correction factors after determining the amount of instrumental error.
3. calibrating the instrument against a standard.

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

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

c) Observational Errors: Observational errors are errors introduced by the observer. The most common error is the parallax error introduced in reading a meter scale, and the error of estimation when obtaining a reading from a meter scale.

These errors are caused by the habits of individual observers. For example, an observer may always introduce an error by consistently holding his head too far to the left while reading a needle and scale reading.

In general, systematic errors can also be subdivided into static and dynamic errors. Static errors are caused by limitations of the measuring device or the physical laws governing its behavior. Dynamic errors are caused by the instrument not responding fast enough to follow the changes in a measured variable

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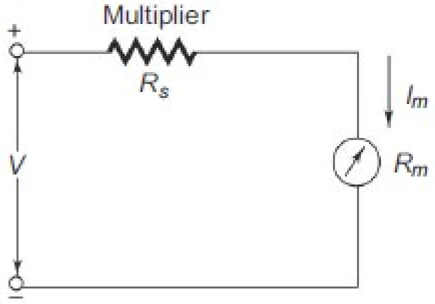
DC VOLTMETERS

A basic D'Arsonval movement can be converted into a dc voltmeter by adding a series resistor known as multiplier, as shown in Fig. 4.1. The function of the multiplier is to limit the current through the movement so that the current does not exceed the full scale deflection value.

A dc voltmeter measures the potential difference between two points in a dc circuit or a circuit component. To measure the potential difference between two points in a dc circuit or a circuit component, a dc voltmeter is always connected across them with the proper polarity. The value of the multiplier required is calculated as follows. Referring to Fig. below



I_m = full scale deflection current of the movement (I_{fsd})
R_m = internal resistance of movement
R_s = multiplier resistance
V = full range voltage of the instrument

From the circuit of Fig. 4.1

$$V = I_m (R_s + R_m)$$

$$R_s = \frac{V - I_m R_m}{I_m} = \frac{V}{I_m} - R_m$$

Therefore $$R_s = \frac{V}{I_m} - R_m$$

The multiplier limits the current through the movement, so as to not exceed the value of the full scale deflection I_{fsd}. The above equation is also used to further extend the range in DC voltmeter

MULTI-RANGE DC VOLTMETER

As in the case of an ammeter, to obtain a multi range ammeter, a number of shunts are connected across the movement with a multi-position switch. Similarly, a dc voltmeter can be converted into a multi range voltmeter by connecting a number of resistors (multipliers) along with a range switch to provide a greater number of workable ranges.

Figure 4.2 shows a multi range voltmeter using a three position switch and three multipliers R_1, R_2, and R_3 for voltage values V_1, V_2, and V_3. Figure 4.2 can be further modified to Fig. 4.3, which is a more practical arrangement of the multiplier resistors of a multi range voltmeter. In this arrangement, the multipliers are connected in a series string, and the range selector selects the appropriate amount of resistance required in series with the movement.

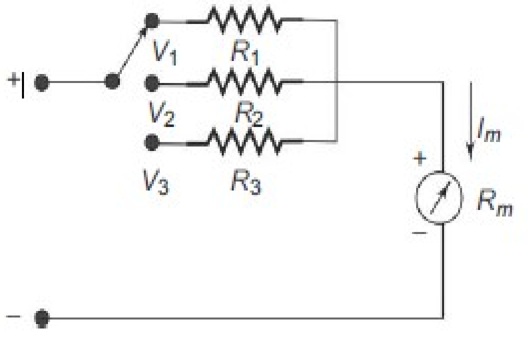


Fig. 4.2 Multirange voltmeter

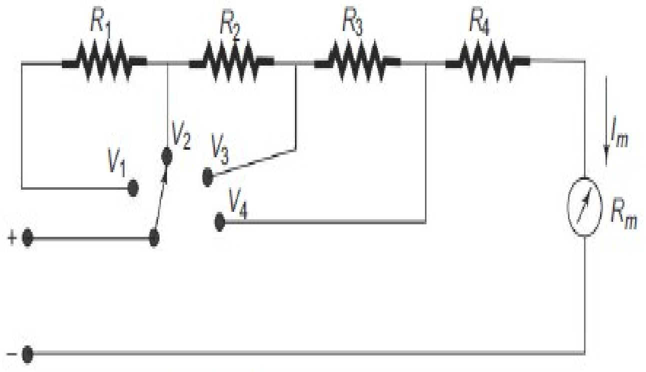


Fig. 4.3 Multipliers connected in series string

This arrangement is advantageous compared to the previous one, because all multiplier resistances except the first have the standard resistance value and are also easily available in precision tolerances.

The first resistor or low range multiplier, R_4, is the only special resistor which has to be specially manufactured to meet the circuit requirements.

Voltmeter Range Extension:

The range of a voltmeter can be extended to measure high voltages, by using a high voltage probe or by using an external multiplier resistor, as shown in Fig. 4.4.

In most meters the basic movement is used on the lowest current range. Values for multipliers can be determined using the procedure of Section 4.4. The basic meter movement can be used to measure very low voltages. However, great care must be used not to exceed the voltage drop required for full scale deflection of the basic movement.

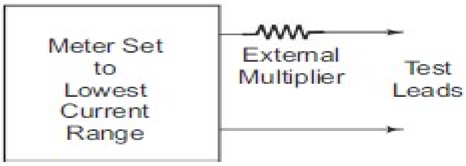


Fig. 4.4 Extending voltage range

Sensitivity: The sensitivity or Ohms per Volt rating of a voltmeter is the ratio of the total circuit resistance R_t to the voltage range. Sensitivity is essentially the reciprocal of the full scale deflection current of the basic movement.

Therefore, $S = 1/I_{fsd}\ \Omega/V$. The sensitivity 'S' of the voltmeter has the advantage that it can be used to calculate the value of multiplier resistors in a dc voltmeter. As,

R_t = total circuit resistance [$R_t = R_s + R_m$]
S = sensitivity of voltmeter in ohms per volt
V = voltage range as set by range switch
R_m = internal resistance of the movement
Since $R_s = R_t - R_m$ and $R_t = S \times V$
Therefore $R_s = (S \times V) - R_m$

MULTI RANGE AC VOLTMETERS:

Figure 4.24 is circuit for measuring ac voltages for different ranges. Resistances R1, R2, R3 and R4 form a chain of multipliers for voltage ranges of 1000 V, 250 V, 50 V, and 10 V respectively. On the 2.5 V range, resistance R5 acts as a multiplier and corresponds to the multiplier R_s shown in Fig. 4.17. R_{sh} is the meter shunt and acts to improve the rectifier operation.

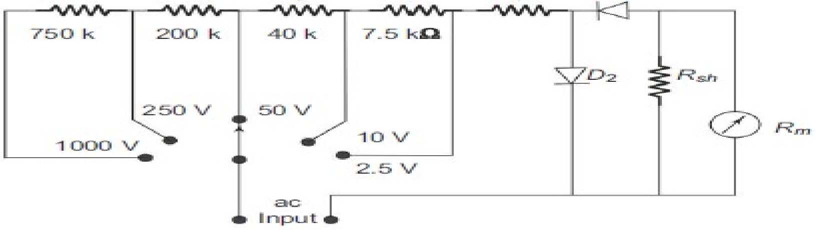


Fig. 4.24 Multirange ac voltmeter

MULTIRANGE AMMETERS:

The current range of the dc ammeter maybe further extended by a number of shunts, selected by a range switch. Such a meter is called a multi-range ammeter, shown in Fig. 3.2.

The circuit has four shunts R1, R2, R3and R4, which can be placed in parallel with the movement to give four different current ranges. Switch S is a multi position switch,(having low contact resistance and high current carrying capacity, since its contacts are in series with low resistance shunts). Make before break type switch is used for range changing. This switch protects the meter movement from being damaged without a shunt during range changing.

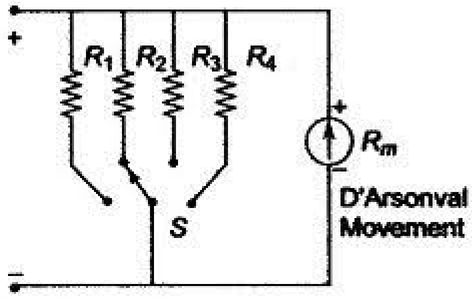


Fig. 3.2 Multirange Ammeter

If we use an ordinary switch for range changing, the meter does not have any shunt in parallel while the range is being changed, and hence full current passes through the meter movement, damaging the movement. Hence a make before break type switch is used. The switch is so designed that when the switch position is changed, it makes contact with the next terminal (range) before breaking contact with the previous terminal. Therefore the meter movement is never left unprotected. Multi range ammeters are used for ranges up to 50A. When using a multi range ammeter, first use the highest current range, then decrease the range until good upscale reading is obtained. The resistance used for the various ranges are of very high precision values, hence the cost of the meter increases.

Range extension AC Voltmeters (Aryton shunt):

The Aryton shunt eliminates the possibility of having the meter in the circuit without a shunt. This advantage is gained at the price of slightly higher overall resistance. Figure 3.3 shows a circuit of an Aryton shunt ammeter. In this circuit, when the switch is in position "1", resistance Ra is in parallel with the series combination of Rb, Rc and the meter movement.

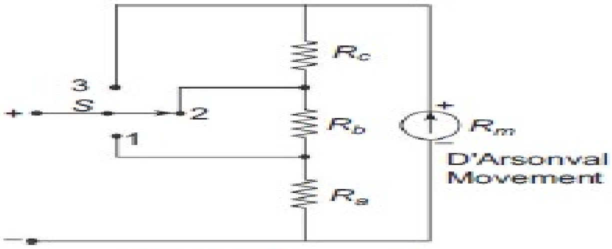


Fig. 3.3 Aryton shunt

Hence the current through the shunt is more than the current through the meter movement, thereby protecting the meter movement and reducing its sensitivity. If the switch is connected to position "2", resistance R_a and R_b are together in parallel with the series combination of Rc and the meter movement. Now the current through the meter is more than the current through the shunt resistance. If the switch is connected to position "3" R_a, R_b and R_c are together in parallel with the meter. Hence maximum current flows through the meter movement and very little through the shunt. This increases the sensitivity

Series type Ohmmeter

A D'Arsonval movement is connected in series with a resistance R1 and a battery which is connected to a pair of terminals A and B, across which the unknown resistance is connected. This forms the basic type of series ohmmeter, as shown in Fig. 4.30 (a). The current flowing through the movement then depends on the magnitude of the unknown resistance. Therefore, the meter deflection is directly proportional to the value of the unknown resistance. Referring to Fig. 4.30 (a)

R1 = current limiting resistance
R2 = zero adjust resistance
V = battery
Rm = meter resistance
Rx = unknown resistance

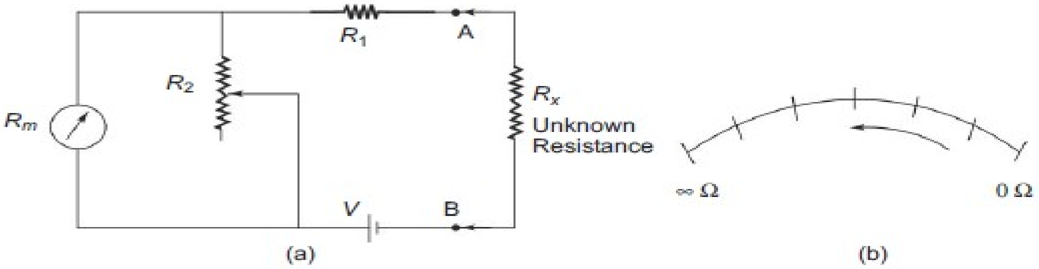


Fig. 4.30 (a) Series type ohmmeter (b) Dial of series ohmmeter

Calibration of the Series Type Ohmmeter

To mark the "0" reading on the scale, the terminals A and B are shorted, i.e. the unknown resistance Rx = 0, maximum current flows in the circuit and the shunt resistance R2 is adjusted until the movement indicates full scale current (I_{fsd}). The position of the pointer on the scale is then marked "0" ohms.

Similarly, to mark the "∞" reading on the scale, terminals A and B are open, i.e. the unknown resistance Rx = ∞, no current flow in the circuit and there is no deflection of the pointer. The position of the pointer on the scale, is then marked as "∞" ohms. By connecting different known values of the unknown resistance to terminals A and B, intermediate markings can be done on the scale. The accuracy of the instrument can be checked by measuring different values of standard resistance, i.e. the tolerance of the calibrated resistance, and noting the readings.

A major drawback in the series ohmmeter is the decrease in voltage of the internal battery with time and age. Due to this, the full scale deflection current drops and the meter does not read "0" when A and B are shorted. The variable shunt resistor R2 across the movement is adjusted to counteract the drop in battery voltage, thereby bringing the pointer back to "0" ohms on the scale.

It is also possible to adjust the full scale deflection current without the shunt R2 in the circuit, by varying the value of R1 to compensate for the voltage drop. Since this affects the calibration of the scale, varying by R2 is much better solution. The internal resistance of the coil R_m is very low compared to R1. When R2 is varied, the current through the movement is increased and the current through R2 is reduced, thereby bringing the pointer to the full scale deflection position.

The series ohmmeter is a simple and popular design, and is used extensively for general service work. Therefore, in a series ohmmeter the scale marking on the dial, has "0" on the right side, corresponding to full scale deflection current, and "•" on the left side corresponding to no current flow, as given in Fig. 4.30 (b).

Values of R1 and R2 can be determined from the value of Rx which gives half the full scale deflection

$$R_h = R_1 + R_2 \,\|\, R_m = R_1 + \frac{R_2 R_m}{R_2 + R_m}$$

where R_h = half of full scale deflection resistance.

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

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

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

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

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

Therefore $$V_{sh} = V_m$$
$$I_2 R_2 = I_{fsd} R_m$$

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

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

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

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

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

Therefore $$R_2 = \frac{I_{fsd} R_m R_h}{V - I_{fsd} R_h} \qquad (4.1)$$

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

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

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

Therefore $$R_1 = R_h - \frac{I_{fsd} R_m R_h}{V} \qquad (4.2)$$

Hence, R_1 and R_2 can be determined.

Shunt type Ohm-meter

The shunt type ohmmeter given in Fig. 4.32 consists of a battery in series with an adjustable resistor R1, and a D'Arsonval movement

The unknown resistance is connected in parallel with the meter, across the terminals A and B, hence the name shunt type ohmmeter. In this circuit it is necessary to have an ON/OFF switch to disconnect the battery from the circuit when the instrument is not used.

Calibration of the Shunt Type Ohmmeter

To mark the "0" ohms reading on the scale, terminals A and B are shorted, i.e. the unknown resistance Rx = 0, and the current through the meter movement is zero, since it is bypassed by the short-circuit. This pointer position is marked as "0" ohms. Similarly, to mark "∞" on the scale, the terminals A and B are opened, i.e. Rx = ∞, and full current flows through the meter movement; by appropriate selection of the value of R1, the pointer can be made to read full scale deflection current. This position of the pointer is marked "∞" ohms. Intermediate marking can be done by connecting known values of standard resistors to the terminals A and B. This ohmmeter therefore has a zero mark at the left side of the scale and an ∞ mark at the right side of the scale, corresponding to full scale deflection current as shown in Fig. 4.33. The shunt type ohmmeter is particularly suited to the measurement of low values of resistance. Hence it is used as a test instrument in the laboratory for special low resistance applications.

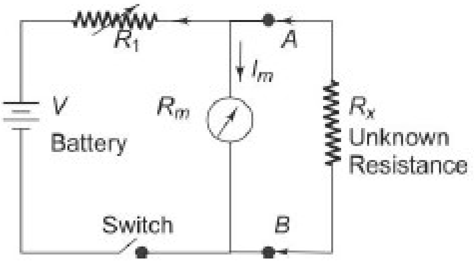


Fig. 4.32 Shunt type ohmmeter

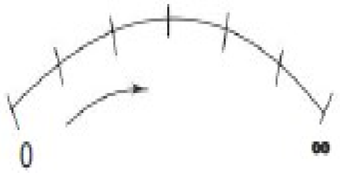


Fig. 4.33 Dial of shunt type ohmmeter

TRUE RMS METER

There exists a fundamental difference between the readings on a normal ac meter and on a true rms meter. The first uses a D'Arsonval movement with a full or half wave rectifier, and averages the values of the instantaneous rectified current .The rms meter, however, averages the squares of the instantaneous current values (proportional, for example, to the instantaneous heating effect). The scale of the true rms meter is calibrated in terms of the square roots of the indicated current values. The resulting reading is therefore the square root of the average of the squared instantaneous input values, which is the rms value of the measured alternating current .

A true rms meter is always a combination of a normal mean value indicating meter and a squaring device whose output at any instant is proportional to the instantaneous squared input.

It can be shown that the ac component of the voltage developed across the common collector resistors of two transistors that are connected in parallel, and between the bases of which a small ac voltage is applied, is proportional to the square of the applied input voltage

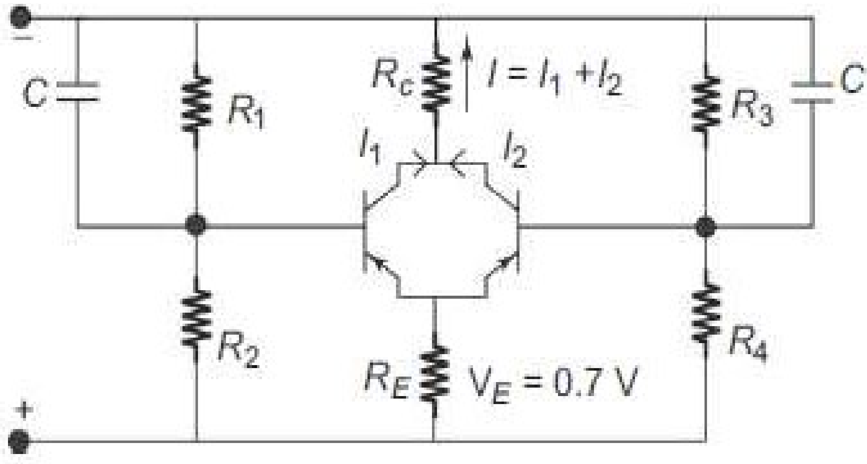


Fig. 4.28 Squaring device

The basic circuit of Fig. 4.28 employing two transistors is completed by abridge arrangement in which the dc component is cancelled out. This bridge arrangement is given in Fig. 4.29.

One side of the bridge consists of two parallel connected transistors Q_2 andQ_3, and a common collector resistor R_{13}. The side of the bridge, employing P_1 for bias setting, is the basic squaring circuit. The other side of the bridge is made of transistor Q_4 (whose base is biased by means of potentiometer P_2 and collector resistance R_{16}.)

Potentiometer P_1, base bias balance of the squaring circuit, must be adjusted for symmetrical operation of transistors Q_2 and Q_3. To do this, the polarity of a small dc input voltage applied to terminals A and B (bases of Q_2 and Q_3) has to be reversed, and the reading of the output meter must be the same for both input polarities.

Potentiometer P_2 must be set so that for zero input signal (terminals A and B short-circuited), the bridge is balanced and the meter reads zero. The balance condition is reached if the voltage drop across the collector resistance R_{13} of Q_2– Q_3, and collector resistance R_{16} of Q4, are equal.

Transistor Q_1 is used to improve the temperature stability of the whole circuit, which is basically obtained by the emitter resistance R_{10}. Optimum temperature compensation is obtained if the voltage drop across the emitter resistance for no signal is 0.7 V for silicon transistor.

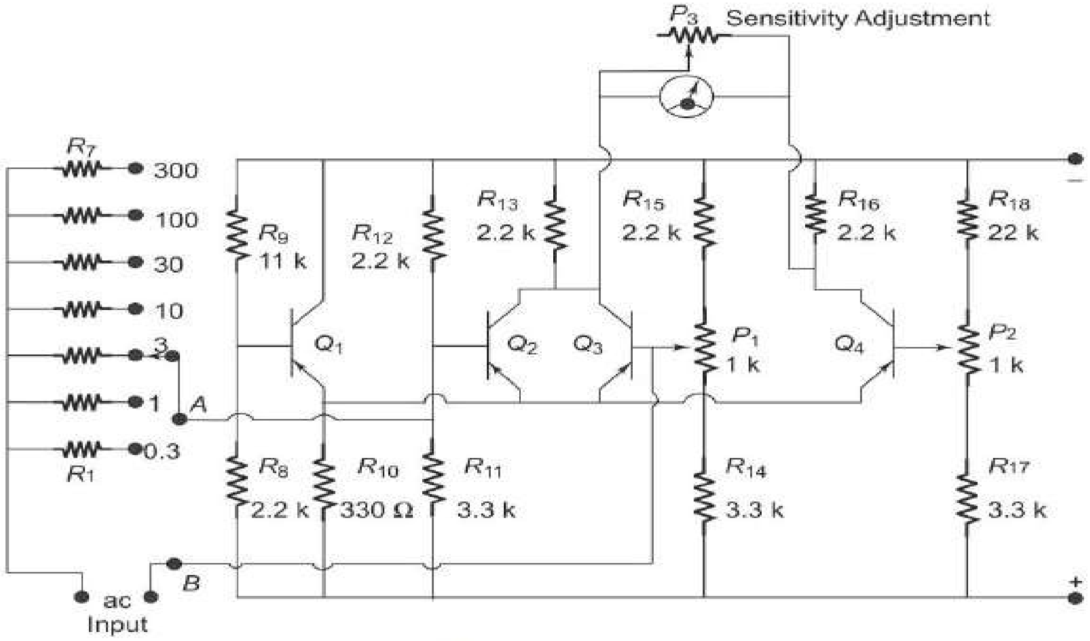


Fig. 4.29 True RMS meter

The low current through Q_2, Q_3, Q_4 requires a large emitter resistance value to fulfil the condition for compensation. Therefore, another transistor, Q_1 has been added to compensate for the temperature changes of Q_2 and Q_3.

The bias on this transistor has to be adjusted by selecting appropriate values of R_8 and R_9 so that the voltage drop across R_{10} in the balanced condition is 0.7 V for silicon transistor.

The input of the squaring devices (AB) is connected to a voltage divider that is calibrated in seven ranges, namely 0.3, 1, 3, 10, 30, 100, and 300 volts.

UNIT II

Specifications and designing aspects of Signal Generator- AF sine and square wave signal generators, Function Generators, Random noise Generators, Arbitrary waveform Generators. Wave Analyzers, Harmonic Distortion Analyzers, Spectrum Analyzers, Digital Fourier Analyzers.

INTRODUCTION

A signal generator is a vital component in a test setup, and in electronic troubleshooting and development, whether on a service bench or in a research laboratory. Signal generators have a variety of applications, such as checking the stage gain, frequency response, and alignment in receivers and in a wide range of other electronic equipment. They provide a variety of waveforms for testing electronic circuits, usually at low powers. The term oscillator is used to describe an instrument that provides only a sinusoidal output signal, and the term generator to describe an instrument that provides several output waveforms, including sine wave, square wave, triangular wave and pulse trains, as well as an amplitude modulated waveform. Hence, when we say that the oscillator generates a signal, it is important to note that no energy is created; it is simply converted from a dc source into ac energy at some specific frequency.

AF SINE AND SQUARE WAVE GENERATOR

The block diagram of an AF Sine-Square wave audio oscillator is illustrated in Fig. 8.4 The signal generator is called an oscillator. A Wien bridge oscillator is used in this generator. The Wien bridge oscillator is the best for the audio frequency range. The frequency of oscillations can be changed by varying the capacitance in the oscillator. The frequency can also be changed in steps by switching in resistors of different values.

The output of the Wien bridge oscillator goes to the function switch. The function switch directs the oscillator output either to the sine wave amplifier or to the square wave shaper. At the output, we get either a square or sine wave. The output is varied by means of an attenuator.

The instrument generates a frequency ranging from 10 Hz to 1 MHz, continuously variable in 5 decades with overlapping ranges. The output sine wave amplitude can be varied from 5 mV to 5 V (rms).The output is taken through a push-pull amplifier. For low output, the impedance is 600W. The square wave amplitudes can be varied from 0 – 20 V (peak). It is possible to adjust the symmetry of the square wave from 30 – 70%. The instrument requires only 7 W of power at 220 V – 50 Hz. The front panel of a signal generator consists of the following.

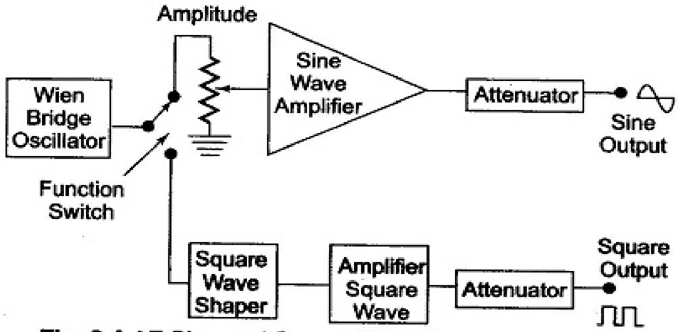


Fig. 8.4 AF Sine and Square Wave Generator

1. *Frequency selector*: It selects the frequency in different ranges and varies it continuously in a ratio of 1 : 11. The scale is non-linear.

2. *Frequency multiplier*: It selects the frequency range over 5 decades, from 10 Hz to 1 MHz.

3. *Amplitude multiplier*: It attenuates the sine wave in 3 decades,× 1, × 0.1 and× 0.01.

4. *Variable amplitude*: It attenuates the sine wave amplitude continuously.

5. *Symmetry control:* It varies the symmetry of the square wave from 30% to 70%.

6. *Amplitude*: It attenuates the square wave output continuously.

7. *Function switch*: It selects either sine wave or square wave output.

8. *Output available:* This provides sine wave or square wave output.

9. *Sync*: This terminal is used to provide synchronisation of the internal signal with an external signal.

10. On-Off Switch

FUNCTION GENERATOR

A function generator produces different waveforms of adjustable frequency. The common output waveforms are the sine, square, triangular and sawtooth waves. The frequency may be adjusted, from a fraction of a Hertz to several hundred kHz.

The various outputs of the generator can be made available at the same time. For example, the generator can provide a square wave to test the linearity of an amplifier and simultaneously provide a sawtooth to drive the horizontal deflection amplifier of the CRO to provide a visual display.

Capability of Phase Lock The function generator can be phase locked to an external source. One function generator can be used to lock a second function generator, and the two output signals can be displaced in phase by adjustable amount.

In addition, the fundamental frequency of one generator can be phase locked to a harmonic of another generator, by adjusting the amplitude and phase of the harmonic, almost any waveform can be generated by addition. The function generator can also be phase locked to a frequency standard and all its output waveforms will then have the same accuracy and stability as the standard source.

The block diagram of a function generator is illustrated in Fig. 8.5. Usually the frequency is controlled by varying the capacitor in the LC or RC circuit. In this instrument the frequency is controlled by varying the magnitude of current which drives the integrator. The instrument produces sine, triangular and square waves with a frequency range of 0.01 Hz to 100 kHz.

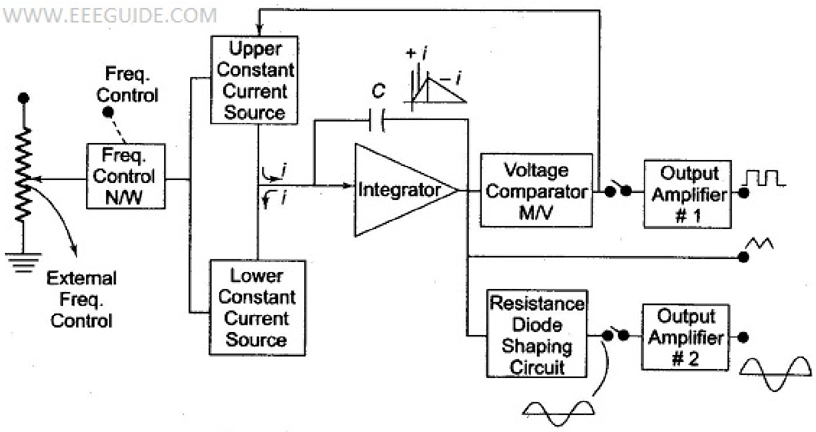


Fig. 8.5 Function Generator

The frequency controlled voltage regulates two current sources. The upper current source supplies constant current to the integrator whose output voltage increases linearly with time, according to the equation of the output signal voltage.

$$e_{out} = -\frac{1}{C}\int_0^t i\,dt$$

An increase or decrease in the current increases or decreases the slope of the output voltage and hence controls the frequency. The voltage comparator multivibrator changes states at a pre-determined maximum level of the integrator output voltage. This change cuts off the upper current supply and switches on the lower current supply.

The lower current source supplies a reverse current to the integrator, so that its output decreases linearly with time. When the output reaches a pre-determined minimum level, the voltage comparator again changes state and switches on the upper current source.

The output of the integrator is a triangular waveform whose frequency is determined by the magnitude of the current supplied by the constant current sources. The comparator output delivers a square wave voltage of the same frequency. The resistance diode network alters the slope of the triangular wave as its amplitude changes and produces a sine wave with less than 1% distortion.

RANDOM NOISE GENERATOR

A simplified block diagram used in the audio frequency range is shown in Fig. 8.8.

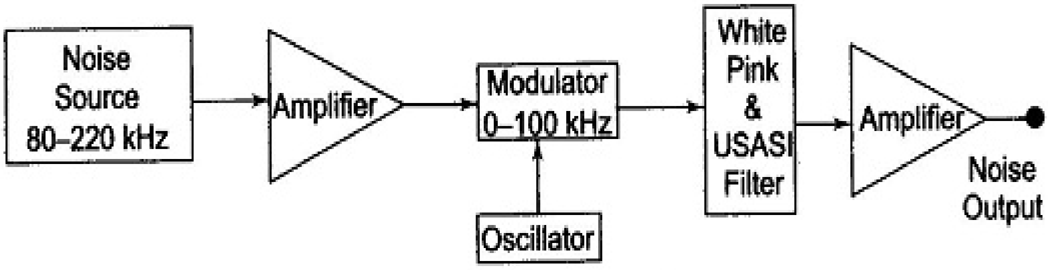


Fig. 8.8 Random Noise Generator

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

The method of generating noise is usually to use a semi conductor noise diode, which delivers frequencies in a band roughly extending from 80 – 220 kHz. The output from the noise diode is amplified and heterodyned down to the audio frequency band by means of a balanced symmetrical modulator. The filter arrangement controls the bandwidth and supplies an output signal in three spectrum choices, white noise, pink noise and Usasi noise. From Fig. 8.9, it is seen that white noise is flat from 20 Hz to 25 kHz and has an upper cutoff frequency of 50 kHz with a cutoff slope of –12 dbs/ octave.

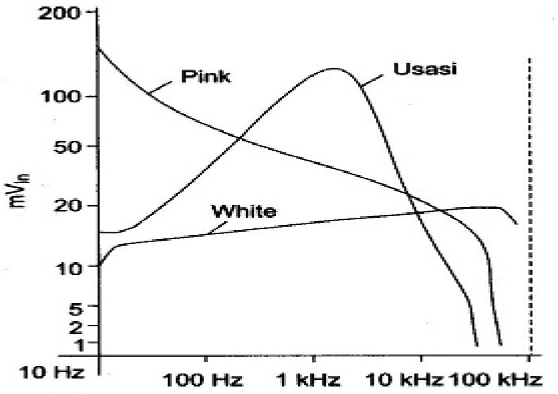


Fig. 8.9 Frequency Response

Pink noise is so called because the lower frequencies have a larger amplitude, similar to red light. Pink noise has a voltage spectrum which is inversely proportional to the square root of frequency and is used in bandwidth analysis. Usasi noise ranging simulates the energy distribution of speech and music frequencies and is used for testing audio amplifiers and loud speakers.

ARBITRARY WAVEFORM GENERATOR

An arbitrary waveform generator allows the instrument user to design and generate virtually and desired waveforms.

PM5139 signal generator is shown in figure described as a function generator with arbitrary waveform capability. This instrument is able to produce virtually all sinusoidal, pulse, ramp and triangular wave shapes. Amplitude, frequency and phase modulation of the various waveforms is possible and DC offset voltages can be superimposed. There are 10 standard wave forms, selectable through menu buttons and precisely set for frequency, amplitude, etc. by means of control knob. A backlit liquid crystal display reads out the status of the generated waveform.

Arbitrary waveform may be created by combining and modeling various standard waveforms. The waveform generating functions includes linear and logarithmic amplitude and frequency sweeps. Up to six arbitrary waveforms may be stored and recalled from memory as required. The output range of the voltage is 1mV to 20 V peak-to-peak, and the frequency range is 0.1mHz to 20MHz

BASIC WAVE ANALYZER

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

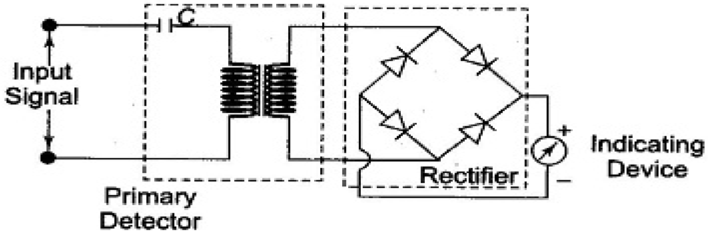


Fig. 9.1 (a) Basic Wave Analyzer

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

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

HARMONIC DISTORTION ANALYZER

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

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

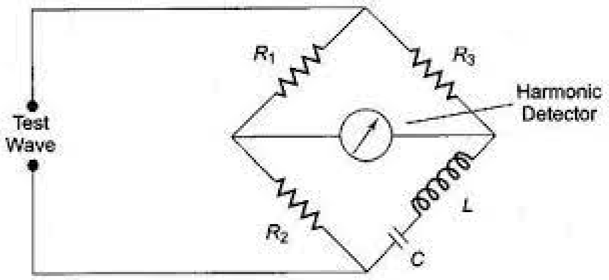


Fig. 9.5 Resonance Bridge

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

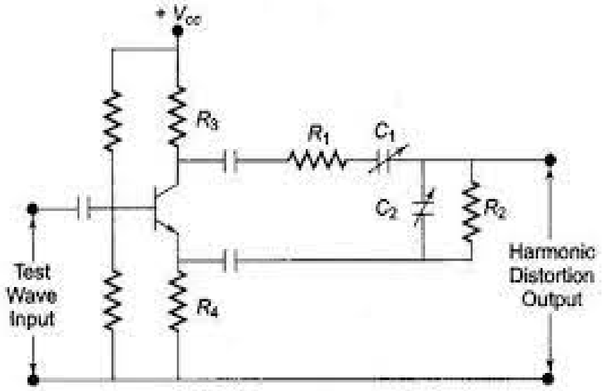


Fig. 9.6 Wien's Bridge Method

3. Bridged T-Network Method*:* Referring to Fig. 9.7 the, L and C's are tuned to the fundamental frequency, and R is adjusted to bypass fundamental frequency. The tank circuit being tuned to the fundamental frequency, the fundamental energy will circulate in the tank and is bypassed by the resistance. Only harmonic components will reach the output terminals and the distorted output can be measured by the meter. The Q of the resonant circuit must be at least 3–5.

One way of using a bridge T-network is given in Fig. 9.8. The switch S is first connected to point A so that the attenuator is excluded and the bridge T-network is adjusted for full suppression of the fundamental frequency, i.e. minimum output. Minimum output indicates that the bridged T-network is tuned to the fundamental frequency and that the fundamental frequency is fully suppressed

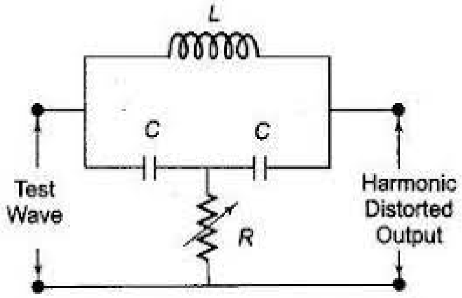


Fig. 9.7 Bridged T-Network Method

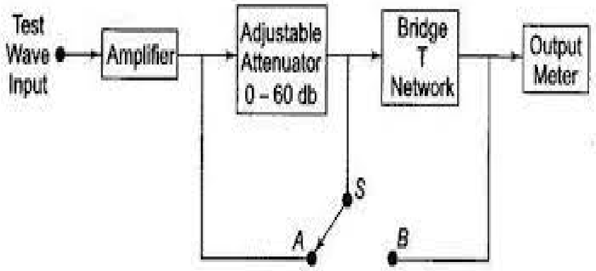


Fig. 9.8 Harmonic Distortion Analyzer Using Bridged T-Network

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

SPECTRUM ANALYZER

The most common way of observing signals is to display them on an oscilloscope, with time as the X-axis (i.e. amplitude of the signal versus time). This is the time domain. It is also useful to display signals in the frequency domain. The instrument providing this frequency domain view is the spectrum analyzer. A spectrum analyzer provides a calibrated graphical display on its CRT, with frequency on the horizontal axis and amplitude (voltage) on the vertical axis. Displayed as vertical lines against these coordinates are sinusoidal components of which the input signal is composed. The height represents the absolute magnitude, and the horizontal location represents the frequency.

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

Parallel filter bank analyzer:

In a parallel filter bank analyzer, the frequency range is covered by a series of filters whose central frequencies and bandwidth are so selected that they overlap each other, as shown in Fig. 9.9(a). Typically, an audio analyzer will have 32 of these filters, each covering one third of an octave.

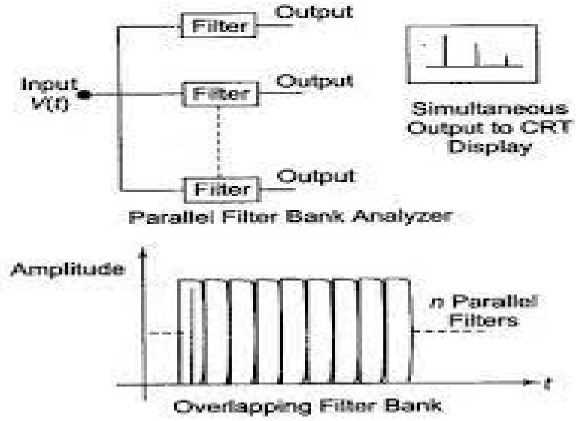


Fig. 9.9 (a) Spectrum Analyzer (Parallel Filter Bank Analyzer)

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

Basic Spectrum Analyzer Using Swept Receiver Design:

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

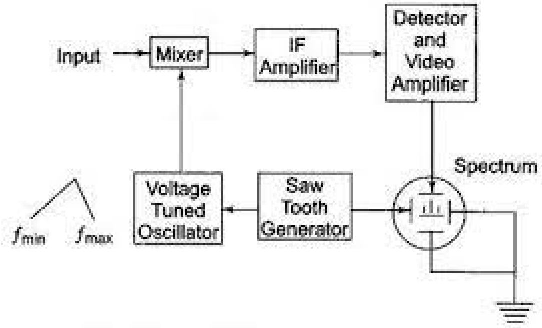


Fig. 9.9 (b) Spectrum Analyzer

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

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

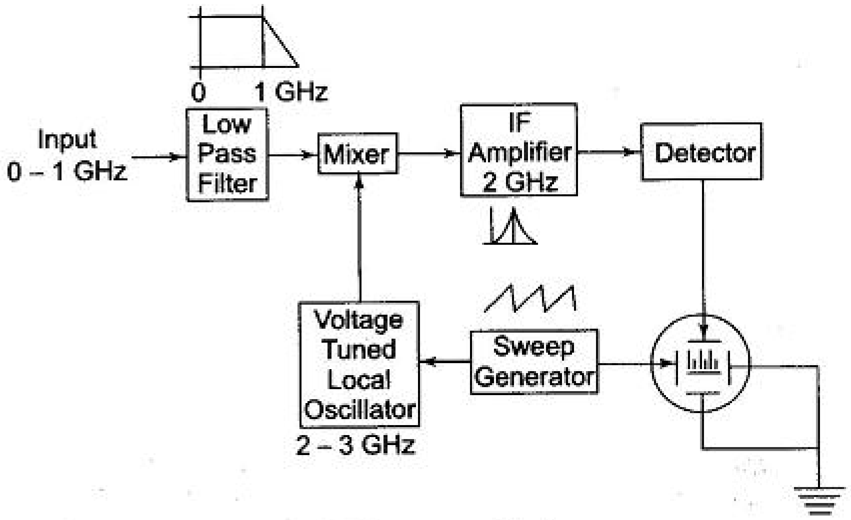


Fig. 9.13 RF Spectrum Analyzer

The input signal is fed into a mixer which is driven by a local oscillator. This oscillator is linearly tunable electrically over the range 2 – 3 GHz. The mixer provides two signals at its output that are proportional in amplitude to the input signal but of frequencies which are the sum and difference of the input signal and local oscillator frequency. The IF amplifier is tuned to a narrow band around 2 GHz, since the local oscillator is tuned over the range of 2 – 3 GHz, only inputs that are separated from the local oscillator frequency by 2 GHz will be converted to IF frequency band, pass through the IF frequency amplifier, get rectified and produce a vertical deflection on the CRT.

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

DIGITAL FOURIER ANALYZER

The basic principle of a digital fourier analyzer is shown in Fig. 9.14. The digital fourier analyzer converts the analogue waveform over time period T into N samples.

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

$$s_x(k.\Delta \mathrm{f}) = \frac{\mathrm{T}}{\mathrm{N}}\sum_{n=1}^{N} x(n.\ \Delta \mathrm{t})\ \exp\left[-\frac{\mathrm{j2\Pi kn}}{\mathrm{N}}\right]$$

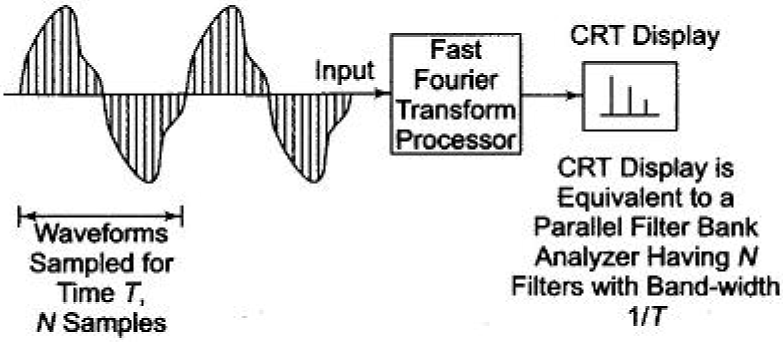


Fig. 9.14 Basic of a Digital Fourier Analyzer

$s_x(k.\Delta \mathrm{f})$ is a complex quantity, which is obtained by operating on all the sample $x(n.\Delta \mathrm{t})$; n = 1, 2, 3, ..., N by the complex factor exp [– j [(2 Π k n)/N]].

The discrete inverse transform is given by

$$x(n.\Delta \mathrm{t}) = \frac{\mathrm{N}}{\mathrm{T}}\sum_{n=1}^{N} s_x(k.\ \Delta \mathrm{f})\ \exp\left[-\frac{\mathrm{j2\Pi kn}}{\mathrm{N}}\right]$$

where k = 1, 2, 3, ..., N. sample $(n.\Delta \mathrm{t})$); n = 1, 2, 3, ..., N by the complex factor exp [– j [(2 P kn)/N]]. The discrete inverse transform is given by 1 2 ( ) ( ) exp N x n N j k n x n t S k f T = N Ê - P ˆ ◊ D = ◊ D Á ˜ Ë ¯ Â where n = 1, 2, ..., N. Since Sx (k ◊ D f); k = 1, 2, ..., N is a complex quantity, the DFT provides both amplitude and phase information at a particular point in the spectrum. The discrete transforms are usually implemented by means of the Fast Fourier Transform (FFT), which is particularly suitable for implementation in a digital computer, since N is constrained to the power of 2, i.e. 210 = 1024.

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

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

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

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

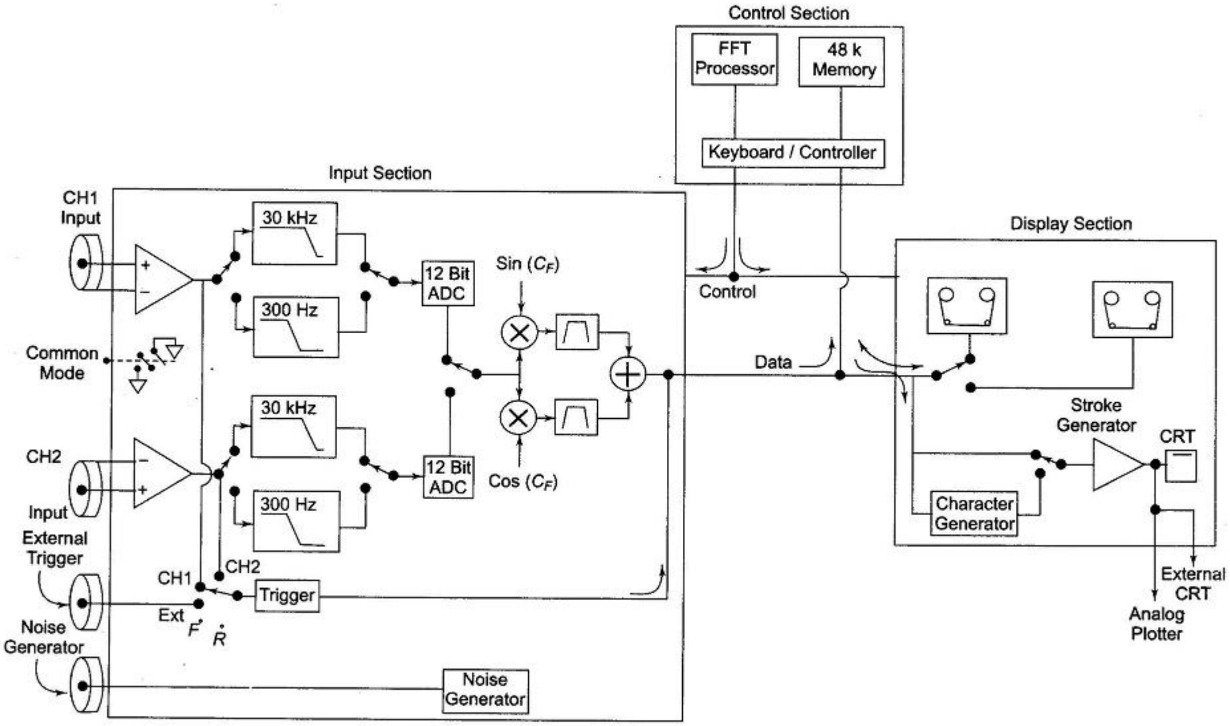


Fig. 9.15 Block Diagram of a Digital Signal Analyzer

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

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

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

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

where F(x (t)) is the Fourier transform of x(t). The auto spectrum G_{xx} (f) which contains no phase information is obtained from $S_x(f)$ as

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

where $S_x(f)^*$ indicates the complex conjugate of $S_x(f)$.

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

The Inverse Fourier Transform of G_{xx} (f) is given by

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

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

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

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

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

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

where S_y (t) is the linear spectrum of y(t) and $S_x(t)^*$ is the complex conjugate spectrum of x(t).

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

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

where the bars indicate the time averaged values. The input signal used for such measurements is often the internal random noise generator.

UNIT III

Oscilloscopes- ***general purpose CROs***; block diagram , functions and implementation of various blocks, specifications, various controls and their functions , types of probes used in CROs. Measurement of frequency and phase difference using Lissajous patterns.

Special purpose CROs**;** sampling oscilloscope, analog storage oscilloscope, digital storage oscilloscope.

INTRODUCTION

The Cathode Ray Oscilloscope (CRO) is probably the most versatile tool for the development of electronic circuits and systems. The CRO allows the amplitude of electrical signals, whether they are voltage, current, or power, to be displayed as a function of time.

The CRO depends on the movement of an electron beam, which is bombarded (impinged) on a screen coated with a fluorescent material, to produce a visible spot. If the electron beam is deflected on both the conventional axes, i.e. X-axis and Y-axis, a two-dimensional display is produced.

The beam is deflected at a constant rate relative of time along the X-axis and is deflected along the Y-axis in response to an stimulus, such as a voltage. This produces a time-dependent variation of the input voltage.

The oscilloscope is basically an electron beam voltmeter. The heart of the oscilloscope is the Cathode Ray Tube (CRT) which makes the applied signal visible by the deflection of a thin beam of electrons. Since the electron has practically no weight, and hence no inertia, therefore the beam of electrons can be moved to follow waveforms varying at a rate of millions of times/second. Thus, the electron beam faithfully follows rapid variations in signal voltage and traces a visible path on the CRT screen. In this way, rapid variations, pulsations or transients are reproduced and the operator can observe the waveform as well as measure amplitude at any instant of time.

Since it is completely electronic in nature, the oscilloscope can reproduce HF waves which are too fast for electro mechanical devices to follow. Thus, the oscilloscope has simplified many tests and measurements. It can also be used in any field where a parameter can be converted into a proportional voltage for observation, e.g. meteorology, biology, and medicine. The oscilloscope is thus a kind of voltmeter which uses beam instead of a pointer, and kind of recorder which uses an electron beam instead of a pen.

BLOCK DIAGRAM OF OSCILLOSCOPE

The major block circuit shown in Fig. 7.4, of a general purpose CRO, is as follows:

1. CRT
2. Vertical amplifier
3. Delay line
4. Time base
5. Horizontal amplifier
6. Trigger circuit
7. Power supply

The function of the various blocks is as follows.

1. **CRT** This is the cathode ray tube which emits electrons that strikes the phosphor screen internally to provide a visual display of signal.

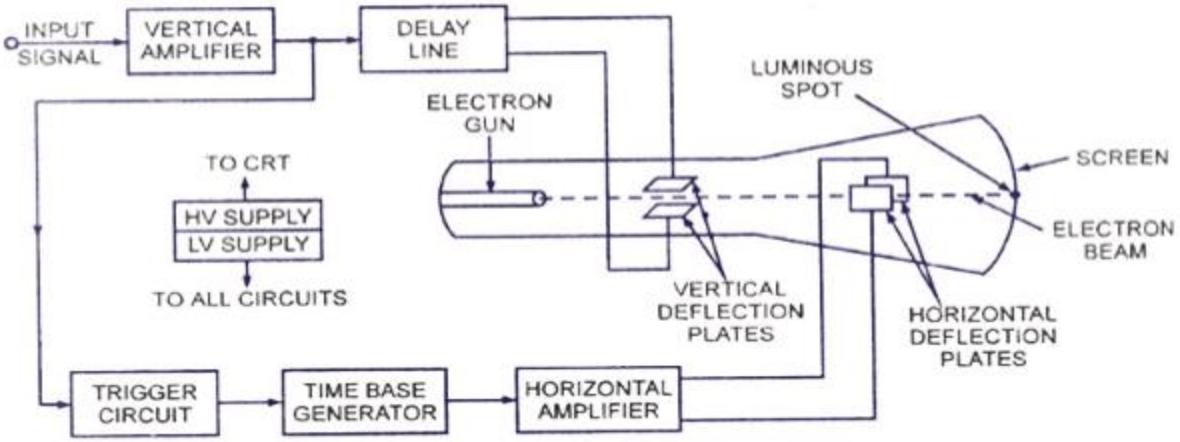


Figure - Block Diagram of General Purpose CRO

2. **Vertical Amplifier** This is a wide band amplifier used to amplify signals in the vertical section

3. **Delay Line** It is used to delay the signal for some time in the vertical sections.

4. **Time Base** It is used to generate the saw-tooth voltage required to deflect the beam in the horizontal section.

5. **Horizontal Amplifier** This is used to amplify the saw-tooth voltage before it is applied to horizontal deflection plates.

6. **Trigger Circuit** This is used to convert the incoming signal into trigger pulses so that the input signal and the sweep frequency can be synchronized

7**. Power Supply** There are two power supplies, a –ve High Voltage (HV) supply and a +ve Low Voltage (LV) supply. Two voltages are generated in the CRO. The +ve volt supply is from + 300 to 400 V. The –ve high voltage supply is from – 1000 to– 1500 V. This voltage is passed through a bleeder resistor at a few mA. The intermediate voltages are obtained from the bleeder resistor for intensity, focus and positioning controls.

Advantages of using –ve HV Supply

(i) The accelerating anodes and the defection plates are close to ground potential. The ground potential protects the operator from HV shocks when making connections to the plates.

(ii) The deflection voltages are measured wrt ground, therefore HV blocking or coupling capacitor are not needed, but low voltage rating capacitors can be used for connecting the HV supply to the vertical and horizontal amplifiers.

(iii) Less insulation is needed between positioning controls and chassis.

FUNCTIONS AND IMPLEMENTATION OF VARIOUS BLOCKS

1. VERTICAL AMPLIFIER

The sensitivity (gain) and frequency bandwidth (B.W.) response characteristics of the oscilloscope are mainly determined by the vertical amplifier. Since the gain B.W. product is constant, to obtain a greater sensitivity the B.W. is narrowed, or vice-versa. Some oscilloscopes give two alternatives, switching to a wide bandwidth position, and switching to a high sensitivity position. Block Diagram of a Vertical Amplifier The block diagram of a vertical amplifier is shown in Fig. 7.7.

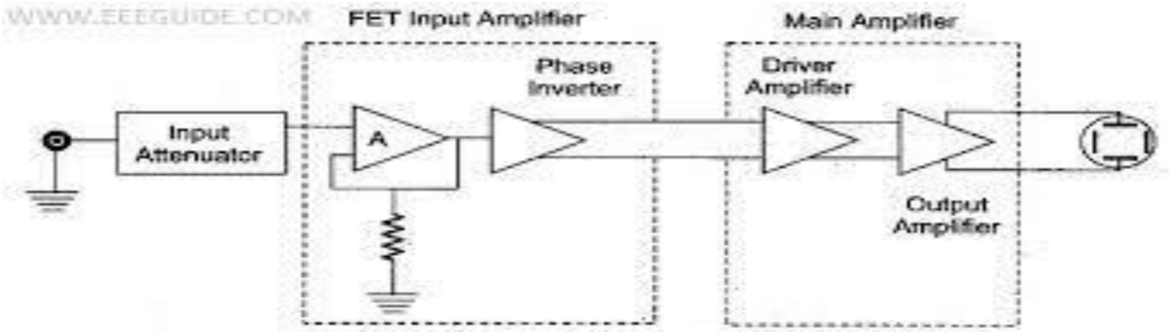


Fig. 7.7 Vertical Amplifier

The vertical amplifier consists of several stages, with fixed overall sensitivity or gain expressed in V/div. The advantage of fixed gain is that the amplifier can be more easily designed to meet the requirements of stability and B.W. The vertical amplifier is kept within its signal handling capability by proper selection of the input attenuator switch. The first element of the pre-amplifier is the input stage, often consisting of a FET source follower whose high input impedance isolates the amplifier from the attenuator.

This FET input stage is followed by a BJT emitter follower, to match the medium impedance of FET output with the low impedance input of the phase inverter.

This phase inverter provides two anti-phase output signals which are required to operate the push-pull output amplifier. The push-pull output stage delivers equal signal voltages of opposite polarity to the vertical plates of the CRT.

The advantages of push-pull operation in CRO are similar to those obtained from push-pull operation in other applications; better hum voltage cancellation from the source or power supply (i.e. dc), even harmonic suppression, especially the large 2nd harmonic is cancelled out, and greater power output per tube as a result of even harmonic cancellation. In addition, a number of defocusing and non-linear effects are reduced, because neither plate is at ground potential.

2. SWEEP GENERATOR (Or) TIME BASE GENERATOR

A continuous sweep CRO using a UJT as a time base generator is shown in Fig. 7.8. The UJT is used to produce the sweep. When the power is first applied, the UJT is off and the CT charges exponentially through RT. The UJT emitter voltage VE rises towards VBB and when VE reaches the peak voltage VP, as shown in Fig. 7.9, the emitter to base ‘1’ (B1) diode becomes forward biased and the UJT triggers ON. This provides a low resistance discharge path and the capacitor discharges rapidly. The emitter voltage VE reaches the minimum value rapidly and the UJT goes OFF. The capacitor recharges and the cycle repeats.

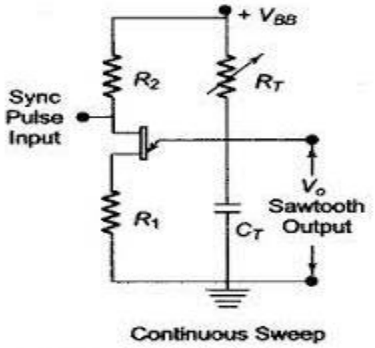


Fig. 7.8 Continuous Sweep

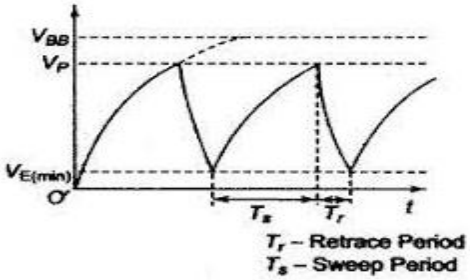


Fig. 7.9 Sawtooth Output Waveform

To improve sweep linearity, two separate voltage supplies are used, a low voltage supply for UJT and a high voltage supply for the R_T C_T circuit.

R_T is used for continuous control of frequency within a range and C_T is varied or changed in steps for range changing. They are sometimes called as timing resistor and timing capacitor respectively. The sync pulse enables the sweep frequency to be exactly equal to the input signal frequency, so that the signal is locked on the screen and does not drift.

3. TRIGGER PULSE CIRCUIT

The trigger circuit is activated by signals of a variety of shapes and amplitudes, which are converted to trigger pulses of uniform amplitude for the precision sweep operation. If the trigger level is set too low, the trigger generator will not operate. On the other hand, if the level is too high, the UJT may conduct for too long and part of the leading edge of the input signal may be lost.

The trigger selection is a 3-position switch, Internal-External-Line, as shown in Fig. 7.12. The trigger input signal is applied to a voltage comparator whose reference level is set by the Trigger Level control on the CRO front panel.

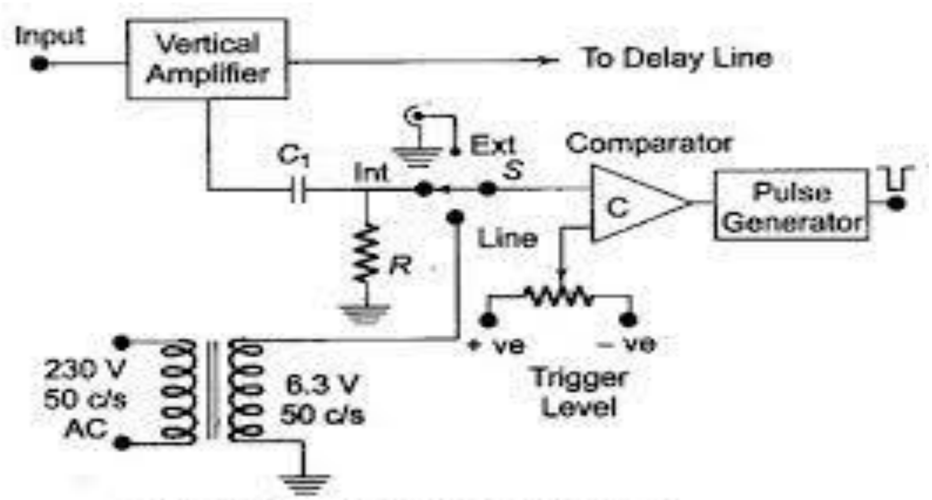


Fig. 7.12 Trigger Pulse Circuit

The comparator circuit C produces a change in the output whenever the trigger input exceeds the present trigger levels. The pulse generator that follows the comparator produces –ve trigger pulses each time the comparator output crosses its quiescent level, which in turn triggers the sweep generator to start the next sweep. The trigger sweep generator contains the stability or sync control, which prevents the display from jittering or running on the screen. Stability is secured by proper adjustments of the sweep speed. Sweep speed is adjustable by means of a sweep rate control and its multiplier, i.e. range control. The timing resistance R_T is used for sweep rate control and timing capacitor C_T is changed in steps for sweep rate control.

4. DELAY LINE

Figure 7.13 shows a delay line circuit

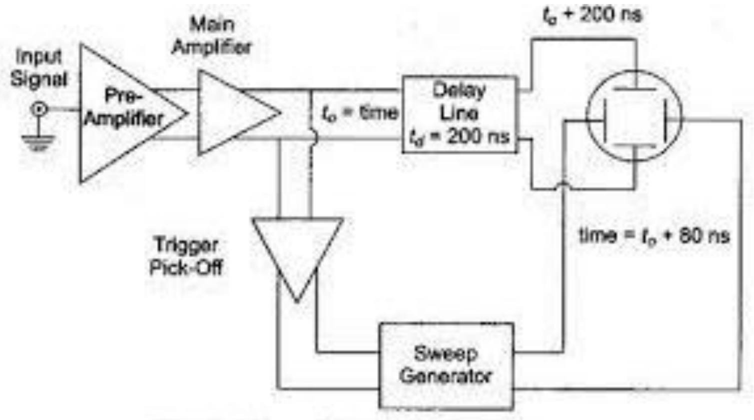


Fig. 7.13 Delay Line Circuit

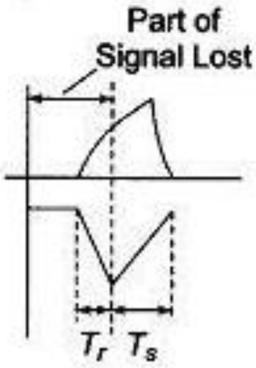


Fig. 7.14 Delay Line Wave-form

Figure 7.14 indicates the amplitude of the signal wrt time and the relative position of the sweep generator output signal. The diagram shows that when the delay line is not used, the initial part of the signal is lost and only part of the signal is displayed. To counteract this disadvantage the signal is not applied directly to the vertical plates but is passed through a delay line circuit, as shown in Fig. 7.13. This gives time for the sweep to start at the horizontal plates before the signal has reached the vertical plates. The trigger pulse is picked off at a time t_o after the signal has passed through the main amplifier. The sweep generator delivers the sweep to the horizontal amplifier and the sweep starts at the HDP at time t_o + 80 ns. Hence the sweep starts well in time, since the signal arrives at the VDP at time t_o + 200 ns.

STANDARD SPECIFICATIONS OF A SINGLE BEAM CRO

Vertical Amplifier

Sensitivity	: 5 mV/Div. to 20 V/Div. in 12 calibrated steps in a 1, 2, 5 sequence. Continuous control (un-calibrated) between steps, reduces the sensitivity by a minimum of 2.5 times.
Accuracy	: ± 3%
Bandwidth	: dc to 20 MHz (– 3 db), dc coupling : 0.5 Hz to 20 MHz (– 3 db)

ac coupling

Rise time : Better than 18 ns
Input Impedance : 1 MW/40 pf
Maximum input voltage : 400 V (dc + ac peak)
Signal delay : Built in delay line sufficient to display leading edge of the waveform

Time Base

Sweep ranges : 0.1 ms/Div. to 0.5 s/Div. in 21 calibrated steps in a 1, 2, 5 Sequence. Continuous un-calibrated control between steps extending slowest speed to 1.5 s/Div.
Accuracy : ± 5%
Magnification : 5 times. Takes the highest speed to 20 ns/Div.
Triggering Auto mode : Free running in the absence of a trigger signal. Triggers to the input signal automatically.
Level : Continuously adjustable on the + ve and – ve going slopes to trigger signal. Level adjustable over 8 Divs.
Source : Internal-External-Line
Polarity : Positive or negative
Maximum trigger input : 250 V (dc + ac peak) short term
Input impedance : 1 MW/30 pf
Internal trigger level : 3 Div from 2 Hz to 20 MHz (1 Div, 30 Hz to 20 MHz in Auto mode)
External trigger level : 3 V peak to peak, 2 Hz to 20 MHz (1 V, 30 Hz to 20 MHz in Auto mode)

Horizontal Amplifier

Bandwidth : dc – 2 MHz (– 3 db)
Sensitivity : 100 mV and 0.5 V/Div
Input impedance : 1 MW/50 pf
Maximum input voltage : 250 V (dc + ac peak)
Calibration : 200 mV peak to peak square wave at 1 kHz
Cathode ray tube : Flat faced medium persistence
Accelerating Potential : 4.5 kV
Graticule : 8 × 10 Div of 8 mm each
Power requirements : 230 V ac, 50 Hz, 50 W
Dimensions : 220 × 275×430 mm
Weight : 10kg approximately
Optional accessories : (i) ×1 probe
(ii) Oscilloscope trolley
(iii) ×10 probe (10 MW/12 pf)

VARIOUS CONTROLS AND THEIR FUNCTIONS

The following controls are available on CRO panel.

1. **Intensity** It controls the magnitude of emission of the electron beam, i.e. the electron beam is adjusted by varying the cathode-to-grid bias voltage. This adjustment is done by the 500 kW potentiometer.

2. **Focus** The focusing anode potential is adjusted with respect to the first and final accelerating anodes. This is done by the 2 MW potentiometer. It adjusts the negative voltage on the focus ring between –500 V and –900 V.

3. **Astigmatism** It adjusts the voltage on the acceleration anode with respect to the VDP of the CRT. This arrangement forms a cylindrical lens that corrects any defocusing that might be present. This adjustment is made to obtain the roundest spot on the screen.

4. **X-shift or Horizontal Position Control** The X-position of the spot is adjusted by varying the voltage between the horizontal plates. When the spot is in the center position, the two horizontal plates have the same potential.

5. **Y-shift or Vertical Position Control** The Y-position of the spot is adjusted by varying the voltage between the vertical plates. When the spot is in the center position, the two vertical plates have the same potential.

6. **Time Base Control** This is obtained by varying the CT and RT of the time base generator.

7. **Sync Selector** It can synchronize the sweep to signals coming internally from the vertical amplifier or an external signal or the line supply i.e. the Int-Ext-Line switch.

TYPES OF PROBES USED IN “CRO”

I. Direct Probe (1:1)

The simplest types of probe (one can hardly call it a probe) is the test lead. Test leads are simply convenient lengths of wire for connecting the CRO input to the point of observation. At the CRO end, they usually terminate with lugs, banana tips or other tips to fit the input jacks of the scope, and at the other end have a crocodile clip or any other convenient means for connection to the electronic circuit.

Since a CRO has high input impedance and high sensitivity, the test leads should be shielded to avoid hum pickup, unless the scope is connected to low impedance high level circuits.

Although the input impedances of most CROs are relatively very high compared to the circuits where they are connected, it is often desirable to increase their impedance to avoid loading of the circuits or causing unstable effects.

The input capacitance of the scope, plus the stray capacitance of the test leads, may be just enough to cause a sensitive circuit to break into oscillation when the CRO is connected. This effect can be prevented by an isolation probe made by placing a carbon resistor in series with the test lead, as shown in Fig. 7.44.

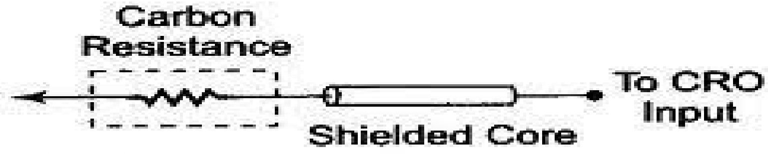


Fig. 7.44 Isolation Probe

A slight reduction in the amplitude of the waveform and a slight change in the wave-shape occurs with this probe. To avoid this possibility, a high impedance compensated probe, called a low capacitance probe or a 10 : 1 probe, is used.

II. Passive Voltage (High Z) Probe

Figure 7.45 (a) shows a 10 : 1 probe. Figure 7.45 (b) shows the equivalent circuit. Referring to Fig.7.45 (b). The capacitor is adjusted so that the elements of the bridge are balanced. Under conditions of balance we have

$$R_1 X_{(C_2 + C_{in})} = R_{in} X (C_1)$$

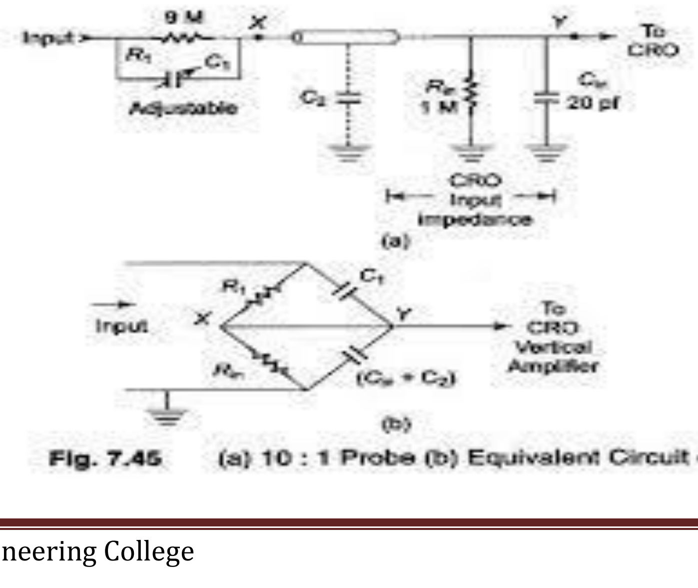


Fig. 7.45 (a) 10 : 1 Probe (b) Equivalent Circuit of 10 : 1 Probe

$$\frac{R_1}{\omega(C_2 + C_{\text{in}})} = \frac{R_{\text{in}}}{\omega C_1}$$

$$R_1\ C_1 = R_{\text{in}}\ (C_2 + C_{\text{in}})$$

Therefore, X and Y are equipotential and the effect of the probe is equivalent to placing a potential divider consisting of R1 and Rin across the input circuit. The attenuation of the signal is 10 : 1, i.e. $(R_1 + R_{in})/R_1$ = 10 : 1 over a wide frequency range. Therefore, it is called a compensated 10 × 1 probe. As far as dc voltage inputs are concerned, the coaxial capacitance equals 30 pf per foot. (Assuming a coaxial length of 3.5 ft, the total coaxial length capacitance is 105 pf). Substituting this value in the balance bridge equation, we have

$$C_1 = \frac{R_{\text{in}}\ (C_{\text{in}} + C_2)}{R_1} = \frac{1\ \text{M}\ (105 + 20)\ \text{pf}}{9\ \text{M}} = 13.88\ \text{pf}$$

Therefore, the input capacitance of a CRO can range from 15–50 pf. C1 should be adjusted from 13–47 pf. It must be adjusted to obtain optimum frequency response from the probe-CRO combination. The C1 adjustment is done by connecting the probe tip to a square wave of 1 kHz and observing the CRT display. When the CRT display has optimum response, the C1 value is deemed to be appropriate.

$$V_{\text{out}} = (0.1)\ V_{\text{in}} = \frac{V_{\text{in}} \times R_{\text{in}}}{R_1 + R_{\text{in}}}$$

III. Active Probes

Active probes are designed to provide an efficient method of coupling high frequency, fast rise time signals to the CRO input. Usually active probes have very high input impedance, with less attenuation than passive probes. Active devices may be diodes, FETs, BJTs, etc. Active probes are more expensive and bulky than passive probes, but they are useful for small signal measurements, because their attenuation is less.

Active Probes Using FETs Figure 7.46 shows a basic circuit of an active probe using a FET. The FET is used as the active element to amplify the input signal. Although the voltage gain of the FET follower circuit shown is unity, the follower circuit provides a power gain so that the input impedance can be increased. To be effective the FET must be mounted directly in the voltage probe tip, so that the capacitance of the interconnecting cable can be eliminated. This requires that the power for the FET be supplied from the oscilloscope to the FET in the probe tip. The FET voltage follower drives a coaxial cable, but instead of the cable connecting directly to the high input impedance of the oscilloscope, it is terminated in its characteristic impedance.

There is no signal attenuation between the FET Amplifier and the probe tip. The range of the signals that can be handled by the FET probe is limited to the dynamic range of the FET amplifier and is typically less than a few volts. To handle a larger dynamic range, external attenuators are added at the probe tip. Active probes have limited use because the FET probe effectively becomes an FET attenuator. Therefore, oscilloscopes are typically used with a 10 to 1 attenuator probe.

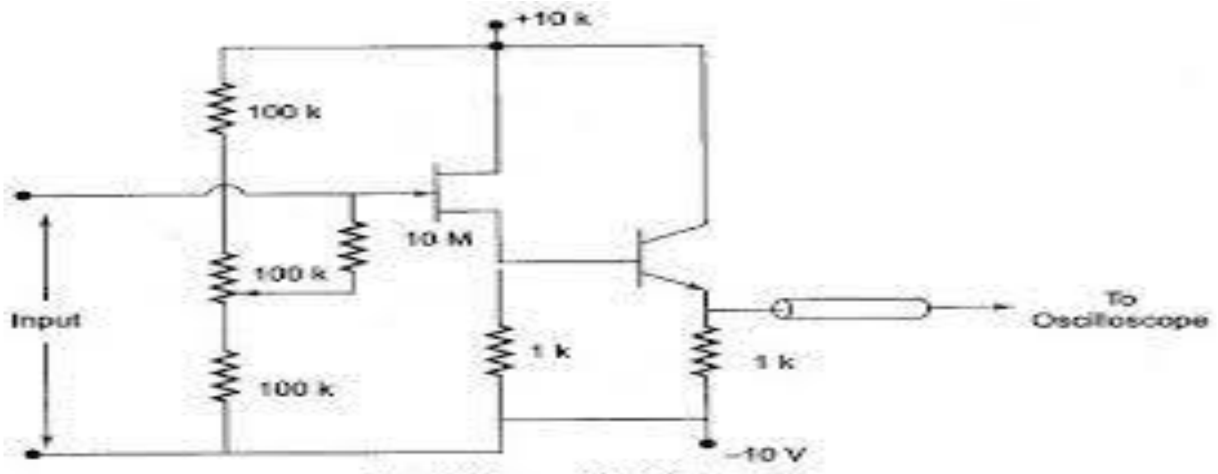


Fig. 7.46 FET Probe

Attenuators are designed to change the magnitude of the input signal seen at the input stage, while presenting a constant impedance on all ranges at the attenuator input.

A compensated RC attenuator is required to attenuate all frequencies equally. Without this compensation, HF signal measurements would always have to take the input circuit RC time constant into account. The input attenuator must provide the correct 1-2-5 sequence while maintaining a constant input impedance, as well as maintain both the input impedance and attenuation over the frequency range for which the oscilloscope is designed.

MEASUREMENT OF FREQUENCY BY LISSAJOUS METHOD

The oscilloscope is a sensitive indicator for frequency and phase measurements. The techniques used are simple and dependable, and measurement may be made at any frequency in the response range of the oscilloscope.

One of the quickest methods of determining frequency is by using Lissajous patterns produced on a screen. This particular pattern results when sine waves are applied simultaneously to both pairs of the deflection plates. If one frequency is an integral multiple (harmonic) of the other, the pattern will be stationary, and is called a Lissajous figure.

In this method of measurement a standard frequency is applied to one set of deflection plates of the CRT tube while the unknown frequency (of approximately the same amplitude) is simultaneously applied to the other set of plates. However, the unknown frequency is presented to the vertical plates and the known frequency (standard) to the horizontal plates. The resulting patterns depend on the integral and phase relationship between the two frequencies. (The horizontal signal is designated as fh and the vertical signal as f_v.) Typical Lissajous figures are shown in Figs 7.31 and 7.32 for sinusoidal frequencies which are equal, integral and in ratio.

Measurement Procedure

Set up the oscilloscope and switch off the internal sweep (change to Ext). Switch off sync control. Connect the signal source as given in Fig. 7.33. Set the horizontal and vertical gain control for the desired width and height of the pattern. Keep frequency f_v constant and vary frequency f_h, noting that the pattern spins in alternate directions and changes shape. The pattern stands still whenever f_v and f_h are in an integral ratio (either even or odd). The $f_v = f_h$ pattern stands still and is a single circle or ellipse. When $f_v = 2f_h$, a two loop horizontal pattern is obtained as shown in Fig. 7.31.

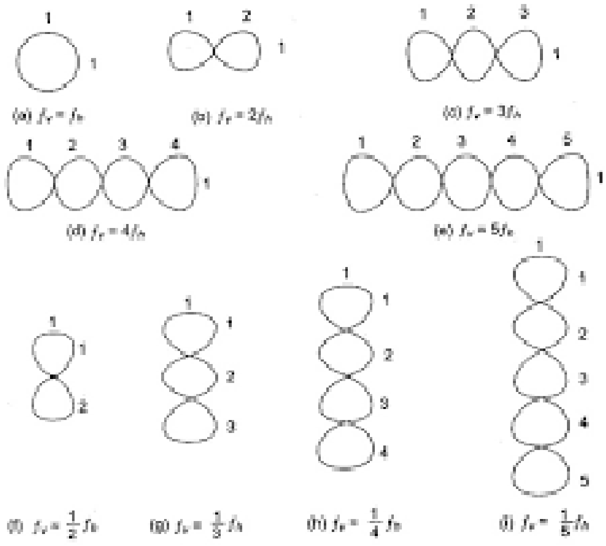


Fig. 7.31 Lissajous Patterns for Integral Frequencies

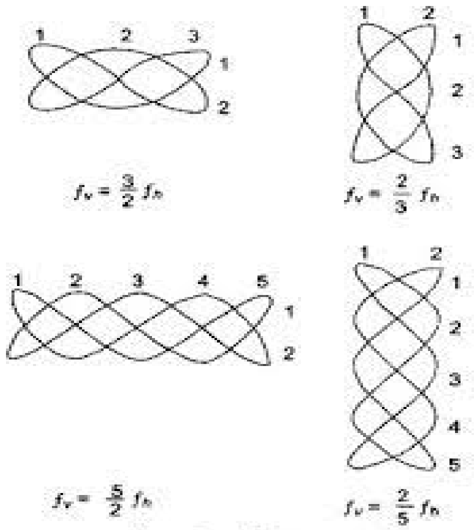


Fig. 7.32 Lissajous Patterns for Non-Integral Frequencies

To determine the frequency from any Lissajous figure, count the number of horizontal loops in the pattern, divide it by the number of vertical loops and multiply this quantity by f_h (known or standard frequency).

In Fig. 7.31 (g), there is one horizontal loop and 3 vertical loops, giving a fraction of 1/3. The unknown frequency f_v is therefore 1/3 f_h. An accurately calibrated, variable frequency oscillator will supply the horizontal search frequency for frequency measurement. For the case where the two frequencies are equal and in phase, the pattern appears as a straight line at an angle of 45° with the horizontal.

As the phase between the two alternating signals changes, the pattern changes cyclically, i.e. an ellipse (at 45° with the horizontal) when the phase difference is p/4, a circle when the phase difference is p/2 and an ellipse (at 135° with horizontal) when the phase difference is 3p/4, and a straight line pattern (at 135° with the horizontal) when the phase difference is p radians. As the phase angle between the two signals changes from p to 2p radians, the pattern changes correspondingly through the ellipse-circle-ellipse cycle to a straight line. Hence the two frequencies, as well as the phase displacement can be compared using Lissajous figures techniques.

When the two frequencies being compared are not equal, but are fractionally related, a more complex stationary pattern results, whose form is dependent on the frequency ratio and the relative phase between the two signals, as in Fig. 7.32.

The fractional relationship between the two frequencies is determined by counting the number of cycles in the vertical and horizontal

$$f_v = (\text{fraction}) \times f_h$$

or

$$\frac{f_v}{f_h} = \frac{\text{number of horizontal tangencies}}{\text{number of vertical tangencies}}$$

Figure 7.33 illustrates the basic circuit for comparing two frequencies by the Lissajous method.

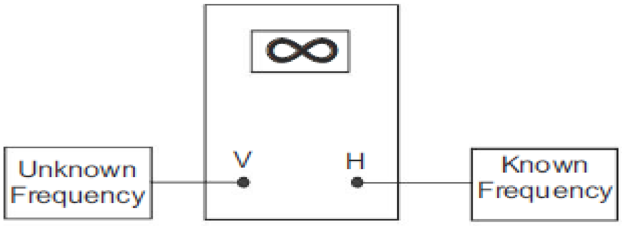


Fig. 7.33 Basic circuit for frequency measurements with lissajous figures

USE OF LISSAJOUS FIGURES FOR PHASE MEASUREMENT

When two signals are applied simultaneously to an oscilloscope without internal sweep, one to the horizontal channel and the other to the vertical channel, the resulting pattern is a Lissajous figure that shows a phase difference between the two signals. Such patterns result from the sweeping of one signal by the other.

Figure 7.42 shows the test setup for phase measurement by means of Lissajous figures. Figure 7.43 shows patterns corresponding to certain phase difference angles, when the two signal voltages are sinusoidal, equal in amplitude and frequency.

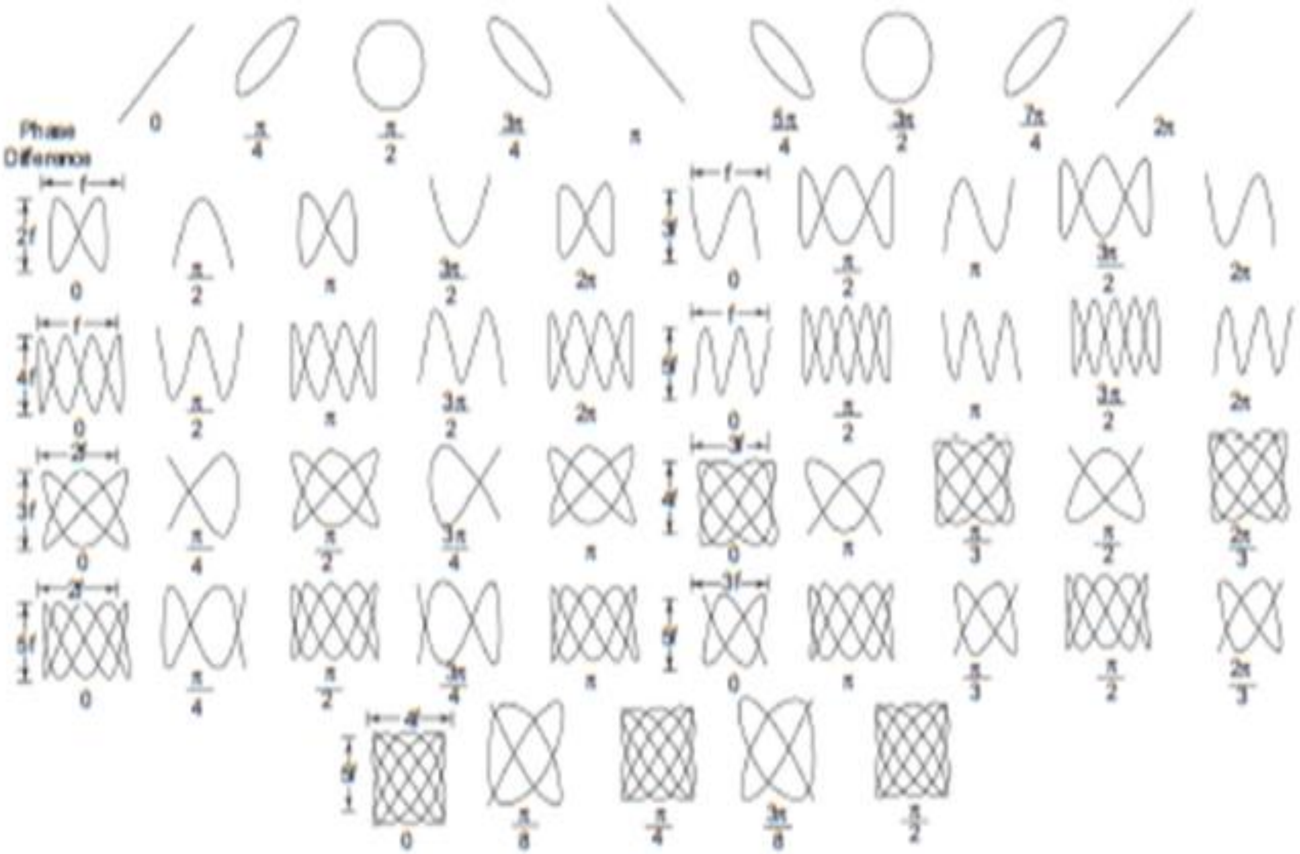


Fig. 7.43 Lissajous pattern

A simple way to find the correct phase angle (whether leading or lagging) is to introduce a small, known phase shift to one of the inputs. The proper angle may be then deduced by noting the direction in which the pattern changes.

SPECIAL PURPOSE CRO's :-

1. SAMPLING OSCILLOSCOPE

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

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

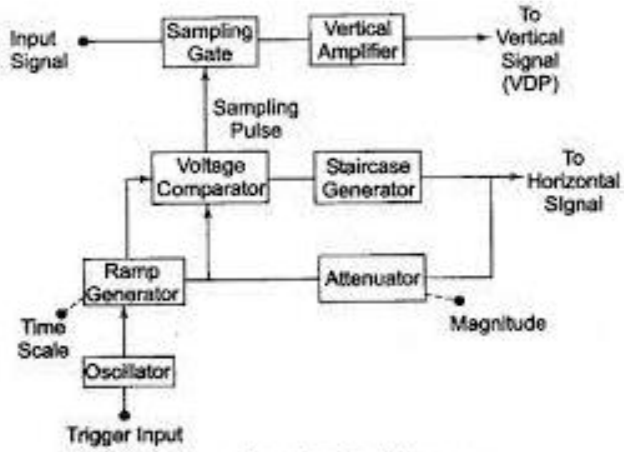


Fig. 7.24 Sampling Oscilloscope

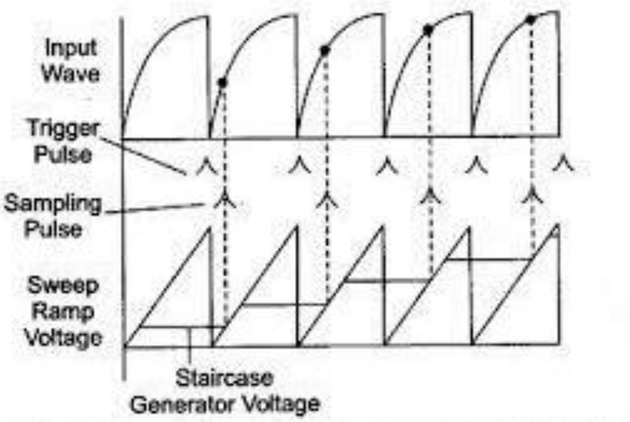


Fig. 7.25 Various Waveforms at Each Block of a Sampling Oscilloscope

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

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

2. STORAGE OSCILLOSCOPE (FOR VLF SIGNAL)

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

A mesh-storage CRT uses a dielectric material deposited on a storage mesh as the storage target. This mesh is placed between the deflection plates and the standard phosphor target in the

CRT. The writing beam, which is the focused electron beam of the standard CRT, charges the dielectric material positively where hit. The storage target is then bombarded with low velocity electrons from a flood gun and the positively charged areas of the storage target allow these electrons to pass through to the standard phosphor target and thereby reproduce the stored image on the screen. Thus the mesh storage has both a storage target and a phosphor display target. The phosphor storage CRT uses a thin layer of phosphor to serve both as the storage and the display element.

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

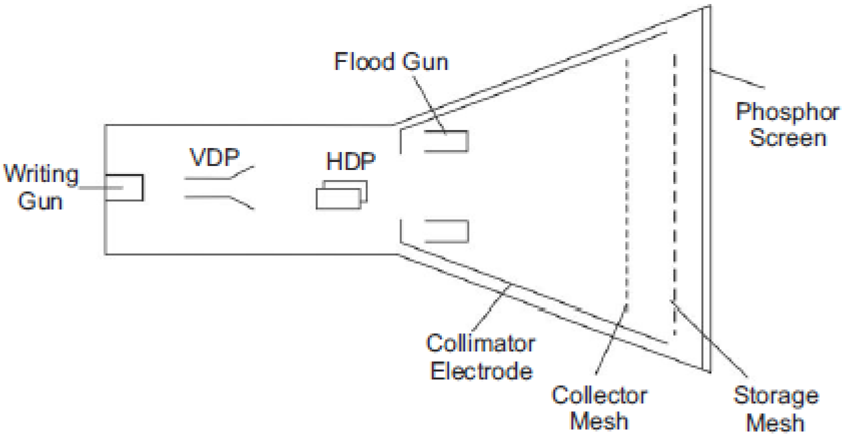


Fig. 7.26 Basic elements of storage mesh CRT

A mesh storage CRT, shown in Fig. 7.26, contains a dielectric material deposited on a storage mesh, a collector mesh, flood guns and a collimator, in addition to all the elements of a standard CRT. The storage target, a thin deposition of a dielectric material such as Magnesium Fluoride on the storage mesh, makes use of a property known as secondary emission. The writing gun etches a positively charged pattern on the storage mesh or target by knocking off secondary emission electrons. Because of the excellent insulating property of the Magnesium Fluoride coating, this positively charged pattern remains exactly in the position where it is deposited. In order to make a pattern visible, a special electron gun, called the flood gun, is switched on (even after many hours). The electron paths are adjusted by the collimator electrode, which constitutes a low voltage electrostatic lens system (to focus the electron beam), as shown in Fig. 7.27. Most of the electrons are stopped and collected by the collector mesh. Only electrons near the stored positive charge are pulled to the storage target with sufficient force to hit the phosphor screen. The CRT will now display the signal and it will remain visible as long as the flood guns operate. To erase the pattern on the storage mesh, a negative voltage is applied to neutralize the stored positive charge.

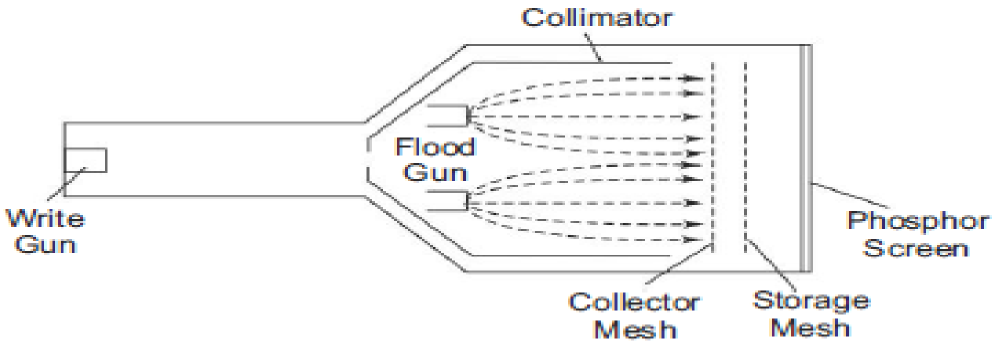


Fig. 7.27 Storage mesh CRT

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

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

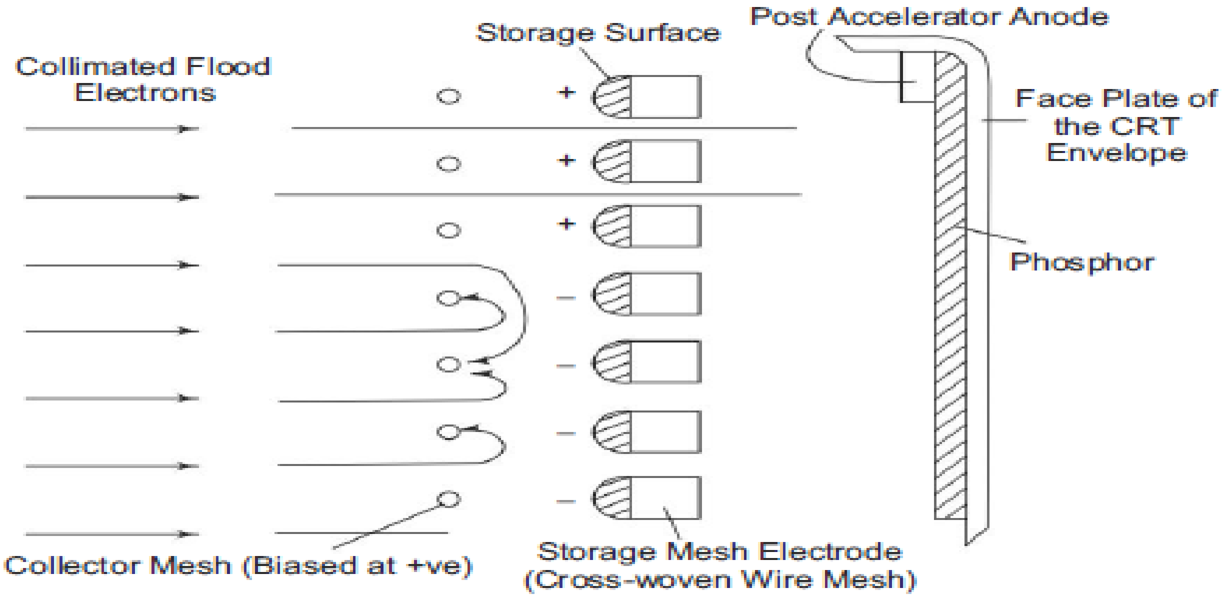


Fig. 7.28 Display of stored charged pattern on a mesh-storage

The flood gun, biased very near the storage mesh potential, emits a flood of electrons which move towards the collector mesh, since it is biased slightly more positive than the deflection region. The collimator, a conductive coating on the CRT envelope with an applied potential, helps to align the flood electrons so that they approach the storage target perpendicularly. When the electrons penetrate beyond the collector mesh, they encounter either a positively charged region on the storage surface or a negatively charged region where no trace has been stored. The positively charged areas allow the electrons to pass through to the post accelerator region and the display target phosphor. The negatively charged region repels the flood electrons back to the collector mesh. Thus the charge pattern on the storage surface appears reproduced on the CRT display phosphor just as though it were being traced with a deflected beam. Figure 7.28 shows a display of the stored charge pattern on a mesh storage.

3.DIGITAL READOUT OSCILLOSCOPE

The digital read out oscilloscope instrument has a CRT display and a counter display. The diagram shown is of an instrument where the counter measures the time (Fig. 7.29).

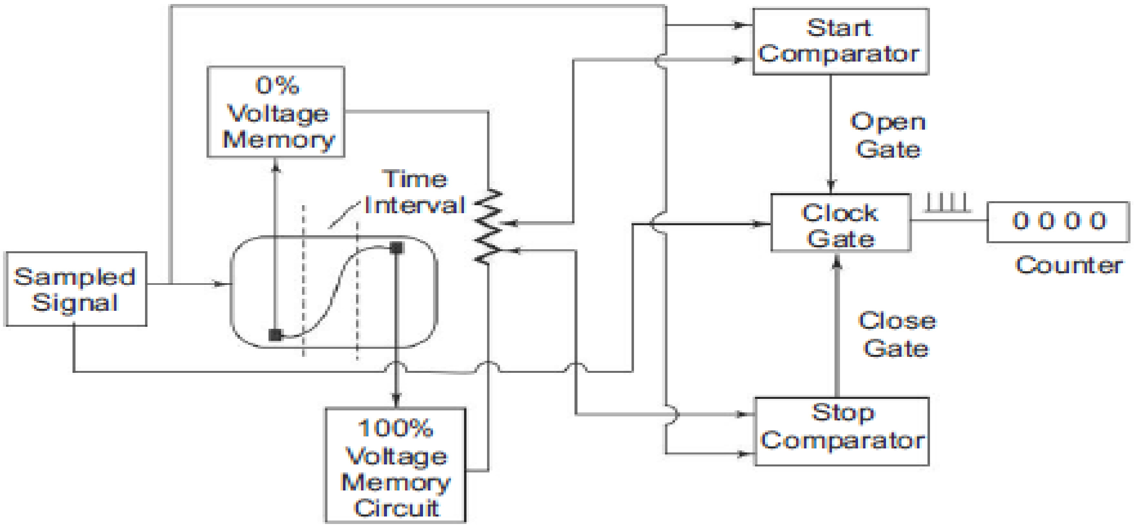


Fig. 7.29 Block diagram of a digital readout oscilloscope when measuring voltage

The input waveform is sampled and the sampling circuit advances the sampling position in fixed increments, a process called strobing. The equivalent time between each sample depends on the numbers of sample taken per cm and on the sweep time/cm, e.g. a sweep rate of 1 nano-sec/cm and a sampling rate of 100 samples/cm gives a time of 10 pico-sec/sample.

Figure 7.29 shows a block diagram of a digital read out oscilloscope when measuring voltage. Two intensified portions of the CRT trace identify 0% and 100% zones position. Each zone can be shifted to any part of the display. The voltage divider taps between the 0% and 100% memory voltage are set for start and stop timing. The coincidence of any of the input waveforms with the selected percentage point is sensed by this voltage comparator. The numbers of the clock pulse which correspond to the actual sample taken are read out digitally in a Nixie display tube in ns, ms, ms or seconds.

Figure 7.30 shows a block diagram of a digital readout CRO when used for voltage to time conversion.

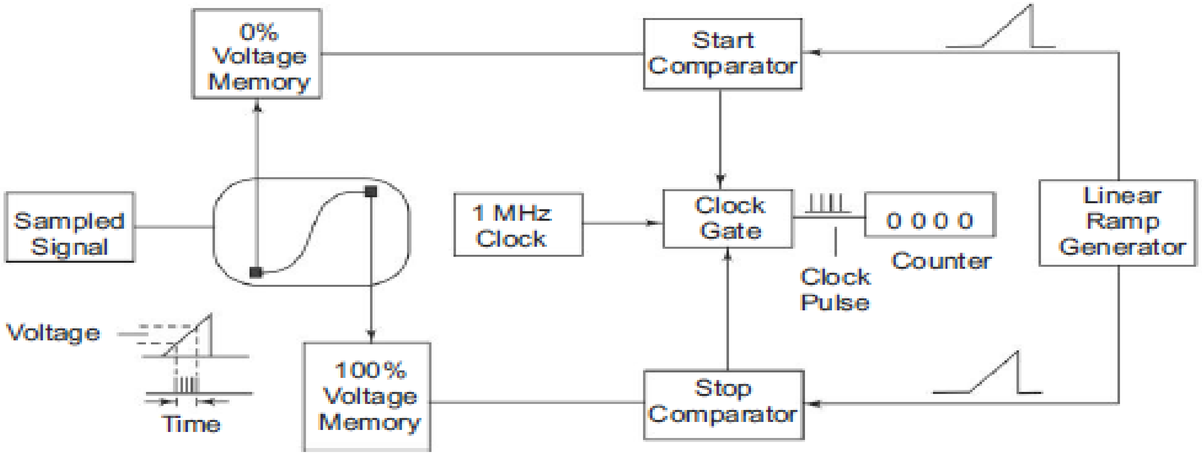


Fig. 7.30 Voltage to time conversion

The CRT display is obtained by sampling the 0% reference voltage as chosen by the memory circuit. A linear ramp generator produces a voltage; when the ramp voltage equals the 0% reference the gate opens. When the ramp equals 100% reference the gate closes. The number of clock pulses that activate the counter is directly proportional to the voltage between the selected reference and is read out in mV or volts by the Nixie tube display.

IV. Bridge Circuits :-

Introduction :-

A bridge circuit in its simplest from consists of a network of four resistance arms forming a closed circuit, with a dc Source of current applied to two opposite junctions and a current detector connected to the other two junctions, as shown in fig. 11.1.

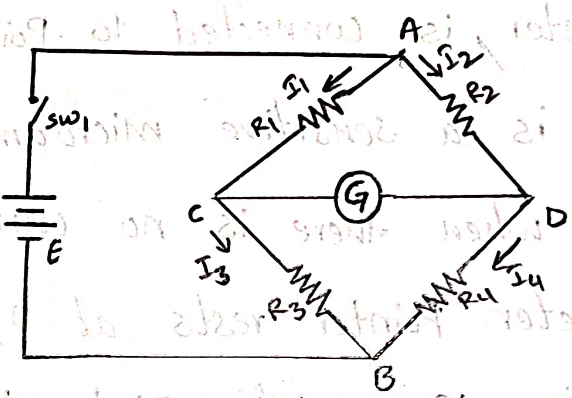


fig. 11.1 Wheatstone Bridge

Bridge circuits are extensively used for measuring component Values such as R, L and C. Since the bridge circuit merely compares the value of an accurately known component (a standard), its measurement accuracy can be Very high. this is because the readout of this comparison is based on the null indication at bridge balance, and is essentially independent of the characteristics of the null detector. The measurement accuracy is therefore directly related to the accuracy of the bridge component and not to that of the null indicator used.

The basic dc bridge is used for accurate measurement of resistance and is called wheatstone's bridge.

Wheatstone's Bridge (Measurement of Resistance)

Wheat stone's bridge is the most accurate method available for measuring resistance and is popular for laboratory use. the circuit diagram of a typical wheat stone bridge is given in fig. 11.1. the Source of emf and Switch is connected to points A and B, while a sensitive current indicating meter, the galvanometer, is connected to Points c and D. the galvanometer is a sensitive microammeter, with a zero center scale. when there is no current through the meter, the galvanometer Pointer rests at 0, i.e., mid Scale. Current in one direction causes the Pointer to deflect on one side and current in the opposite direction to the other side.

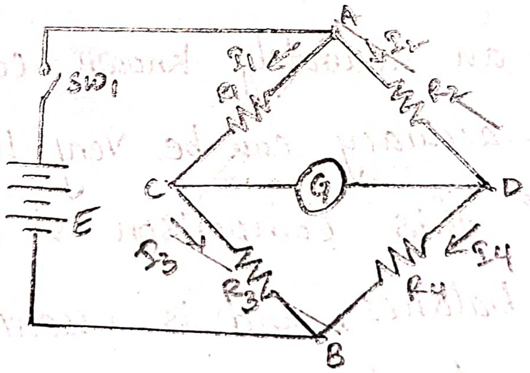


fig. 11.1: wheatstone bridge

When sw_1 is closed, current flows and divides into the two arms at point A, i.e., I_1 and I_2. the bridge is balanced when there is no current through the galvanometer, or when the potential difference at points c and D is equal, i.e., the potential across the galvanometer is zero.

To obtain the bridge balance equation, we have from the fig. 11.1.

$$I_1 R_1 = I_2 R_2 \rightarrow ①$$

for the galvanometer current to be zero, the following conditions should be satisfied.

$$I_1 = I_3 = \frac{E}{R_1+R_3} \rightarrow ②$$

$$I_2 = I_4 = \frac{E}{R_2+R_4} \rightarrow ③$$

Substitute ②, ③ in eq ①

$$i_1 R_1 = i_2 R_2$$

$$\left[\frac{E}{R_1+R_3}\right] R_1 = \left[\frac{E}{R_2+R_4}\right] R_2$$

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

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

$$R_2(R_1+R_3) = R_1(R_2+R_4)$$

$$\cancel{R_1R_2} + R_2R_3 = \cancel{R_1R_2} + R_1R_4$$

$$R_2R_3 = R_1R_4$$

$$\boxed{R_4 = \frac{R_2R_3}{R_1}}$$

This is the equation for the bridge to be balanced.

In a practical wheat stone's bridge, at least one of the resistance is made adjustable, to permit balancing. when the bridge is balanced, the unknown resistance (normally connected at

R_4) may be determined from the setting of the adjustable resistor, which is called a standard resistor because it is a precision device having very small tolerance.

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

Kelvin's Bridge:-

when the resistance to be measured is of the order of magnitude of bridge contact and lead resistance, a modified form of wheat stone's bridge, the kelvin bridge is employed.

Kelvin's bridge is a modification of wheatstone's bridge and is used to measure values of resistance below 1Ω. In low resistance measurement, the resistance of the leads connecting the unknown resistance to the terminal of the bridge circuit may affect the measurement.

Consider the circuit in fig. 11.10, where R_y represents the resistance of the connecting leads from R_3 to R_x (unknown resistance). the galvanometer can be connected (~~to Point a, the resistance~~) either to point c or to point a. when it is connected to point a, the resistance R_y, of the connecting lead is added to the unknown resistance R_x, resulting in too high indication for R_x. when the connection is made to ~~Print~~ Point c, R_y is added to the bridge arm R_3 and resulting measurement of R_x. is lower than the actual value, because now the actual value of R_3 is higher than its nominal value by the resistance R_y. If the galvanometer is connected to Point b, in between Points c and a, in Such a way that the ratio of the resistance from c to b and that from a to b equals the ratio of resistances R_1 and R_2, then

$$\frac{R_{cb}}{R_{ab}} = \frac{R_1}{R_2} \rightarrow ①$$

and the usual balance equations for the bridge give the relationship.

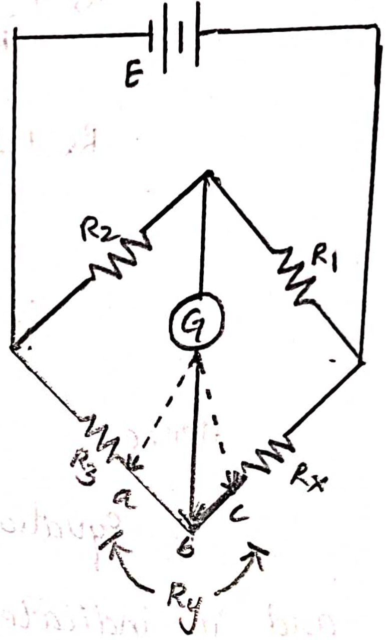


fig 11.10. Kelvin's bridge.

$$(R_x + R_{cb}) = \frac{R_1}{R_2}(R_3 + R_{ab}) \rightarrow ②$$

but $R_{ab} + R_{cb} = R_y$ and $\frac{R_{cb}}{R_{ab}} = \frac{R_1}{R_2}$

$$\frac{R_{cb}}{R_{ab}} + 1 = \frac{R_1}{R_2} + 1 \quad [\because \text{Adding '1' on both sides}]$$

$$\frac{R_{cb} + R_{ab}}{R_{ab}} = \frac{R_1 + R_2}{R_2}$$

i.e., $\frac{R_y}{R_{ab}} = \frac{R_1 + R_2}{R_2}$

$$\therefore \quad R_{ab} = \frac{R_2 R_y}{R_1 + R_2} \rightarrow ③$$

and as $R_{ab} + R_{cb} = R_y$

$$R_{cb} = R_y - R_{ab}$$

$$R_{cb} = R_y - \frac{R_2 R_y}{R_1 + R_2}$$

$$R_{cb} = \frac{R_y R_1 + R_y \cancel{R_2} - R_2 \cancel{R_y}}{R_1 + R_2}$$

$$R_{cb} = \frac{R_1 R_y}{R_1+R_2} \rightarrow ④$$

from eq ② in eq ③ & ④

$$(R_x + R_{bc}) = \frac{R_1}{R_2}(R_3 + R_{ab})$$

$$R_x + \frac{R_1 R_y}{R_1+R_2} = \frac{R_1}{R_2}\left(R_3 + \frac{R_2 R_y}{R_1+R_2}\right)$$

$$R_x + \frac{R_1 R_y}{R_1+R_2} = \frac{R_1 R_3}{R_2} + \frac{\cancel{R_2} R_y}{R_1+R_2}\left(\frac{R_1}{\cancel{R_2}}\right)$$

$$R_x + \cancel{\frac{R_1+R_y}{R_1+R_2}} = \frac{R_1 R_3}{R_2} + \cancel{\frac{R_1 R_y}{R_1+R_2}}$$

$$\therefore \boxed{R_x = \frac{R_1 R_3}{R_2}} \rightarrow (5)$$

Hence,

Equation (5) is the usual wheatstone's balance equation and it indicates that the effect of the resistance of the connecting leads from Point a to Point c has been eliminated by connecting the galvanometer to an intermediate Position, b.

Kelvin's Double bridge :-

The above Principle forms the basis of the Construction of kelvin's Double bridge, Popularly known as Kelvin's Bridge. It is a Double bridge because it incorporates a Second set of ratio arms. figure. 11.11 shows a schematic diagram of kelvin's double bridge.

The second set of arms, a and b, connects the galvanometer to a point c at the appropriate potential between m and n connection, i.e, Ry. The ratio of the resistance of arms a and b is the same as the ratio of R_1 and R_2. The galvanometer indication is zero

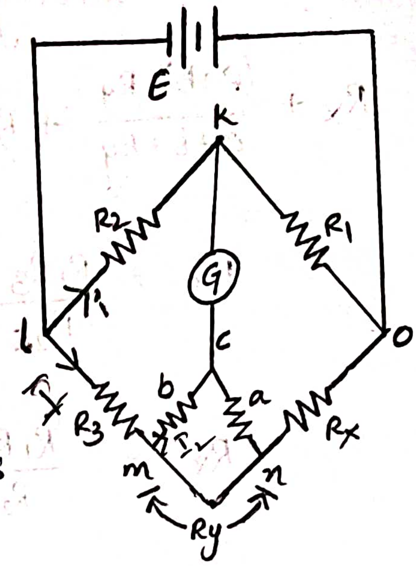
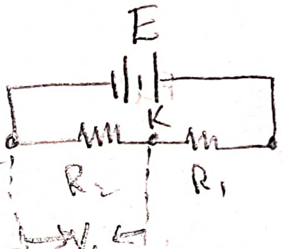


fig.11.11. kelvin's double bridge.

when the Potentials at k and c are equal.

$$\therefore E_{lk} = E_{lmc}.$$



But $\quad E_{lk} = \dfrac{R_2}{R_1+R_2} \times E \longrightarrow ①$

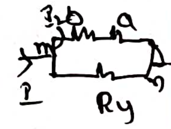
and $\quad E = I\left[R_3 + R_x + \dfrac{(a+b)R_y}{a+b+R_y}\right]$

Substituting for E in eq ①, then

we get $\quad E_{lk} = \dfrac{R_2}{R_1+R_2} \times I\left[R_3 + R_x + \dfrac{(a+b)R_y}{a+b+R_y}\right] \rightarrow ②$

$$E_{lmc} = IR_3 + I_2 b$$

$$I_2 = I \cdot \frac{R_y}{(a+b)}$$



$$E_{lmc} = IR_3 + b\left[I \frac{R_y}{a+b+R_y}\right]$$

Similarly,

$$E_{lmc} = I\left[R_3 + \frac{b}{\cancel{a+b}}\left[\frac{\cancel{(a+b)}R_y}{a+b+R_y}\right]\right] \rightarrow ③$$

But $\quad E_{lk} = E_{lmc}$

i.e.,

$$\frac{\cancel{I}R_2}{R_1+R_2}\left[R_3 + R_x + \frac{(a+b)R_y}{a+b+R_y}\right] = \cancel{I}\left[R_3 + \frac{b}{\cancel{a+b}}\left\{\frac{\cancel{(a+b)}R_y}{a+b+R_y}\right\}\right]$$

$$R_3 + R_x + \frac{(a+b)R_y}{a+b+R_y} = \frac{R_1+R_2}{R_2}\left[R_3 + \frac{bR_y}{a+b+R_y}\right]$$

$$R_3 + R_x + \frac{(a+b)\,R_y}{a+b+R_y} = \left[\frac{R_1}{R_2} + 1\right]\left[R_3 + \frac{bR_y}{a+b+R_y}\right]$$

$$R_x + \frac{(a+b)\,R_y}{a+b+R_y} + \cancel{R_3} = \frac{R_1R_3}{R_2} + \cancel{R_3} + \frac{bR_1R_y}{(a+b+R_y)R_2} + \frac{bR_y}{a+b+R_y}$$

$$R_x = \frac{R_1R_3}{R_2} + \frac{bR_1R_y}{R_2(a+b+R_y)} + \frac{bR_y}{a+b+R_y} - \frac{(a+b)\,R_y}{a+b+R_y}$$

$$R_x = \frac{R_1R_3}{R_2} + \frac{bR_1R_y}{R_2(a+b+R_y)} + \frac{\cancel{bR_y} - aR_y - \cancel{bR_y}}{a+b+R_y}$$

$$R_x = \frac{R_1R_3}{R_2} + \frac{bR_1R_y}{R_2(a+b+R_y)} - \frac{aR_y}{a+b+R_y}$$

$$R_x = \frac{R_1R_3}{R_2} + \frac{bR_y}{a+b+R_y}\left[\frac{R_1}{R_2} - \frac{a}{b}\right]$$

But

$$\frac{R_1}{R_2} = \frac{a}{b}$$

$$\therefore \quad R_x = \frac{R_1R_3}{R_2} + \frac{bR_y}{a+b+R_y}\left[\cancel{\frac{a}{b}} - \cancel{\frac{a}{b}}\right]$$

$$R_x = \frac{R_1R_3}{R_2} + 0$$

$$\therefore \quad \boxed{R_x = \frac{R_1R_3}{R_2}}$$

this is the usual equation for kelvin's bridge. It indicates that the resistance of the connecting lead R_y, has no effect on the measurement, Provided that the ratios of the Resistances of the two sets of Ratio arms are equal. In a typical kelvin's bridge the range of a resistance covered is 1-0.00001 Ω (10 μohm) with an accuracy of ±0.05% to ±0.2%.

Maxwell's Bridge :-

Maxwell's bridge, shown in fig. 11.22, measures an unknown inductance in terms of a known ~~(resistor)~~ capacitor. The use of standard arm offers the advantage of compactness and easy shielding. The capacitor is almost a loss-less component. One arm has a resistance R_1 in parallel with C_1, and hence it is easier to write the balance equation using the admittance of arm 1 instead of the impedence.

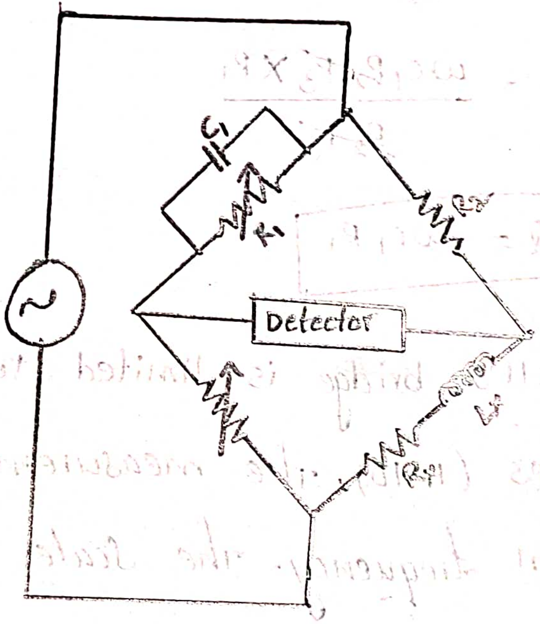


fig. 11.22. Maxwell's bridge

The general equation for bridge balance is

$$Z_1 Z_X = Z_2 Z_3$$

i.e., $$Z_X = \frac{Z_2 Z_3}{Z_1} \rightarrow ①$$

$$Z_X = Z_2 Z_3 Y_1$$

where,

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

$$Z_X = R_X + j\omega L_X$$

$Z_2 = R_2$

$Z_3 = R_3$

from eq -① we have,

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

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

Equating real terms and imaginary terms we have

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

Also

$$Q = \frac{\omega L_x}{R_x}$$

$$= \frac{\omega C_1 \cancel{R_2} \cancel{R_3} \times R_1}{\cancel{R_2} \cancel{R_3}}$$

$$\therefore \boxed{Q = \omega C_1 R_1}$$

Maxwell's bridge is limited to the measurement of low Q values (1-10). The measurement is independent of the excitation frequency. The scale of the resistance can be calibrated to read inductance directly.

The Maxwell bridge using a fixed capacitor has the disadvantage that there is an interaction between the resistance and reactance balances. This can be avoided by varying the capacitances, instead of R_2 and R_3, to obtain a reactance balance. However, the bridge can be made to read directly in Q.

The bridge is particularly suited for inductances measurements, since comparison with a capacitor is more ideal than with another inductance, commercial bridges measure from 1- 1000 H, with ±2% error. (if the Q is very large, R_1 becomes excessively large and it is impractical to obtain a satisfactory variable standard resistance in the range of values required).

Schering's Bridge :-

A very important bridge used for the precision measurement of capacitors and their insulating properties is the schering bridge. Its basic circuit arrangement is given in fig.11.26. The standard capacitor C_3 is a high quality mica capacitor (low-loss) for general measurements, or an air capacitor (having a very stable value and a very small electric field) for insulation measurement.

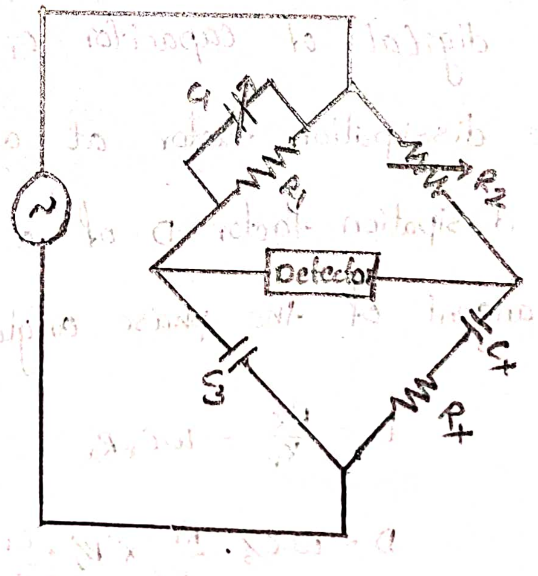


fig.11.26 schering's bridge

for balance, the general equation is

$$Z_1 Z_x = Z_2 Z_3$$

$$\therefore \quad Z_x = \frac{Z_2 Z_3}{Z_1} = Z_2 Z_3 Y_1 .$$

where,

$$Z_x = R_x - j/\omega C_x$$

$$Z_2 = R_2$$

$$Z_3 = \frac{-j}{\omega C_3}$$

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

as $Z_x = Z_2 Z_3 Y_1$

$$\left[R_x - \frac{j}{\omega C_x}\right] = R_2\left[\frac{-j}{\omega C_3}\right] \times \left[\frac{1}{R_1} + j\omega C_1\right]$$

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

Equating the real and imaginary terms, we get

$$\boxed{R_x = \frac{R_2 C_1}{C_3}} \rightarrow \text{real Part}$$

and $$\boxed{C_x = \frac{R_1}{R_2} C_3} \rightarrow \text{imaginary Part}$$

The digital of capacitor C_1 can be calibrated directly to give the dissipation factor at a Particular frequency.

The dissipation factor D of a Series RC Circuit is defined as the cotangent of the phase angle.

$$D = \frac{R_x}{X_x} = \omega C_x R_x$$

$$D = \omega . \cancel{C_3} . \frac{R_1}{\cancel{R_2}} \times \cancel{R_2} . \frac{C_1}{\cancel{C_3}}$$

$$\boxed{D = \omega R_1 C_1}$$

Also, D is the reciprocal of the quality factor Q, i.e., $D = 1/Q$. D indicates the quality of the capacitor.

Commercial units measure from 100pf - 1μf, with ±2% accuracy. The dial of C_3 is graduated in terms of direct readings for C_x, if the resistance ratio is maintained at a fixed value.

This bridge is widely used for testing small capacitors at low voltages with very high precision.

The lower junction of the bridge is grounded. At the frequency normally used on this bridge, the reactances of capacitor C_3 and C_x are much higher than the resistances of R_1 and R_2. Hence, most of the voltage drops across C_3 and C_x, and very little across R_1 and R_2. Hence if the junction of R_1 and R_2 is grounded, the detector is effectively at ground potential. this reduces any stray-capacitance effect, and makes the bridge more stable.

Wien's Bridge:-

The wien bridge shown in fig. 11.28 has a series RC combination in the adjoining arm. wein's bridge in its basic form, is designed to measure frequency. It can also be used for the measurement of an unknown capacitor with great accuracy.

The impedance of one arm is

$$Z_1 = R_1 - \frac{j}{\omega C_1}$$

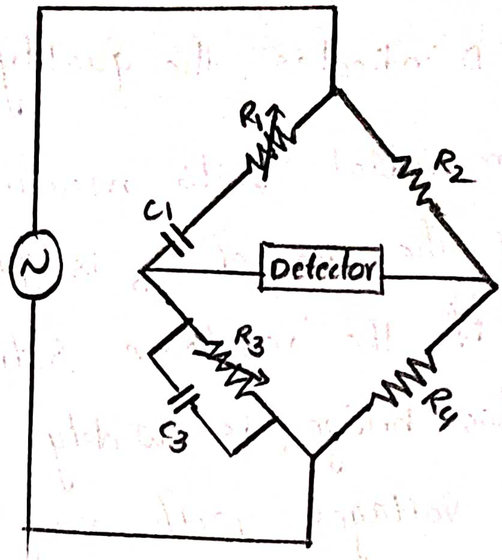


fig.11.28. wien's bridge

The admittance of the Parallel arm is

$$y_3 = \frac{1}{R_3} + j\omega C_3$$

Using the bridge balance equation, we have

$$Z_1 Z_4 = Z_2 Z_3.$$

$$\therefore \quad Z_1 Z_4 = \frac{Z_2}{y_3},$$

i.e., $Z_2 = Z_1 Z_4 Y_3$

$$\therefore \quad R_2 = R_4\left[R_1 - \frac{j}{\omega C_1}\right]\left[\frac{1}{R_3} + j\omega C_3\right]$$

$$R_2 = \frac{R_1 R_4}{R_3} - \frac{jR_4}{\omega C_1 R_3} + j\omega C_3 R_1 R_4 + \frac{C_3 R_4}{C_1}$$

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

Equating the real and imaginary terms we have

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

and $\quad \dfrac{R_4}{\omega C_1 R_3} - \omega C_3 R_1 R_4 = 0.$

$$\therefore \quad \frac{R_2}{R_4} = \frac{R_1}{R_3} + \frac{C_3}{C_1} \longrightarrow ①$$

and $\quad \dfrac{1}{\omega C_1 R_3} = \omega C_3 R_1 \longrightarrow ②$

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

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

as $\omega = 2\pi f$

$$\therefore \quad f = \frac{1}{2\pi\sqrt{C_1R_1C_3R_3}} \rightarrow ③$$

The two conditions for bridge balance, eq (1) and eq (3), result in an expression determining the required resistance ratio R_2/R_4 and another expression determining the frequency of the applied voltage. if we satisfy eq.(1) and also excite the bridge with the frequency of eq.(3), the bridge will be balanced.

In most wien bridge circuits, the components are chosen such that $R_1 = R_3 = R$ and $C_1 = C_3 = C$. equation (1) therefore reduces to $R_2/R_4 = 2$ and eq (3) to $f = \frac{1}{2\pi RC}$, which is the general equation for the frequency of the bridge circuit.

The bridge circuit is used for measuring divided into 20 - 200 - 2k - 20kHz ranges. In this case, the resistances can be used for range changing and capacitors C_1 and C_3 for the frequency control with in the range. the bridge can also ~~called~~ be used for measuring capacitances. In that cases, the frequency determining element.

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

Anderson's Bridge:-

Anderson's bridge is one of the bridge that is used for the measurement of self inductance. Basically the Anderson's bridge is a modification of Maxwell's inductance capacitance bridge (is also used for the measurement of self inductance). The Anderson's bridge measures the unknown value of self inductance interms of standard fixed capacitor. The fig. 6.2.7 shows the Anderson's bridge.

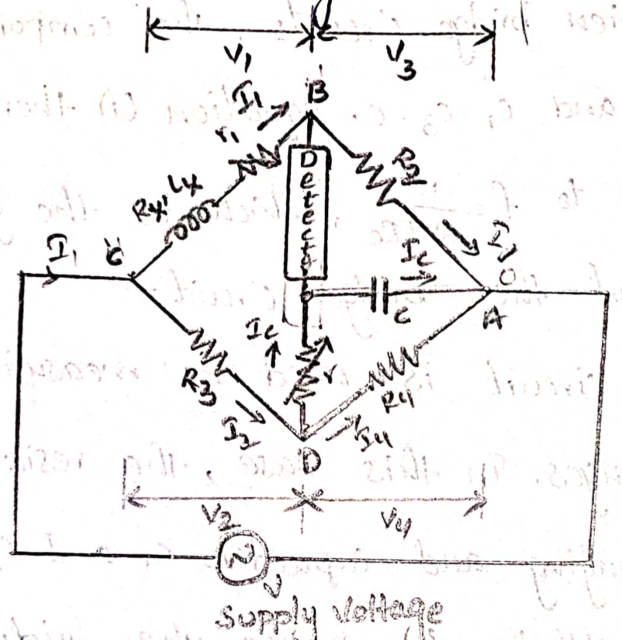


fig. 6.2.7 Anderson's Bridge.

In the fig. 6.2.7, assume that L_1 is the self inductance which is to be measured and R_1 is its resistance. r_1 is the resistance connected in series with L_1 and r, R_2, R_3, R_4 are non-inductive resistances whose values are known. c is a standard fixed capacitor.

when the circuit is balanced,

$$V_{AB} = V_{AE}$$

$$I_1 R_2 = I_c \frac{1}{j\omega c}$$

~~A~~

$$I_c = j\omega C I_1 R_2 \rightarrow ①$$

$$V_{BC} = V_{CDE}$$

$$I_1 [R_x + j\omega L_x] = I_2 R_3 + I_c R_5$$

from eq (1)

$$I_1 [R_x + j\omega L_x] = I_2 R_3 + j\omega C I_1 R_2 R_5$$

$$I_2 R_3 = I_1 [R_x + j\omega L_x] - j\omega C I_1 R_2 R_5$$

$$I_2 R_3 = I_1 [R_x + j\omega L_x - j\omega C R_2 R_5]$$

$$I_2 = \frac{I_1}{R_3} [R_x + j\omega L_x - j\omega C R_2 R_5] \rightarrow ②$$

$$V_{DA} = V_{DEA}$$

$$I_4 R_4 = I_c \left[R_5 + \frac{1}{j\omega C}\right]$$

we have $I_2 = I_4 + I_c$ then

$$I_4 = I_2 - I_c$$

$$R_4 [I_2 - I_c] = I_c \left[R_5 + \frac{1}{j\omega C}\right]$$

$$I_2 R_4 - I_c R_4 = I_c \left[R_5 + \frac{1}{j\omega C}\right]$$

$$(I_2 - I_c) R_4 = I_c \left[R_5 + \frac{1}{j\omega C}\right]$$

$$I_2 - I_c = I_c \left[\frac{R_5}{R_4} + \frac{1}{j\omega C R_4}\right]$$

$$I_2 = I_c \left[\frac{R_5}{R_4} + \frac{1}{j\omega C R_4}\right] + I_c$$

$$I_2 = I_c \left[\frac{R_5}{R_4} + \frac{1}{j\omega C R_4} + 1\right]$$

from eq (1) substitute I_c value

$$I_2 = j\omega C I_1 R_2 \left[\frac{R_5}{R_4} + \frac{1}{j\omega C R_4} + 1\right] \rightarrow ③$$

comparing eq -(2) and (3)

$$\frac{\cancel{I_1}}{R_3}\left[R_x + j\omega L_x - j\omega C R_2 R_5\right] = j\omega C R_2 \cancel{I_1}\left[\frac{R_5}{R_4} + \frac{1}{j\omega C R_4} + 1\right]$$

$$\frac{R_x}{R_3} + \frac{j\omega L_x}{R_3} - \frac{j\omega C R_2 R_5}{R_3} = \frac{j\omega C R_2 R_5}{R_4} + \frac{\cancel{j\omega C} R_2}{\cancel{j\omega C} R_4} + j\omega C R_2$$

$$\frac{R_x}{R_3} + \frac{j\omega L_x}{R_3} - \frac{j\omega C R_2 R_5}{R_3} = \frac{j\omega C R_2 R_5}{R_4} + \frac{R_2}{R_4} + j\omega C R_2$$

Compare real and imaginary terms.

$$\frac{R_x}{R_3} = \frac{R_2}{R_4}$$

$$\boxed{R_x = \frac{R_2 R_3}{R_4}} \rightarrow \text{real part}$$

$$\frac{L_x}{R_3} - \frac{C R_2 R_5}{R_3} = \frac{C R_2 R_5}{R_4} + C R_2$$

$$\frac{L_x}{R_3} = \frac{C R_2 R_5}{R_4} + \frac{C R_2 R_5}{R_3} + C R_2$$

$$L_x = \frac{C R_2 R_3 R_5}{R_4} + \frac{C R_2 R_5 \cancel{R_3}}{\cancel{R_3}} + C R_2 R_3$$

$$L_x = C R_2\left[\frac{R_3 R_5}{R_4} + R_5 + R_3\right]$$

$$\therefore \boxed{L_x = C R_2\left[\frac{R_3 R_5}{R_4} + R_5 + R_3\right]} \rightarrow \text{imaginary Part.}$$

Errors And Precautions in Using Bridges:-

Assuming that a suitable method of measurement has been selected and that the source and detector are given, there are some precautions which must be observed to obtain accurate readings.

The leads should be carefully laid out in such a way that no loops or long lengths ~~of~~ enclosing magnetic flux are produced, with consequent stray inductance errors.

With a large L, the self-capacitance of the leads is more important than their inductances, so they should be spaced relatively far apart.

In measuring a capacitor, it is important to keep the lead capacitance as low as possible. for this reason the leads should not be too close together and should be made of fine wire.

In very precise inductive and capacitances measurements, leads are encased in metal tubes to shield them from mutual electromagnetic action, and are used or designed to completely shield the bridge.

Q - Meter

Q-Meter circuit:-

The Q meter is an instrument designed to measure Some of the electrical Properties of coils and capacitors. The operation of this useful Laboratory instrument is based on the familiar characteristics of a Serial- resonant circuit, namely, that the the voltage across the coil or the capacitor is equal to the applied voltage times the Q of the circuit. If a fixed voltage is applied to the circuit, a voltmeter across the capacitor can be calibrated to read Q directly.

The voltage and current relationships of a series - reasonant circuit are shown in fig. At resonance, the following Conditions are Valid :

$$X_C = X_L$$

$$E_C = IX_C = IX_L$$

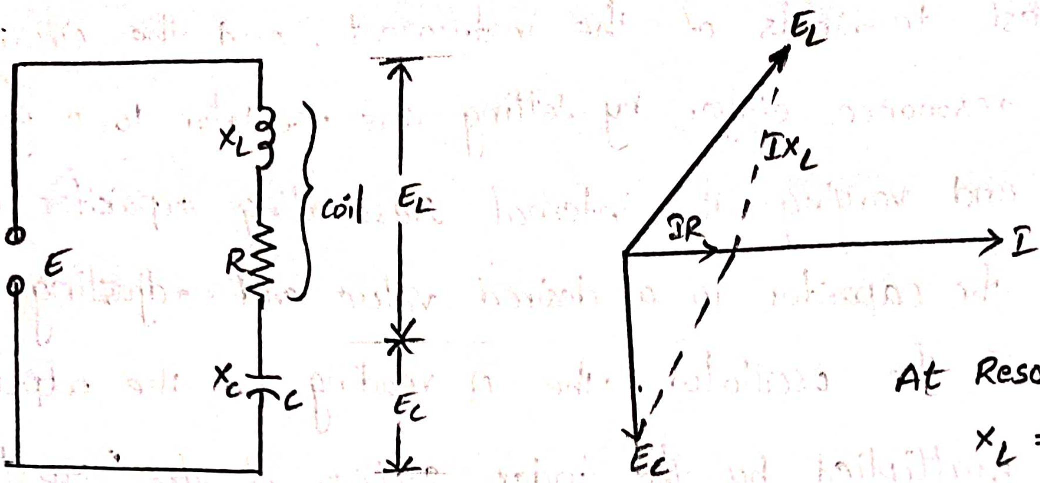
$$E = IR.$$

where,

E = applied Voltage
I = Circuit current
E_C = Voltage across the capacitor
X_C = capacitive reactance
X_L = inductive reactance
R = coil resistance.

The magnification of the circuit, by definition is Q, where,

$$Q = \frac{X_L}{R} = \frac{X_C}{R} = \frac{E_C}{E}$$



At Resonance :

$X_L = X_C$

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

fig: Series- resonant circuit

Therefore if E is maintained at a constant and known level, a voltmeter connected across the capacitor can be calibrated directly in terms of the circuit Q.

A Parallel Q-meter circuit is shown in fig. The wide-range oscillator with a frequency range from 50KHz to 50MHz delivers current to a low-value shunt resistance R_{SH}. The value of this shunt is very low, typically on the order of 0.02Ω. It introduces almost no resistance into the oscillatory circuit and it therefore represents a voltage source of magnitude E with a very small (in most cases negligible) internal resistance. The voltage E across the shunt, corresponding to E in fig, is measured with a thermocouple meter, marked "Multiply Q by." The voltage across the variable capacitor, corresponding to E_C in fig, is measured with an electronic voltmeter whose scale is calibrated directly in Q-values.

To make a measurement, the unknown coil is connected to the test terminals of the instrument, and the circuit is tuned to resonance either by setting the oscillator to a given frequency and varying the internal resonating capacitor or by Resetting the capacitor to a desired value and adjusting the frequency of the oscillator. the Q reading on the output meter must be multiplied by the index setting of the "Multiply Q" by meter to obtain the actual Q value.

The indicated Q (which is the resonant reading on the "circuit Q" meter) is called the circuit Q because the losses of the ~~(resonanating)~~ resonating capacitor, voltmeter, and insertion resistor are all ~~(indicate)~~ included in the measuring circuit. The effective Q of the measured coil will be somewhat greater than the indicated Q. This difference can generally be neglected, except in certain cases where the resistance of the coil is relatively small in comparision with the value of the insertion resistor. (The problem is discussed in eg).

The inductance of the coil can be calculated from the known values of frequency (f) and resonating capacitance (C), since

$$X_L = X_C \quad \text{and} \quad L = \frac{1}{(2\pi f)^2 C} \text{ henry.}$$

Measurement Methods :-

There are three methods for connecting unknown components to the test terminals of a Q meter: direct, Series, and Parallel. the type of component and its size determine the method of connection.

(i) Direct connection :-

Most coils can be connected directly across the test terminals, exactly as shown in the basic Q-circuit of fig. the circuit is resonated by adjusting either the oscillator frequency or the resonating capacitor. the ~~indicating~~ indicated Q is read directly from the "circuit Q" meter, modified by the setting of the "Multiply Q by" meter. when the last meter is set at the unity mark, the "circuit Q" meter reads the correct value of Q directly.

(ii) Series connections :-

Low-impedence components, such as low-value resistors, small coils, and large capacitors, are measured in series with the measuring circuit. fig shows the connections. the component to be measured, here indicated by [z], is placed in series with a stable work coil across the test terminals. (The work coil is usually supplied with the instrument.) Two measurements are made: In the first measurement the unknown is short-circuited by a small shorting strap and the circuit is resonated, establishing a reference condition. the values of the tuning capacitor (C_1) and the indicated Q (Q_1) are noted. In the second measurement the shorting

Strap is removed and the circuit is returned, giving a new value for the tuning capacitor (C_2) and a change in the Q value from Q_1 to Q_2.

for the reference condition,

$$X_{C_1} = X_L \text{ or } \frac{1}{\omega C_1} = \omega L \quad \rightarrow ①.$$

and neglecting the resistance of the measuring circuit,

$$Q_1 = \frac{\omega L}{R} = \frac{1}{\omega C_1 R} \quad \rightarrow ②$$

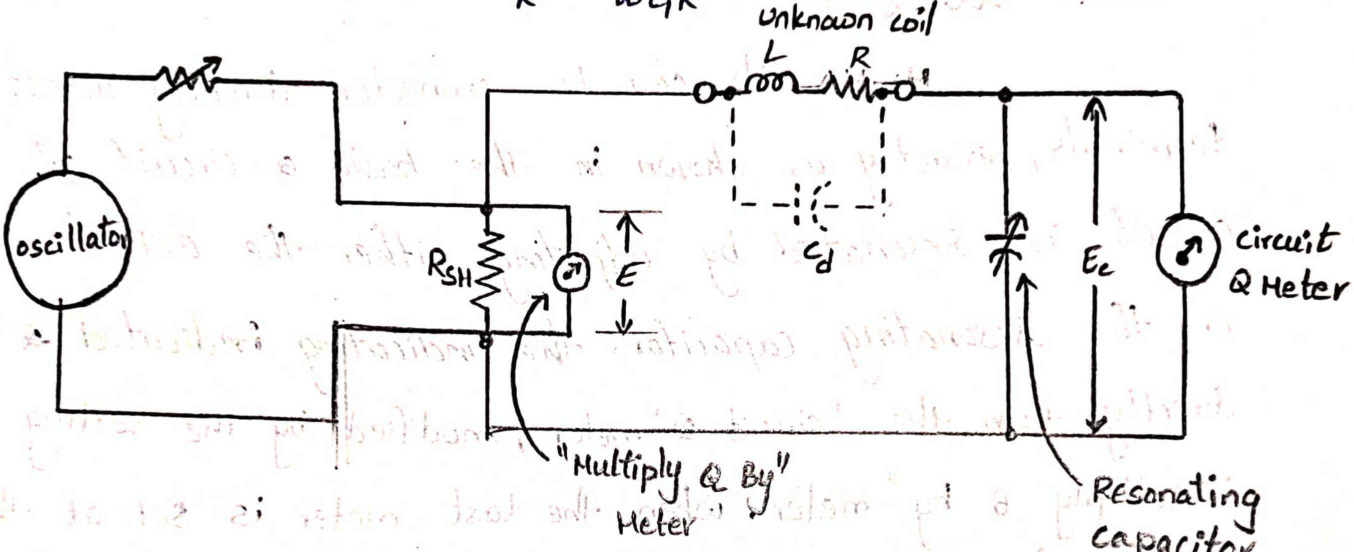


fig: Basic Q-Meter circuit

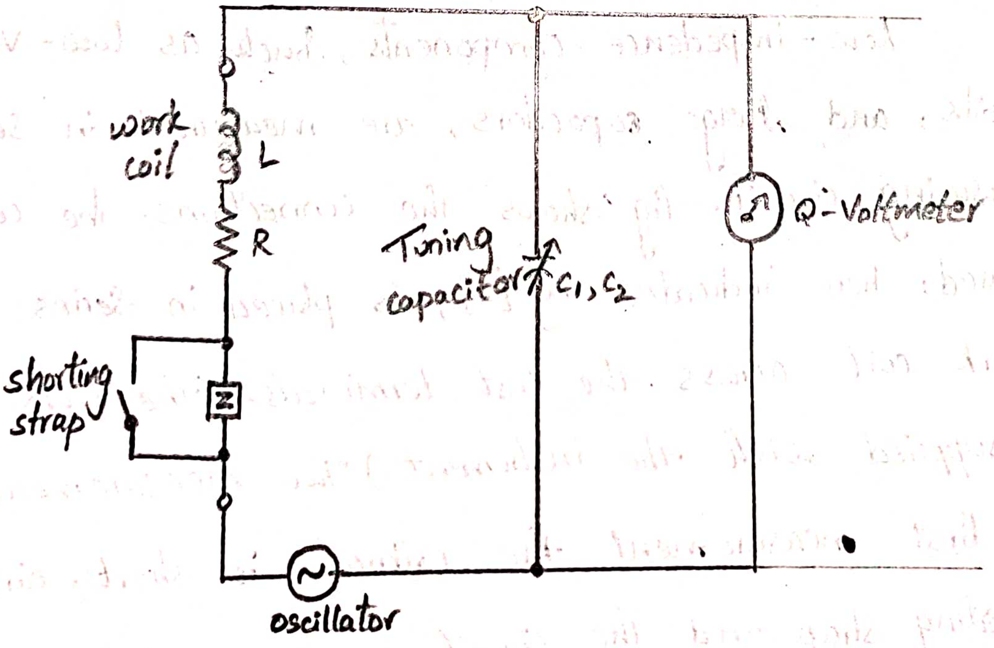


fig: Q-meter measurement of a low-impedence component in the series connection for the second measurement, the reactance of the unknown can be expressed in terms of the new value of the tuning capacitor (C_2) and the in-circuit value of the inductor (L). this yields

$$X_S = X_{C_2} - X_L \quad \text{or} \quad X_S = \frac{1}{\omega C_2} - \frac{1}{\omega C_1} \rightarrow \text{③}$$

So that

$$X_S = \frac{C_1 - C_2}{\omega C_1 C_2} \rightarrow \text{④}$$

X_S is inductive if $C_1 > C_2$ and capacitive if $C_1 < C_2$. The resistive component of the unknown impedence can be found interms of reactance X_S and the indicated values of circuit Q, since

$$R_1 = \frac{X_1}{Q_1} \quad \text{and} \quad R_2 = \frac{X_2}{Q_2} \rightarrow \text{⑤}$$

Also,

$$R_S = R_2 - R_1 = \frac{1}{\omega C_2 Q_2} - \frac{1}{\omega C_1 Q_1} \rightarrow \text{⑥}$$

So that

$$R_S = \frac{C_1 Q_1 - C_2 Q_2}{\omega C_1 C_2 Q_1 Q_2} \rightarrow \text{⑦}$$

If the unknown is purely resistive, the setting of the tuning capacitor would not have changed in the measuring process, and $C_1 = C_2$. The equation for resistance reduces to

$$R_S = \frac{Q_1 - Q_2}{\omega C_1 Q_1 Q_2} = \frac{\Delta Q}{\omega C_1 Q_1 Q_2} \rightarrow \text{⑧}$$

If the unknown is a small inductor, the value of the inductance is found from eq(4) and equals.

$$L_S = \frac{C_1 - C_2}{\omega^2 C_1 C_2} \rightarrow \text{⑨}$$

The Q of the coil is found from eqs (4) + (7) since, by definition,

$$Q_S = \frac{X_S}{R_S}$$

and

$$Q_S = \frac{(C_1 - C_2)(Q_1 Q_2)}{C_1 Q_1 - C_2 Q_2} \rightarrow \text{⑩}$$

If the unknown is a large capacitor, its value is determined from eq (4), and

$$C_s = \frac{C_1 C_2}{C_2 - C_1} \rightarrow \text{⑪}$$

The Q of the capacitor may be found by using eq (10).

(iii) Parallel Connection :-

High - impedence components, such as high-value resistors, certain inductors, and small capacitors, are measured by connecting them in parallel with the measuring circuit. fig shows the connections. Before the unknown is connected, the circuit is resonated, by using a suitable work coil, to establish reference values for Q and C (Q_1 and C_1). Then, when the component under test is connected to the circuit, the capacitor is readjusted for resonance, and a new value for the tuning capacitance (C_2) is obtained and a change in the value of circuit Q (ΔQ) from Q_1 to Q_2.

In a parallel ckt, computation of the unknown impedence is best approached in terms of its parallel components X_p and R_p, as indicated in fig. At the initial resonance condition, when the unknown is not yet connected into the circuit, the working coil (L) is tuned by the capacitor (C_1) Therefore

$$\omega L = \frac{1}{\omega C_1} \rightarrow \text{①}$$

and

$$Q = \frac{\omega L}{R} = \frac{1}{\omega C_1 R} \rightarrow \text{②}$$

When the unknown impedence is not connected into the circuit and the capacitor is tuned for resonance, the reactance of the working coil (X_L) equals the parallel reactances of the tuning capacitor (X_{C_2}) and the unknown (X_P).

Therefore

$$X_L = \frac{(X_{C_2})(X_P)}{X_{C_2} + X_P}$$

which reduces to

$$X_P = \frac{1}{\omega(C_1 - C_2)} \rightarrow ③$$

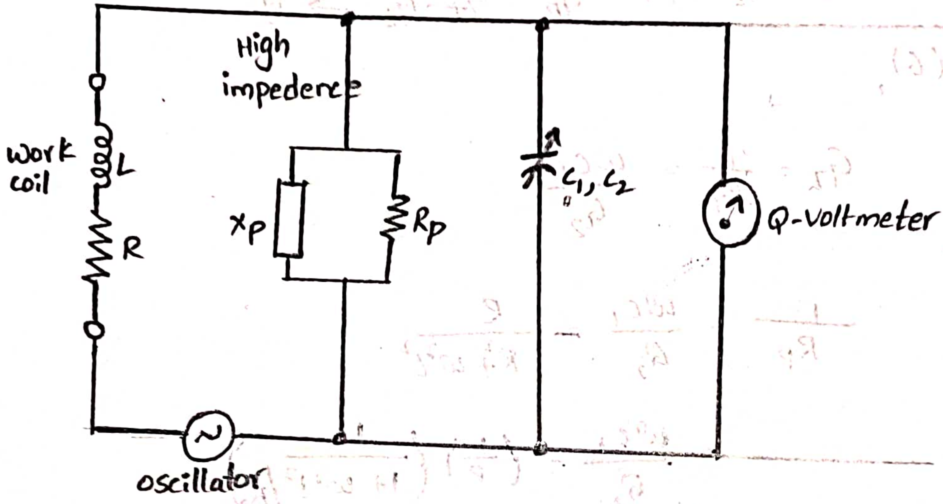


fig: Q-meter measurement of a high-impedence component in the parallel connection.

If the unknown is inductive, $X_P = \omega L_P$, and eq-(3) yields of the value of the unknown impedence:

$$L_P = \frac{1}{\omega^2(C_1 - C_2)} \rightarrow ④$$

If the unknown is capacitive, $X_P = \frac{1}{\omega C_P}$ and eq (3) yields the value of the unknown capacitor:

$$C_P = C_1 - C_2 \rightarrow ⑤$$

In a parallel resonant circuit the total resistance at resonance is equal to the product of the circuit Q and the reactance of the coil. therefore

$$R_T = Q_2 X_L$$

or by substitution of eq (1),

$$R_T = Q_2 X_{C_1} = \frac{Q_2}{\omega C_1} \rightarrow ⑥$$

The resistance (R_P) of the unknown impedence is most easily found by computing the conductance in the circuit a of fig. let

G_T = total conductance of the resonant circuit

G_P = conductance of the unknown impedence

G_L = conductance of the working coil

Then

$$G_T = G_P + G_L \quad \text{or} \quad G_P = G_T - G_L \rightarrow ⑦$$

from eq-(6),

$$G_T = \frac{1}{R_T} = \frac{\omega C_1}{Q_2}$$

therefore

$$\frac{1}{R_P} = \frac{\omega C_1}{Q_2} - \frac{R}{R^2 + \omega^2 L^2}$$

$$= \frac{\omega C_1}{Q_2} - \left(\frac{1}{R}\right)\left(\frac{1}{1 + \omega^2 L^2 / R^2}\right)$$

$$= \frac{\omega C_1}{Q_2} - \frac{1}{R Q_1^2}$$

Substituting eq-(2) in the foregoing expression, we obtain

$$\frac{1}{R_P} = \frac{\omega C_1}{Q_2} - \frac{\omega C_1}{Q_1}$$

and after simplifying, we obtain

$$R_P = \frac{Q_1 Q_2}{\omega C_1 (Q_1 - Q_2)} = \frac{Q_1 Q_2}{\omega C_1 \Delta Q} \rightarrow ⑧$$

The Q of the unknown is then found by using eqns.(3) and (8) So that

$$Q_P = \frac{R_P}{X_P} = \frac{(C_1 - C_2)(Q_1 Q_2)}{C_1 (Q_1 - Q_2)} = \frac{(C_1 - C_2)(Q_1 Q_2)}{C_1 \Delta Q} \rightarrow ⑨$$

Sources of Errors :-

Probably the most important factor affecting measurement accuracy, and the most often overlooked, is the distributed Capacitance or self-capacitance of the measuring circuit. The Presence of distributed capacitance in a coil modifies the actual or effective Q and the inductance of the coil. At the frequency at which the self-capacitance and the inductance of the coil are resonant, the circuit exhibits a purely ~~(distributed capacitance)~~ resistive impedence. This characteristic may be used for measuring the distributed capacitance.

One simple method of finding the distributed Capacitance (C_d) of a coil involves making 2 measurements at different frequencies. The coil under test is connected directly to the test terminals of the Q-meter, as shown in the circuit of fig. The tuning capacitor is set to a high value, Preferably to its maximum Position, and the circuit is resonated by adjusting the oscillator frequency. Resonance is indicated by maximum deflection on the "circuit Q" meter. The values of the tuning capacitor (C_1) and the oscillator frequency (f_1) are noted. The frequency is then increased to twice its original value ($f_2 = 2f_1$) and the circuit is returned by adjusting the resonating capacitor (C_2).

The resonant frequency of an LC circuit is given by the well known equation

$$f = \frac{1}{2\pi\sqrt{LC}} \rightarrow ①$$

At the initial resonance condition, the capacitance of the circuit equals $C_1 + C_d$, and the resonant frequency equals.

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

After the oscillator and the tuning capacitor are adjusted, the capacitance of the circuit is $C_2 + C_d$, and the resonant frequency equals.

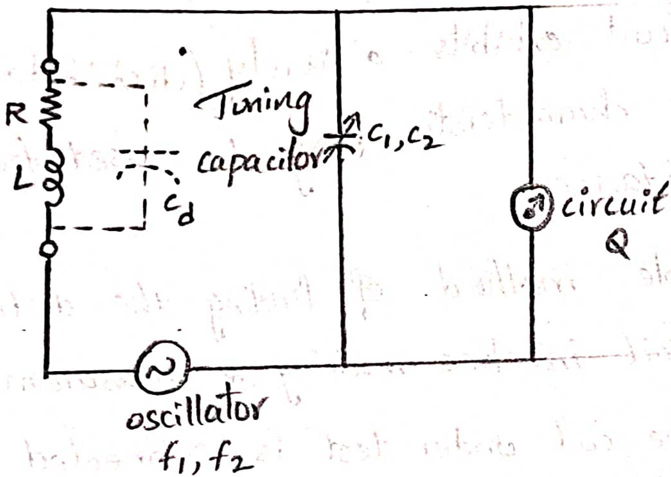


fig: Determination of the distributed capacitance of an inductor

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

Since $f_2 = 2f_1$, eqs (2) + (3) are related so that

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

and

~~&~~ the effective Q of the coil with distributed capacitance is less than the true Q by a factor that depends on the value of the self-capacitance and the resonating capacitor. It can be shown that

$$\text{true } Q = Q_e\left(\frac{C+C_d}{C}\right) \rightarrow (4)$$

where

Q_e = Effective Q of the coil.

C = resonating capacitance

C_d = distributed capacitace.

The effiective Q can usually be considered the indicated Q.

for many measurements, the residual & insertion resistance (R_{SH}) of the Q-meter circuit of fig. is sufficiently small to be considered negligible. Under certain circumstances, it can contribute an error to the measurement of Q. the Effect of the insertion resistor on the measurement depends on the magnitude of the unknown impedence and, of course, on the size of the insertion resistor. for instance, the 0.02Ω of insertion resistance may be neglected in comparision with a coil resistance of 10Ω, but it assumes importance when compared to a coil resistance of 0.1Ω. The effect of the 0.02Ω insertion resistance is illustrated by eg.

i) A coil with a resistance of 10Ω is connected in the "direct - measurement" mode. Resonance occurs when the oscillator frequency is 1.0MHz and the resonating capacitor is set at 65pF. Calculate the percentage error introduced in the calculated value of Q by the 0.02Ω insertion resistance.

Soln:- The effictive Q of the coil equals

$$Q_e = \frac{1}{\omega C R}$$

$$= \frac{1}{(2\pi)(10^6)(65\times10^{-12})(10)}$$

$$= 244.9$$

The indicated Q of the coil equals

$$Q_1 = \frac{1}{\omega C(R + 0.02)} = 244.4$$

The Percentage error is then

$$= \frac{244.9 - 244.4}{244.9} \times 100\%$$

$$= 0.2\%$$

Counters

The decade counter can be easily incorporated in a Commercial test instrument called an electronic counter. A decade Counter, by itself, behaves as a totaliser by totalling the pulses applied to it during the time interval that a gate pulse is Present. Typical modes of operation are totalising, frequency, Period, ratio, time interval and averaging.

(i) Totalising:-

In the totalising mode, as shown in fig, the input Pulses are counted (totalised) by the decade counter as long as the switch is closed. If the count pulse exceeds the capacity of the decade counter, the overflow indicator is activated and the counter starts counting again.

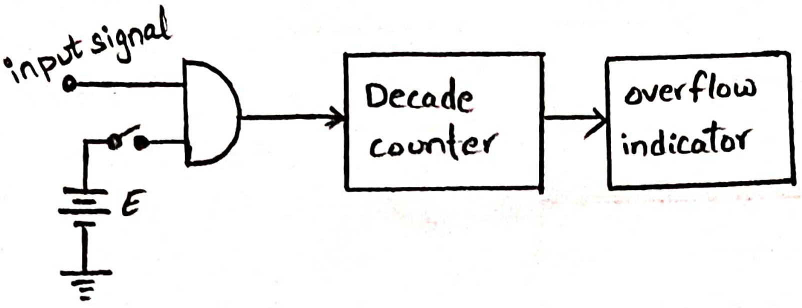


fig: Block diagram of the totalising mode of an electronic counter

(ii) Frequency Mode:-

If the time interval in which the pulses are being totalised is accurately controlled, the counter operates in the frequency mode. Accurate control of the time interval is achieved by applying a rectangular pulse of known duration to the AND gate, as shown in fig, in place of the dc voltage Source. This technique is reffered to as gating the counter. A block diagram of an electonic counter operating in the frequency mode is shown in fig. the frequency of the input signal is computed as

$$f = N/t.$$

where

f = frequency of the input signal
N = pulse counted
t = duration of the gate pulse.

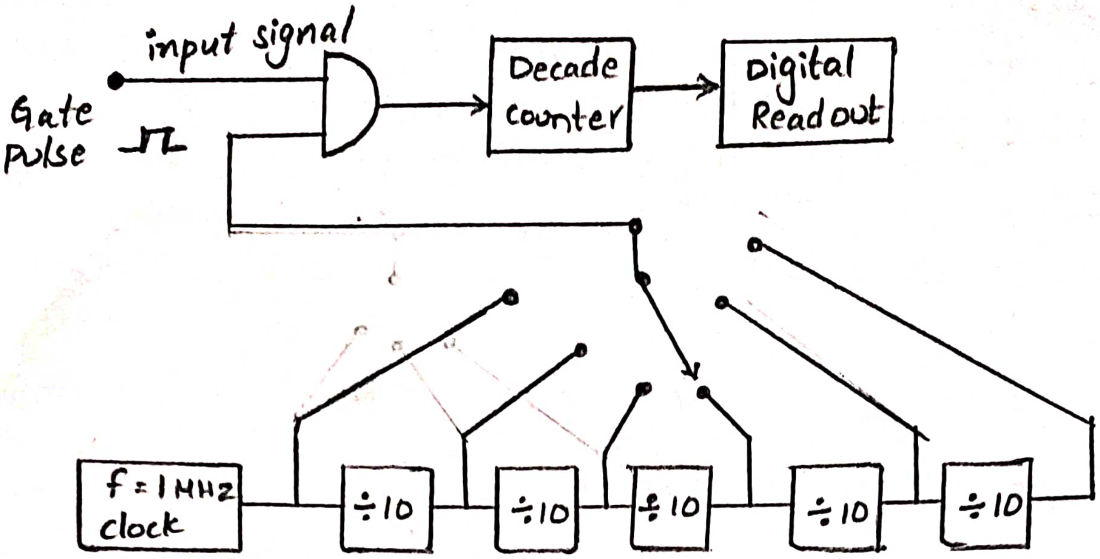
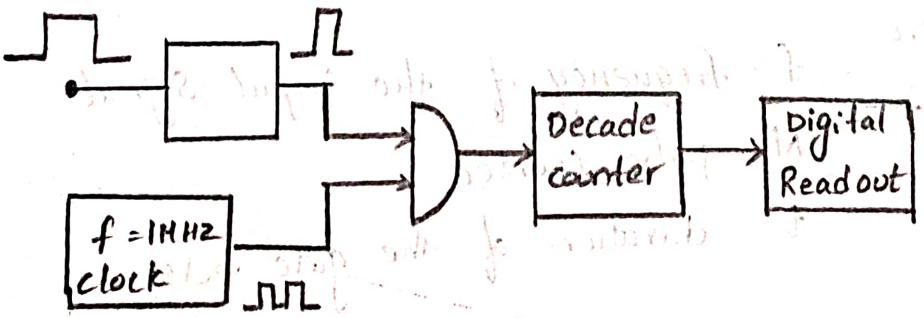


fig:- Block digriam of electronic counter frequency mode.

(iii) Ratio Mode:-

The ratio mode of operation simply displays the numerical value of the ratio of the frequencies of the two signals.

The low frequency signal is used in place of the clock to provide a gate pulse. The number of cycles of the high frequency signal, which are stored in the decade counter during the Presence of an ~~extremely~~ externally generated gate Pulse, is read directly as a ratio of the frequency. A basic circuit ~~for~~ the ratio mode of operation is shown in fig.



(iv) Period mode :-

In Some applications, it is desirable to measure the Period of the Signal rather than its frequency. Since the Period of is the reciprocal of the frequency, it can easily be measured by using the input signal as a gatting pulse and counting the clock pulses, as shown in fig.

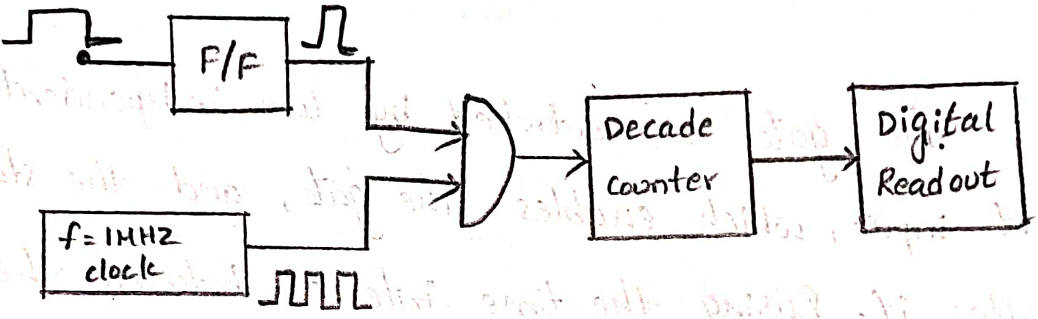


fig: Block diagram of electronic counter in period mode.

The period of the input Signal is determined from the no.of pulses of known frequency or known time duration which are counted by the counter during one cycle of the input signal. The period is computed as:

$$T = N/f$$

where

N = Pulse counted

f = frequency of the clock.

(v) Time Interval mode :-

The time interval mode of operation measures the time elapsed between two events. The measurement can be done using the circuit of fig.6.

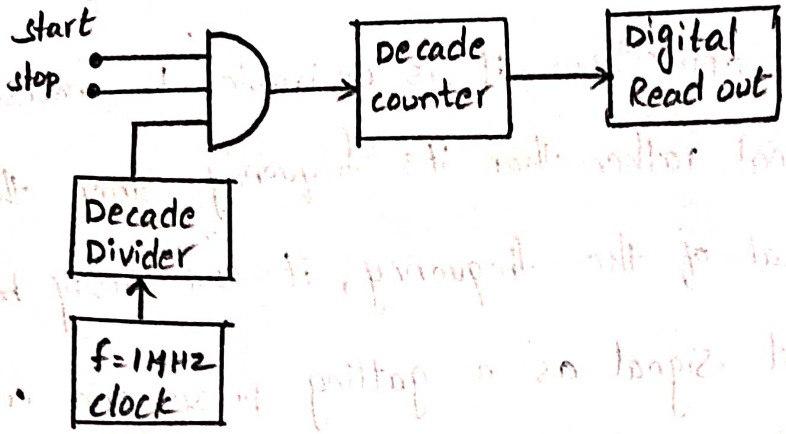


fig:- Block diagram of electronic counter in time interval mode.

The gate is controlled by two independent inputs, the start input, which enables the gate, and the stop input which disables it. During the time interval between the start and stop signal, clock pulses accumulate in the register. thus Providing an indication of the time interval between the start and stop of the event.

Electronic counters find many applications in research and development laboratories, in standard laboratories, on Service benches and in everyday operations of many electronics installations.

Counters are used in communication to measure the carrier frequency, in a digital system to measure the clock frequency, and so on.

UNIT V

Transducers- active & passive transducers: Resistance, Capacitance, inductance; Strain gauges, LVDT, Piezo Electric transducers.
Measurement of physical parameters temperature, force, pressure, velocity, acceleration and displacement.

INTRODUCTION

A transducer is defined as a device that receives energy from one system and transmits it to another, often in a different form. Broadly defined, the transducer is a device capable of being actuated by an energizing input from one or more transmission media and in turn generating a related signal to one or more transmission systems. It provides a usable output in response to a specified input measurand, which may be a physical or mechanical quantity, property, or conditions. The energy transmitted by these systems may be electrical, mechanical or acoustical. The nature of electrical output from the transducer depends on the basic principle involved in the design. The output may be analog, digital or frequency modulated. Basically, there are two types of transducers, electrical, and mechanical.

ACTIVE & PASSIVE TRANSDUCERS

Electrical transducers can be broadly classified into two major categories,
(i) Active, (ii) Passive.

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

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

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

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

Electrical transducers are used mostly to measure non-electrical quantities. For this purpose a detector or sensing element is used, which converts the physical quantity into a displacement.

This displacement actuates an electric transducer, which acts as a secondary transducer and give an output that is electrical in nature. This electrical quantity is measured by the standard method used for electrical measurement. The electrical signals may be current, voltage, or frequency; their production is based on R, L and C effects.

RESISTIVE TRANSDUCER

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

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

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

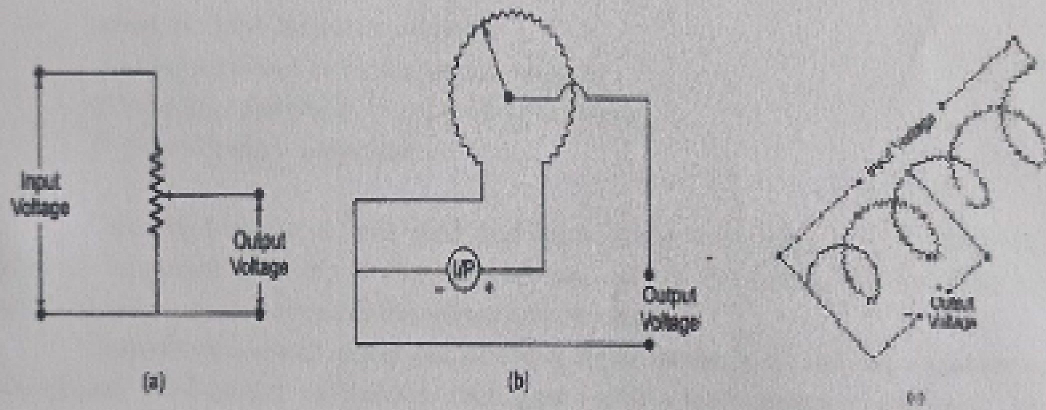


Fig. 13.1 (a) Translatory Type (b) Rotational Type (c) Helipot (Rotational)

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

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

Advantage of Potentiometers

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

Disadvantages of Potentiometers

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

CAPACITIVE TRANSDUCER

A linear change in capacitance with changes in the physical position of the moving element may be used to provide an electrical indication of the element's position. The capacitance is given by

$$C = K\,A/d$$

where K = the dielectric constant
A = the total area of the capacitor surfaces
d = distance between two capacitive surfaces
C = the resultant capacitance.

From this equation, it is seen that capacitance increases (i) if the effective area of the plate is increased, and (ii) if the material has a high dielectric constant. The capacitance is reduced if the spacing between the plates is increased.

Transducers which make use of these three methods of varying capacitance have been developed. With proper calibration, each type yields a high degree of accuracy. Stray magnetic and capacitive effects may cause errors in the measurement produced, which can be avoided by proper shielding. Some capacitive dielectrics are temperature sensitive, so temperature variations should be minimized for accurate measurements.

A variable plate area transducer is made up of a fixed plate called Stator and a movable plate called the Rotor.

The rotor is mechanically coupled to the member under test. As the member moves, the rotor changes its position relative to the stator, thereby changing the effective area between the plates. A transducer of this type is shown in Fig. 13.29

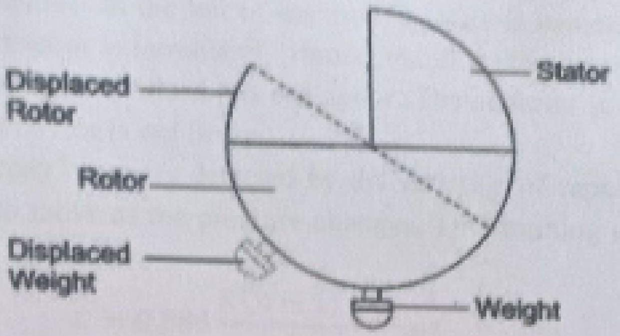


Fig. 13.28 Capacitive Transducer

Such a device is used to detect the amount of roll in an aircraft. As the aircraft rolls to the left, the plates moves to the relative position shown by dashed lines in Fig. 13.29 and the capacitance decreases by an amount proportional to the degree of roll. Similarly to the right. In this case the stator, securely attached to the aircraft, is the moving element. The weight on the rotor keeps its position fixed with reference to the surface of the earth, but the relative position of the plates changes and this is the factor that determines the capacitance of the unit.

Figure 13.30 shows a transducer that makes use of the variation in capacitance resulting from a change in spacing between the plates. This particular transducer is designed to measure pressure (in vacuum).

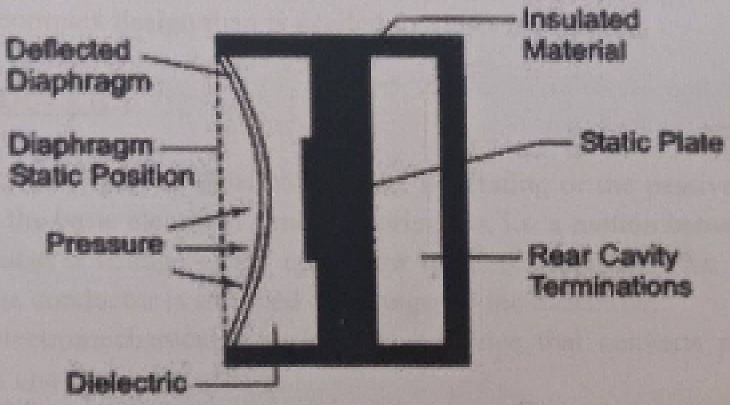


Fig. 13.29 Capacitive Pressure Transducer

Enclosed in an airtight container is a metallic diaphragm which moves to the left when pressure is applied to the chamber and to the right when vacuum is applied. This diaphragm is used as one plate of a variable capacitor. Its distance from the stationary plate to its left, as determined by the pressure applied to the unit, determines the capacitance between the two plates. The monitor indicates the pressure equivalent of the unit's capacitance by measuring the capacitor's reactance to the ac source voltage.

(The portion of the chamber to the left of the moving plate is isolated from the side into which the pressurised gas or vapour is introduced. Hence, the dielectric constant of the unit does not change for different types of pressurised gas or vapour. The capacity is purely a function of the diaphragm position.) This device is not linear.

Changes in pressure may be easily detected by the variation of capacity between a fixed plate and another plate free to move as the pressure changes. The resulting variation follows the basic capacity formula.

$$C = 0.885\frac{K(n-1)A}{t} \quad pf$$

where A = area of one side of one plate in cm2
n = number of plates t = thickness of dielectric in cm
K = dielectric constant

The capacitive transducer, as in the capacitive microphone, is simple to construct and inexpensive to produce. It is particularly effective for HF variations.

However, when the varying capacitance is made part of an ac bridge to produce an ac output signal, the conditions for resistive and reactive balance generally require much care to be taken against unwanted signal pickup in the high impedance circuit, and also compensation for temperature changes. As a result, the receiving instrument for the capacitive sensor usually calls for more advanced and complex design than is needed for other transducers

INDUCTIVE TRANSDUCER

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

An inductive electromechanical transducer is a device that converts physical motion (position change) into a change in inductance.

Transducers of the variable inductance type work upon one of the following principles.

1. Variation of self inductance
2. Variation of mutual inductance

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

1. Number of turns
2. Geometric configuration
3. Permeability of the magnetic material or magnetic circuits

For example, let us considers the case of a general inductive transducer. The inductive transducer has N turns and a reluctance R. When a current i is passed through it, the flux is

$$\phi = \frac{Ni}{R}$$

Therefore $$\frac{d\phi}{dt} = \frac{N}{2} \times \frac{di}{dt} - \frac{Ni}{R^2} \times \frac{dR}{dt}$$

If thel current varies very rapidly,

$$\frac{d\phi}{dt} = \frac{N}{2} \times \frac{di}{dt}$$

But emf induced in the coil is given by $e = N \times d\phi/dt$

Therefore $$e = N \times \frac{N}{2} \times \frac{di}{dt} = \frac{N^2}{R} \times \frac{di}{dt}$$

Also the self inductance is given by

$$L = \frac{e}{di/dt} = \frac{N^2}{R}$$

Therefore, the output from an inductive transducer can be in the form of either a change in voltage or a change in inductance.

STRAIN GAUGES

The strain gauge is an example of a passive transducer that uses the variation in electrical resistance in wires to sense the strain produced by a force on the wires. It is well known that stress (force/unit area) and strain (elongation or compression/unit length) in a member or portion of any object under pressure is directly related to the modulus of elasticity.

Since strain can be measured more easily by using variable resistance transducers, it is a common practice to measure strain instead of stress, to serve as an index of pressure. Such transducers are popularly known as strain gauges. If a metal conductor is stretched or compressed, its resistance changes on account of the fact that both the length and diameter of the conductor changes. Also, there is a change in the value of the resistivity of the conductor when subjected to strain, a property called the piezo-resistive effect. Therefore, resistance strain gauges are also known as piezo resistive gauges.

Many detectors and transducers, e.g. load cells, torque meters, pressure gauges, temperature sensors, etc. employ strain gauges as secondary transducers. When a gauge is subjected to a positive stress, its length increases while its area of cross-section decreases. Since the resistance of a conductor is directly proportional to its length and inversely proportional to its area of cross-section, the resistance of the gauge increases with positive strain. The change in resistance value of a conductor under strain is more than for an increase in resistance due to its dimensional changes. This property is called the piezo-resistive effect.

The following types of strain gauges are the most important.

1. Wire strain gauges
2. Foil strain gauges
3. Semiconductor strain gauges

1. ***Resistance Wire Gauge***

Resistance wire gauges are used in two basic forms, the unbonded type, and the bonded type.

a.. Unbonded Resistance Wire Strain Gauge:

An unbonded strain gauge consists of a wire streched between two points in an insulating medium, such as air. The diameter of the wire used is about 25 mm. The wires are kept under tension so that there is no sag and no free vibration. Unbonded strain gauges are usually connected in a bridge circuit. The bridge is balanced with no load applied as shown in Fig. 13.3.

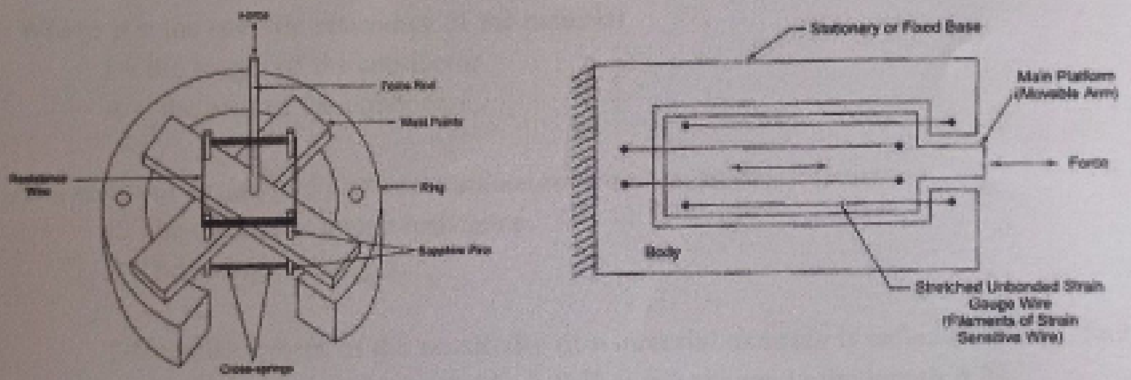


Fig. 13.3 Unbonded Strain Gauge

When an external load is applied, the resistance of the strain gauge changes, causing an unbalance of the bridge circuit resulting in an output voltage. This voltage is proportional to the strain. A displacement of the order of 50 µm can be detected with these strain gauges.

b. Bonded Resistance Wire Strain Gauges

A metallic bonded strain gauge is shown in Fig. 13.4. A fine wire element about 25 µm (0.025 in.) or less in diameter is looped back and forth on a carrier (base) or mounting plate, which is usually cemented to the member undergoing stress. The grid of fine wire is cemented on a carrier which may be a thin sheet of paper, Bakelite, or Teflon. The wire is covered on the top with a thin material, so that it is not damaged mechanically. The spreading of the wire permits uniform distribution of stress. The carrier is then bonded or cemented to the member being studied. This permits a good transfer of strain from carrier to wire.

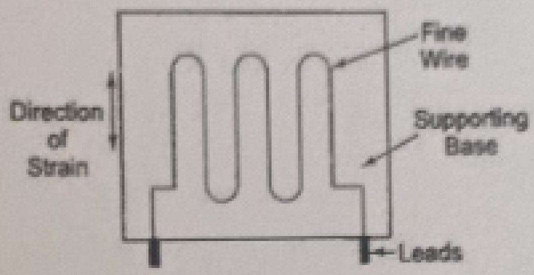


Fig. 13.4 Bonded resistance Wire Strain Gauge

A tensile stress tends to elongate the wire and thereby increase its length and decrease its cross-sectional area. The combined effect is an increase in resistance, as seen from the following equation

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

Where ρ = the specific resistance of the material
l = the length of the conductor
A = the area of the conductor .

As a result of strain, two physical parameters are of particular interest.

1. The change in gauge resistance.
2. The change in length.

The measurement of the sensitivity of a material to strain is called the gauge factor (GF). It is the ratio of the change in resistance Δ R/R to the change in the length Δ l/l

$$GF\ (K) = \frac{\Delta R/R}{\Delta l/l}$$

where K = gauge factor
Δ R = the change in the initial resistance
R = the initial resistance (without strain)
Δ l = the change in the length
l = the initial length (without strain)

Since strain is defined as the change in length divided by the original length, i.e.

$$\sigma = \frac{\Delta l}{l}$$

Eq. (13.1) can be written as

$$K = \frac{\Delta R/R}{\sigma} \tag{13.2}$$

where σ is the strain in the lateral direction.

The resistance of a conductor of uniform cross-section is

$$R = \rho \frac{\text{length}}{\text{area}}$$

$$R = \rho \frac{l}{\pi r^2}$$

Since

$$r = \frac{d}{2} \quad \therefore \quad r^2 = \frac{d^2}{4}$$

$$\therefore \quad R = \rho \frac{l}{\pi d^2/4} = \rho \frac{l}{\pi/4\, d^2} \tag{13.3}$$

where ρ = specific resistance of the conductor
l = length of conductor
d = diameter of conductor

When the conductor is stressed, due to the strain, the length of the conductor increases by Δl and the simultaneously decreases by Δd in its diameter. Hence the resistance of the conductor can now be written as

$$R_s = \rho \frac{(l + \Delta l)}{\pi/4 (d - \Delta d)^2} = \frac{\rho (l + \Delta l)}{\pi/4 (d^2 - 2d\,\Delta d + \Delta d^2)}$$

Since Δd is small, Δd^2 can be neglected

$$\therefore \quad R_s = \frac{\rho (l + \Delta l)}{\pi/4 (d^2 - 2d\,\Delta d)}$$

$$= \frac{\rho (l + \Delta l)}{\pi/4 d^2 \left(1 - \dfrac{2\Delta d}{d}\right)} = \frac{\rho l (1 + \Delta l/l)}{\pi/4 d^2 \left(1 - \dfrac{2\Delta d}{d}\right)} \tag{13.4}$$

Now, Poisson's ratio μ is defined as the ratio of strain in the lateral direction to strain in the axial direction, that is,

$$\mu = \frac{\Delta d/d}{\Delta l/l} \tag{13.5}$$

$$\therefore \quad \frac{\Delta d}{d} = \mu \frac{\Delta l}{l} \tag{13.6}$$

Substituting for $\Delta d/d$ from Eq. (13.6) in Eq. (13.4), we have

$$R_s = \frac{\rho l\,(1 + \Delta l/l)}{(\pi/4)\, d^2\,(1 - 2\mu\,\Delta l/l)}$$

Rationalising, we get

$$R_s = \frac{\rho l\,(1 + \Delta l/l)}{(\pi/4)\, d^2\,(1 - 2\mu\,\Delta l/l)} \, \frac{(1 + 2\mu\,\Delta l/l)}{(1 + 2\mu\,\Delta l/l)}$$

$$\therefore \quad R_s = \frac{\rho l}{(\pi/4)\, d^2} \left[\frac{(1 + \Delta l/l)}{(1 - 2\mu\,\Delta l/l)} \, \frac{(1 + 2\mu\,\Delta l/l)}{(1 + 2\mu\,\Delta l/l)}\right]$$

$$\therefore \quad R_s = \frac{\rho l}{(\pi/4)\, d^2} \left[\frac{1 + 2\mu\,\Delta l/l + 2\,\Delta l/l + 2\mu\;\Delta l/e\;\Delta l/l}{1 - 4\mu^2\,(\Delta l/l)^2}\right]$$

$$\therefore \quad R_s = \frac{\rho l}{(\pi/4)\, d^2} \left[\frac{1 + 2\mu\,\Delta l/l + \Delta l/l + 2\mu\,\Delta l^2/l^2}{1 - 4\mu^2\,\Delta l^2/l^2}\right]$$

Since Δl is small, we can neglect higher powers of Δl.

$$\therefore \quad R_s = \frac{\rho l}{(\pi/4)\, d^2}\,[1 + 2\,\mu\,\Delta l/l + \Delta l/l]$$

$$R_s = \frac{\rho l}{(\pi/4)\, d^2}\,[1 + (2\,\mu + 1)\,\Delta l/l]$$

$$R_s = \frac{\rho l}{(\pi/4)\, d^2}\,[1 + (1 + 2\,\mu)\,\Delta l/l]$$

$$\therefore \quad R_s = \frac{\rho l}{(\pi/4)\, d^2} + \frac{\rho l}{(\pi/4)\, d^2}\,(\Delta l/l)\,(1 + 2\,\mu)$$

Since from Eq. (13.3), $R = \dfrac{\rho l}{(\pi/4)\, d^2}$

$$\therefore \quad R_s = R + \Delta R \qquad (13.7$$

where $\quad \Delta R = \dfrac{\rho l}{(\pi/4)\, d^2}\,(\Delta l/l)\,(1 + 2\,\mu)$

∴ The gauge factor will now be

$$K = \frac{\Delta R/R}{\Delta l/l} = \frac{(\Delta l/l)\,(1 + 2\mu)}{\Delta l/l}$$

$$= 1 + 2\,\mu$$

$$K = 1 + 2\,\mu \qquad (13.8$$

2. *Foil Strain Gauge*

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

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

Foil type strain gauges have similar characteristics to wire strain gauges. Their gauge factors are typically the same. The advantage of foil type strain gauges is that they can be fabricated on a large scale, and in any shape. The foil can also be etched on a carrier.

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

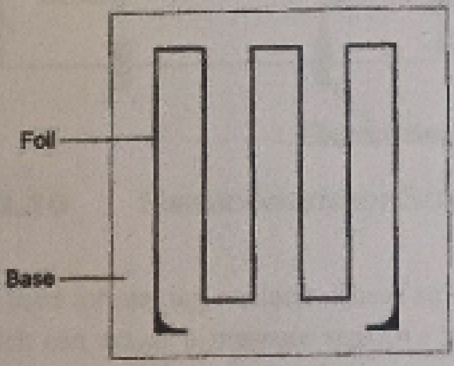


Fig. 13.9 Foil Type Strain Gauge

This method of construction enables etched foil strain gauges to be made thinner than comparable wire units, as shown in Fig. 13.9. This characteristics, together with a greater degree of flexibility, allows the etched foil to be mounted in more remote and restricted places and on a wide range of curved surfaces.

The longitudinal sensitivity of the foil gauge is approximately 5% greater than that of similar wire elements. The transverse strain sensitivity of this gauge is smaller 1/3 to 1/2 of similar wire gauges. The hysteresis of the foil gauge is also 1/3 to 1/2 of a wire strain gauge.

The resistance film formed is typically 0.2 mm thick. The resistance value of commercially available foil gauges is between 50 and 1000 W. The resistance films are vacuum coated with ceramic film and deposited on a plastic backing for insulation.

3. *Semiconductor Strain Gauge*

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

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

Semiconductor strain gauges depend for their action upon the piezo resistive effect, i.e. change in value of the resistance due to change in resistivity, unlike metallic gauges where change in resistance is mainly due to the change in dimension when strained. Semiconductor materials such as germanium and silicon are used as resistive materials. A typical strain gauge consists of a strain material and leads that are placed in a protective box, as shown in Fig. 13.10. Semiconductor wafer or filaments which have a thickness of 0.05 mm are used. They are bonded on suitable insulating substrates, such as teflon.

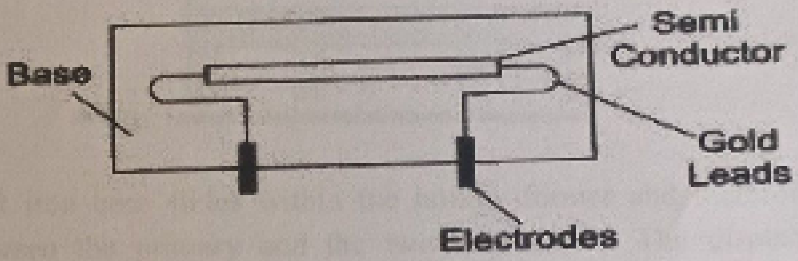


Fig. 13.10 Semiconductor Strain Gauge

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

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

The gauge factor of this type of semiconductor strain gauge is 130 ± 10% for a unit of 350 Ω, 1" long, 1/2" wide and 0.005" thick. The gauge factor is determined at room temperature at a tensile strain level of 1000 micro strain (1000 micro in/in. of length). The maximum operating tensile strain is ± 3000 micro strain, with a power dissipation of 0.1 W. The semiconductor strain gauge also has low hysteresis and is susceptible to regular methods of temperature compensation. The semiconductor strain gauge has proved itself to be a stable and practical device for operation with conventional indicating and recording systems, to measure small strains from 0.1–500 micro strain.

LINEAR VARIABLE DIFFERENTIAL TRANSDUCER (LVDT)

The differential transformer is a passive inductive transformer. It is also known as a Linear Variable Differential Transformer (LVDT). The basic construction is as shown in Fig. 13.19.

The transformer consists of a single primary winding P1 and two secondary windings S1 and S2 wound on a hollow cylindrical former. The secondary windings have an equal number of turns and are identically placed on either side of the primary windings. The primary winding is connected to an ac source.

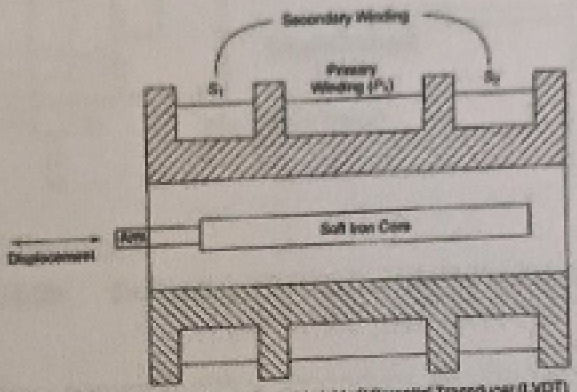
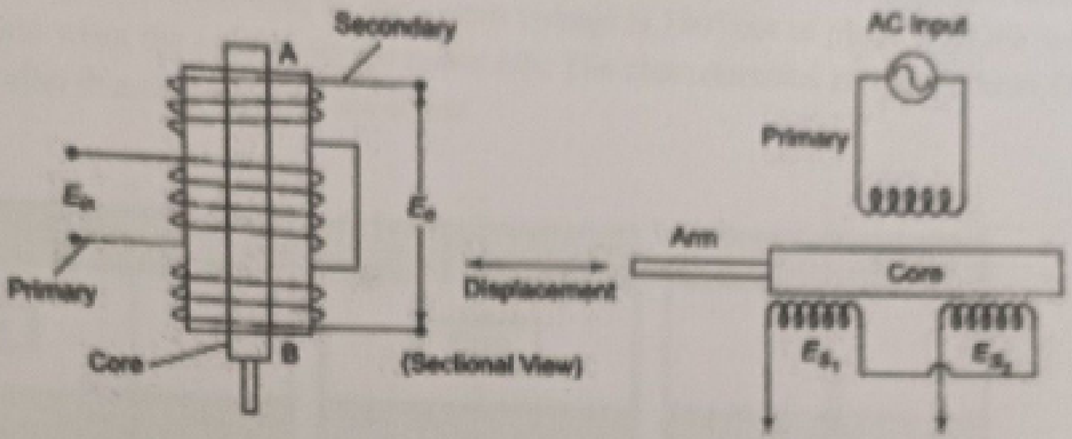


Fig. 13.19 Construction of a Linear Variable Differential Transducer (LVDT)

An movable soft iron core slides within the hollow former and therefore affects the magnetic coupling between the primary and the two secondaries. The displacement to be measured is applied to an arm attached to the soft iron core. When the core is in its normal (null) position, equal voltages are induced in the two secondary windings. The frequency of the ac applied to the primary winding ranges from 50 Hz to 20 kHz. The output voltage of the secondary windings S1 is ES1 and that of secondary winding S2 is ES2.

In order to convert the output from S1 to S2 into a single voltage signal, the two secondaries S1 and S2 are connected in series opposition, as shown in Fig. 13.20. Hence the output voltage of the transducer is the difference of the two voltages. Therefore the differential output voltage Eo = ES1 ~ ES2. When the core is at its normal position, the flux linking with both secondary windings is equal, and hence equal emfs are induced in them. Hence, at null position ES1 = ES2. Since the output voltage of the transducer is the difference of the two voltages, the output voltage Eo is zero at null position.

Now, if the core is moved to the left of the null position, more flux links with winding S1 and less with winding S2. Hence, output voltage ES1 of the secondary winding S1 is greater than ES2. The magnitude of the output voltage of the secondary is then ES1 – ES2, in phase with ES1 (the output voltage of secondary winding S1). Similarly, if the core is moved to the right of the null position, the flux linking with winding S2 becomes greater than that linked with winding S1. This results in ES2 becoming larger than ES1. The output voltage in this case is Eo = ES2 – ES1 and is in phase with ES2.



(a) Construction

(b) Basic Circuit

Fig. 13.20 Secondary Winding Connected for Differential Output

The amount of voltage change in either secondary winding is proportional to the amount of movement of the core. Hence, we have an indication of the amount of linear motion. By noting which output is increasing or decreasing, the direction of motion can be determined. The output ac voltage inverts as the core passes the centre position. The farther the core moves from the centre, the greater the difference in value between ES1 and ES2 and consequently the greater the value of Eo. Hence, the amplitude is function of the distance the core has moved, and the polarity or phase indicates the direction of motion, as shown in Fig. 13.21.

As the core is moved in one direction from the null position, the difference voltage, i.e. the difference of the two secondary voltages increases, while maintaining an in-phase relation with the voltage from the input source. In the other direction from the null position, the difference voltage increases but is 180° out of phase with the voltage from the source. By comparing the magnitude and phase of the difference output voltage with that of the source, the amount and direction of the movement of the core and hence of the displacement may be determined. The amount of output voltage may be measured to determine the displacement. The output signal may also be applied to a recorder or to a controller that can restore the moving system to its normal position.

The output voltage of an LVDT is a linear function of the core displacement within a limited range of motion (say 5 mm from the null position). Figure 13.21(d) shows the variation of the output voltage against displacement for various position of the core. The curve is practically linear for small displacements (up to 5 mm). Beyond this range, the curve starts to deviate. The diagram in Figs 13.21(a), (b) and (c) shows the core of an LVDT at three different positions.

In Fig. 13.21(b), the core is at O, which is the central zero or null position. Therefore, ES1 = ES2 and Eo = 0. When the core is moved to the left, as in Fig. 13.21(a) and is at A, ES1 is more than ES2 and Eo is positive. This movement represents a positive value and therefore the phase angle, is f = 0°. When the core is moved to the right towards B, ES2 is greater than ES1 and hence Eo is negative. Therefore, S2 the output voltage is 180° out of phase with the voltage which is obtained when the core is moved to the left. The characteristics are linear from O – A and O – B, but after that they become non-linear.

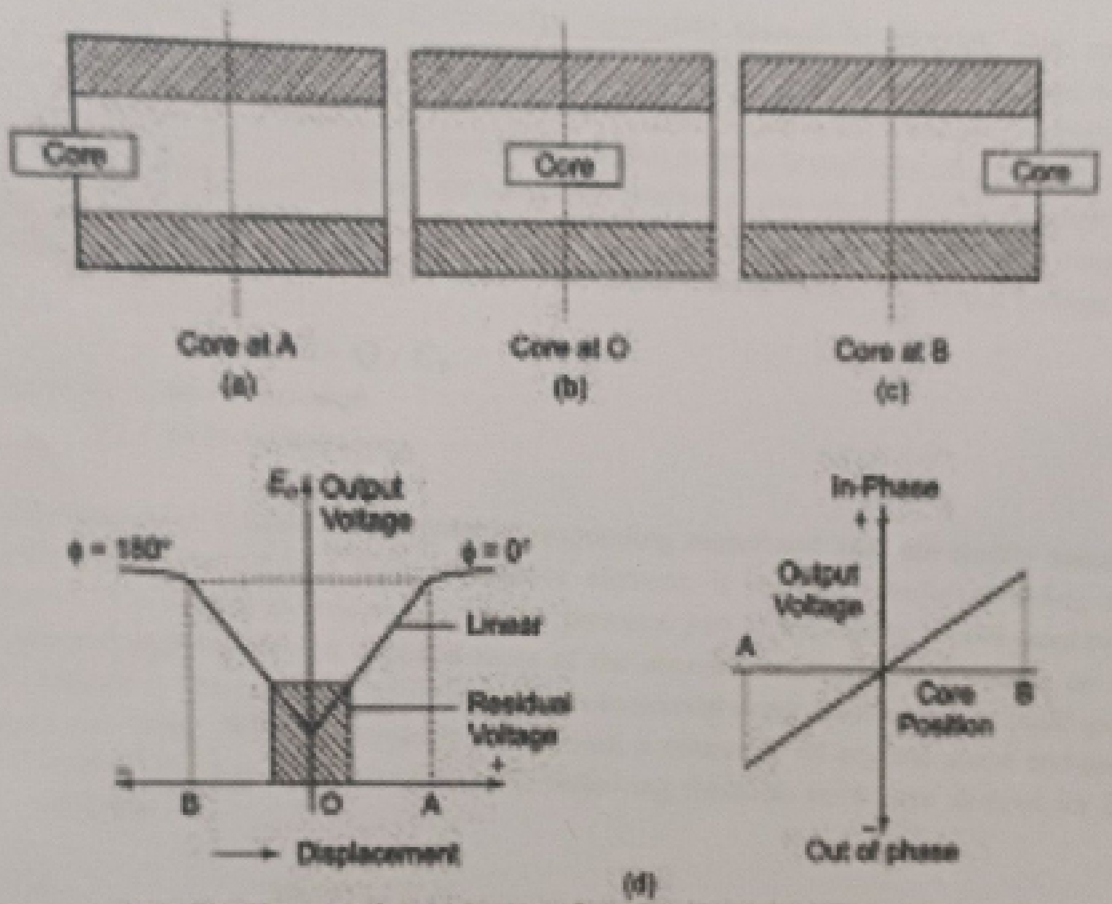


Fig. 13.21 (a), (b), (c) Various Core Position of LVDT
(d) Variation of Output Voltage vs Displacement

One advantage of an LVDT over the inductive bridge type is that it produces higher output voltage for small changes in core position. Several commercial models that produce 50 mV/mm to 300 mV/mm are available. 300 mV/mm implies that a 1 mm displacement of the core produces a voltage output of 300 mV. LVDTs are available with ranges as low as ± 0.05 in. to as high as ± 25 in. and are sensitive enough to be used to measure displacements of well below 0.001 in. They can be obtained for operation at temperatures as low as – 265°C and as high as + 600°C and are also available in radiation resistance designs for nuclear operations.

PIEZO ELECTRICAL TRANSDUCER

A symmetrical crystalline materials such as Quartz, Rochelle salt and Barium titanate produce an emf when they are placed under stress. This property is used in piezo electric transducers, where a crystal is placed between a solid base and the force-summing member, as shown in Fig. 13.32.

An externally applied force, entering the transducer through its pressure port, applies pressure to the top of a crystal. This produces an emf across the crystal proportional to the magnitude of applied pressure. Since the transducer has a very good HF response, its principal use is in HF accelerometers. In this application, its output voltage is typically of the order of 1 – 30 mV per gm of acceleration. The device needs no external power source and is therefore self generating. The disadvantage is that it cannot measure static conditions. The output voltage is also affected by temperature variation of the crystal. The basic expression for output voltage E is given by

$$\mathbf{E = Q / C_p}$$

where Q = generated charge

C_p = shunt capacitances

This transducer is inherently a dynamic responding sensor and does not readily measure static conditions. (Since it is a high impedance element, it requires careful shielding and compensation.) For a piezo electric element under pressure, part of the energy is converted to an electric potential that appears on opposite faces of the element, analogous to a charge on the plates of a capacitor. The rest of the applied energy is converted to mechanical energy, analogous to a compressed spring. When the pressure is removed, it returns to its original shape and loses its electric charge. From these relationships, the following formulas have been derived for the coupling coefficient K.

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

Or

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

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

Measurement of Pysical Parameters :-

Construction and working of thermocouples (Temperature)

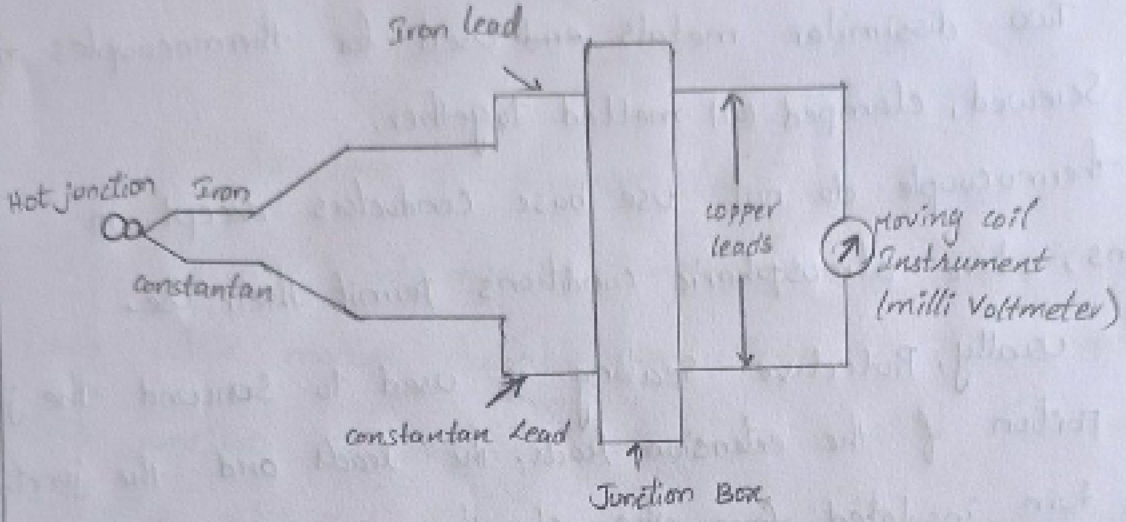


fig Construction of Thermocouple

Thermocouple hot junction will be exposed to the process media, where the temperature has to be measured. The thermocouple cold junction will be maintained at a constant reference temperature.

Since, the 2 junctions are at different temperatures, a Voltage is setup at the free ends & since the free ends are connected to a milli voltmeter the e.m.f setup will establish a flow of current which can be measured directly by using the milli Voltmeter.

Since, the reference junctions is kept at 0°c, the e.m.f measured is a function of the temperature of the hot junction. The milli Voltmeter is calibrated to indicate the readings in terms of temparature.

the e.m.f developed in a thermocouple depends upon the difference in temperature between the hot junction and cold junction. the temperature of the cold junction is purposefully kept at 0°c to avoid errors which may be introduced on account of change in room temperature.

Two dissimilar metals ~~and~~ used for thermocouples may be twisted, Screwed, clamped (or) melted together.

thermocouple do not use base conductors except in applications, where atmospheric conditions permit their use.

Usually, Protective seating is used to Surround the junction and a portion of the extension leads. the leads and the junction are in turn insulated from the sheath using various oxides.

Thermocouples are usually installed inside the protective wells, so that they can be easily removed (or) replaced with out interruption to the plant. Protective wells of 12.5 mm to 25mm diameter made from ~~Sats~~ stainless steel are usually used.

Laws of thermocouples:-

there are three Laws of thermocouples namely,

1, Law of thermo electricity (or) intermediate temperatures.
2, Law of intermediate metals.
3, Law of homogeneous circuits.

1. Law of Thermo electricity (or) Intermediate Temperatures:

If a thermocouples circuit develops an e.m.f. E_1, when its junctions are at temperatures T_1 and T_2 and an e.m.f. E_2, when its junctions are at temperature T_2 and T_3, then it will develop an emf (E_1+E_2), when its junction are at temperatures T_1

and T_3 as shown in fig.

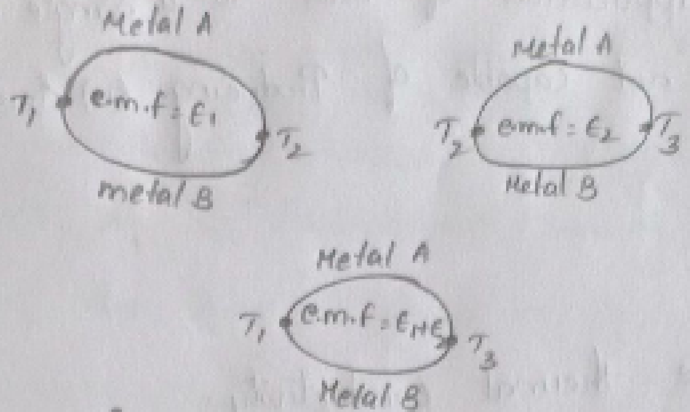


fig:- Law of thermoelectricity

Law of intermediate temperature of thermocouple is practically used while making suitable corrections if the temperature of the cold junction is deviating from one for which the thermocouple was actually calibrated. Let, a thermocouple is calibrated for a cold junction temperature of 0°c, but is used with junction of 20°c then the required correction for thermocouple reading would be the voltage generated (by the thermocouple) between 0°c and 20°c.

2) Law of Intermediate Metals:-

If a third metal is introduced into a thermocouple circuit, it will not affect the net e.m.f of the two junctions (J_1 & J_2) introduced by the third metal & are at same temperatures as shown in fig.

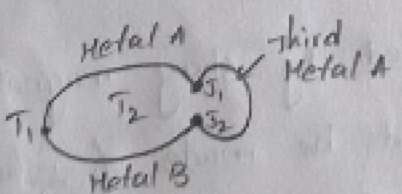


fig:- Law of intermediate metals

3) law of Homogeneous Circuit :-

The application of heat to a single homogeneous metal is in itself not capable of Producing (or) Sustaining an electric current.

Applications:

1, Used to measure thermal conductivity.
2, Can be used in the measurement of Pressure, level, flow of Liquids & to know the composition of gases.
3 can be applied to measure Vacum.
4, Applied in the measurement of Voltage & currents.

Advantages:-

1, can measure fast changes in the temperature.
2, Produces electrical o/p
3 It is an active transducer i.e., no need of any excitation to operate.
4, can be used to measure wide ranges of temperatures from 0°c to 1400°c.
5, the temperature of a Particular point can be measured.

Disadvantages.

1, Produces low o/p voltages in terms of mV.
2, Accuracy of measurement is low
3, the o/p voltage is effected by stray magnetic field.
4, the extension wires should be made of those metals which are used in the construction of thermocouple.

force Measurement using LVDT or Proving ring.

A proving ring consists of a high grade steel ring with two loading bosses attached at the ends of one of its diameters with a displacement sensing device ~~suited~~ situated at the center of the ring as shown in fig.

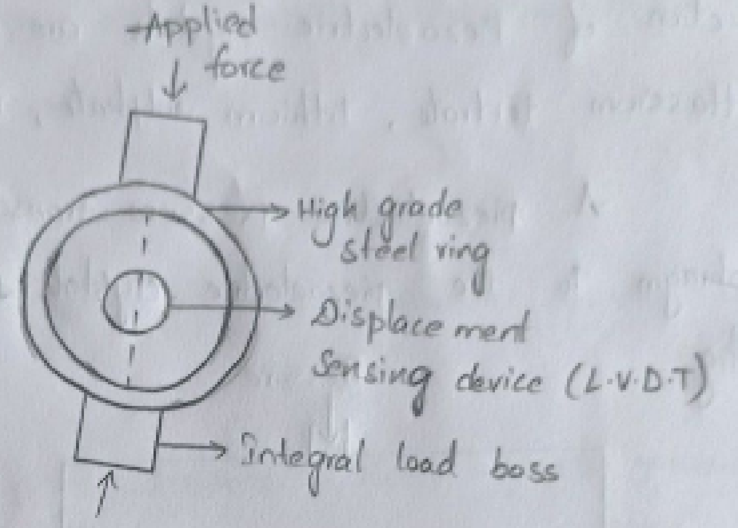


fig:- force Transducer Proving Ring

When the force is aplied on the load boss, the ring tends to distort & this distortion is directly Proportional to the applied force. This distortion is measured by a displacement sensing device. for low accuracy the distortion is measured by dial guage or micrometer, where as for high accuracy applications L.V.D.T. is used as displacement sensor. This displacement measurement is a measure of force applied.

The proving rings may be used for both tensile & compression force measurements. The range of Proving ring is 2kN to 2000kN with accuracy of 0.2 to 0.5 Percent. Proving rings are high Precision devices which are extensively used for materials - testing machines.

Measurement of Pressure using Piezoelectric Transducer.

Piezoelectric pressure transducers depends on the principle of "Piezoelectric effect" i.e., when some Pressure or stress is applied to the surface of the Piezoelectric crystal, an electric charge voltage will be developed by the crystal. The materials used in the construction of Piezoelectric crystals are quartz, rochelle salt, diapottassium tertrate, lithium sulphate, barium titanate etc.

A piezoelectric pressure transducer is formed by connecting a diaphragm to the piezoelectric crystals & this assembly is shown in fig.

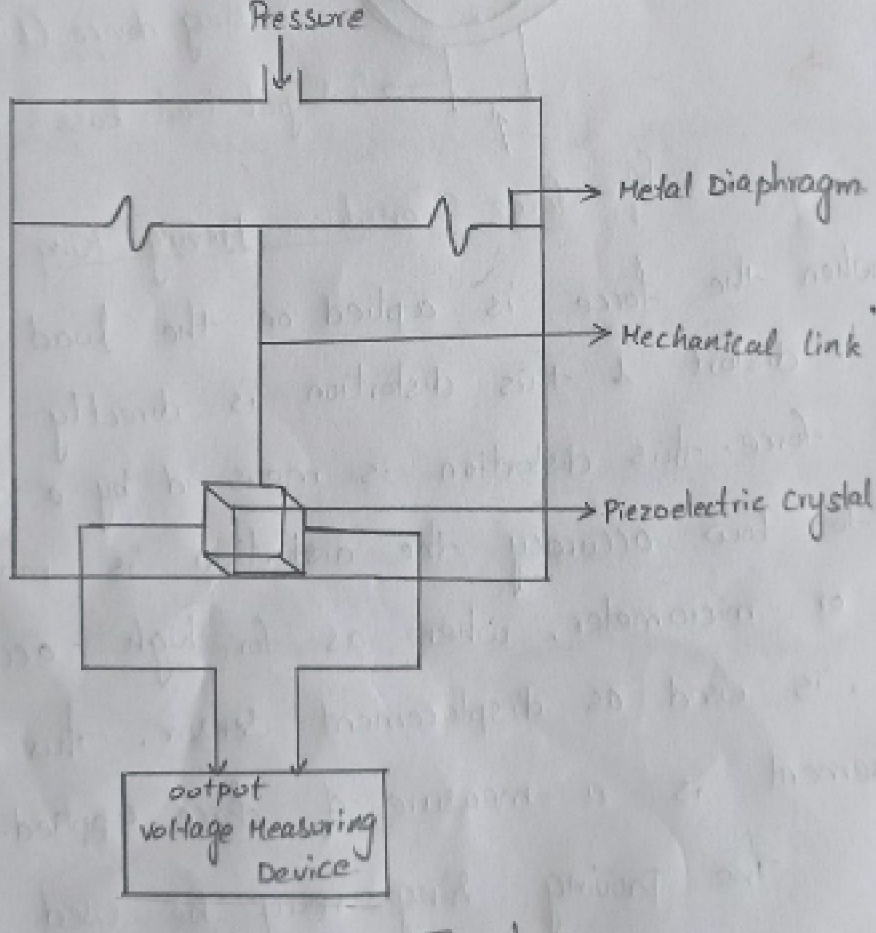


fig: Piezoelectric pressure Transducer.

force Measurement using LVDT or) Proving rings

A proving ring consists of a high grade steel ring with two loading bosses attached at the ends of one of its diameters with a displacement sensing device ~~sited~~ situated at the center of the ring as shown in fig.

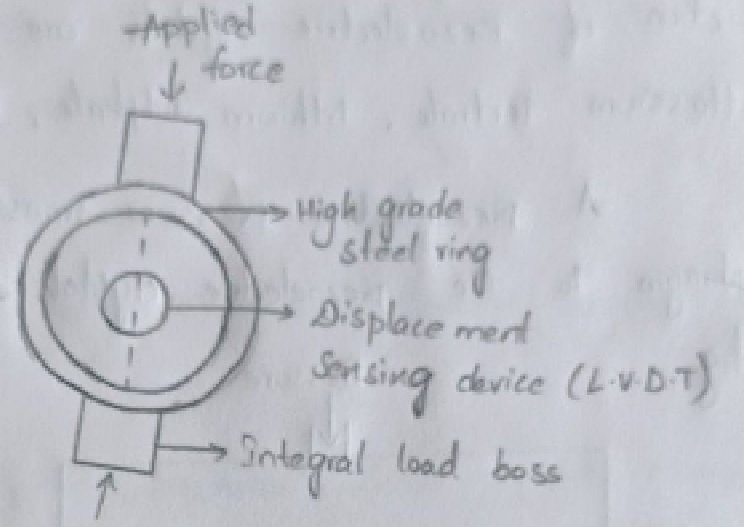


fig:- force Transducer Proving Ring

When the force is aplied on the load boss, the ring tends to distort & this distortion is directly Proportional to the applied force. this distortion is measured by a displacement sensing device. for low accuracy the distortion is measured by dial guage or micrometer, where as for high accuracy applications, L.V.D.T. is used as displacement sensor. This displacement measurement is a measure of force applied.

The proving rings may be used for both tensile & compression force measurements. The range of Proving ring is 2kN to 2000kN with accuracy of 0.2 to 0.5 Percent. Proving rings are high Precision devices which are extensively used

The pressure which is to be measured is applied to Corrugated metal diaphragm. the diaphragm deflects depending on the applied pressure & this deflection s/g is transmitted to the crystal through the mechanical link. In other words, the Pressure is applied to the crystal through the (~~median~~) diaphragm & the link. when the crystal senses the pressure it will generate Some voltage corresponding to the applied Pressure & is measured in the o/p Voltage measuring device which is calibrated in terms of applied pressure.

Applications

1, these can be used in the Process, which requires measurement of high pressure.

2, Can be applied in these systems, which requires measured variable in electrical form.

Merits:-

1, Provides electrical o/p.

2, This transducer does not require any external Power supply. (Since it is known as active transducer).

3, it can be used for dynamic Pressure measurement.

4, Rugged construction.

5, Small in size.

Demerits:-

1, It cannot be used for static Pressure measurements.

2, The response will get affected by the variations in temperatur

3, In Some cases it requires s/g conditioning circuitary, which is complex.

4, cost is high.

Measurement of linear Displacement using Capacitive Transducer.

Capacitive transducer operates on the principle of capacitance of a Parallel plate capacitor which is given by,

$$C = \frac{\epsilon A}{d} \longrightarrow ①$$

(or)

$$C = \frac{\epsilon_r \epsilon_0 A}{d}$$

where,

$C \rightarrow$ Capacitance of a capacitor (farads)

$\epsilon \rightarrow \epsilon_r \epsilon_0 \rightarrow$ Permitivity of medium (f/m)

$\epsilon_r \rightarrow$ Relative permitivity (dielectric constant)

$\epsilon_0 \rightarrow$ Permitivity of free space (8.5×10^{-12} f/m)

$d \rightarrow$ Distance b/w 2 plates (m)

$A \rightarrow$ Overlapping area of 2 plates (m^2)

The Capacitance of a capacitor varies when,

1. the overlapping area (A) of the plates changes.
2. the distance (d) between the two plates changes.
3. the dielectric constant ϵ_r changes.

1. Capacitive Transducer using the effect of variation of overlapping Area of plates:-

from eq (1). it is clear that the capacitance of the capacitor is directly Proportional to the Area of plates. Hence, the capacitance varies linearly with the variation in area of Plates. The area linearly varies with applied displacement. therefore the capacitive transducer using this

Principle is used to measure linear displacements of about 1mm to 10mm.

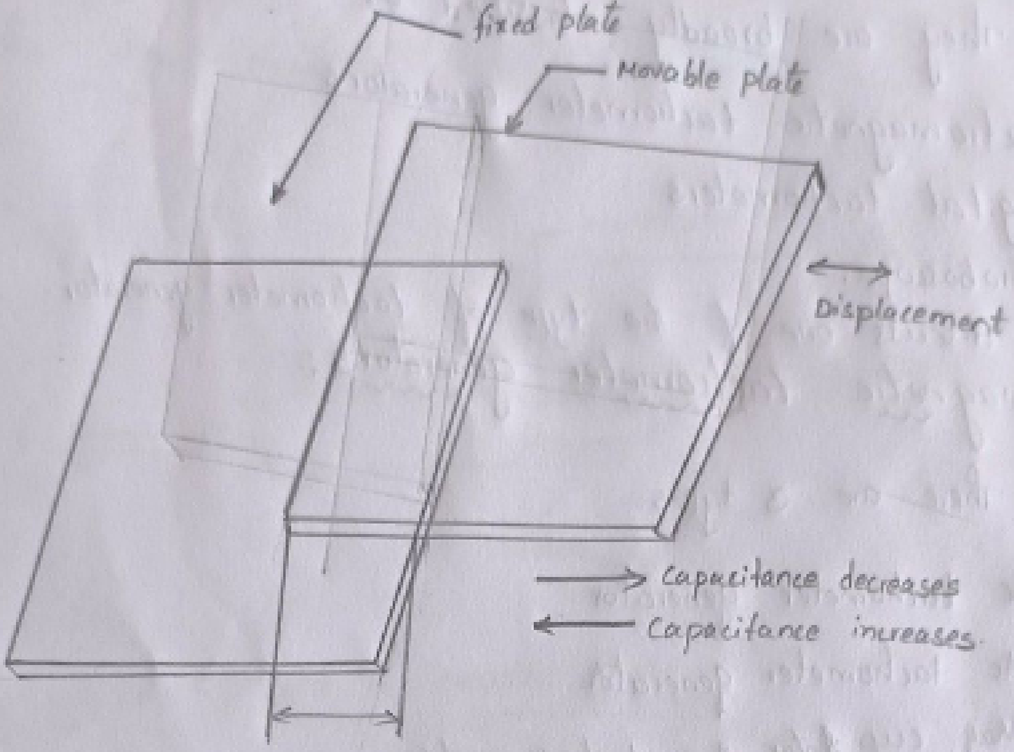


fig. capacitive Transducer using the principle of change in capacitance Due to change in overlapping Area of Plates.

from the fig, the capacitance of Parallel plate capacitor is,

$$C = \frac{\epsilon A}{d}$$

$$C = \frac{\epsilon l b}{d}$$

where,

l → length of overlapping Area of plates.

b → width of overlapping area of plates.

Measurement of Angular Velocity (or) Angular Speed.

Angular Speed can be measured using either a mechanical or electrical type of techometer.

An electrical techometers possess all the advantages of

Electrical transducers they are widely used when compared to mechanical tachometers

Electrical Tachometers:-

they are broadly classified as follows,

1, electromagnetic tachometer generators
2, Digital tachometers.
3, Stroboscope.

Let us discuss one of the type of tachometer generator.

I) Electromagnetic tachometer generators:-

there are 3 types:

1, Dc tachometer generator
2, Ac tachometer generator
3, Drag cup Rotor A.c tachogenerator.

1. Dc tachometer generator:-

It consists of a permanent magnet & a small armature. the armature is placed b/w the poles of the magnet. the object whose angular speed/velocity is to be measured is coupled to the armature.

So, when the object rotates the armature also revolves in the magnetic field of the permanent magnet. As the armature made up of a conducting material its rotation results in the generation of emf. the current flowing in the armature. is collected through commutator & brushes & thus voltage is generated, which can be measured using a moving coil voltmeter. In case of a short circuit, the current from the generator is limited by a series of resistance.

The voltage is generated is Proportional to the speed of the object & the direction of rotation is determined from the Polarity of the o/p voltage.

the figure shows a DC tachogenerator.

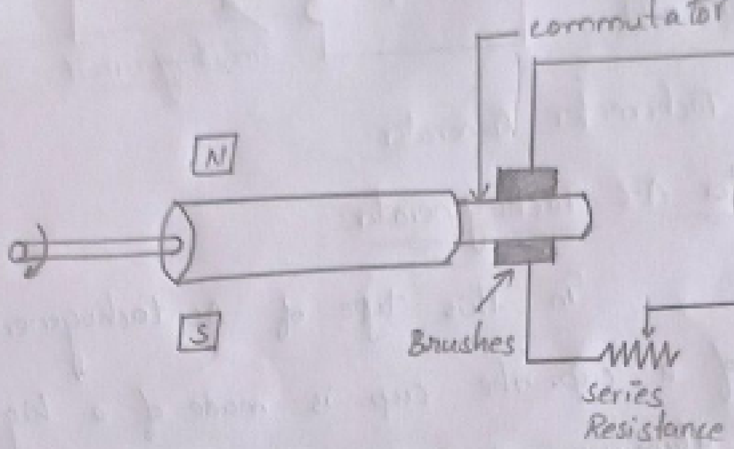


fig: D.C Tachometer Generator

2. AC Tachoge-meter generator: The problem associated with commutator (as in DC tachometers) are not in present in A.C tachometers because in A.c tachometers the coil is wound on the stator & the magnet is allowed to rotate. The rotating magnet can be either an electromagnet or Permanent magnet.

the machine whose angular speed is to be measured is connected to the rotating magnet. when the magnet rotates the flux lines are cut by the stationary coil & thus according to the electromagnetic induction law an emf is induced in the stator coil. The amplitude or frequency of the induced voltage gives the measure of speed as both the parameters are proportional to speed of rotation.

The ckt shown in fig is used when it is required to measure speed in terms of amplitude of induced voltage. The voltage generated by Ac tachometer generator is rectified & smoothened before it is measured by moving coil voltmeter.

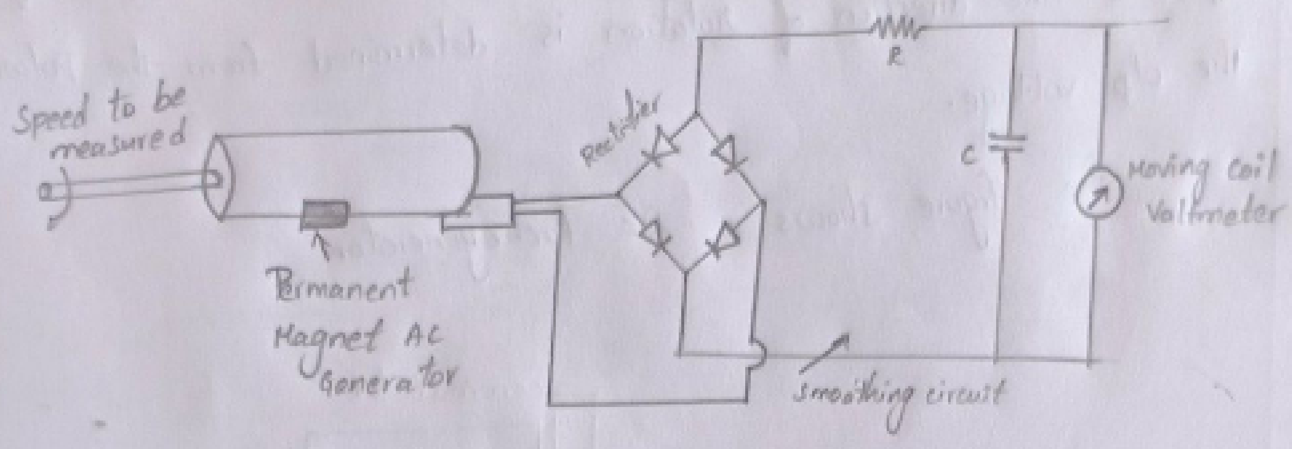


fig: Ac Tachometer Generator

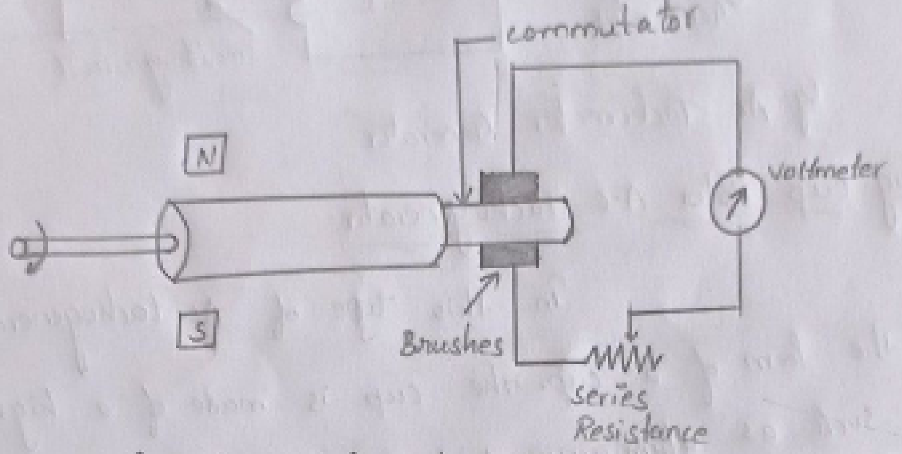
3. Drag cup Rotor A.C Tachogenerator:

In this type of Ac tachogenerator, the rotor is in the form of a cup. The cup is made of a high conductive material such as aluminium & it has very low intertia (i.e., the cup is thin). The stator of the generator consists of 2 field windings wound on it. These two fields windings are mounted on stator, so that they are at right angles to each other. These windings are said to be in space quadrature with each other and are reffered as quadrature winding & reference winding.

The reference winding is supplied with an A.C voltage & the o/p voltage is taken from the quadrature winding. The cup is known as drag cup as it is connected to the object whose speed is to be measured.

the voltage is generated is Proportional to the speed of the object & the direction of rotation is determined from the polarity of the o/p voltage.

The figure shows a Dc tachogenerator.



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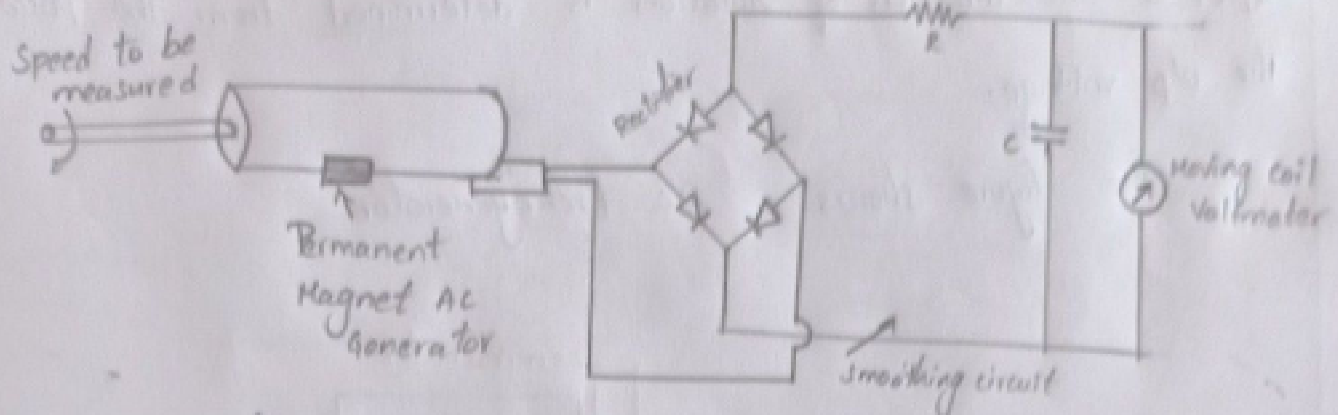

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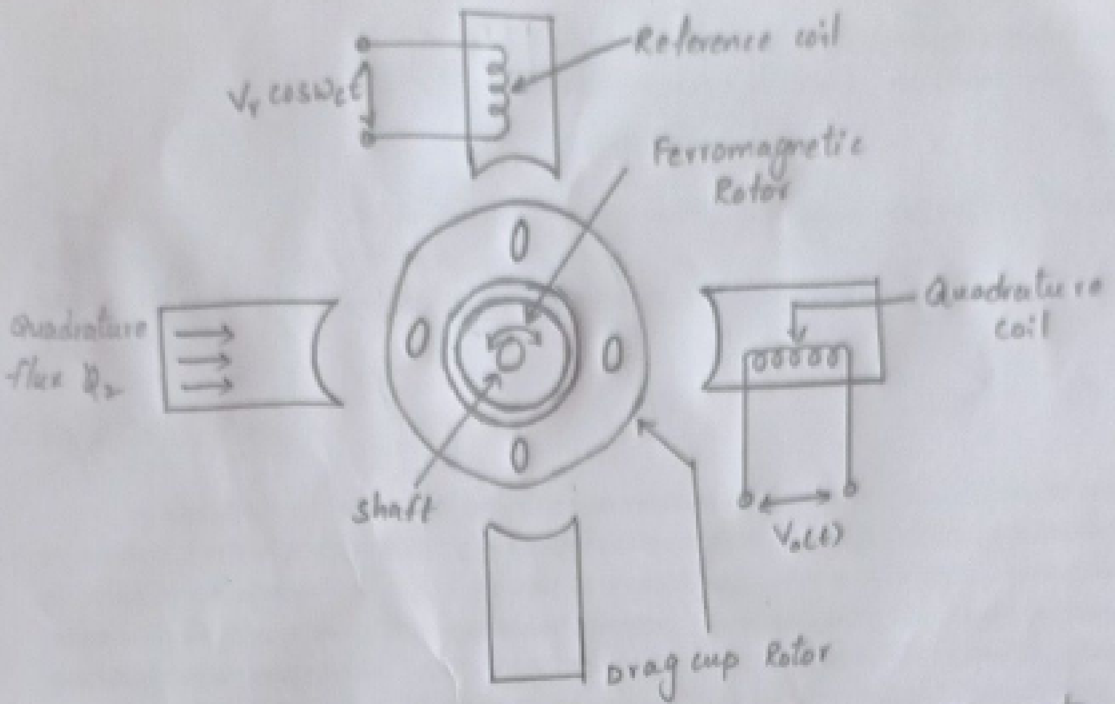

fig:- Drag cup Rotor AC Tachometer Generator

A reference voltage $V_r \cos \omega_c t$ is applied to the reference coil. If the resistance & reactance of the coil are ~~ad~~ negligible then a reference flux $\phi_r \sin \omega_c t$ is producd vth lags the reference voltage by 90°.

When the drag cup rotates in the air gap of this fiel
an emf is induced in the cup & a current flows through it.
Due to this induced emf a quadrature flux ϕ_q is produced whic
in turn leads to a transformer action & an emf e_q is induced
in the quadrature coil.

Thus, the voltage o/p $v_t(t)$ at the terminals of quadrat
coil is proportional to the speed of rotation, & is a function of speed.