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Second Edition

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Preface to the Second Edition

The tremendous response to the first edition of this book has inspired me to bring out this second edition, which has been revised and updated, based on the suggestions received from the students and teachers using the book.

As in the first edition, the book is written in a simple and lucid manner with the chapters arranged systematically to enable the reader to get thorough knowledge of all types of measuring instruments and measurement techniques. With the advancement of technology in integrated circuits, instruments are becoming increasingly compact and accurate. In view of this, sophisticated types of instruments covering digital and microprocessor-based instruments are dealt in detail, in a simple and systematic manner for easy understanding. The basic concepts, working operation, capabilities and limitations of the instruments discussed in the book will also guide the users in selecting the right instrument for certain application.

Chapter 1 covers the basic characteristics and the errors associated with an instrument. Different types of indicating and display devices are dealt in Chapter 2. This chapter discusses different types of printers and printer heads used with the computers.

The basic analog-type ammeters for both DC and RF frequencies and different types of voltmeters, ohmmeters to multimeters are discussed in Chapters 3 and 4.

Digital instruments ranging from a simple digital voltmeter to a microprocessor-based instrument and their measurement techniques are presented in a comprehensible style for easy understanding. Chapter 7 on oscilloscopes has been dealt in depth to familiarize the students with the working of all types of Cathode Ray Oscilloscopes (CROs) and their measurement techniques. Chapter 8 pertains to signal generation. Chapter 9 analyses the frequency component of a generated wave, and its distortion.

Every instrument consists of an input sensing element or transducer, a signal conditioner, and a recording or display unit. Chapters 12, 13 and 14 cover the essential components of industrial instruments used for measurements and their usage.

Different types of analog and digital filters are given in Chapter 15. A mathematical approach to explaining digital filters has been adopted to provide the students a clear insight into their working. Chapter 16 is on the measurement of microwave frequencies. A detailed discussion on the data

acquisition system along with the latest data logger is covered in Chapter 17. Instruments from remote places transmit signals over long distances to a master control room where they are displayed. This transmission of signals has been explained in detail in Chapter 18.

Frequency standards and measurement of Power at RF and Microwave frequencies are dealt with in Chapters 19 and 20 respectively.

The last chapter, newly added to this edition, deals with Control Systems, electronic control systems, in particular. This chapter covers the basic control systems, electronic controllers, PLC and advanced control systems such as DCS, used in process control plants.

I hope that this edition of the book will prove useful to all readers, students as well as teachers. All suggestions for further improvement of the book are welcome and will be gratefully acknowledged.

H S Kalsi

Preface to the First Edition

This book is written to cater specifically to the needs of the students of electronics engineering. It will also be of use to the electronics students at polytechnics and other technical institutes.

It is written in a simple and lucid manner with the chapters arranged systematically to enable the reader to get a thorough knowledge of all types of measuring instruments and their measurement techniques. With the advancement of technology in integrated circuits, instruments are becoming more and more compact and accurate. In view of this, sophisticated types of instruments covering digital and microprocessor-based instruments are dealt in detail, in a simple, step-by-step manner for easy understanding. The basic concepts, working operation, capabilities and limitations of instruments are discussed in the book which will guide the users in selecting instruments for various applications.

Chapter 1 covers the basic characteristics and the errors associated with an instrument. Different types of indicating and display devices are dealt in Chapter 2. Computer technology is a rapidly advancing field; and the hardcopy is of prime importance, for which printers are used. This chapter also discusses different types of printers and printer heads.

The basic analog type ammeters both for dc and RF frequency and different types of voltmeters, ohmmeters to multimeters are discussed in Chapter 3 and 4.

Digital instruments ranging from a simple digital voltmeter to a microprocessor-based instrument and their measurement techniques are presented in a comprehensible style for easy understanding. Chapter 7 on oscilloscopes has been dealt in depth to familiarise the students with the working of all types of Cathode-Ray Oscilloscopes (CRO) and their measurement techniques. Chapter 8 pertains to signal generation. Chapter 9 analyses the frequency component of a wave generated, and its distortion.

Any instrument basically consists of an input sensing element or transducer, signal conditioner, and recording or display unit. Chapters 12, 13 and 14 cover the essential components of industrial instruments and their measurement techniques.

Different types of analog and digital filters are given in the next chapter. A mathematical approach to explain digital filters has been adopted to provide the students a clear insight into its working. Chapter 16 is on the measurement of microwave frequencies. A detailed discussion on data acquisition system along

with the latest data logger is covered in Chapter 17. Instruments from remote places transmit signals over long distances to a master control room where they are displayed. This transmission of signals has been explained in detail in Chapter 18. The last two chapters pertain to frequency standards and measurement of power, respectively.

I hope this book will prove to be useful to all readers. I will appreciate any suggestions which will help in the improvement of the book.

H S Kalsi

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CHAPTER 1

Qualities of Measurements

1.1 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 indepth knowledge of any parameter can be easily understood by the use of measurement, and further modifications 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 minimises 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 minimise these interference effects.

1.2 PERFORMANCE CHARACTERISTICS

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.

1.3 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.

[illegible] 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

$$\text{Therefore } \% \text{ Error} = \frac{\text{Absolute value}}{\text{Expected value}} \times 100$$

$$= \frac{e}{Y_n} \times 100$$

$$\text{Therefore } \% \text{ Error} = \left(\frac{Y_n - X_n}{Y_n}\right) \times 100$$

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

$$\text{Therefore} \qquad A = 1 - \left|\frac{Y_n - X_n}{Y_n}\right|$$

where A is the relative accuracy.

Accuracy is expressed as % accuracy

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

$$a = A \times 100\ \%$$

where a is the % accuracy.

Example 1.1 The expected value of the voltage across a resistor is 80 V. However, the measurement gives a value of 79 V. Calculate (i) absolute error, (ii) % error, (iii) relative accuracy, and (iv) % of accuracy.

Solution

(i) Absolute error $e = Y_n - X_n = 80 - 79 = 1$ V

(ii) % Error $= \dfrac{Y_n - X_n}{Y_n} \times 100 = \dfrac{80 - 79}{80} \times 100 = 1.25\%$

(iii) Relative Accuracy

$$A = 1 - \left|\frac{Y_n - X_n}{Y_n}\right| = 1 - \left|\frac{80 - 79}{80}\right|$$

$$\therefore \quad A = 1 - 1/80 = 79/80 = 0.9875$$

(iv) % of Accuracy $a = 100 \times A = 100 \times 0.9875 = 98.75\%$

or $a = 100\% - \%$ of error $= 100\% - 1.25\% = 98.75\%$

If a measurement is accurate, it must also be precise, i.e. Accuracy means precision. However, a precision measurement may not be accurate. (The precision of a measurement is a quantitative or numerical indication of the closeness with which a repeated set of measurement of the same variable agree with the average set of measurements.) Precision can also be expressed mathematically as

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

where X_n = value of the nth measurement

$\overline{X}_n$ = average set of measurement

Example 1.2 Table 1.1 gives the set of 10 measurement that were recorded in the laboratory. Calculate the precision of the 6th measurement.

Table 1.1

Measurement number	*Measurement value X_n*
1	98
2	101
3	102
4	97
5	101
6	100
7	103
8	98
9	106
10	99

The average value for the set of measurements is given by

$$\bar{X}_n = \frac{\text{Sum of the 10 measurement values}}{10}$$

$$= \frac{1005}{10} = 100.5$$

$$\text{Precision} = 1 - \left| \frac{X_n - \bar{X}_n}{\bar{X}_n} \right|$$

For the 6th reading

$$\text{Precision} = 1 - \left| \frac{100 - 100.5}{100.5} \right| = 1 - \frac{0.5}{100.5} = \frac{100}{100.5} = 0.995$$

The accuracy and precision of measurements depend not only on the quality of the measuring instrument but also on the person using it. However, whatever the quality of the instrument and the case exercised by the user, there is always some error present in the measurement of physical quantities.

1.5 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 categorised as gross errors or human errors, systematic errors, and random errors.

1.5.1 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 minimise 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. (Refer Examples 1.3(a) and (b)).

(One should therefore not be completely dependent on one reading only; at least three separate readings should be taken, preferably under conditions in which instruments are switched off and on.)

1.5.2 Systematic Error

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

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

(i) Instrumental Errors

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

Instrumental errors can be avoided by

(a) selecting a suitable instrument for the particular measurement applications. (Refer Examples 1.3 (a) and (b)).
(b) applying correction factors after determining the amount of instrumental error.
(c) calibrating the instrument against a standard.

(ii) Environmental Errors

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

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

(iii) Observational Errors

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

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

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

Example 1.3 (a) A voltmeter having a sensitivity of 1 kΩ/V is connected across an unknown resistance in series with a milliammeter reading 80 V on 150 V scale. When the milliammeter reads 10 mA, calculate the (i) Apparent resistance of the unknown resistance, (ii) Actual resistance of the unknown resistance, and (iii) Error due to the loading effect of the voltmeter.

Solution

(i) The total circuit resistance $R_T = \dfrac{V_T}{I_T} = \dfrac{80}{10\text{ mA}} = 8\text{ k}\Omega$

(Neglecting the resistance of the milliammeter.)

(ii) The voltmeter resistance equals $R_v = 1000\ \Omega/\text{V} \times 150 = 150\text{ k}\Omega$

$$\therefore \text{actual value of unknown resistance } R_x = \frac{R_T \times R_v}{R_v - R_T} = \frac{8\text{k} \times 150\text{k}}{150\text{k} - 8\text{k}}$$

$$= \frac{1200\text{k}^2}{142\text{k}} = 8.45\text{ k}\Omega$$

(iii) $$\%\text{ error} = \frac{\text{Actual value} - \text{Apparent value}}{\text{Actual value}} = \frac{8.45\text{k} - 8\text{k}}{8.45\text{k}} \times 100$$

$$= 0.053 \times 100 = 5.3\%$$

Example 1.3(b) Referring to Ex. 1.3 (a), if the milliammeter reads 600 mA and the voltmeter reads 30 V on a 150 V scale, calculate the following: (i) Apparent, resistance of the unknown resistance. (ii) Actual resistance of the unknown resistance. (iii) Error due to loading effect of the voltmeter.

Comment on the loading effect due to the voltmeter for both Examples 1.3 (a) and (b). (Voltmeter sensitivity given 1000 Ω/V.)

Solution

1. The total circuit resistance is given by

$$R_T = \frac{V_T}{I_T} = \frac{30}{0.6} = 50\ \Omega$$

2. The voltmeter resistance R_v equals

$$R_v = 1000\ \Omega/V \times 150 = 150\ k\Omega$$

Neglecting the resistance of the milliammeter, the value of unknown resistance = 50 Ω

$$R_x = \frac{R_T \times R_v}{R_v - R_T} = \frac{50 \times 150\ k}{150\ k - 50} = \frac{7500\ k}{149.5\ k} = 50.167\ \Omega$$

$$\%\ Error = \frac{50.167 - 50}{50.167} \times 100 = \frac{0.167}{50.167} \times 100 = 0.33\%$$

In Example 1.3 (a), a well calibrated voltmeter may give a misleading resistance when connected across two points in a high resistance circuit. The same voltmeter, when connected in a low resistance circuit (Example 1.3 (b)) may give a more dependable reading. This show that voltmeters have a loading effect in the circuit during measurement.

1.5.3 Random Errors

These are errors that remain after gross and systematic errors have been substantially reduced or at least accounted for. Random errors are generally an accumulation of a large number of small effects and may be of real concern only in measurements requiring a high degree of accuracy. Such errors can be analyzed statistically.

These errors are due to unknown causes, not determinable in the ordinary process of making measurements. Such errors are normally small and follow the laws of probability. Random errors can thus be treated mathematically.

For example, suppose a voltage is being monitored by a voltmeter which is read at 15 minutes intervals. Although the instrument operates under ideal environmental conditions and is accurately calibrated before measurement, it still gives readings that vary slightly over the period of observation. This variation cannot be corrected by any method of calibration or any other known method of control.

1.6 SOURCES OF ERROR

The sources of error, other than the inability of a piece of hardware to provide a true measurement, are as follows:

1. Insufficient knowledge of process parameters and design conditions
2. Poor design
3. Change in process parameters, irregularities, upsets, etc.
4. Poor maintenance
5. Errors caused by person operating the instrument or equipment
6. Certain design limitations

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 behaviour of the instrument is as important as the static behaviour.

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, (ii) fidelity, (iii) lag, and (iv) dynamic error.

(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.

1.7.1 Dynamic Response of Zero-order Instruments

We would like an equation that describes the performance of the zero order instrument exactly. The relations between any input and output can, by using suitable simplifying assumptions, be written as

$$a_n \frac{d^n x_o}{dt^n} + a_{n-1} \frac{d^{n-1} x_o}{dt^{n-1}} + \cdots + a_1 \frac{d x_o}{dt} + a_0 x_o$$

$$= b_m \frac{d^m x_i}{dt^m} + \cdots + b_{m-1} \frac{d^{m-1} x_i}{dt^{m-1}} + \cdots + b_1 \frac{dx_i}{dt} + b_0 x_i \quad (1.1)$$

where x_o = output quantity

x_i = input quantity

t = time

a's and b's are combinations of systems physical parameters, assumed constant.

When all the a's and b's, other than a_0 and b_0 are assumed to be zero, the differential equation degenerates into the simple equation given as

$$a_0 x_o = b_0 x_i \quad (1.2)$$

Any instrument that closely obeys Eq. (1.2) over its intended range of operating conditions is defined as a zero-order instrument. The static sensitivity (or steady state gain) of a zero-order instrument may be defined as follows

$$x_o = \frac{b_0}{a_0} x_i = K\, x_i$$

where $K = b_0/a_0$ = static sensitivity

Since the equation $x_o = K\, x_i$ is an algebraic equation, it is clear that no matter how x_i might vary with time, the instrument output (reading) follows it perfectly with no distortion or time lag of any sort. Thus, a zero-order instrument represents ideal or perfect dynamic performance. A practical example of a zero order instrument is the displacement measuring potentiometer.

1.7.2 Dynamic Response of a First Order Instrument

If in Eq. (1.1) all a's and b's other than a_1, a_0, b_0 are taken as zero, we get

$$a_1 \frac{dx_o}{dt} + a_0 x_o = b_0 x_i$$

Any instrument that follows this equation is called a first order instrument. By dividing by a_0, the equation can be written as

$$\frac{a_1}{a_0} \frac{dx_o}{dt} + x_o = \frac{b_0}{a_0} x_i$$

or

$$(\tau \cdot D + 1) \cdot x_o = K\, x_i$$

where $\tau = a_1/a_0$ = time constant

$K = b_0/a_0$ = static sensitivity

The time constant τ always has the dimensions of time while the static sensitivity K has the dimensions of output/input. The operational transfer function of any first order instrument is

$$\frac{x_o}{x_i} = \frac{K}{\tau D + 1}$$

A very common example of a first-order instrument is a mercury-in-glass thermometer.

1.7.3 Dynamic Response of Second Order Instrument

A second order instrument is defined as one that follows the equation

$$a_2 \frac{d^2 x_o}{dt^2} + a_1 \frac{d x_o}{dt} + a_0 x_o = b_0 x_i$$

The above equations can be reduced as

$$\left(\frac{D^2}{\omega_n^2} + \frac{2\xi D}{\omega_n} + 1 \right) \cdot x_o = K x_i$$

where $\omega_n = \sqrt{\frac{a_0}{a_2}}$ = undamped natural frequency in radians/time

$2\xi = a_1 / \sqrt{a_0 a_2}$ = damping ratio

$K = b_0 / a_0$ = static sensitivity

Any instrument following this equation is a second order instrument. A practical example of this type is the spring balance. Linear devices range from mass-spring arrangements, transducers, amplifiers and filters to indicators and recorders.

Most devices have first or second order responses, i.e. the equations of motion describing the devices are either first or second order linear differentials. For example, a search coil and mercury-in-glass thermometer have a first order response. Filters used at the output of a phase sensitive detector and amplifiers used in feedback measuring systems essentially have response due to a single time constant. First order systems involve only one kind of energy, e.g. thermal energy in the case of a thermometer, while a characteristic feature of second order system is an exchange between two types of energy, e.g. electrostatic and electromagnetic energy in electrical LC circuits, moving coil indicators and electromechanical recorders.

1.8 STATISTICAL ANALYSIS

The statistical analysis of measurement data is important because it allows an analytical determination of the uncertainty of the final test result. To make sta-

tistical analysis meaningful, a large number of measurements is usually required. Systematic errors should be small compared to random errors, because statistical analysis of data cannot remove a fixed bias contained in all measurements.

1.8.1 Arithmetic Mean

The most probable value of a measured variable is the arithmetic mean of the number of readings taken. The best approximation is possible when the number of readings of the same quantity is very large. The arithmetic mean of n measurements at a specific count of the variable x is given by the expression

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n} = \frac{\sum_{n=1}^{n} x_n}{n}$$

where $\bar{x}$ = Arithmetic mean

x_n = nth reading taken

n = total number of readings

1.8.2 Deviation from the Mean

This is the departure of a given reading from the arithmetic mean of the group of readings. If the deviation of the first reading, x_1, is called d_1 and that of the second reading x_2 is called d_2, and so on,

The deviations from the mean can be expressed as

$$d_1 = x_1 - \bar{x},\ d_2 = x_2 - \bar{x}\ \ldots\text{, similarly } d_n = x_n - \bar{x}$$

The deviation may be positive or negative. The algebraic sum of all the deviations must be zero.

Example 1.4 For the following given data, calculate

(i) Arithmetic mean

(ii) Deviation of each value

(iii) Algebraic sum of the deviations

Given $x_1 = 49.7$

$x_2 = 50.1$

$x_3 = 50.2$

$x_4 = 49.6$

$x_5 = 49.7$

Solution

(i) The arithmetic mean is calculated as follows

$$\bar{x} = \frac{x_1 + x_2 + x_3 + x_4 + x_5}{5}$$

$$= \frac{49.7 + 50.1 + 50.2 + 49.6 + 49.7}{5} = 49.86$$

(ii) The deviations from each value are given by

$$d_1 = x_1 - \bar{x} = 49.7 - 49.86 = -0.16$$

$$d_2 = x_2 - \bar{x} = 50.1 - 49.86 = +0.24$$

$$d_3 = x_3 - \bar{x} = 50.2 - 49.86 = +0.34$$

$$d_4 = x_4 - \bar{x} = 49.6 - 49.86 = -0.26$$

$$d_5 = x_5 - \bar{x} = 49.7 - 49.86 = -0.16$$

(iii) The algebraic sum of the deviation is

$$d_{total} = -0.16 + 0.24 + 0.34 - 0.26 - 0.16$$

$$= +0.58 - 0.58 = 0$$

1.8.3 Average Deviations

The average deviation is an indication of the precision of the instrument used in measurement. Average deviation is defined as the sum of the absolute values of the deviation divided by the number of readings. The absolute value of the deviation is the value without respect to the sign.

Average deviation may be expressed as

$$D_{av} = \frac{|d_1| + |d_2| + |d_3| + \cdots + |d_n|}{n}$$

or

$$D_{av} = \frac{\sum |d_n|}{n}$$

where D_{av} = average deviation

$|d_1|, |d_2|, \ldots, |d_n|$ = Absolute value of deviations

and n = total number of readings

Highly precise instruments yield a low average deviation between readings.

Example 1.5 Calculate the average deviation for the data given in Example 1.4.

Solution The average deviation is calculated as follows

$$D_{av} = \frac{|d_1| + |d_2| + |d_3| + \cdots + |d_n|}{n}$$

$$= \frac{|-0.16| + |0.24| + |0.34| + |-0.26| + |-0.16|}{5}$$

$$= \frac{1.16}{5} = 0.232$$

Therefore, the average deviation = 0.232.

1.8.4 Standard Deviation

The standard deviation of an infinite number of data is the Square root of the sum of all the individual deviations squared, divided by the number of readings. It may be expressed as

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

$$\sigma = \sqrt{\frac{d_n^2}{n}}$$

where σ = standard deviation

The standard deviation is also known as root mean square deviation, and is the most important factor in the statistical analysis of measurement data. Reduction in this quantity effectively means improvement in measurement.

For small readings ($n < 30$), the denominator is frequently expressed as $(n - 1)$ to obtain a more accurate value for the standard deviation.

Example 1.6 Calculate the standard deviation for the data given in Example 1.4.

Solution

$$\text{Standard deviation} = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \cdots + d_n^2}{n-1}}$$

$$\sigma = \sqrt{\frac{(-0.16)^2 + (0.24)^2 + (0.34)^2 + (-0.26)^2 + (-0.16)^2}{5-1}}$$

$$\sigma = \sqrt{\frac{0.0256 + 0.0576 + 0.1156 + 0.0676 + 0.0256}{4}}$$

$$\sigma = \sqrt{\frac{0.292}{4}} = \sqrt{0.073} = 0.27$$

Therefore, the standard deviation is 0.27.

1.8.5 Limiting Errors

Most manufacturers of measuring instruments specify accuracy within a certain % of a full scale reading. For example, the manufacturer of a certain voltmeter may specify the instrument to be accurate within ± 2% with full scale deflection. This specification is called the limiting error. This means that a full scale deflection reading is guaranteed to be within the limits of 2% of a perfectly accurate reading; however, with a reading less than full scale, the limiting error increases.

Example 1.7 A 600 V voltmeter is specified to be accurate within ± 2% at full scale. Calculate the limiting error when the instrument is used to measure a voltage of 250 V.

Solution

The magnitude of the limiting error is $0.02 \times 600 = 12$ V.
Therefore, the limiting error is 250 V is $12/250 \times 100 = 4.8\%$

Example 1.8 A voltmeter reading 70 V on its 100 V range and an ammeter reading 80 mA on its 150 mA range are used to determine the power dissipated in a resistor. Both these instruments are guaranteed to be accurate within ± 1.5% at full scale deflection. Determine the limiting error of the power.

Solution The magnitude of the limiting error for the voltmeter is

$$0.015 \times 100 = 1.5 \text{ V}$$

The limiting error at 70 V is

$$\frac{1.5}{70} \times 100 = 2.143\ \%$$

The magnitude of limiting error of the ammeter is

$$0.015 \times 150 \text{ mA} = 2.25 \text{ mA}$$

The limiting error at 80 mA is

$$\frac{2.25 \text{ mA}}{80 \text{ mA}} \times 100 = 2.813\ \%$$

Therefore, the limiting error for the power calculation is the sum of the individual limiting errors involved.

Therefore, limiting error = 2.143 % + 2.813 % = 4.956 %

1.9 STANDARD

A standard is physical representation of a unit of measurement. A known accurate measure of physical quantity is termed as a standard. These standards are used to determine the values of other physical quantities by the comparison method.

In fact, a unit is realized by reference to a material standard or to natural phenomena, including physical and atomic constants. For example, the fundamental unit of length in the International system (SI) is the metre, defined as the distance between two fine lines engraved on gold plugs near the ends of a platinum-iridium alloy at 0°C and mechanically supported in a prescribed manner.

Similarly, different standards have been developed for other units of measurement (including fundamental units as well as derived mechanical and electrical units). All these standards are preserved at the International Bureau of Weight and Measures at Sèvres, Paris.

Also, depending on the functions and applications, different types of "standards of measurement" are classified in categories (i) international, (ii) primary, (iii) secondary, and (iv) working standards.

1.9.1 International Standards

International standards are defined by International agreement. They are periodically evaluated and checked by absolute measurements in terms of fundamental units of Physics. They represent certain units of measurement to the closest possible accuracy attainable by the science and technology of measurement. These International standards are not available to ordinary users for measurements and calibrations.

International ohms It is defined as the resistance offered by a column of mercury having a mass of 14.4521 gms, uniform cross-sectional area and length of 106.300 cm, to the flow of constant current at the melting point of ice.

International amperes It is an unvarying current, which when passed through a solution of silver nitrate in water (prepared in accordance with stipulated specifications) deposits silver at the rate of 0.00111800 gm/s.

Absolute units International units were replaced in 1948 by absolute units. These units are more accurate than International units, and differ slightly from them. For example,

1 International ohm = 1.00049 Absolute ohm

1 International ampere = 0.99985 Absolute ampere

1.9.2 Primary Standards

The principle function of primary standards is the calibration and verification of secondary standards. Primary standards are maintained at the National Standards Laboratories in different countries.

The primary standards are not available for use outside the National Laboratory. These primary standards are absolute standards of high accuracy that can be used as ultimate reference standards.

1.9.3 Secondary Standards

Secondary standards are basic reference standards used by measurement and calibration laboratories in industries. These secondary standards are maintained by the particular industry to which they belong. Each industry has its own secondary standard. Each laboratory periodically sends its secondary standard to the National standards laboratory for calibration and comparison against the primary standard. After comparison and calibration, the National Standards Laboratory returns the Secondary standards to the particular industrial laboratory with a certification of measuring accuracy in terms of a primary standard.

1.9.4 Working Standards

Working standards are the principal tools of a measurement laboratory. These standards are used to check and calibrate laboratory instrument for accuracy and performance. For example, manufacturers of electronic components such as capacitors, resistors, etc. use a standard called a working standard for checking the component values being manufactured, e.g. a standard resistor for checking of resistance value manufactured.

1.10 ATOMIC FREQUENCY AND TIME STANDARDS

The measurement of time has two different aspects, civil and scientific. In most scientific work, it is desired to know how long an event lasts, or if dealing with an oscillator, it is desired to know its frequency of oscillation. Thus any time standard must be able to answer both the question "what time is it" and the two related questions "how long does it last" or "what is its frequency".

Any phenomena that repeats itself can be used as a measure of time, the measurement consisting of counting the repetitions. Of the many repetitive phenomena occurring in nature, the rotation of the earth on its axis which determines the length of the day, has been long used as a time standard. Time defined in terms of rotation of the earth is called *Universal time* (UT).

Time defined in terms of the earth's orbital motion is called *Ephemersis time* (ET). Both UT and ET are determined by astronomical observation. Since these astronomical observations extend over several weeks for UT and several years for ET, a good secondary terrestrial clock calibrated by astronomical observation is needed. A quartz crystal clock based on electrically sustained natural periodic vibrations of a quartz wafer serves as a secondary time standard. These clocks have a maximum error of 0.02 sec per year. One of the most common of time standards is the determination of frequency.

In the RF range, frequency comparisons to a quartz clock can be made electronically to a precision of atleast 1 part in 10^{10}.

To meet a better time standard, atomic clocks have been developed using periodic atomic vibrations as a standard. The transition between two energy levels, E_1 and E_2 of an atom is accompanied by the emission (or absorption) of radiation given by the following equation

$$v = \frac{E_2 - E_1}{h}$$

where v = frequency of emission and depends on the internal structure of an atom

h = Planck's constant = 6.636×10^{-34} J-sec.

Provided that the energy levels are not affected by the external conditions such as magnetic field etc.

Since frequency is the inverse of the time interval, time can be calibrated in terms of frequency.

The atomic clock is constructed on the above principle. The first atomic clock was based on the Cesium atom.

The International Committee of Weights and Measures defines the second in terms of the frequency of Cesium transitions, assigning a value of 9,192, 631,770 Hz to the hyperfine transitions of the Cesium atom unperturbed by external fields. If two Cesium clocks are operated at one precision and if there are no other sources of error, the clocks will differ by only 1s in 5000 years.

1.11 ELECTRICAL STANDARDS

All electrical measurements are based on the fundamental quantities, I, R and V. A systematic measurement depends upon the definition of these quantities. These quantities are related to each other through Ohm's law, $V = IR$. It is sufficient to define two parameters to obtain the definition of the third. Hence, in electrical measurements, it is possible to assign values to the remaining standard, by defining units of the other two standards. Standards of emf and resistance are therefore usually maintained at the National laboratory. The base values of the other standards are defined from these two standards.

GRAPHICAL REPRESENTATION OF MEASUREMENTS AS A DISTRIBUTION

Suppose that a certain voltage is measured 51 times. The result which might be obtained are shown in Table 1.2.

Table 1.2

x Voltage (V)	Number of Occurrences (n)	x_n (v)	$d_n = x_n - \bar{x}$	$n\,\lvert d_n \rvert$	$(d_n)^2$	$n\,(d_n)^2$
1.01	1	1.01	– 0.04	0.04	16×10^{-4}	16×10^{-4}
1.02	3	3.06	– 0.03	0.09	9×10^{-4}	27×10^{-4}
1.03	6	6.18	– 0.02	0.12	4×10^{-4}	24×10^{-4}
1.04	8	8.32	– 0.01	0.08	1×10^{-4}	8×10^{-4}
1.05	10	10.50	0.00	0.00	0×10^{-4}	00×10^{-4}
1.06	7	7.42	+ 0.01	0.07	1×10^{-4}	7×10^{-4}
1.07	8	8.56	+ 0.02	0.16	4×10^{-4}	32×10^{-4}
1.08	4	4.32	+ 0.03	0.12	9×10^{-4}	36×10^{-4}
1.09	3	3.27	+ 0.04	0.12	16×10^{-4}	48×10^{-4}
1.10	0	0.00	+ 0.05	0.00	25×10^{-4}	00×10^{-4}
1.11	1	1.11	+ 0.06	0.06	36×10^{-4}	36×10^{-4}
	51	53.75		0.86		234×10^{-4}
	$= \Sigma_n$	$= \sum_{n=1}^{51} x_n$		$= \sum_{n=1}^{51} \lvert d_n \rvert$		$= \sum_{n=1}^{51} (d_n)^2$

$$\text{Average } \bar{x} = \frac{\sum_{n=1}^{51} x_n}{n} = \frac{53.75}{51} = 1.054 \text{ V}$$

$$\text{Average deviation } D_{av} = \frac{\sum_{n=1}^{51} \lvert d_n \rvert}{n} = \frac{0.86}{51} = 0.0168 \text{ V}$$

$$\text{Standard deviation } \sigma = \sqrt{\frac{\sum_{n=1}^{51} (d_n)^2}{n}} = \sqrt{\frac{234 \times 10^{-4}}{51}} = 4.588 \times 10^{-4} \text{ V}$$

The first column shows the various measured values and the second column, the number of times each reading has occurred. For example, in the fourth row, the measured value is 1.04 V and the next column indicates that this reading is obtained 8 times.

The data given in Table 1.2 may be represented graphically as shown in Fig. 1.1.

We imagine the range of values of x to be divided into equal intervals dx, and plot the number of values of x lying in the interval versus the average value of x within that interval. Hence the eight measurements of 1.04 V might be thought of lying in an 0.01 V interval centred upon 1.04 V, i.e. between 1.035 V to 1.045 V on the horizontal scale. Since with a small number (such as 51), these points do not lie on a smooth curve, it is conventional to represent such a plot by a histogram consisting of series of horizontal lines of length dx centred upon the individual points. The ends of adjacent horizontal lines being connected by vertical lines of appropriate length.

If another 51 measurements are taken and plotted we would, in general get a graph which does not coincide with the previous one. The graph plotted is called a Gauss error or Gaussian graph, shown in Fig. 1.1.

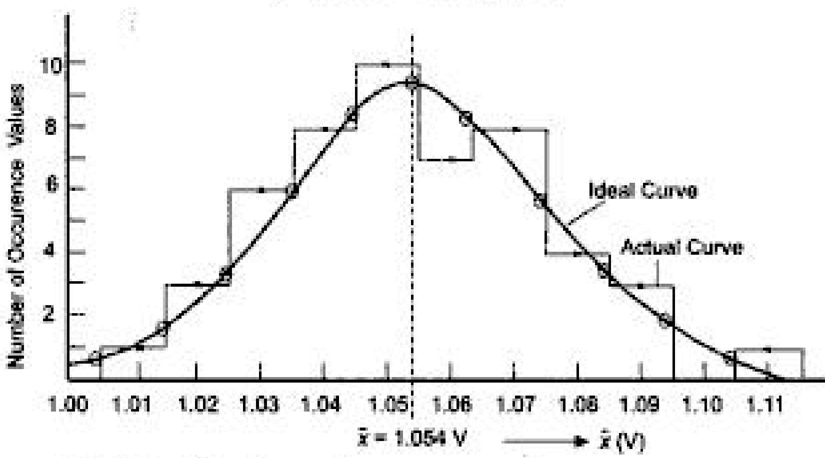

Fig. 1.1 ■■ Gaussian graph

Review Questions

1. Define the terms accuracy, error, precision, resolution, expected value, and sensitivity.
2. State the three major categories of error.
3. A person using an ohmmeter reads the measured value as 470 Ω, when the actual value is 47 Ω. What kind of error does this represent?
4. State the three types of systematic errors, giving examples of each.
5. State the difference between accuracy and precision of a measurement.
6. Define the following terms:
   (i) Average value (ii) Arithmetic mean
   (iii) Deviation (iv) Standard deviation
7. What are the differences between International and Absolute standards?
8. State the classifications of standards.

9. What are primary standards? Where are they used?
10. What is the difference between secondary standards and working standards?

Practice Problems

1. The current through a resistor is 2.5 A, but the measurement yields a value of 2.45 A. Calculate the absolute error and the percentage error of the measurement.
2. The value of a resistance is 4.7 kΩ, while measurements yield a value of 4.63 kΩ calculate
   (i) the relative accuracy of measurement, and
   (ii) % accuracy.
3. The output voltage of an amplifier was measured at eight different intervals using the same digital voltmeter with the following results:
   20.00, 19.80, 19.85, 20.05, 20.10, 19.90, 20.25, 19.95 V
   Which is the most precise measurement?
4. A 270 Ω ± 10% resistance is connected to a power supply source operating at 300 V dc. What range of current would flow if the resistor varied over the range of ± 10% of its expected value? What is the range of error in the current?
5. A voltmeter is accurate to 98% of its full scale reading.
   (i) If a voltmeter read 200 V on 500 V range, what is the absolute error?
   (ii) What is the percentage error reading of part (i)?

Further Reading

1. Barry Jones, *Instrumentation Measurements and Feedback.*
2. Larry D. Jones and A. Foster Chin, *Electronic Instruments and Measurement*, John Wiley and Sons, 1987.
3. Yardley Beers, *Theory of Errors*, 1967.
4. Resnick and Halliday, *Physics*, Wiley Eastern, 1987.

CHAPTER

2

Indicators and Display Devices

2.1 INTRODUCTION

Analogue ammeters and voltmeters are classified together, since there is no basic difference in their operating principles. The action of all ammeters and voltmeters, except those of the electrostatic variety, depends upon a deflecting torque produced by an electric current. In an ammeter this torque is produced by the current to be measured, or by a definite fraction of it. In a voltmeter it is produced by a current that is proportional to the voltage to be measured. Hence both voltmeters and ammeters are essentially current measuring devices.

The essential requirements of a measuring instrument are (a) that its introduction into the circuit where measurements are to be made, should not alter the circuit conditions, and (b) the power consumed by it be small.

2.1.1 Types of Instrument

The following types of instrument are mainly used as ammeters and voltmeters.

1. PMMC
2. Moving Iron
3. Electrodynamometer
4. Hot wire
5. Thermocouple
6. Induction type
7. Electrostatic
8. Rectifier

Of these, the PMMC type can be used for dc measurements only, and the induction type for ac measurements only. The other types can be used for both.

The moving coil and moving iron types depend upon the magnitude effect of current. The latter is the most commonly used form of indicating instrument, as

well as the cheapest. It can be used for both ac and dc measurements and is very accurate, if properly designed.

The PMMC instrument is the most accurate type for dc measurement. Instrument of this type are frequently constructed to have substandard accuracy.

The calibration of the electrodynamometer type of instrument is the same for ac and dc. The same situation prevails for thermal instruments. These are particularly suitable for ac measurements, since their deflection depends directly upon the heating effect of the ac, i.e. upon the rms value of the current. Their readings are therefore independent of the frequency.

Electrostatic instruments used as voltmeters have the advantage that their power consumption is exceedingly small. They can be made to cover a large range of voltage and can be constructed to have sub-standard accuracy.

The induction principle is most generally used for Watt-hour meters. This principle is not preferred for use in ammeters and voltmeters because of the comparatively high cost and inaccuracy of the instrument.

BASIC METER MOVEMENT

The action of the most commonly dc meter is based on the fundamental principle of the motor. The motor action is produced by the flow of a small current through a moving coil, which is positioned in the field of a permanent magnet. This basic moving coil system is often called the D'Arsonval galvanometer.

The D'Arsonval movement shown in Fig. 2.1 employs a spring-loaded coil through which the measured current flows. The coil (rotor) is in a nearly homogeneous field of a permanent magnet and moves in a rotary fashion. The amount of rotation is proportional to the amount of current flowing through the coil. A pointer attached to the coil indicates the position of the coil on a scale calibrated in terms of current or voltage. It responds to dc current only, and has an almost linear calibration. The magnetic shunt that varies the field strength is used for calibration.

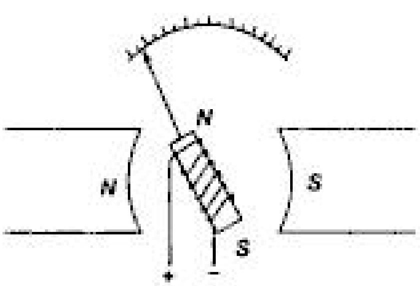

Fig. 2.1 ■ D'Arsonval Principle

2.2.1 Permanent Magnetic Moving Coil Movement

In this instrument, we have a coil suspended in the magnetic field of a permanent magnet in the shape of a horse-shoe. The coil is suspended so that it can rotate freely in the magnetic field. When current flows in the coil, the developed (electromagnetic) torque causes the coil to rotate. The electromagnetic

(EM) torque is counterbalanced by a mechanical torque of control springs attached to the movable coil. The balance of torques, and therefore the angular position of the movable coil is indicated by a pointer against a fixed reference called a scale. The equation for the developed torque, derived from the basic law for electromagnetic torque is

$$\tau = B \times A \times I \times N$$

where τ = torque, Newton-meter
B = flux density in the air gap, Wb/m^2
A = effective coil area (m^2)
N = number of turns of wire of the coil
I = current in the movable coil (amperes)

The equation shows that the developed torque is proportional to the flux density of the field in which the coil rotates, the current coil constants (area and number of turns). Since both flux density and coil constants are fixed for a given instrument, the developed torque is a direct indication of the current in the coil. The pointer deflection can therefore be used to measure current.

Example 2.1 A moving coil instrument has the following data.

Number of turns = 100
Width of the coil = 20 mm
Depth of the coil = 30 mm
Flux density in the gap = 0.1 Wb/m^2

Calculate the deflecting torque when carrying a current of 10 mA. Also calculate the deflection, if the control spring constant is 2×10^{-6} Nm/degree.

Solution The deflecting torque is given by

$$\tau_d = B \times A \times N \times I$$
$$= 0.1 \times 30 \times 10^{-3} \times 20 \times 10^{-3} \times 100 \times 10 \times 10^{-3}$$
$$= 600 \times 1000 \times 0.1 \times 10^{-9}$$
$$= 600 \times 1000 \times 10^{-10}$$
$$= 60 \times 10^{-6} \text{ Nm}$$

The spring control provides a restoring torque, i.e. $\tau_c = K\theta$, where K is the spring constant

As deflecting torque = restoring torque

$$\therefore \quad \tau_c = 6 \times 10^{-5} \text{ Nm} = K\theta, \ \therefore \theta = \frac{6 \times 10^{-5}}{2 \times 10^{-6}} = 3 \times 10 = 30°$$

Therefore, the deflection is 30°.

2.2.2 Practical PMMC Movement

The basic PMMC movement (also called a D'Arsonval movement) offers the largest magnet in a given space, in the form of a horse-shoe, and is used when a large flux is required in the air gap. The D'Arsonval movement is based on the principle of a moving electromagnetic coil pivoted in a uniform air gap between the poles of a large fixed permanent magnet. This principle is illustrated in Fig. 2.1 With the polarities as shown, there is a repelling force between like poles, which exerts a torque on the pivoted coil. The torque is proportional to the magnitude of current being measured. This D'Arsonval movement provides an instrument with very low power consumption and low current required for full scale deflection (fsd).

Figure 2.2 shows a permanent horse-shoe magnet with soft iron pole pieces attached to it. Between the pole pieces is a cylinder of soft iron which serves to provide a uniform magnetic field in the air gap between the pole pieces and the cylindrical core.

The coil is wound on a light metal frame and is mounted so that it can rotate freely in the air gap. The pointer attached to the coil moves over a graduated scale and indicates the angular deflection of the coil, which is proportional to the current flowing through it.

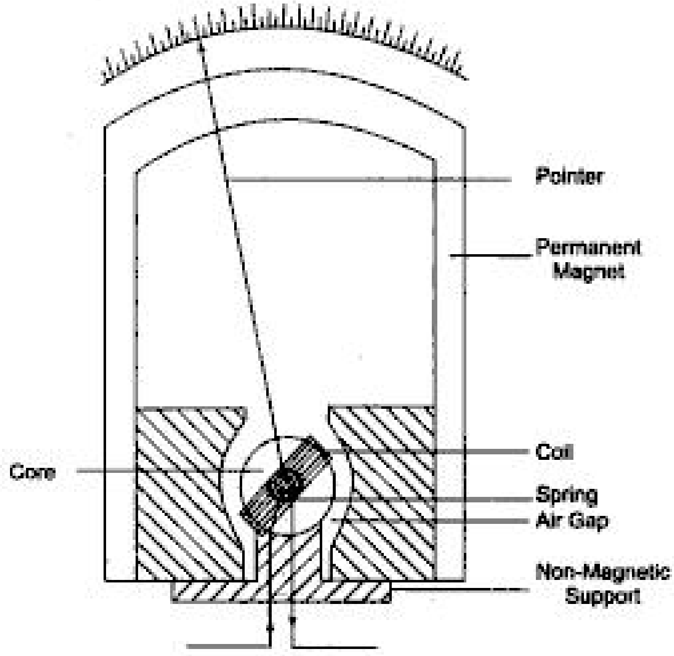

Fig. 2.2 Modern D'Arsonval Movement

The Y-shaped member shown in Fig. 2.3 is the zero adjust control, and is connected to the fixed end of the front control spring. An eccentric pin through the instrument case engages the Y-shaped member so that the zero position of

the pointer can be adjusted from outside. The calibrated force opposing the moving torque is provided by two phosphor-bronze conductive springs, normally equal in strength. (This also provides the necessary torque to bring the pointer back to its original position after the measurement is over.)

The accuracy of the instrument can be maintained by keeping spring performance constant. The entire moving system is statically balanced at all positions by three (counterweights) balance weights. The pointer, springs, and pivots are fixed to the coil assembly by means of pivot bases and the entire movable coil element is supported by jewel bearings.

PMMC instruments are constructed to produce as little viscious damping as possible and the required degree of damping is added.

In Fig. 2.4, Curve 2 is the underdamped case; the pointer attached to the movable coil oscillates back and forth several times before coming to rest. As in curve 1, the overdamped case, the pointer tends to approach the steady state position in a sluggish manner. In Curve 3, the critically damped case, the pointer moves up to its steady state position without oscillations. Critical damping is the ideal behaviour for a PMMC movement.

In practice, however, the instrument is usually slightly underdamped, causing the pointer to overshoot a little before coming to rest.

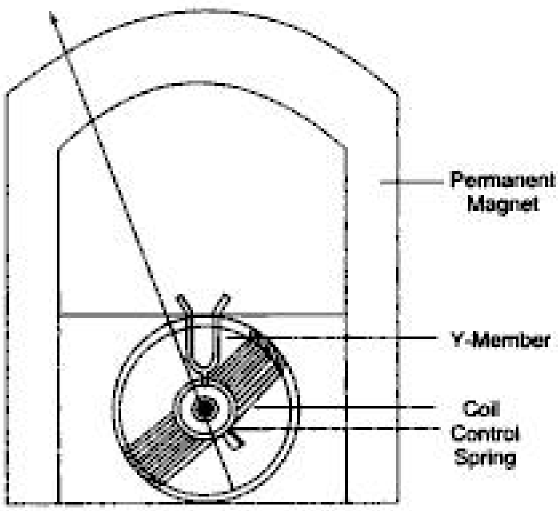

Fig. 2.3 ■■■ Simplified Diagram of a PMMC Movement Showing the Y-member

The various methods of damping are as follows.

One of the simplest methods is to attach an aluminium vane to the shaft of the moving coil. As the coil rotates, the vane moves in an air chamber, the amount of clearance between the chamber walls and the air vane effectively controlling the degree of damping.

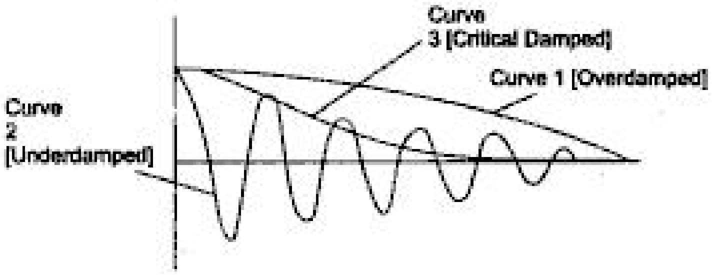

Fig. 2.4 ▬ Degree of Damping

Some instruments use the principle of electromagnetic damping (Lenz's law), where the movable coil is wound on a light aluminium frame. The rotation of the coil in the magnetic field sets up a circulating current in the conductive frame, causing a retarding torque that opposes the motion of the coil.

A PMMC movement may also be damped by a resistor across the coil. When the coil rotates in the magnetic field, a voltage is generated in the coil, which circulates a current through it and the external resistance. This produces an opposing or retarding torque that damps the motion. In any galvanometer, the value of the external resistance that produces critical damping can be found. This resistance is called critically damping external resistance (CDRX). Most voltmeter coils are wound on metal frames to provide Electro-Magnetic damping. The metal frames constitute a short-circuit turn in a magnetic field.

Ammeters coils, are however wound in a non-conductive frame, because the coil turns are effectively shorted by the ammeter shunt. The coil itself provides the EM damping.

If low frequency alternating current is applied to the movable coil, the deflection of the pointer would be upscale for half the cycle of the input waveform and downscale (in the opposite direction) for the next half. At power line frequency (50 Hz) and above, the pointer cannot follow the rapid variations in direction and quivers slightly around the zero mark, seeking the average value of the ac (which equals zero). The PMMC instrument is therefore unsuitable for ac measurements, unless the current is rectified before reaching the coil.

Practical coil areas generally range from 0.5 – 2.5 cm^2.

The flux density for modern instruments usually ranges from 1500 – 5000 Wb/cm^2.

The power requirements of D'Arsonval movements are quite small, typically from 25 – 200 μW.

The accuracy of the instrument is generally of the order of 2 – 5% of full scale deflection.

The permanent magnet is made up of Alnico material.

Scale markings of basic dc PMMC instruments are usually linearly spaced, because the torque (and hence the pointer deflection) is directly proportional to the coil current. The basic PMMC instrument is therefore a linear-reading device.

The advantages and disadvantages of PMMC are as follows.

Advantages

1. They can be modified with the help of shunts and resistance to cover a wide range of currents and voltages.
2. They display no hystersis.
3. Since operating fields of such instruments are very strong, they are not significantly affected by stray magnetic fields.

Disadvantages

1. Some errors may set in due to ageing of control springs and the permanent magnet.
2. Friction due to jewel-pivot suspension.

2.3 TAUT BAND INSTRUMENT

The taut band movement utilises the same principle as the D'Arsonval movable coil and fixed magnet. The primary difference between the two is the method of mounting the movable coil.

The taut band movement has the advantage of eliminating the friction caused by a jewel-pivot suspension. The meter has a coil mounted in a cradle and surrounded by a ring-bar magnet, as shown in Fig. 2.5. The cradle is secured to a support bracket, which in turn is suspended between two steel taut bands (ribbon), i.e. the movable coil is suspended by means of two taut torsion ribbons. The ribbons are placed under sufficient tension to eliminate any sag. This tension is provided by the tension spring, so that the instrument can be used in any position.

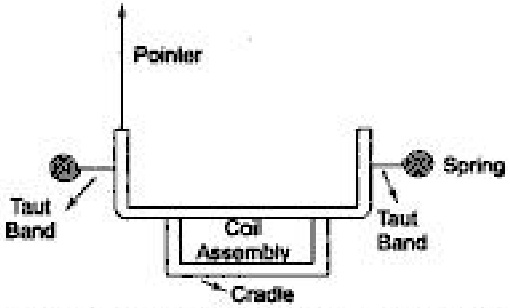

Fig. 2.5 ▬ (a) Taut Band Instrument (Side View)

The current to be measured is passed through the coil, thereby energising it. The interaction of the magnetic fields deflects the cradle to one side and moves the pointer along the scale.

The movement of the cradle exerts a twisting force on the steel bands. These twisted bands supply the torque to return the pointer to zero, when no current flows. There are no bearings, and there is a constant level of sensitivity throughout the range of movement.

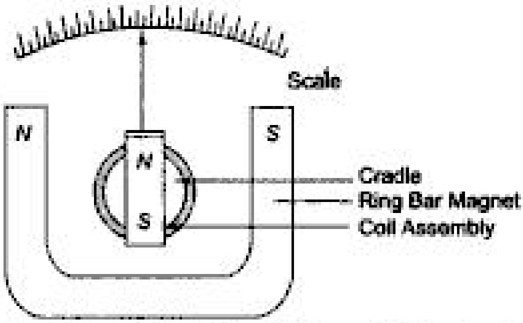

Fig. 2.5 (b) Taut Band Instrument (Top View)

Taut band instruments have a higher sensitivity than those using pivots and jewels. In addition taut band instruments are relatively insensitive to shock and temperature and are capable of withstanding greater overloads than PMMC or other types.

2.4 ELECTRODYNAMOMETER

The D'Arsonval movement responds to the average or dc value of the current flowing through the coil.

If ac current is sought to be measured, the current would flow through the coil with positive and negative half cycles, and hence the driving torque would be positive in one direction and negative in the other. If the frequency of the ac is very low, the pointer would swing back and forth around the zero point on the meter scale.

At higher frequencies, the inertia of the coil is so great that the pointer does not follow the rapid variations of the driving torque and vibrates around the zero mark.

Therefore, to measure ac on a D'Arsonval movement, a rectifier has to be used to produce a unidirectional torque. This rectifier converts ac into dc and the rectified current deflects the coil. Another method is to use the heating effect of ac current to produce an indication of its magnitude. This is done using an electrodynamometer (EDM).

An electrodynamometer is often used in accurate voltmeter and ammeters not only at power line frequency but also at low AF range. The electrodynamometer can be used by slightly modifying the PMMC movement. It may also serve as a transfer instrument, because it can be calibrated on dc and then used directly on ac thereby equating ac and dc measurements of voltage and current directly.

A movable coil is used to provide the magnetic field in an electrodynamometer, instead of a permanent magnet, as in the D'Arsonval movement. This movable coil rotates within the magnetic field. The EDM uses the current under measurement to produce the required field flux. A fixed coil, split into two equal halves provides the magnetic field in which the movable coil

rotates, as shown in Fig. 2.6 (a). The coil halves are connected in series with the moving coil and are fed by the current being measured. The fixed coils are spaced far apart to allow passage for the shaft of the movable coil. The movable coil carries a pointer, which is balanced by counterweights. Its rotation is controlled by springs, similar to those in a D'Arsonval movement.

The complete assembly is surrounded by a laminated shield to protect the instrument from stray magnetic field which may affect its operation.

Damping is provided by aluminium air vanes moving in a sector shaped chamber. (The entire movement is very solid and rigidly constructed in order to keep its mechanical dimensions stable, and calibration intact.)

The operation of the instrument may be understood from the expression for the torque developed by a coil suspended in a magnetic field, i.e.

$$\tau = B \times A \times N \times I$$

indicating that the torque which deflects the movable coil is directly proportional to the coil constants (A and N), the strength of the magnetic field in which the coil moves (B), and the current (I) flowing through the coil.

In an EDM the flux density (B) depends on the current through the fixed coil and is therefore proportional to the deflection current (I). Since the coil constants are fixed quantities for any given meter, the developed torque becomes a function of the current squared (I^2).

If the EDM is used for dc measurement, the square law can be noticed by the crowding of the scale markings at low current values, progressively spreading at higher current values.

For ac measurement, the developed torque at any instant is proportional to the instantaneous current squared (i^2). The instantaneous values of i^2 are always positive and torque pulsations are therefore produced.

The meter movement, however, cannot follow rapid variations of the torque and take up a position in which the average torque is balanced by the torque of the control springs. The meter deflection is therefore a function of the mean of the squared current. The scale of the EDM is usually calibrated in terms of the square root of the average current squared, and therefore reads the effective or rms value of the ac.

The transfer properties of the EDM become apparent when we compare the effective value of the alternating current and the direct current in terms of their heating effect, or transfer of power.

(If the EDM is calibrated with a direct current of 500 mA and a mark is placed on the scale to indicate this value, then that ac current which causes the pointer to deflect to the same mark on the scale must have an rms value of 500 mA.)

The EDM has the disadvantage of high power consumption, due to its construction. The current under measurement must not only pass through the movable coil, but also provide the necessary field flux to get a sufficiently strong magnetic field. Hence high mmf is required and the source must have a high current and power.

In spite of this high power consumption the magnetic field is still weaker than that of the D'Arsonval movement because there is no iron in the path, the entire flux path consisting of air.

The EDM can be used to measure ac or dc voltage or current, as shown in Figs. 2.6 (a) and (b).

Typical values of EDM flux density are in the range of approximately 60 gauss as compared to the high flux densities (1000 – 4000 guass) of a good D'Arsonval movement. The low flux density of the EDM affects the developed torque and therefore the sensitivity of the instrument.

The addition of a series multiplier converts the basic EDM into a voltmeter [Fig. 2.6 (b)] which can be used for ac and dc measurements. The sensitivity of the EDM voltmeter is low, approximately 10 – 30 Ω/V, compared to 20 kΩ/V of the D'Arsonval movement. It is however very accurate at power line frequency and can be considered as a secondary standard.

The basic EDM shown in Fig. 2.6 (a) can be converted into an ammeter (even without a shunt), because it is difficult to design a moving coil which can carry more than approximately 100 mA.

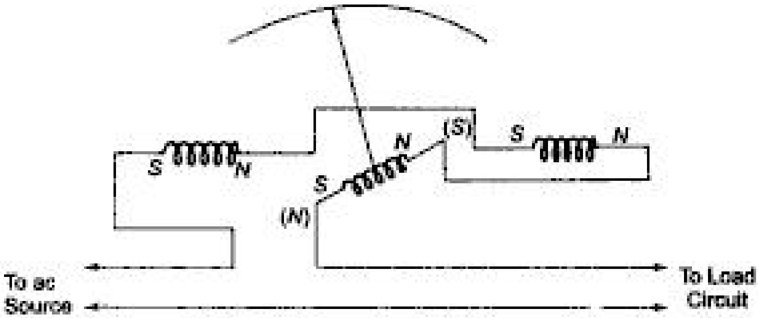

Fig. 2.6 (a) Basic EDM as an Ammeter

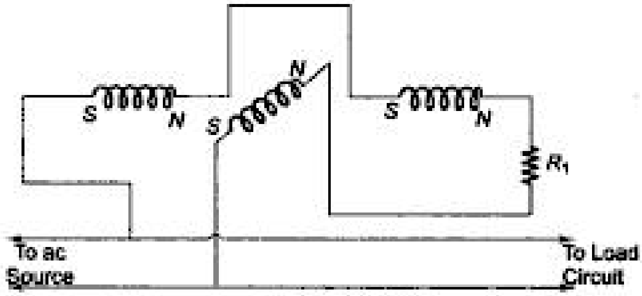

Fig. 2.6 (b) Basic EDM as a Voltmeter

The EDM movement is extensively used to measure power, both dc and ac, for any waveform of voltage and current.

An EDM used as a voltmeter or ammeter has the fixed coils and movable coil connected in series, thereby reacting to I^2.

When an EDM is used as a single phase wattmeter, the coil arrangement is different, as shown in Fig. 2.7.

The fixed coils, shown in Fig. 2.7 as separate elements, are connected in series and carries the total line current. The movable coil located in the magnetic field of the fixed coils is connected in series with a current-limiting resistor across the power line, and carries a small current.

The deflection of the movable coil is proportional to the product of the instantaneous value of current in the movable coil and the total line current. The EDM wattmeter consumes some power for the maintenance of its magnetic field, but this is usually small compared to the load power.

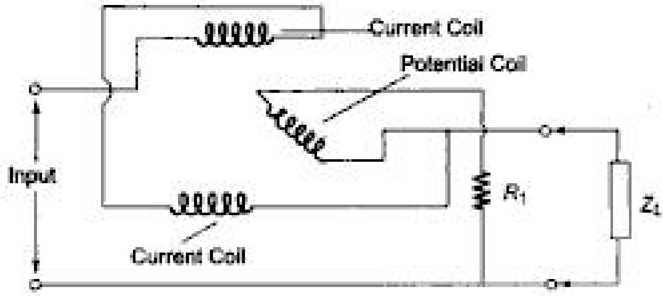

Fig. 2.7 ■ EDM as a Wattmeter

2.5 MOVING IRON TYPES INSTRUMENT

Moving iron instruments can be classified into attraction and repulsion types. Repulsion type instruments are the most commonly used.

Iron vane ammeters and voltmeters depend for their operations on the repulsion that exists between two like magnetic poles.

The movement consists of a stationary coil of many turns which carries the current to be measured. Two iron vanes are placed inside the coil. One vane is rigidly attached to the coil frame, while the other is connected to the instrument shaft which rotates freely. The current through the coil magnetises both the vanes with the same polarity, regardless of the instantaneous direction of current. The two magnetised vanes experience a repelling force, and since only one vane can move, its displacement is an indicator of the magnitude of the coil current. The repelling force is proportional to the current squared, but the effects of frequency and hysteresis tend to produce a pointer deflection that is not linear and that does not have a perfect square law relationship.

Figure 2.8 shows a radial vane repulsion instrument which is the most sensitive of the moving iron mechanisms and has the most linear scale. One of these like poles is created by the instrument coil and appears as an iron vane fixed in its position within the coil, as shown in Fig. 2.8. The other like pole is induced on the movable iron piece or vane, which is suspended in the induction field of the coil and to which the needle of the instrument is attached. Since the

instrument is used on ac, the magnetic polarity of the coil changes with every half cycle and induces a corresponding amount of repulsion of the movable vane against the spring tension. The deflection of the instrument pointer is therefore always in the same direction, since there is always repulsion between the like poles of the fixed and the movable vane, even though the current in the inducing coil alternates.

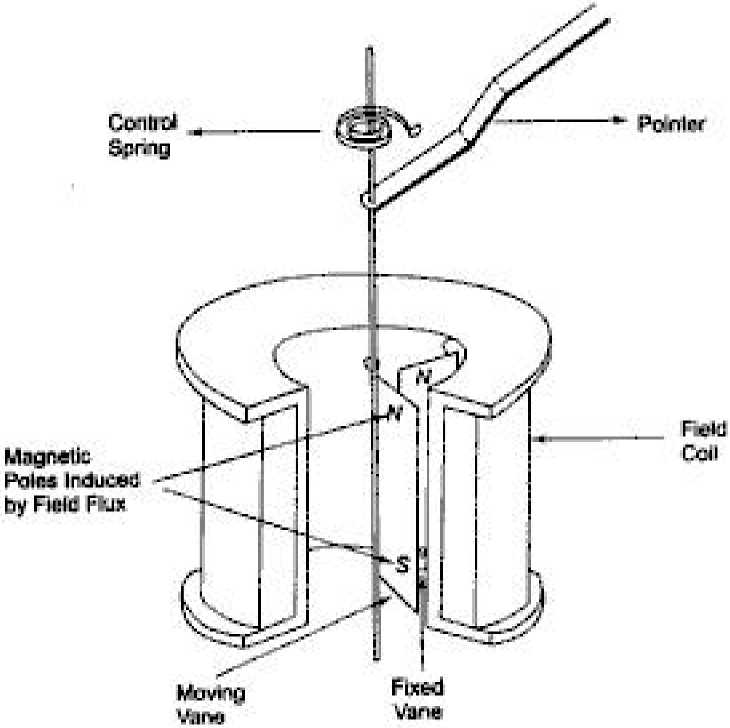

Fig. 2.8 ■ Repulsion Type AC Meter (Radial Vane Type)

The deflection of the pointer thus produced is effectively proportional to the actual current through the instrument. It can therefore be calibrated directly in amperes and volts.

The calibrations of a given instrument will however only be accurate for the ac frequency for which it is designed, because the impedance will be different at a new frequency.

The moving coil or repulsion type of instrument is usually calibrated to read the effective value of amperes and volts, and is used primarily for rugged and inexpensive meters.

The iron vane or radial type is forced to turn within the fixed current carrying coil by the repulsion between like poles. The aluminium vanes, attached to the lower end of the pointer, acts as a damping vane, in its close fitting chamber, to bring the pointer quickly to rest.

CONCENTRIC VANE REPULSION TYPE (MOVING IRON TYPE) INSTRUMENT

A variation of the radial vane instrument is the concentric vane repulsion movement. The instrument has two concentric vanes.

One vane is rigidly attached to the coil frame while the other can rotate coaxially inside the stationary vane, as shown in Fig. 2.9. Both vanes are magnetised by the current in the coil to the same polarity, causing the vanes to slip laterally under repulsion. Because the moving vane is attached to a pivoted shaft, this repulsion results in a rotational force that is a function of the current in the coil. As in other mechanisms the final pointer position is a measure of the coil current. Since this movement, like all iron vane instruments, does not distinguish polarity, the concentric vane may be used on dc and ac, but it is most commonly used for the latter.

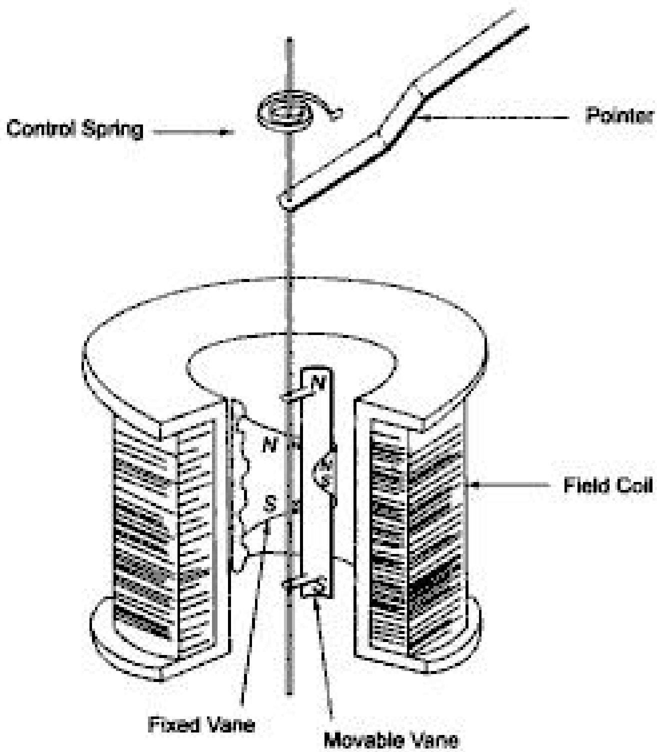

Fig. 2.9 ■ Concentric Iron Vane (Repulsion Type)

Damping is obtained by a light aluminium damping vane, rotating with small clearance in a closed air chamber. When used on ac, the actual operating torque is pulsating and this may cause vibration of the pointer. Rigid (trussed) pointer construction effectively eliminates such vibration and prevents bending of the pointer on heavy overloads. The concentric vane moving iron instrument is

only moderately sensitive and has square law scale characteristics. The accuracy of the instrument is limited by several factors: (i) the magnetisation curve of the iron vane is non-linear. (ii) at low current values, the peak to peak of the ac produces a greater displacement per unit current than the average value, resulting in an ac reading that may be appreciably higher than the equivalent dc reading at the lower end of the scale. Similarly, at the higher end of the scale, the knee of the magnetisation curve is approached and the peak value of the ac produces less deflection per unit current than the average value, so that the ac reading is lower than the equivalent dc value.

(Hysteresis in iron and eddy currents in the vanes and other metal parts of the instrument further affect the accuracy of the reading.) The flux density is very small even at full scale values of current, so that the instrument has a low current sensitivity. There are no current carrying parts in the moving system, hence the iron vane meter is extremely rugged and reliable. It is not easily damaged even under severe overload conditions.

Adding a suitable multiplier converts the iron vane movement into a voltmeter; adding a shunt produces different current ranges. When an iron vane movement is used as an ac voltmeter, the frequency increases the impedance of the instrument and therefore a lower reading is obtained for a given applied voltage. An iron vane voltmeter should therefore always be calibrated at the frequency at which it is to be used. The usual commercial instrument may be used within its accuracy tolerance from 25–125 Hz.

2.7 DIGITAL DISPLAY SYSTEM AND INDICATORS

The rapid growth of electronic handling of numerical data has bought with it a great demand for simple systems to display the data in a readily understandable form. Display devices provide a visual display of numbers, letters, and symbols in response to electrical input, and serve as constituents of an electronic display system.

2.8 CLASSIFICATION OF DISPLAYS

Commonly used displays in the digital electronic field are as follows.

1. Cathode ray tube (CRT)
2. Light emitting diode (LED)
3. Liquid crystal display (LCD)
4. Gas discharge plasma displays (Cold cathode displays or Nixies)
5. Electro-luminescent (EL) displays
6. Incandescent display
7. Electrophoretic image displays (EPID)
8. Liquid vapour display (LVD)

In general, displays are classified in a number of ways, as follows.

1. On methods of conversion of electrical data into visible light
   (a) Active displays
   (Light emitters – Incandescent, i.e. due to temperature, luminescence, i.e. due to non-thermal means or physio-thermal, and gas discharge-glow of light around the cathode.)
   — CRTs, Gas discharge plasma, LEDs, etc.
   (b) Passive displays
   Light controllers, LCDs, EPIDs, etc.
2. On the applications
   (a) Analog displays — Bar graph displays (CRT)
   (b) Digital displays — Nixies, Alphanumeric, LEDs, etc.
3. According to the display size and physical dimensions
   (a) Symbolic displays — Alphanumeric, Nixie tubes, LEDs, etc.
   (b) Console displays — CRTs, LEDs, etc.
   (c) Large screen display — Enlarged projection system
4. According to the display format
   (a) Direct view type (Flat panel planar) — Segmental, dotmatrix — CRTs
   (b) Stacked electrode non-planar type — Nixie
5. In terms of resolution and legibility of characters
   (a) Simple single element indicator
   (b) Multi-element displays

2.9 DISPLAY DEVICES

When displaying large quantities of alphanumeric data, the read out system employed most commonly is a familiar CRT. Conventionally, CRTs form the basis of CROs and TV systems. To generate characters on the CRT, the generation system of characters on CRTs requires relatively simple electronic circuitry.

A typical CRT display has easy facilities for the control of digit size by controlling the deflection sensitivity of the system (either electromagnetic or electrostatic deflection). The number of characters displayed can be changed with the help of time shared deflection and modulator circuits.

Importantly, the intensity and brightness can be realised, with different gray scales, and the display can have different colour depending on the phosphor used in the screen. Generally the phosphor is chosen to be white or green.

Storage type CRTs facilitate storing a stationary pattern on the screen without flickering display and it is possible to retain the pattern for a long time, independent of the phosphor persistence.

2.10 LIGHT EMITTING DIODES (LED)

The LED, Fig. 2.10 (a) is basically a semiconductor PN junction diode capable of emitting electromagnetic radiation under forward conductions. The radiation emitted by LEDs can be either in the visible spectrum or in the infrared region, depending on the type of the semiconductor material used. Generally, infra-red emitting LED's are coated with Phosphor so that, by the excitation of phosphor visible light can be produced. LEDs are useful for electronics display and instrumentation. Figure 2.10 (b) shows the symbol of an LED.

The advantage of using LEDs in electronic displays are as follows.

1. LEDs are very small devices, and can be considered as point sources of light. They can therefore be stacked in a high-density matrix to serve as a numeric and alphanumeric display. (They can have a character density of several thousand per square metre).
2. The light output from an LED is function of the current flowing through it. An LED can therefore, be smoothly controlled by varying the current. This is particularly useful for operating LED displays under different ambient lighting conditions.
3. LEDs are highly efficient emitters of EM radiation. LEDs with light output of different colours, i.e. red, amber, green and yellow are commonly available.
4. LEDs are very fast devices, having a turn ON-OFF time of less than 1 ns.
5. The low supply voltage and current requirements of LEDs make them compatible with DTL and TTL, ICs.

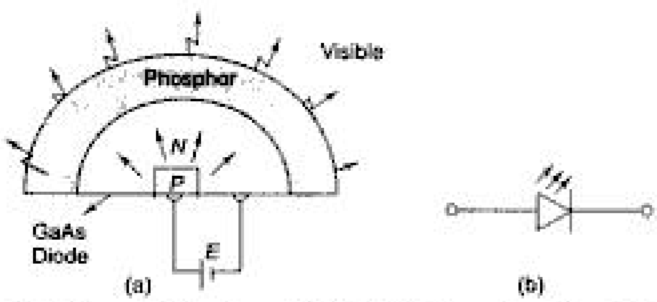

Fig. 2.10 (a) Structure of a Visible Emitter using GaAs PN Junction
(b) Symbol of LED

In germanium and silicon semiconductors, most of the energy is released in the form of heat. In Gallium Phosphide (GaP) and Gallium Arsenide Phosphide (GaAsP) most of the emitted photons have their wavelengths in the visible regions, and therefore these semiconductors are used for the construction of LEDs. The colour of light emitted depends upon the semiconductor material and doping level.

Different materials used for doping give out different colours.

1. Gallium Arsenide (GaAs) — red

2. Gallium Arsenide Phosphide (GaAsP) — red or yellow
3. Gallium Phosphide (GaP) — red or green

Alphanumeric displays using LEDs employ a number of square and oblong emitting areas, arranged either as dotmatrix or segmented bar matrix.

Alphanumeric LEDs are normally laid out on a single slice of semiconductor material, all the chips being enclosed in a package, similar to an IC, except that the packaging compound is transparent rather than opaque. Figure 2.10 (c) and (d) gives typical LED packages for single element LEDs.

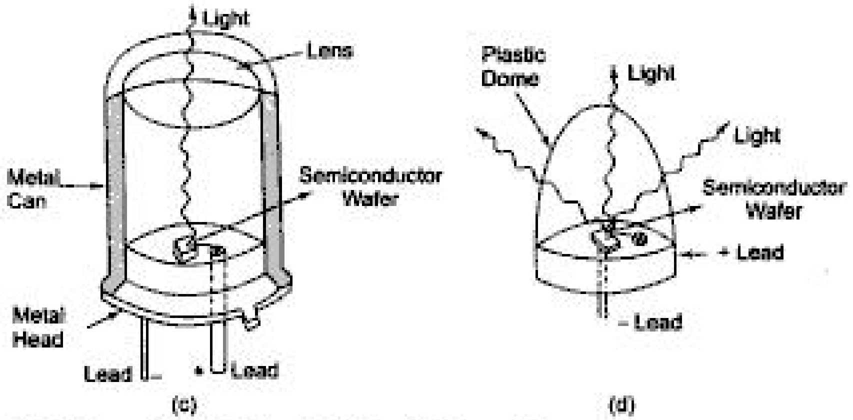

Fig. 2.10 ▬ (c) Metal Can To-5 Type (d) Epoxy Type

2.11 LIQUID CRYSTAL DISPLAY (LCD)

LCDs are passive displays characterised by very low power consumption and good contrast ratio. They have the following characteristics in common.

1. They are light scattering.
2. They can operate in a reflective or transmissive configuration.
3. They do not actively generate light and depend for their operation on ambient or back lighting.

A transmissive LCD has a better visual characteristic than a reflective LCD. The power required by an LCD to scatter or absorb light is extremely small, of the order of a few μW/cm. LCDs operate at low voltages, ranging from 1 – 15 V.

The operation of liquid crystals is based on the utilisation of a class of organic materials which remain a regular crystal-like structure even when they have melted. Two liquid crystal materials which are important in display technology are nematic and cholesteric, as shown in Fig. 2.11.

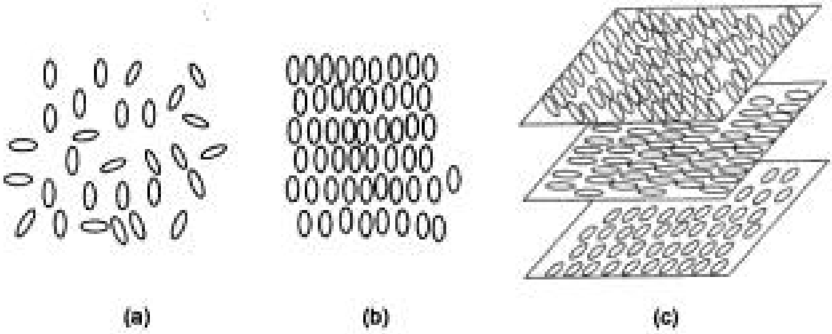

Fig. 2.11 ▬ Liquid Crystal Materials (a) Ordinary Liquids (b) Nematic Liquid Crystal (c) Cholesteric Liquid Crystal

The most popular liquid crystal structure is the nematic liquid crystal (NLC). The liquid is normally transparent, but if it is subjected to a strong electric field, ions move through it and disrupt the well ordered crystal structure, causing the liquid to polarise and hence turn opaque. The removal of the applied field allows the crystals structure to reform and the material regains its transparency.

Basically, the LCD comprises of a thin layer of NLC fluid, about 10 μ thick, sandwiched between two glass plates having electrodes, at least one of which is transparent.

(If both are transparent, the LCD is of the transmissive type, whereas a reflective LCD has only one electrode transparent.)

The structure of a typical reflective LCD is shown in Fig. 2.12.

The NLC material in Fig. 2.12 has a homogeneous alignment of molecules. While the glass substrate supports the LCD and provides the required transparency, the electrode facilitates electrical connections for the display. The insulating spacers are the hermetic seal.

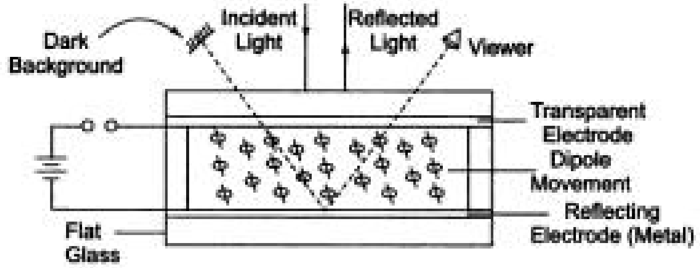

Fig. 2.12 ▬ Reflective Display Using NLC

The LCD material is held in the centre cell of a glass sandwich, the inner surface of which is coated with a very thin conducting layer of tin-oxide, which can be either transparent or reflective. The oxide coating on the front sheet of the indicator is etched to produce a single or multisegment pattern of characters and each segment of character is properly insulated from each other.

LCDs can be read easily in any situation, even when the ambient light is strong. If the read electrode is made transparent instead of reflective, back illumination is possible by a standard indicator lamp. Extending back illumination a step further by adding a lens arrangement. LCDs can be used as the slide in a projection system, to obtain an enlarged image.

Important Features of LCDs

1. The electric field required to activate LCDs is typically of the order of 10^4 V/cm. This is equivalent to an LCD terminal voltage of 10 V when the NLC layer is 10 μ thick.
2. NLC materials possess high resistivity > 10^{10} Ω. Therefore the current required for scattering light in an NLC is very marginal (typically 0.1 μA/cm^2).
3. Since the light source for a reflective LCD is the ambient light itself, the only power required is that needed to cause turbulence in the cell, which is very small, typically 1 μW/cm.
4. LCDs are very slow devices. They have a turn-on time of a few milliseconds, and a turn-off time of tens of milliseconds.

To sum up, LCDs are characterised by low power dissipation, low cost, large area and low operating speed.

LCDs are usually of the seven segment type for numeric use and have one common back electrode and seven transparent front electrodes characters, as shown in Fig. 2.13.

The back electrode may be reflective or transmissive, depending on the mode of operation of the display device.

Generally arrays of such characters are simultaneously fabricated using thin-film or hybrid IC technology for segments and conductors on glass plates, and then filled in with NLC material, followed by hermetic sealing.

LCD arrays utilising a dot-matrix are also possible, but they are not popular because of their slow operation.

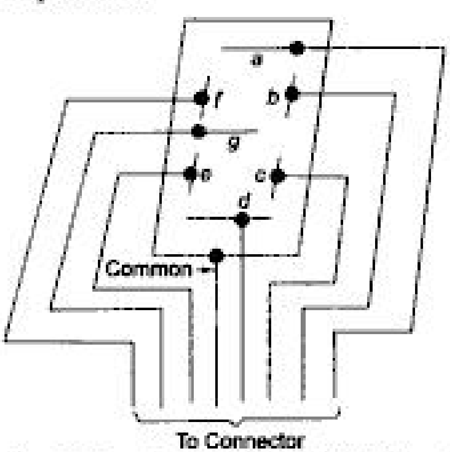

Fig. 2.13 ▬ Seven Segment LCD Character

2.12 OTHER DISPLAYS

Other important displays for use in electronic instrumentation are gas discharge plasma, electroluminescent, incandescent, electrophoretic, and liquid vapour display.

2.12.1 Gas Discharge Plasma Displays

These are the most well-known type of alphanumeric displays. Their operation is based on the emission of light in a cold cathode gas filled tube under breakdown condition.

These cold cathode numerical indicators are called Nixies (Numicators and Numbertrons).

This Nixie tube is a numeric indicator based on glow discharge in cold cathode gas filled tubes. It is essentially a multicathode tube filled with a gas such as neon and having a single anode, as shown in Fig. 2.14.

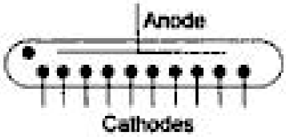

Fig. 2.14 ■ Nixie Tube — Symbolic Representation

Each of the cathodes is made of a thin wire and is shaped in the form of characters to be displayed, for example, numerals 0 to 9. The anode is also in the form of a thin frame.

In its normal operation, the anode is returned to positive supply through a suitable current limiting resistor, the value of the supply being greater than the worst-case breakdown voltage of the gas within the tube. The gas in the vicinity of the appropriate cathode glows when the cathode is switched to ground potential.

(The characteristic orange-red glow in the case of neon covers the selected cathode completely, thereby illuminating the character brightly.)

Since 10 cathodes have to be associated with a single anode inside the glass bulb, they have necessarily to be stacked in different planes. This requires different voltages for different cathodes to enable the glow discharge.

Many Nixie tubes also possess dot-cathodes either on the left or right of the character to serve as decimal points.

The standard Nixie is not the only format used with cold cathode technology—both bar and dot matrix versions are available. The bar types have a cathode which forms the segment and operates in a fashion similar to the standard neon tube. Identical supply voltage and drivers are required. In the dot type display, each dot is in matrix fashion and operates as an individual glow discharge light source. The required dots are selected by an *X-Y* addressing array of thin film metal lines, as shown in Fig. 2.15 (a).

Nixie tubes have the following important characteristics.

1. The numerals are usually large, typically 15–30 mm high, and appear in the same base line for in-line read-out.

2. Nixie tubes are single digit devices with or without a decimal point.
3. They are either side viewing or top viewing (as shown in Figs 2.15 (b) and (c)).

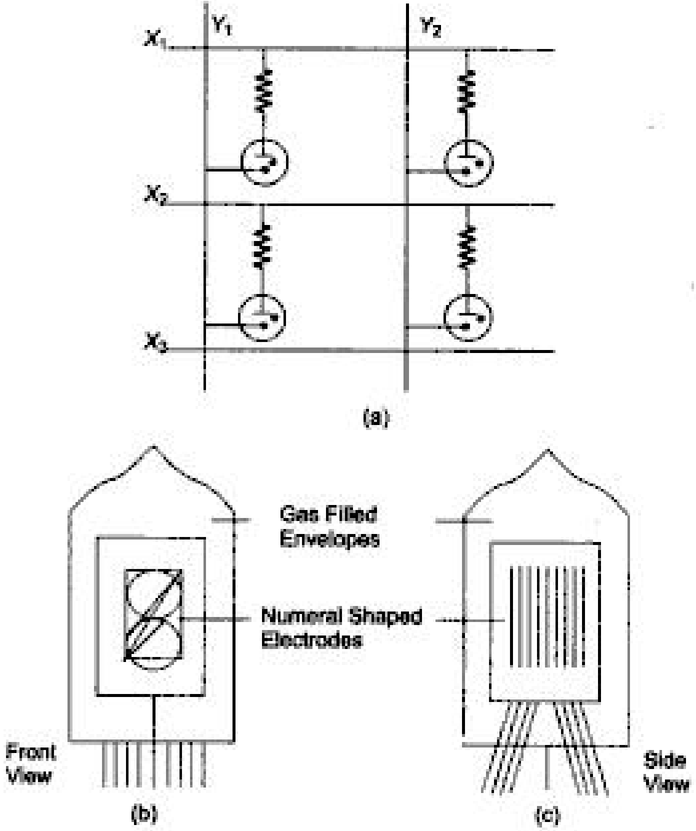

Fig. 2.15 (a) Matrix Operation of Display Panel Using Gas Filled Devices (b) and (c) Nixie Tube

4. Most Nixie tubes require dc supply of 150–220 V, and the selected cathode carries current in the range of 1–5 mA.
5. The Nixie tube can be pulse operated and hence can be used in multiplexed displays.
6. Alphabetical symbols can also be introduced in the Nixie tube.

2.12.2 Segmented Gas Discharge Displays

Segmented gas discharge displays work on the principle of gas discharge glow, similar to the case of Nixie tubes. They are mostly available in 7 segment or 14 segment form, to display numeric and alphanumeric characters.

Since these devices require high voltages, special ICs are developed to drive them. The construction of a 7 segment Display is shown in Fig. 2.16. Each segment (decimal point) of the 7 segment display formed on a base has a

separate cathode. The anode is common to each member of the 7 segment group which is deposited on the covering face plate. The space between the anodes and cathodes contains the gas. For each group of segments, a 'keep alive' cathode is also provided. For improving the switching speeds of the display a small constant current (a few micro amps) is passed through this keep alive cathode, which acts as a source of ions. Pins are connected to the electrodes at the rear of the base plate, with the help of which external connections can be made.

The major disadvantage of this gas discharge tube is that high voltage is required for operating it. Therefore, high voltage transistors, in the range of 150 – 200 V, are required as switches for the cathodes. A major advantage is that the power consumed is extremely small, because a bright display can be obtained even for currents as low as 200 μA.

This display follows a simple construction. Figure 2.17 gives the structure of a typical 7 segment display making use of a gas discharge plasma.

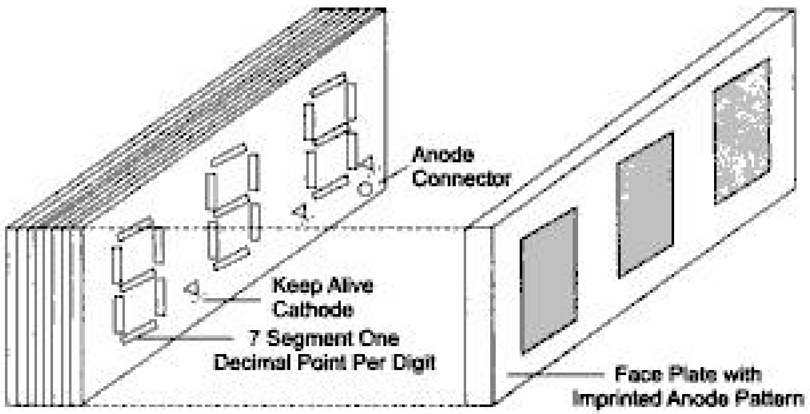

Fig. 2.16 ■ Seven Segment Display Using Gaseous Discharge

The device uses a glass substrate, shown in Fig. 2.17. Back electrodes of the thick film type serve as cathode segments, and front electrodes of the thin film type serve as transparent anodes. A gas, typically neon, is filled in the discharge space between the cathode and anode segment. The gas is struck between the cathode and anode of a chosen segment so that the cathode glow provides the illumination. All numeric characters can be displayed by activating the appropriate segment.

Display panels of rows or columns of such characters can be easily constructed by extending a single character. The power requirements of such devices are more or less in the same range as those for Nixie tubes.

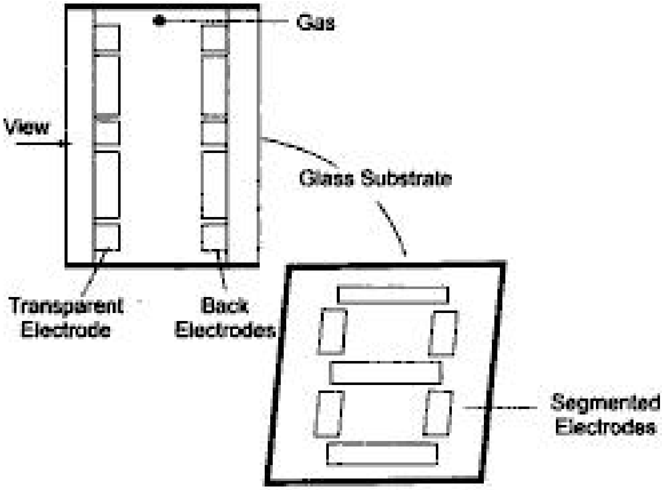

Fig. 2.17 ■ Seven Segment Gas Filled Character

2.12.3 Segmental Displays using LEDs

In segmental displays, it is usual to employ a single LED for each segment.

For conventional 7 segment LED displays (including the decimal point, i.e. the 8th segment), the wiring pattern is simplified by making one terminal common to all LEDs and other terminals corresponding to different segments. The terminals can be either of the common anode (CA) form or common cathode (CC) form, shown in Figs 2.18 (b) and (c).

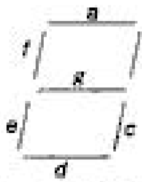

Fig. 2.18 ■ (a) LED 7 Segment Format

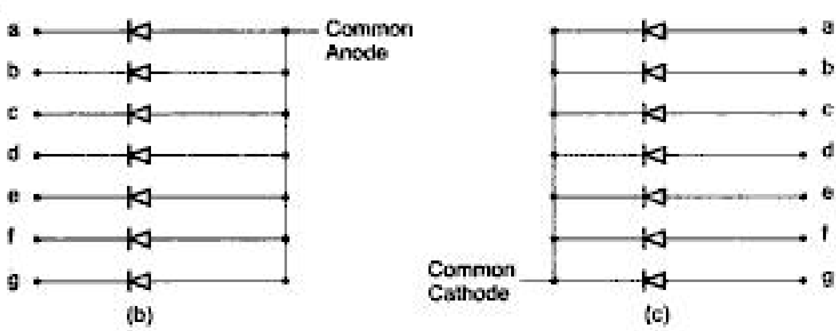

Fig. 2.18 ■ (b) Common Anode Connections (c) Common Cathode Connections

A typical static single digit 7 segment LED display system and multi-digit are shown in Figs. 2.18 (a) and (d).

Multi-digit display system may be static or dynamic.

Common anode type displays require an active low (or current sinking) configuration for code converter circuitry, whereas an active high (or current sourcing) output circuit is necessary for common-cathode LED type display.

Both multi-digit and segmental displays require a code converter; one code converter per character for static display systems and a single code converter for time shared and multiplexed dynamic display systems, which are illuminated one at a time.

The typical circuit schemes described in the figures are only of the decimal numeric character. An 8 digit display system, operating on this principle and suitable for digital instrumentation is given in Fig. 2.18 (d).

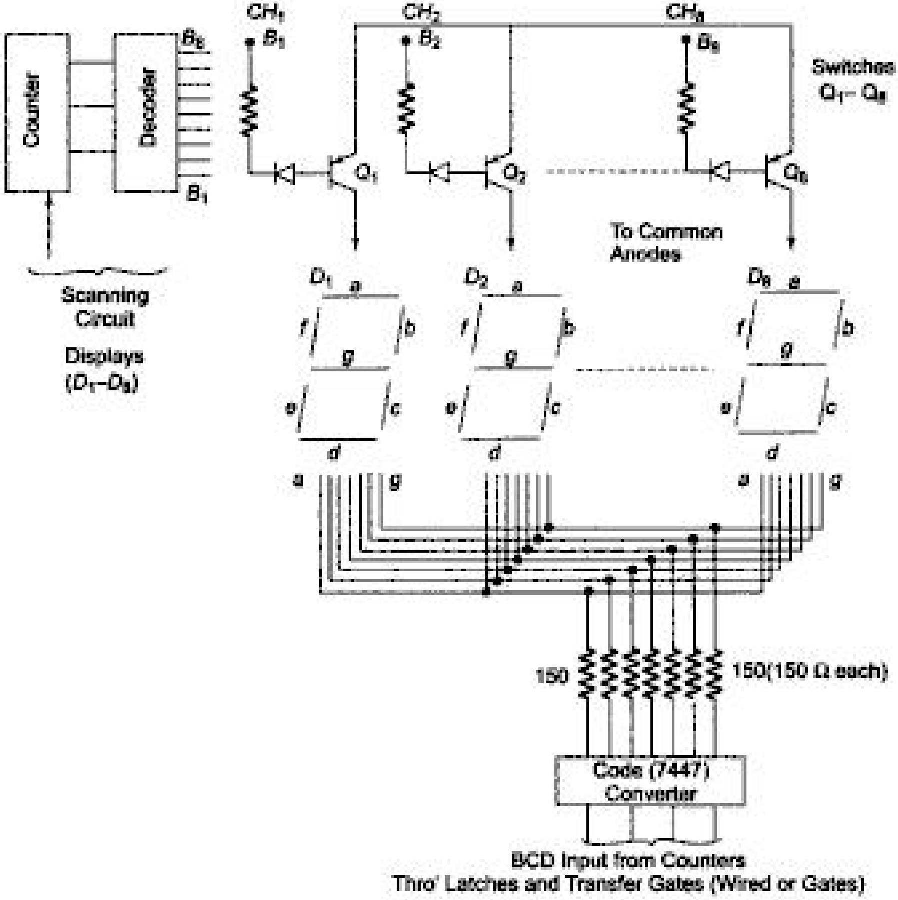

Fig. 2.18 (d) Multi-Digit Display System (8 Digit) Using LED 7 Segment Characters

It is also possible to generate hexadecimal numeric characters and conventional alphanumeric characters using 7 segment and 14 or 16 segment LED display units respectively, with a proper code converter. Both static and dynamic displays can be realised using LCDs, either in a common format (7 segment) or in single or multi character.

A chopped dc supply may be used, for simplicity, but conventionally an ac voltage is applied either to the common electrode or to the segment. Various segmental LCD driver circuits are displayed in Fig. 2.19.

Referring to Figs 2.19 (a) and (b), it is seen that an ac voltage (V_{ac}) is applied to either the common electrode or to the segment. High value resistances ($R > 1M$) are included in the circuit, as shown. The code converter controls the switches (S). V_{ac} is present across the selected segment and the common electrode when S is ON, and the voltage between any other segment (S-OFF) and the common electrode is zero. Hence the desired segments are energised, provided V_{ac} has a magnitude greater than or equal to the operating voltage of the LCD.

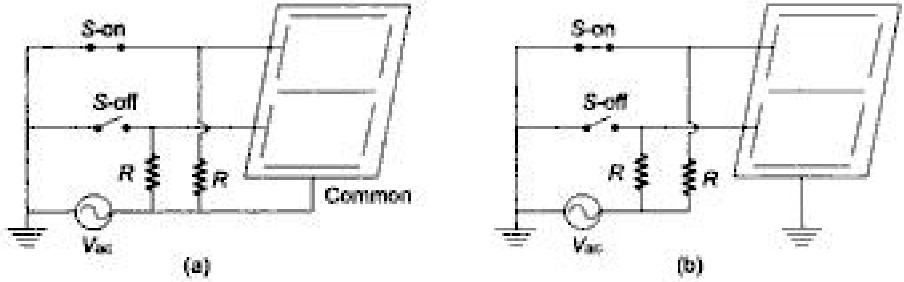

Fig. 2.19 ■ (a) Segments Driving Circuits for LCD, Switching Method Common Electrode (b) Segments Driving Circuits for LCD, Switching Method

The basic operation of the phase shift method for driving the segment is shown in Fig. 2.19 (c). In this circuit, ac voltages of the same amplitude and frequency (not necessarily same phase) are supplied to the common electrode as well as the segments.

There will be a finite voltage drop between a segment and the common electrode only when the ac voltages applied are out of phase, and thus the selected segment is energised. On the other hand, when in-phase voltages are present, the voltage drop between a segment and the common electrode is zero, leading to the off state.

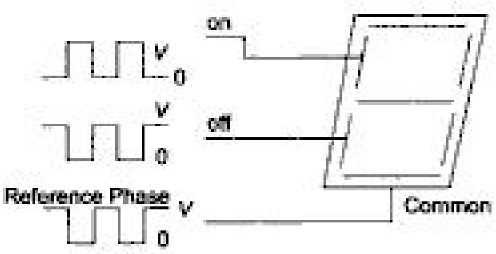

Fig. 2.19 ■ (c) Segments Driving Circuits for LCD, Using Phase Shift Method

2.12.4 Dot Matrix Displays

Excellent alphanumeric characters can be displayed by using dot matrix LEDs with an LED at each dot location. Commonly used dot matrices for the display of prominent characters are 5 × 7, 5 × 8, and 7 × 9, of which 5 × 7 shown in

Fig. 2.20 (a), is very popular due to economic considerations. The two wiring patterns of dotmatrix displays are as follows.

1. Common anode or common cathode connection (uneconomical).
2. $X - Y$ array connection (economical and can be extended vertically or horizontally using a minimum number of wires, Fig. 2.20 (b)).

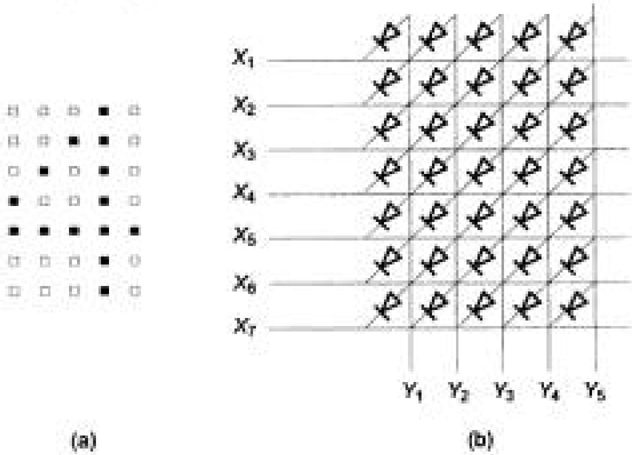

Fig. 2.20 ■ (a) 5 x 7 Dot Matrix Character Using LED
(b) Wiring Pattern for 5 x 7 LED Character

A typical 3 digit alphanumeric character display system using 5 × 7 dot matrix LEDs is shown in Fig. 2.21.

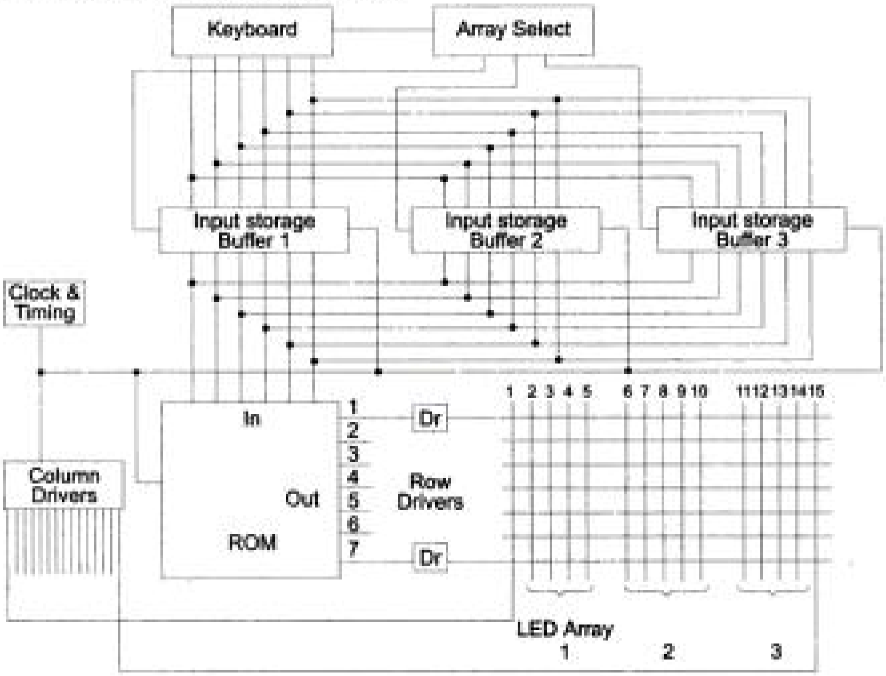

Fig. 2.21 ■ A 3 Digit Alphanumeric Display System Using 5 x 7 Characters

2.12.5 Bar Graph Displays

Bar graph displays are analogue displays which are an alternative to conventional D'Arsonval moving coil meters. They use a closely packed linear array or column of display elements, i.e. "DOT-LED'S", which are independently driven so that the length of the array (or the height of the column) corresponds to the voltage or current being measured. These displays are generally used in the panel meters to accept analog input signals and produce an equivalent display of the input signal level by illuminating the corresponding LEDs, as shown in Fig. 2.22.

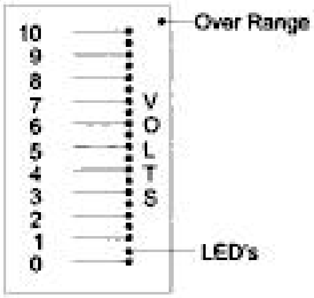

Fig. 2.22 ■■ Analog Meter Using Bar Graph of LEDs

2.12.6 Electro Luminescent (EL) Displays

Electro luminescent displays are an important means of light generation. They can be fabricated using polycrystalline semiconductors, and in view of their simple technology, brightness of display and possibility of different colours, are rapidly gaining in popularity.

The semiconductors used for EL displays are essentially phosphor powder or film type structures.

The powder type consist of powder phosphor with some binding material e.g. organic liquids deposited on a sheet of glass. The glass has transparent conductive segments (e.g. 7 segment displays) or dots (dot matrix display) along with the required conductive leads on the side on which phosphor is coated for electrical connections.

A metallic electrode, usually aluminium, is placed over the phosphor in a pressure cell by vacuum evaporation, so as to form an electrical connection on the other side of the phosphor. The resulting device is capacitive, because of poor conduction paths in phosphor. An ac field applied across the chosen segment (or dot) and aluminium electrode excites the phosphor, resulting in emission of light. In film type structures the EL powder structure is replaced by a polycrystalline phosphor film which is deposited on a glass substrate using a vacuum or pressure cell. These devices can be operated by ac as well as dc.

2.12.7 Incandescent Display

Incandescence has been a basic process of light generation for several decades. This process is now down in fully integrated electronic displays.

Incandescent displays using 16 segment as well as 5 × 7 dot matrix formats fabricated using thin film micro electronics are now available for alphanumeric

characters. Such displays are characterised by simple technology, bright output and compatibility with ICs, but at very low operating speeds.

A thin film of tungsten can be made to emit light if its temperature is raised to about 1200°C by electrical excitation. A 5 × 7 character array is formed on a ceramic substrate employing such films in a matrix form and is used as an integrated electronic display unit. Figure 2.23 gives a typical tungsten film or filament suitable for a dot location in the display.

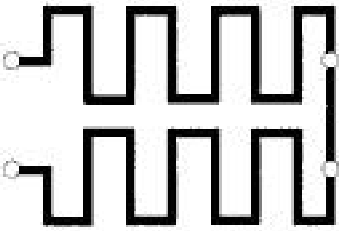

Fig. 2.23 Tungsten Filament Suitable for Incandescent Display

An array of such filaments can be formed on ceramic substrates using conventional thin film technology commonly used in semiconductor fabrication.

Considering the filament dimensions and the dimensions of commonly available substrates, an array of three characters can be located on a 2.5 cm ceramic substrate.

16 segment incandescent displays are also available, but their display is slow, because of the large thermal time constant associated with the filaments.

2.12.8 Electrophoretic Image Display (EPID)

Electrophoresis is the movement of charged pigment particles suspended in a liquid under the influence of an electric field. This pheonomenon has been utilised in electrophoretic image displays, as shown in Fig. 2.24.

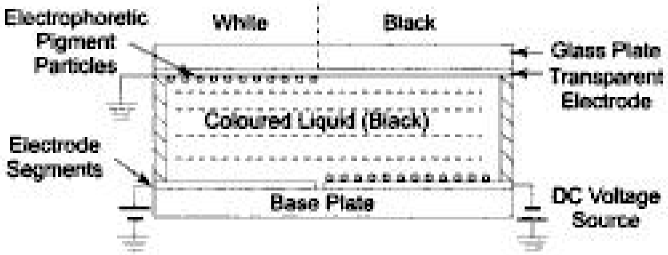

Fig. 2.24 Structure of an EPID

The basic principle; fabrication and operating characteristics of a reflective type Electrophoretic Image Display (EPID) panel are as follows. These displays are characterised by large character size, low power dissipation and internal memory.

The relatively slow speed of these displays is a major limitation, particularly for use as a dynamic display. The life span of an EPID is a few thousand hours only.

The EPID panel makes use of the electrophoretic migration of charged pigment particles in a supension. The suspension, 25 – 100 μ thick, which largely

contains the pigment particles and a suspending liquid, is sandwiched between a pair of electrodes, one of which is transparent.

The application of a dc electric field, across the electrodes, as shown in Fig. 2.24 moves the particles electrophoretically towards either electrode, the movement depending mainly on the polarity of the charge on the particles. The reflective colour of the suspension layer changes on account of this migration. EPID panels generally follow a segmented character format – typically 7 segment for numeric characters.

It is usual to have the transparent electrode as a common electrode. The back electrodes are generally segmented. Two such segments are shown in Fig. 2.24.

During the normal operation of the display, the transparent electrode is maintained at ground potential and the segmented electrodes at the back are given different potentials.

If the pigment particles are white and positively charged in the black suspending liquid, the application of a positive voltage to the chosen segment moves the pigment particles away from it and towards the transparent electrode. This is shown on the left side of Fig. 2.24. Pigment particles appear white in reflective colour as viewed through the transparent electrodes.

On the other hand, when a segment has a negative voltage with reference to the transparent electrode, the white pigment particles go towards it and get immersed in the black suspension. In this case, the viewer sees the reflection from the black liquid itself.

Colour combinations of both the pigment particles and the suspending liquid can be used to achieve a desired colour display.

Moreover, the colours between the displayed pattern and its background can be reversed, by changing the polarities of segment voltages.

In addition, the EPID panel has a memory, because the pigment particles deposited on an electrode surface remain there even after the applied voltage is removed.

2.12.9 Liquid Vapour Display (LVD)

LVDs are the latest in economical display technology. They employ a new reflective passive display principle and depend on the presence of ambient lights for their operation. Figure 2.25 gives the structure of a typical LVD cell.

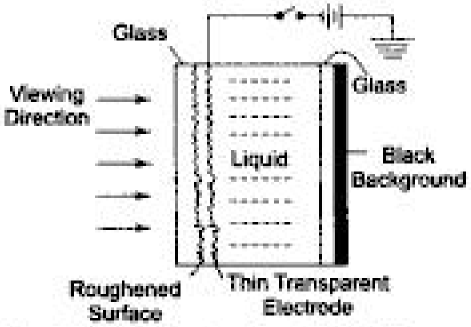

Fig. 2.25 ■ Structure of an LVD Cell

It consists of a transparent volatile liquid encased between two glass plates and side spacers. The rear glass plate has a black background and the front glass surface in contact with the liquid is roughened, so that the liquid wets it, i.e. in its simplest form, an LVD consists of a

roughened glass surface wetted with a transparent volatile liquid of the same refractive index as that of the glass. The rear surface is blackened.

The transparent electrode is heated by using a voltage drive, which is the basis for the display function.

In the OFF condition of display with no voltage applied across the transparent electrode, the viewer sees the black background through the front transparent glass electrode and the liquid.

To achieve an ON condition of the display, a voltage is applied to the transparent electrode. This causes sufficient heat in the electrode, which evaporates the liquid in contact with it, and a combination of vapour film and vapour bubbles is formed around the roughened glass surface. As the refractive index of vapour is approximately 1, there is a discontinuity established at the interface between the front glass plate and the liquid, which gives rise to light scattering. This makes it a simple display device.

The organic liquid selected for LVD should have the following features.

1. Refractive index close to that of the glass plate.
2. Minimum energy for vapourising the liquid in contact with the roughened surface.

The electrical heating of a thin film of liquid adjacent to the roughened surface using transparent electrodes and the applied voltage, makes it an unusually good display with a better contrast ratio than an LCD. The speed of operation of LVDs is low. A summary of some important display devices is given in Tables 2.1 and 2.2.

Table 2.1 Some Popular Display Devices

Display devices	*Applications*	*Advantages*	*Disadvantages*
1. CRTs	Large display, small and large group viewing, console display.	Bright, efficient, uniform, planar display—all colours, high reliability	Bulky, high voltage, non-digital address, high initial cost.
2. LEDs	Indicators and small displays, individual viewing, flat-panel.	Bright, efficient, red, yellow, amber, green colours, compatible with ICs, small size	High cost per element, limited reliability, low switching speed
3. LCDs	do	Good contrast in bright ambient light, low power, compatible with ICs, low cost element	Limited temperature range (0 – 60°C) Limited reliability, ac operation necessary, low switching speed.
4. NIXIEs	Indicators, small, medium and large displays, small group viewing.	Bright, range of colours, low cost element, compatible with ICs	High drive power
5. ELs	Indicator and small display, flat panel	Low cost element, many columns	Not compatible with ICs

Table 2.2 Typical Applications of Digital Display

Field of applications	*Displays*
1. *Industrial Electronics* Meters, positioner and instrumentation, test equipment, guages and counters	Incandescent, LED, LCD, CRT, Nixie
2. *Medical* Digital thermometer, Pulse rate meter, manometer, patient monitoring	CRT, LED's
3. *Computers, Commerce and Business* Peripheral and ALU status, calculators and cash register	LED, CRT, EL, Nixie, LCD
4. *Domestic* Electronic Oven, telephone, dial indicator, TV channel indicators, clock and calendars, video games	LED, CRT, LCD, Nixie
5. *Military and Space Research* Situation indicators	Traditional

2.13 PRINTERS

Character printers and graphic plotters are the two devices used to prepare a permanent (or hard copy) record of computer output.

The basic difference between printers and plotters is that the former are devices whose purpose is to print letters, numbers and similar characters in text-readable form, while the latter print diagrams with continuous lines.

2.14 CLASSIFICATION OF PRINTERS

Printers used in computers are classified in the following three broad categories.

1. Impact and Non-impact Printers

Impact printers form characters on a paper by striking the paper with a print head and squeezing an inked ribbon between the print head and the paper.

Non-impact printers form characters without engaging the print mechanism with the print surface, e.g. by heating sensitised paper or by spraying ink from a jet.

2. Fully Formed Character and Dot Matrix Printer

Fully formed characters are like those made by a standard typewriter—all parts of characters are embossed in the reverse on the type bars of the typewriter. When printed, all type elements appear connected or fully formed.

Dot matrix characters are shaped by combinations of dots that form a group representing a letter or number when viewed together.

3. Character at a Time and Line at a Time Printer

Character at a time printers (character printers or serial printers), print each character serially, and virtually instantaneously.

Line at a time printers (line printers), print each line virtually instantaneously.

(Some advanced printers, e.g. those using lasers and xerographic methods, print lines so rapidly that they virtually print a page at a time, and are therefore called page printers. They are rarely used in mini computers and microcomputers, for special purposes like phototype setting.)

2.15 PRINTER CHARACTER SET

Most printers used with mini or micro computers use ASCII codes. Printers are specified as using the 48 character set, the 64 character set, the 96 character set or the 128 character set.

The 48 and 64 character sets include commonly used special symbols, numbers, a space, and upper case (capital) English alphabets.

The 96 ASCII character set includes the lower case English alphabet and several additional special symbols. Of the 96 characters, 'space' and 'delete' do not print, leaving only 94 printable characters.

The entire 128 character ASCII set contains 32 characters normally used for communication and control. These characters usually do not print, but correspond to expandable functions, such as communication and control.

2.16 CHARACTER AT A TIME IMPACT PRINTERS FOR FULLY FORMED CHARACTERS (DRUM WHEEL)

The typewriter is the classic example of this printer, with characters fully formed because they are embossed on each type bar.

Ordinary type bar typewriters cannot be used with computers, because they lack a computer coding interface for easy communications.

(The classic printer used with mini and micro computers in the past was the Teletype Model 33 printer. The ready availability and low cost of these printers, plus their relatively easy interfacing, made them natural for use in small computers. The model 33 prints at a rate of 10 characters per second which is slow compared to today's printer of 55 characters per second for similar printers.) The print mechanism is a vertical cylinder. Characters are embossed in several rows and columns around the cylinder, as shown in Fig. 2.26 (a).

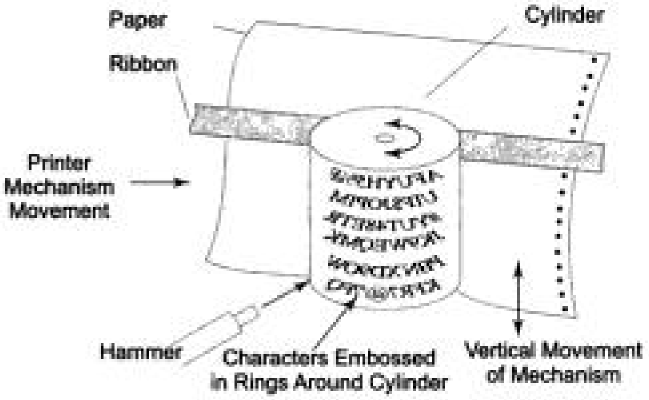

Fig. 2.26 ■ (a) Drum Wheel Printer

The ASCII character code sent to the printer, is translated into motion that rotates the cylinder, so that the column containing the desired character faces the paper. The cylinder is then raised or lowered (depending on the ASCII code) to present the column containing the desired character to be printed directly to the paper. A hammer mechanism propels (hits) the cylinder towards the paper, where only the positioned character strikes the ribbon, creating the printed impression of the character on the paper.

These printers are interfaced with small computers by a 20 – 60 mA current used to transmit ASCII coded bits serially.

Another type of fully formed character printer, designed for computer use, has characters mounted on the periphery of a spinning print head, known as a daisy wheel printer, and is shown in Fig. 2.26 (b).

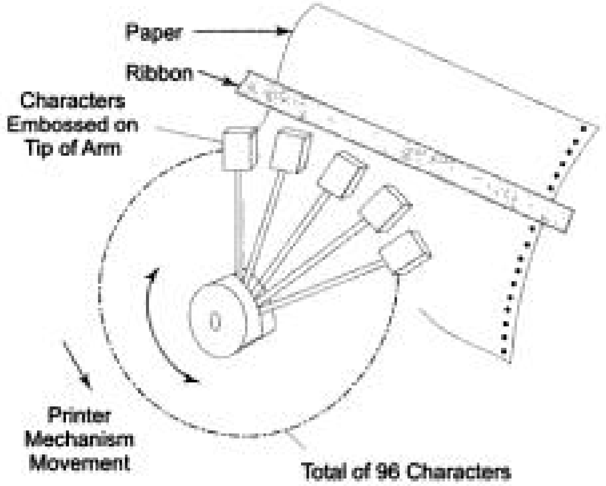

Fig. 2.26 ■ (b) Daisy Wheel Printer

A daisy wheel print head is mounted on a rotating disk with flexible flower like petals similar to a daisy flower. Each petal contains the embossed character in reverse. As the daisy wheel spins, a hammer strikes the desired flexible petal containing the character, in turn impacting the paper with the embossed character through an inked ribbon.

To print a letter, the wheel is rotated until the desired letter is in position over the paper. A solenoid driven hammer then hits the petal against the ribbon to print the letter.

Daisy wheel printers are slow, with a speed of about 50 characters per second (cps). The advantage of the daisy wheel mechanism is high print quality, and interchangeable fonts.

Character at a time printing follows the following sequence of steps; left to right printing to the end of the line, stop, return carriage and start a second line, and again print left to right. It is unidirectional.

Spinning wheel printers are capable of bidirectional printing. The second line is stored in a buffer memory within the printer control circuitry and can be printed in either direction, depending on which takes the least printer time.

2.17 LINE AT A TIME IMPACT PRINTERS FOR FULLY FORMED CHARACTERS (LINE PRINTERS)

In line printers, characters or spaces constituting printable lines (typically 132 character positions wide) are printed simultaneously across the entire line. Paper is spaced up and the next line is printed. Speeds for line printers range from several hundreds to thousands of lines per minute.

Line printers are used for high volumes of printed output and less frequently in micro computers, because of their high equipment cost relative to character at a time printers.

An embossed type font is positioned across a line for printing by using embossed type, either on a carrier consisting of a chain, train or band moving horizontally across the paper and print line, or a drum rotating in front of the paper with characters embossed. Typically, there are 132 columns on the drum. As the drum rotates, the column of characters pan vertically across the paper and the print line (shown in Fig. 2.27). In both methods, hammers (one for each of 132 print positions) strikes when the correct character is positioned, imprinting the character on the paper with an inked ribbon.

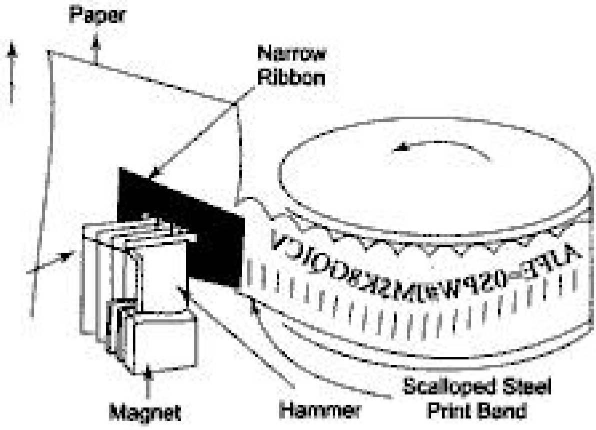

Fig. 2.27 ■ Band Printers (Line Printer)

Print characters are embossed on the band. The band revolves between two capstans, passing in front of the paper. An inked ribbon is positioned between the moving band and the paper. As the print characters on the band move by 132 horizontal print positions, the 132 corresponding print hammers behind the paper strike the band at the appropriate time, causing the line of characters to print each desired character in 132 print positions.

In band printers, a metallic or plastic band has a fully formed etched character on it. The band rotates at high speed. There is one hammer for one print position, because several hammers can strike simultaneously for many print positions. These printers are faster than dot matrix printers. These line printers have speeds varying from 75 to 4000 lines per minute (l pm). These printers are both noisier and costlier than dot-matrix printers.

A band always contains more than one character set. This reduces access time needed to match the characters, thereby reducing the printing time. Below the characters are the timing marks which are sensed by the printers electronic circuitry. It compares the character to be printed with the character corresponding to the timing mark, senses it and if a match occurs, fires the corresponding hammer.

A chain printer is similar to a band printer, except that in the former the characters sets are held in a metal or rubber chain and rotated across the paper along a print line.

A chain revolves in front of the ribbon and paper. Each link in the chain is designed to hold a pallet on which type characters are embossed. Hammers are located behind the paper and each of 132 hammers strikes the moving type pallet when the desired character passes the position in which it is timed to print.

2.18 DRUM PRINTER

Figure 2.28 illustrates a drum printer. Each of the 64 or 96 characters used is embossed in 132 columns around the drum, corresponding to the print positions. The drum rotates in front of the paper and ribbon. Print hammers strike the paper, imprinting characters from the drum through the ribbon and forming an impression on the paper.

The drum printer uses a cylindrical drum which contains characters embossed around it. There is one complete character set for each print position. To print characters, magnetically driven hammers in each character position strike the paper and ribbon against the spinning drum. An entire line of characters can be printed during each rotation of the drum. Printing speeds of drum printers vary from 200 – 300 lpm. The drawbacks of drum printers are that the fonts are not easily changeable, and the print lines may be wavy.

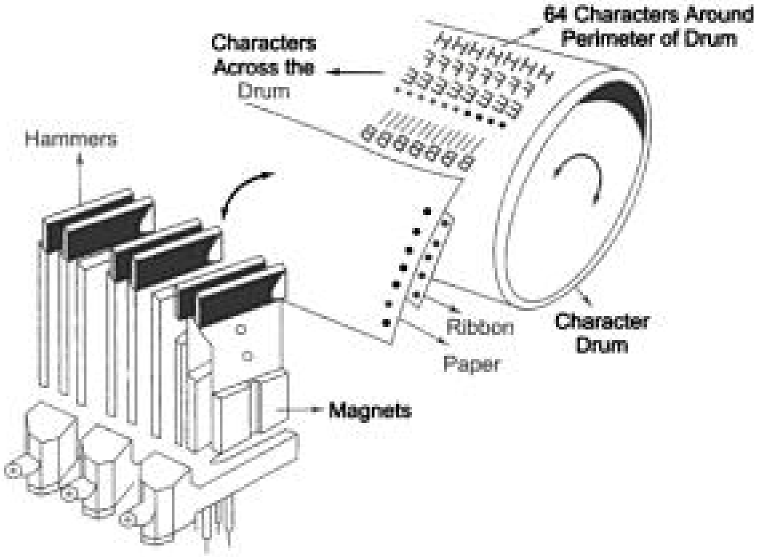

Fig. 2.28 ■ **Drum Printers**

2.19 DOT-MATRIX PRINTERS

Dot matrix characters are formed by printing a group of dots to form a letter, number or other symbol. This method is widely used with mini and micro computers.

Dots are formed both by impact and non impact print methods and are both character at a time and line at a time printers.

Figure 2.29 shows the letter 'A' formed by a dot-matrix, five dots wide and seven dots high (5 × 7) and in a 9 × 7 matrix. A 5 × 7 dot-matrix is frequently used when all letters are acceptable, in upper case.

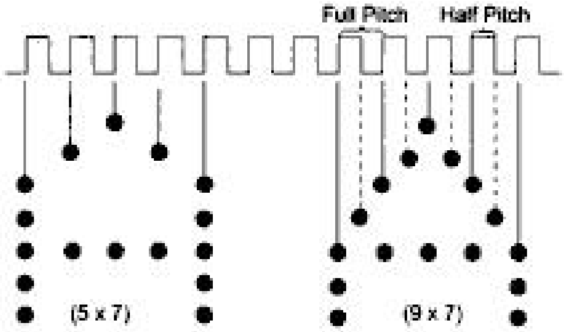

Fig. 2.29 ■ Dot Matrix Sizes

Dot-matrix printers can print any combination of dots with all available print positions in the matrix. The character is printed when one of 128 ASCII codes is signalled and controlled by the ROM (read only memory) chip, which in turn controls the patterns of the dots. By changing the ROM chip a character set for any language or graphic character set can be used by the printer.

2.20 CHARACTER AT A TIME DOT-MATRIX IMPACT PRINTER

The print head for an impact dot matrix character is usually composed for an array of wires (or pins) arranged in a tabular form, that impact the character through an inked ribbon, as shown in Fig. 2.30. For this reason, these printers are sometimes also called wire printers.

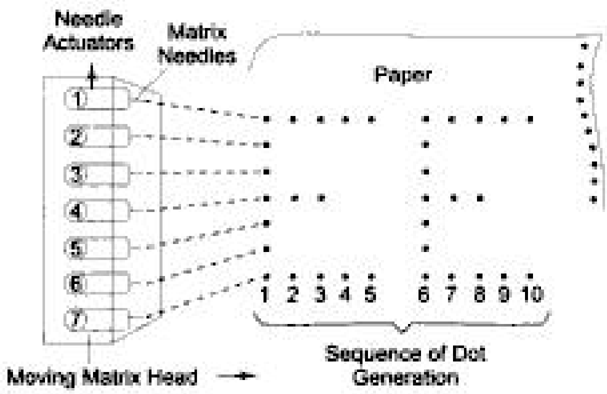

Fig. 2.30 ■ Impact Dot Matrix Print Head

The print head often contains a single column seven wires high, though it may be two or more columns wide (Fig. 2.31 (a)).

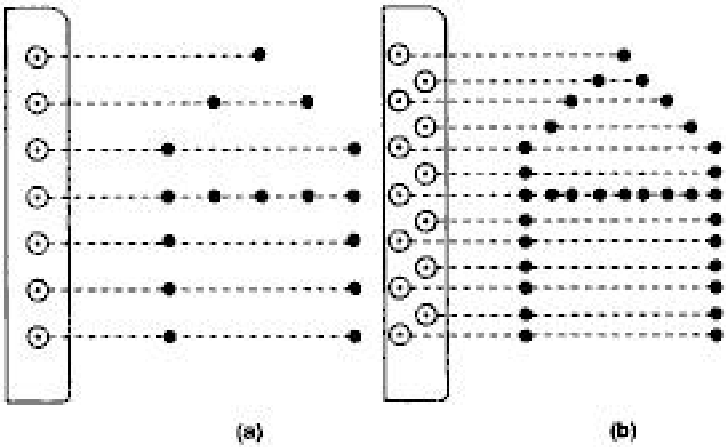

Fig. 2.31 ▬ (a) 5 x 7 Single Element (b) 5 x 7 Double Element

For purpose of illustration, assume that the print head contains a single column seven wires high. The seven wires are thrust from the print head (usually electromagnetically) in whatever combination the print controller requires to create a character. The wire strikes the ribbon and in turn impacts the paper, printing one vertical column of a single character.

The dot-matrix print head contains wires (or pins) arranged in tabular form. Characters are printed as a matrix of dots. The thin wire, driven by solenoids at the rear of the print head, strikes the ribbon against the paper to produce dots. The print wires are arranged in a vertical column, so that characters are printed out one dot column at a time as the print head moves on a line.

For a 5 × 7 full step dot-matrix character, the print head spaces one step, prints the second column of dots and repeats the pricess until all five columns are printed.

If the printer is designed to print dots in half steps, the same process is used, except that five horizontal print steps are used to form the characters (the five normal steps, plus four intervening half steps), thereby forming a 9 × 7 half step dot matrix character.

The dot-matrix character printer, strictly speaking, does not actually print a character at a time, but one column of a dot-matrix character at a time. However, the print speeds of a dot-matrix printer are very high, up to 180 characters per second.

Early dot-matrix print heads had only seven print wires, and consequently poor print quality. Currently available dot-matrix printers use 9, 14, 18 or even 24 print wires in the print head. Using a large number of print wires and/or printing a line twice with the dots for the second printing offset slightly from those of the first, ensures a better quality of print (Fig. 2.31 b).

Common speeds of dot-matrix printers range from 50 – 200 cps, but printers with speed as high as 300 cps are also available.

The dot-matrix codes of the characters are stored in EPROM. The fonts or print graphics can be changed under program control. This is the main advantage of dot-matrix printers.

The font of dot-matrix printers can be changed during printing by including the desired formats in RAM or ROM. Hence, it is possible to include standard ASCII characters, italics, subscripts, etc. on the same line. Special graphics can also be programmed into the printer.

2.21 NON-IMPACT DOT-MATRIX (NIDM) PRINTERS

Non-impact dot-matrix printers cause a mark without directly touching the paper. They are therefore quiet compared to impact printers.

They cannot make carbon copies, however, as there is no force to impress the character through multiple carbon copies. NIDM printers are useful for printing single copies of computer output, for recording the output of printing calculators and video displays, and for logging industrial data.

There are four types of NIDM printers thermal, electrosensitive, electrostatic, and ink jet.

Review Questions

1. Give the basic principle of a D'Arsonval movement.
2. Explain the operation of a PMMC movement.
3. What are the functions of counter weights in a PMMC movement.
4. Explain the basic construction of a taut band movement.
5. Compare a PMMC movement with a taut band movement.
6. State the operating principle of an electrodynamometer.
7. Why is the electrodynamometer called a square law device?
8. What is a transfer instrument? Why is an electrodynamometer a transfer instrument?
9. Differentiate between moving iron and moving coil measurement.
10. State the difference between radial and concentric iron-vane movement.
11. State the difference between an analog and a digital indicator.
12. Explain a 7 segment LED display.
13. Draw the structure of an LED and explain its operation. What are the condition to be satisfied by the device for emission of visible light?
14. Discuss with a neat diagram, a method of realising a 7 segment numeric display using LEDs.
15. Bring out the important differences between the common anode and common cathode type circuit arrangements for a 7 segment numeric display using LEDs.
16. What are the operating principles of LCD display?
17. What are the advantages of LCD display over Nixie tube and LED display?
18. Give reasons for the following.
    (i) Dot matrix presentation is more popular than the bar matrix in alphanumeric character generation in CRT.

(ii) Reflective LCDs have many advantages over transmissive LCDs.
(iii) Bar graph displays have a unique role in an electronic display system.

19. Compare the relative performance of the following display devices in numeric display applications.
    (i) Electrophoretic image display
    (ii) Liquid vapour display
    (iii) Nixie tubes
    (iv) Flat panel alphanumeric CRT
20. What are printers, and where are they used?
21. State different types of printers.
22. How is character at a time printing done?
23. How is line at a time printing done?
24. What are impact and non-impact printers?
25. What are the different methods of character at a time printing?
26. What is a daisy wheel?
27. What are dot-matrix printers? How is printing done?
28. How is the quality of printing improved?
29. What are the main advantages of dot-matrix over other printers?
30. What are half steps in a dot-matrix? Why are they used?

Further Reading

1. B.S. Sonde, *Transducers and Display Systems*, Tata McGraw-Hill, 1979.
2. Philco Technological Centre, *Electronic Precision Measurement Techniques and Experiment*.
3. C. Louis Hohenstein, 'Computer Peripherals for Mini Computer', *Microprocessor and P.C.*, McGraw-Hill, 1980.
4. A.K. Sawhney, *Electronic and Electrical Measurements*, Khanna Publishers.

CHAPTER

3 Ammeters

3.1 DC AMMETER

The PMMC galvanometer constitutes the basic movement of a dc ammeter. Since the coil winding of a basic movement is small and light, it can carry only very small currents. When large currents are to be measured, it is necessary to bypass a major part of the current through a resistance called a shunt, as shown in Fig. 3.1. The resistance of shunt can be calculated using conventional circuit analysis.

Referring to Fig. 3.1

R_m = internal resistance of the movement.

I_{sh} = shunt current

I_m = full scale deflection current of the movement

I = full scale current of the ammeter + shunt (i.e. total current)

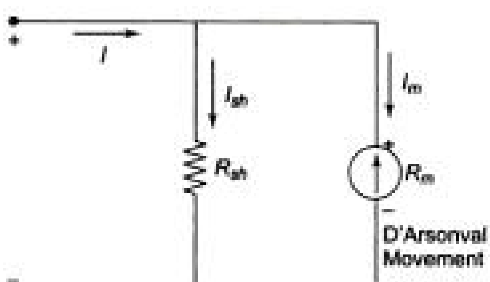

Fig. 3.1 Basic dc Ammeter

Since the shunt resistance is in parallel with the meter movement, the voltage drop across the shunt and movement must be the same.

Therefore $V_{sh} = V_m$

$$\therefore \qquad I_{sh} R_{sh} = I_m R_m, \qquad R_{sh} = \frac{I_m R_m}{I_{sh}}$$

But $\qquad I_{sh} = I - I_m$

hence $\qquad R_{sh} = \frac{I_m R_m}{I - I_m}$

For each required value of full scale meter current, we can determine the value of shunt resistance.

Example 3.1 A 1 mA meter movement with an internal resistance of 100 Ω is to be converted into a 0 – 100 mA. Calculate the value of shunt resistance required.

Solution Given $R_m = 100\ \Omega$, $I_m = 1$ mA, $I = 100$ mA

$$R_{sh} = \frac{I_m R_m}{I - I_m} = \frac{1\text{ mA} \times 100\ \Omega}{99\text{ mA}} = \frac{100\text{ mA}\Omega}{99\text{ mA}} = \frac{100\ \Omega}{99} = 1.01\ \Omega$$

The shunt resistance used with a basic movement may consist of a length of constant temperature resistance wire within the case of the instrument. Alternatively, there may be an external (manganin or constantan) shunt having very low resistance.

The general requirements of a shunt are as follows.

1. The temperature coefficients of the shunt and instrument should be low and nearly identical.
2. The resistance of the shunt should not vary with time.
3. It should carry the current without excessive temperature rise.
4. It should have a low thermal emf.

Manganin is usually used as a shunt for dc instruments, since it gives a low value of thermal emf with copper.

Constantan is a useful material for ac circuits, since it's comparatively high thermal emf, being unidirectional, is ineffective on the these circuits.

Shunt for low current are enclosed in the meter casing, while for currents above 200 A, they are mounted separately.

3.3 MULTIRANGE AMMETERS

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

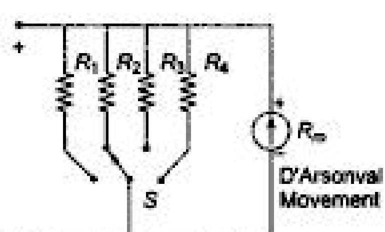

Fig. 3.2 Multirange Ammeter

The circuit has four shunts R_1, R_2, R_3 and R_4, which can be placed in

parallel with the movement to give four different current ranges. Switch S is a multiposition 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.

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. Multirange ammeters are used for ranges up to 50A. When using a multirange 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.

3.3 THE ARYTON SHUNT OR UNIVERSAL SHUNT

The Aryton shunt eliminates the possibility of having the meter in the circuit without a shunt. This advan-tage 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 R_a is in parallel with the series combi-nation of R_b, R_c and the meter movement. 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 R_c and the meter movement. Now the current through the meter is more than the current through the shunt resistance.

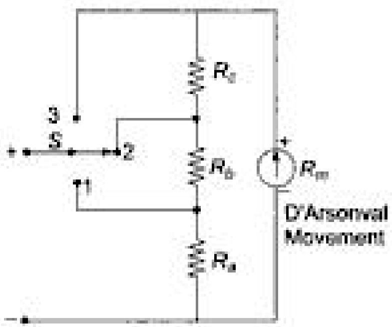

Fig. 3.3 Aryton Shunt

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.

Example 3.2 Design an Aryton shunt (Fig. 3.4) to provide an ammeter with a current range of 0 – 1 mA, 10 mA, 50 mA and 100 mA. A D'Arsonval movement with an internal resistance of 100 Ω and full scale current of 50 μA is used.

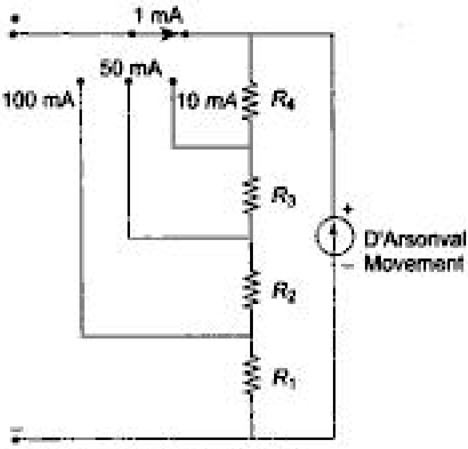

Fig. 3.4 ■ For Example 3.2

Solution Given $R_m = 100\ \Omega$, $I_m = 50\ \mu A$.

For 0 – 1 mA range

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

$\therefore$ 950 μA $(R_1 + R_2 + R_3 + R_4) = 50\ \mu A \times 100.$

$$\therefore \quad R_1 + R_2 + R_3 + R_4 = \frac{50\ \mu A \times 100}{950\ \mu A} = \frac{5000}{950} = 5.26\ \Omega \qquad (3.1)$$

For 0 – 10 mA

$$9950\ \mu A\ (R_1 + R_2 + R_3) = 50\ \mu A \cdot (100 + R_4) \qquad (3.2)$$

For 0 – 50 mA

$$49950\ \mu A\ (R_1 + R_2) = 50\ \mu A \cdot (100 + R_3 + R_4) \qquad (3.3)$$

For 0 – 100 mA

$$99950\ \mu A\ (R_1) = 50\ \mu A\ (100 + R_2 + R_3 + R_4) \qquad (3.4)$$

But $R_1 + R_2 + R_3 = 5.26 - R_4$. Substituting in Eq. 3.2, we have

$$9950\ \mu A\ (5.26 - R_4) = 50\ \mu A\ (100 + R_4)$$

$$9950\ \mu A \times 5.26 - 500\ \mu A \times R_4 = 5000\ \mu A + 50\ \mu A\ R_4$$

$$(9950\ \mu A - 5.26 - 5000\ \mu A) = 9950\ \mu A\ R_4 + 50\ \mu A\ R_4$$

Therefore $$R_4 = \frac{9950\ \mu A \times 5.26 - 5000\ \mu A}{10\ mA} = \frac{47377\ mA}{10\ mA} = 4.737$$

$$R_4 = 4.74\ \Omega$$

In Eq. 3.1, substituting for R_4 we get

$$R_1 + R_2 + R_3 = 5.26 - 4.74 = 0.52$$

$$\therefore \quad R_1 + R_2 = 0.52 - R_3$$

Substituting in Eq. 3.3, we have

$$49950\ \mu A\ (0.52 - R_3) = 50\ \mu A\ (R_3 + 4.74 + 100)$$

$$49950\ \mu A \times 0.52 - 49950\ \mu A \times R_3$$
$$= 50\ \mu A \times R_3 + 50\ \mu A \times 4.74 + 50\ \mu A \times 100$$

$$49950\ \mu A \times 0.52 - 50\ \mu A \times 4.74$$
$$= 49950\ \mu A \times R_3 + 50\ \mu A \times R_3 + 5000\ \mu A$$

$$(25974 - 237)\ \mu A = 50\ mA \times R_3 + 5000\ \mu A$$

$$25737\ \mu A = 50\ mA \times R_3 + 5000\ \mu A$$

$$R_3 = \frac{25737\ \mu A - 5000\ \mu A}{50\ mA} = \frac{20737\ \mu A}{50\ mA}$$

$$R_3 = 0.4147 = 0.42\ \Omega$$

But $\quad R_1 + R_2 = 0.52 - R_3$

$$\therefore \quad R_1 + R_2 = 0.52 - 0.4147 = 0.10526$$

Therefore $\quad R_2 = 0.10526 - R_1 \qquad (3.5)$

From Eq. 3.4

$$99950\ \mu A\ (R_1) = 50\ \mu A \times (100 + R_2 + R_3 + R_4)$$

But $\quad R_2 + R_3 + R_4 = 5.26 - R_1 \qquad$ (from Eq. 3.1)

Substituting in Eq. 3.4

$$99950\ \mu A \times R_1 = 50\ \mu A \times (100 + 5.26 - R_1)$$

$$99950\ \mu A \times R_1 = 5000\ \mu A + (50\ \mu A \times 5.26) - (R_1 \times 50\ \mu A)$$

$$99950\ \mu A \times R_1 + 50\ \mu A \times R_1 = 5000\ \mu A + 50\ \mu A \times 5.26$$

$$(99950\ \mu A + 50\ \mu A)\ R_1 = 5000\ \mu A + 263\ \mu A$$

$$100\ mA \times R_1 = 5263\ \mu A$$

$$R_1 = \frac{5263\ \mu A}{100\ mA} = 0.05263$$

Therefore $\quad R_1 = 0.05263\ \Omega$

From Eq. 3.5, we have

$$R_2 = 0.10526 - R_1$$

$$= 0.10526 - 0.05263 = 0.05263\ \Omega$$

Hence the value of shunts are

$$R_1 = 0.05263\ \Omega\ ;\quad R_2 = 0.05263\ \Omega$$

$$R_3 = 0.4147\ \Omega\ ;\quad R_4 = 4.74\ \Omega$$

3.4 REQUIREMENTS OF A SHUNT

The type of material that should be used to join the shunts should have two main properties.

1. Minimum Thermo Dielectric Voltage Drop

Soldering of joint should not cause a voltage drop.

2. Solderability

Resistance of different sizes and values must be soldered with minimum change in value.

The following precautions should be observed when using an ammeter for measurement.

1. Never connect an ammeter across a source of emf. Because of its low resistance it would draw a high current and destroy the movement. Always connect an ammeter in series with a load capable of limiting the current.
2. Observe the correct polarity. Reverse polarity causes the meter to deflect against the mechanical stopper, which may damage the pointer.
3. When using a multirange meter, first use the highest current range, then decrease the current range until substantial deflection is obtained. To increase the accuracy use the range that will give a reading as near full scale as possible.

3.5 EXTENDING OF AMMETER RANGES

The range of an ammeter can be extended to measure high current values by using external shunts connected to the basic meter movement (usually the lowest current range), as given in Fig. 3.5.

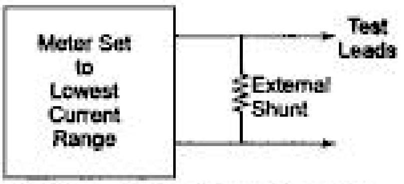

Fig. 3.5 Extending of Ammeters

Note that the range of the basic meter movement cannot be lowered.

(For example, if a 100 µA movement with 100 scale division is used to measure 1 µA, the meter will deflect by only one division. Hence ranges lower than the basic range are not practically possible.)

3.6 RF AMMETER (THERMOCOUPLE)

3.6.1 Thermocouple Instruments

Thermocouples consists of a junction of two dissimilar wires, so chosen that a voltage is generated by heating the junction. The output of a thermocouple is delivered to a sensitive dc microammeter.

(Calibration is made with dc or with a low frequency, such as 50 cycles, and applies for all frequencies for which the skin effect in the heater is not appreciable. Thermocouple instruments are the standard means for measuring current at radio frequencies.)

The generation of dc voltage by heating the junction is called thermoelectric action and the device is called a thermocouple.

3.6.2 Different Types of Thermocouples

In a thermocouple instrument, the current to be measured is used to heat the junction of two metals. These two metals form a thermocouple and they have the property that when the junction is heated it produces a voltage proportional to the heating effect. This output voltage drives a sensitive dc microammeter, giving a reading proportional to the magnitude of the ac input.

The alternating current heats the junction; the heating effect is the same for both half cycles of the ac, because the direction of potential drop (or polarity) is always be the same. The various types of thermocouples are as follows.

Mutual Type (Fig. 3.6 (a))

In this type, the alternating current passes through the thermocouple itself and not through a heater wire. It has the disadvantages that the meter shunts the thermocouple.

Contact Type (Fig. 3.6 (b))

This is less sensitive than the mutual type. In the contact type there are separate thermocouple leads which conduct away the heat from the heater wire.

Separate Heater Type (Fig. 3.6 (c))

In this arrangement, the thermocouple is held near the heater, but insulated from it by a glass bead. This makes the instrument sluggish and also less sensitive because of temperature drop in the glass bead. The separate type is useful for certain applications, like RF current measurements. To avoid loss of heat by radiation, the thermocouple arrangement is placed in a vacuum in order to increase its sensitivity.

Bridge Type (Fig. 3.6 (d))

This has the high sensitivity of the mutual type and yet avoids the shunting effect of the microammeter.

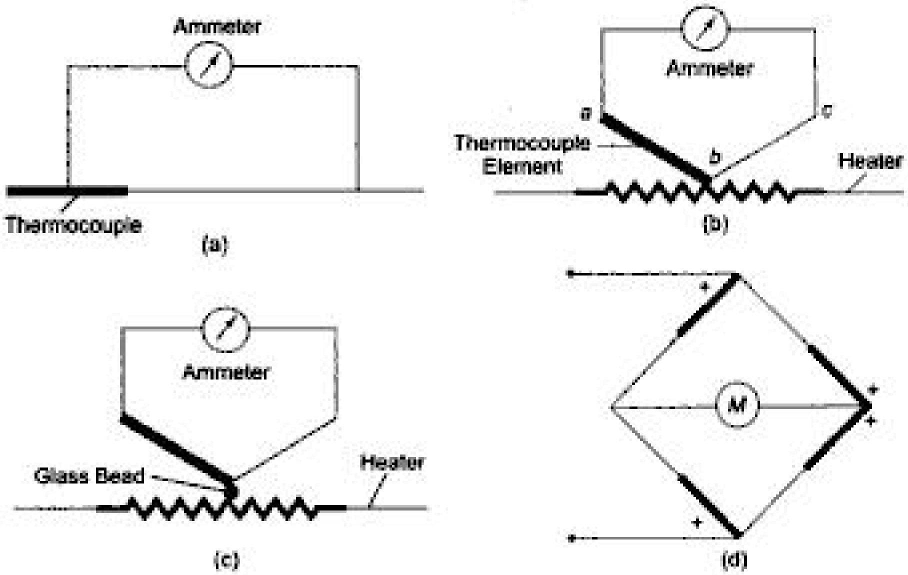

Fig. 3.6 ▬ (a) Mutual Type (b) Contact Type (c) Separate Heater Type (d) Bridge Type Thermocouple

The sensitivity of a thermocouple is increased by placing it in a vacuum since loss of heat by conduction is avoided, and the absence of oxygen permits operation at a much higher temperature. A vacuum thermocouple can be designed to give a full scale deflection of approximately 1 mA. A similar bridge arrangement in air would require about 100 mA for full scale deflection.

Material commonly used to form a thermocouple are constantan against copper, manganin or a platinum alloy. Such a junction gives a thermal emf of approximately 45 μV/°C.

The heating element of open air heaters is typically a non-corroding platinum alloy. Carbon filament heaters are used in vacuum type.

Thermocouple heaters operate so close to the burnout point under normal conditions, that they can withstand only small overloads without damage, commonly up to 50%. This is one of the limitations of the thermocouple instrument.

(Commonly used metal combinations are copper-constantan, iron-constantan, chromel-constantan, chromel-alumel, and platinum-rhodium. Tables are available that show the voltages produced by each of the various metal combination at specific temperatures.)

3.7 LIMITATIONS OF THERMOCOUPLES

Following are the limitations of thermocouples

1. Heaters can stand only small overload.
2. A rise in temperature (higher operating temperatures) causes a change in the resistance of the heater.
3. Presence of harmonics changes meter reading, because the heating effect is proportional to the square of current.

This can be understood by the following example.

The effective value of input wave is

$$= \sqrt{I_1^2 + I_2^2 + I_3^2 + I_4^2 + \cdots}$$

where I_1 is the fundamental
I_2 is second harmonic
I_3 is third harmonic

If 20% harmonics are present, then $I_2 = \frac{I_1}{5}$.

Therefore, the error in the current reading if 20% harmonics is present, is calculated as follows. Therefore effective value of input wave

$$= \sqrt{I_1^2 + I_2^2} = \sqrt{I_1^2 + \left(\frac{I_1}{5}\right)^2}$$

$$= \sqrt{I_1^2 + \frac{I_1^2}{25}} = \sqrt{\frac{26}{25} I_1^2} = \sqrt{1.04\, I_1^2}$$

$$= 1.02\, I_1 = I_1 + 0.02\, I_1$$

But 0.02 = 2%. Hence 20% harmonics increase the error by 2%.

3.8 EFFECT OF FREQUENCY ON CALIBRATION

The frequency effect arises because of various factors such as:

1. Skin effect
2. Non uniform distribution of current along the heater wires
3. Spurious capacitive currents

1. Skin Effect

The skin effect causes a higher reading at higher frequencies, especially if the heater wire is small. A low current instrument with a circular cross-section, used in vacuum, may have a skin effect error of less than 1% at frequencies up to 30,000 MHz. Ribbon heaters are often used for large currents, but they have larger skin effects. Solid wire, and better still hollow conductors are ideal with a view to minimising from the skin effect.

Calibration done with dc or low frequency as such as 50 Hz for which the skin effect of the heater is not appreciable. Accuracy can be as high as 1% for frequencies up to 50 MHz. For this reason, thermocouple instruments are classified as RF instruments.

Above 50 MHz the skin effect forces the current to the outer surface of the conductor, increasing the effective resistance of the heating wire and reducing the instrument's accuracy. For small currents of up to 3 A, the heating wire should be solid and very thin. Above 3 A the heating element should be hollow and tubular in design to reduce the skin effect.

2. Non-uniform Distribution of Current

This occurs at frequencies where the heater length is of the order of a fraction of a wavelength (magnitude of one wavelength). The current distribution along the heater is not uniform and the meter indication is uncertain. Hence to avoid this the heater length and its associated leads should be less than 1/10th of a wavelength.

3. Spurious Capacitive Currents

These occur when the thermocouple instrument is connected in such a manner that both terminals are at a potential above ground. As the frequency is increased, a large current flows through the capacitance formed by the thermocouple leads, with the meter acting as one electrode and the ground as the other. To avoid this, proper shielding of the instrument should be provided. The calibration of a thermocouple is reasonably permanent. When calibrating Contact and Mutual with dc, it is always necessary to reverse the polarity to take the average reading. This is because of the resistance drop in the heater at the contact may cause a small amount of dc-current to flow; reversing the calibrating current averages out this effect.

3.9 MEASUREMENTS OF VERY LARGE CURRENTS BY THERMOCOUPLES

Thermocouples instruments with heaters large enough to carry very large currents may have an excessive skin effect. Ordinary shunts cannot be used because the shunting ratio will be affected by the relative inductance and resistance, resulting in a frequency effect.

One solution to this problem consists of minimising the skin effect by employing a heater, which is a tube of large diameter, but with very thin walls.

Another consists of employing an array of shunts of identical resistance arranged symmetrically as shown in Fig. 3.7 (a).

In Fig. 3.7 (a) each filament of wire has the same inductance, so that the inductance causes the current to divide at high frequencies, in the same way as does the resistance at low frequencies. In Fig. 3.7 (b) the condensor shunt is used such that the current divides between the two parallel capacitors proportional to their capacitance, and maintains this ratio independent of frequency, as long as the capacitor that is in series with the thermocouple has a higher impedance than the thermocouple heater and the lead inductance is inversely proportional to the capacitances.

In Fig. 3.7 (c) the current transformer is used to measure very large RF currents at low and moderate frequencies using a thermocouple instrument of ordinary range. Such transformers generally use a magnetic dust core. The current ratio is given by $\dfrac{\text{Primary Current}}{\text{Secondary Current}}$

$$= \frac{1}{K}\sqrt{\frac{L_s}{L_p}}\sqrt{1+\frac{1}{Q_s}}$$

where L_s = secondary inductance

L_p = primary inductance

K = coefficient of coupling between L_p and L_s

r_s = resistance of secondary, including meter resistance

$Q_s = \omega L_s/r_s$ = Q of the secondary circuit taking into account meter resistance

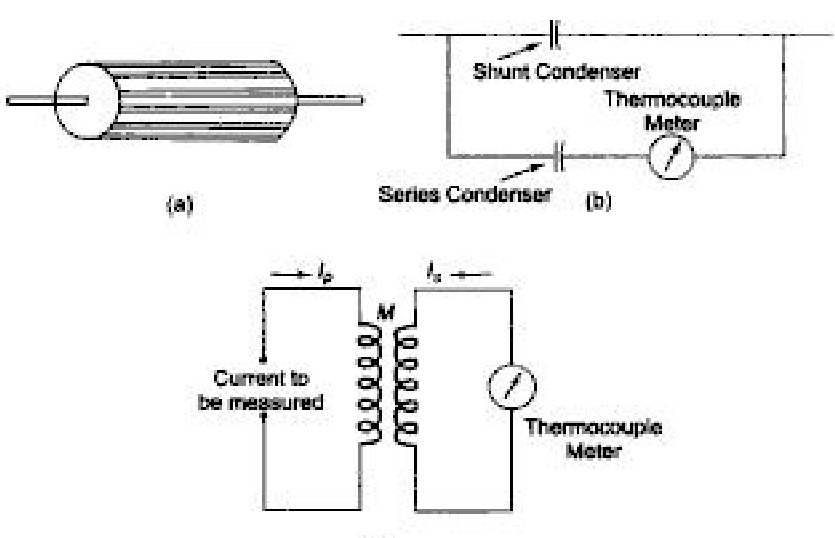

Fig. 3.7 ■ (a) Array of Shunts (b) Condenser Shunt (c) Current Transformer

If Q of the secondary winding is appreciable (i.e. greater than 5), the transformation ratio is independent of frequency.

A current ratio of 1000 or more can be obtained at low and moderate RF by using a many turn secondary wound on a toroidal ring.

Review Questions

1. What type of movement is used for an ammeter?
2. What are the advantages of an Aryton shunt ammeter over a multirange ammeter?
3. What are the requirements of a shunt?
4. What precautions are to be observed when using an Ammeter?
5. What is a thermocouple? State its range of measurement.
6. Explain the construction and working of a thermocouple measuring instrument.
7. Why is a thermocouple measuring instrument classified as an RF instrument?
8. State the different types of thermocouple.
9. How is a large current measured using a thermocouples?
10. What are the limitations of a thermocouple?
11. What are the effects of frequency on the calibration of a thermocouple?

Practice Problems

1. What value of shunt resistance is required for using a 50 μA meter movement, with an internal resistance of 250 Ω for measuring 0 – 500 mA?
2. Design a multirange ammeter with ranges of 0 – 1 A, 5 A, 25 A and 125 A, employing individual shunts in each. A D'Arsonval movement with an internal resistance of 730 Ω and a full scale current of 5 mA is available.
3. Design an Aryton shunt to provide an ammeter with current ranges of 0 – 1 mA, 10 mA, 50 mA, and 100 mA, using a D'Arsonval movement having an internal resistance of 100 Ω and full scale deflections of 50 μA.
4. Design an Aryton shunt to provide an ammeter with current ranges 0 – 10 mA, 100 mA, and 500 mA using a D'Arsonval movement having an internal resistance of 50 Ω and full scale deflections of 1 mA.

Further Reading

1. Terman and Petit, *Electronic Measurements*, McGraw-Hill Book Co, New York, 1952.
2. Sol. D. Prensky, *Electronic Instrumentation*, Prentice-Hall of India, 1963.
3. John. H. Fasal, *Simplified Electronic Measurements*, Hayden Book Co. Inc., Mumbai, 1971.
4. Larry. D. Jones and A. Foster Chin, *Electronic Instruments and Measurements*, John Wiley and Sons, New York, 1987.
5. W.D. Copper and A.D. Helfrick, *Electronic Instrumentation and Measurements Techniques*, 3rd Edition, Prentice-Hall of India, 1985.

CHAPTER 4

Voltmeters and Multimeters

4.1 INTRODUCTION

The most commonly used dc meter is based on the fundamental principle of the motor. The motor action is produced by the flow of a small amount of current through a moving coil which is positioned in a permanent magnetic field. This basic moving system, often called the D'Arsonval movement, is also referred to as the basic meter.

Different instrument forms may be obtained by starting with the basic meter movement and adding various elements, as follows.

1. The basic meter movement becomes a dc instrument, measuring
   (i) dc current, by adding a shunt resistance, forming a microammeter, a milliammeter or an ammeter.
   (ii) dc voltage, by adding a multiplier resistance, forming a milli voltmeter, voltmeter or kilovoltmeter.
   (iii) resistance, by adding a battery and resistive network, forming an ohmmeter.
2. The basic meter movement becomes an ac instrument, measuring
   (i) ac voltage or current, by adding a rectifier, forming a rectifier type meter for power and audio frequencies.
   (ii) RF voltage or current, by adding a thermocouple-type meter for RF.
   (iii) Expanded scale for power line voltage, by adding a thermistor in a resistive bridge network, forming an expanded scale (100 – 140 V) ac meter for power line monitoring.

4.2 BASIC METER AS A DC VOLTMETER

To use the basic meter as a dc voltmeter, it is necessary to know the amount of current required to deflect the basic meter to full scale. This current is known as full scale deflection current (I_{fsd}). For example, suppose a 50 μA current is required for full scale deflection.

This full scale value will produce a voltmeter with a sensitivity of 20,000 Ω per V.

The sensitivity is based on the fact that the full scale current of 50 μA results whenever 20,000 Ω of resistance is present in the meter circuit for each voltage applied.

Sensitivity = $1/I_{fsd}$ = 1/50 μA = 20 kΩ/V

Hence, a 0 – 1 mA would have a sensitivity of 1 V/1 mA = 1 kΩ/V or 1000 Ω.

Example 4.1 Calculate the sensitivity of a 200 μA meter movement which is to be used as a dc voltmeter.

Solution The sensitivity

$$S = \frac{1}{(I_{fsd})} = \frac{1}{200\ \mu\text{A}}$$

Therefore $\qquad S = 5\ \text{k}\Omega/\text{V}$

4.3 DC VOLTMETER

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.

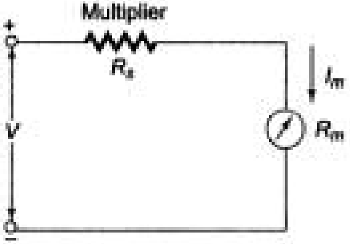

Fig. 4.1 ■ Basic dc Voltmeter

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. 4.1,

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.

A basic D'Arsonval movement with a full scale deflection of 50 μA and internal resistance of 500 Ω is used as a voltmeter. Determine the value of the multiplier resistance needed to measure a voltage range of 0 – 10 V.

Given

$$R_s = \frac{V}{I_m} - R_m = \frac{10}{50\,\mu A} - 500$$

$$= 0.2 \times 10^6 - 500 = 200\text{ k} - 500$$

$$= 199.5\text{ k}\Omega$$

MULTIRANGE VOLTMETER

As in the case of an ammeter, to obtain a multirange ammeter, a number of shunts are connected across the movement with a multi-position switch. Similarly, a dc voltmeter can be converted into a multirange 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 multirange 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 multirange 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.

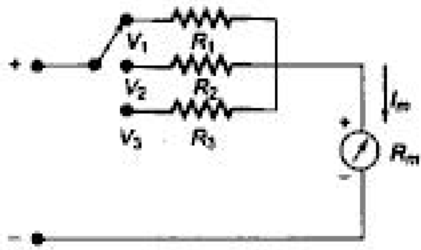

Fig. 4.2 ▬ Multirange Voltmeter

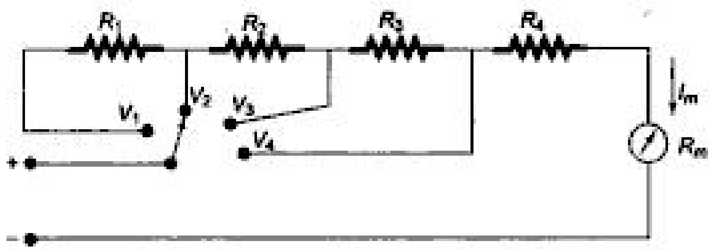

Fig. 4.3 ▬ Multipliers Connected in Series String

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.

Example 4.3 Convert a basic D'Arsonval movement with an internal resistance of 50 Ω and a full scale deflection current of 2 mA into a multirange dc voltmeter with voltage ranges of 0 – 10 V, 0 – 50 V, 0 – 100 V and 0 – 250 V. Refer to Fig. 4.3.

Solution For a 10 V range (V_4 position of switch), the total circuit resistance is

$$R_t = \frac{V}{I_{fsd}} = \frac{10}{2\text{ mA}} = 5\text{ k}\Omega$$

Therefore $\quad R_4 = R_t - R_m = 5\text{ k} - 50 = 4950\ \Omega.$

For 50 V range (V_3 position of switch), the total circuit resistance is

$$R_t = \frac{V}{I_{fsd}} = \frac{50}{2\text{ mA}} = 25\text{ k}\Omega$$

Therefore $\quad R_3 = R_t - (R_4 + R_m) = 25\text{ k} - (4950 + 50) = 25\text{ k} - 5\text{ k}$

$\therefore \quad R_3 = 20\text{ k}\Omega$

For 100 V range (V_2 position of switch), the total circuit resistance is

$$R_t = \frac{V}{I_{fsd}} = \frac{100}{2\text{ mA}} = 50\text{ k}\Omega$$

Therefore, $R_2 = R_t - (R_3 + R_4 + R_m)$

$= 50\text{ k} - (20\text{ k} + 4950 + 50)$

$\therefore \quad R_2 = 50\text{ k} - 25\text{ k} = 25\text{ k}\Omega$

For 250 V range, (V_1 position of switch), the total circuit resistance is

$$R_t = \frac{V}{I_{fsd}} = \frac{250}{2\text{ mA}} = 125\text{ k}\Omega$$

Therefore $R_1 = R_t - (R_2 + R_3 + R_4 + R_m)$

$= 125\text{ k} - (25\text{ k} + 20\text{ k} + 4950 + 50)$

$= 125\text{ k} - 50\text{ k}$

$= 75\text{ k}\Omega$

Only the resistance R_4 (low range multiplier) has a non-standard value.

4.5 EXTENDING VOLTMETER RANGES

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, $S = 1/I_{fsd}$ Ω/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 $R_t = S \times V$

$\therefore$ $R_s = (S \times V) - R_m$

Example 4.4 Calculate the value of the multiplier resistance on the 50 V range of a dc voltmeter, that uses a 200 µA meter movement with an internal resistance of 100 Ω.

Solution As $R_s = S \times$ Range – internal resistance, and $S = 1/I_{fsd}$.

$\therefore$ The sensitivity of the meter movement is

$$S = 1/I_{fsd} = 1/200\ \mu A = 5\ k\Omega/V.$$

The value of multiplier R_s is calculated as

$$R_s = S \times \text{Range} - \text{internal resistance} = S \times V - R_m$$
$$= 5\ k \times 50 - 100$$
$$= 250\ k - 100$$
$$= 249.9\ k\Omega$$

Example 4.5 Calculate the value of multiplier resistance for the multiple range dc voltmeter circuit shown in Fig. 4.5.

Solution The sensitivity of the meter movement is given as follows.

$$S = 1/I_{fsd} = 1/50\ \mu A = 20\ k\Omega/V$$

The value of the multiplier resistance can be calculated as follows.
For 5V range

$$R_{s_1} = S \times V - R_m$$
$$= 20\ k \times 5 - 1\ k$$
$$= 100\ k - 1\ k$$
$$= 99\ k\Omega$$

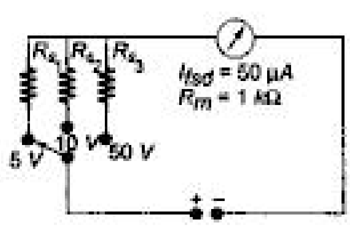

Fig. 4.5

For 10 V range

$$R_{s_2} = S \times V - R_m$$
$$= 20\ k \times 10 - 1\ k$$
$$= 200\ k - 1\ k$$
$$= 199\ k\Omega$$

For 50 V range

$$R_{s_3} = S \times V - R_m$$

$$= 20\ k \times 50 - 1\ k$$
$$= 1000\ k - 1\ k$$
$$= 999\ k\Omega$$

4.8 LOADING

When selecting a meter for a certain voltage measurement, it is important to consider the sensitivity of a dc voltmeter. A low sensitivity meter may give a correct reading when measuring voltages in a low resistance circuit, but it is certain to produce unreliable readings in a high resistance circuit. A Voltmeter when connected across two points in a highly resistive circuits, acts as a shunt for that portion of the circuit, reducing the total equivalent resistance of that portion as shown in Fig. 4.6. The meter then indicates a lower reading than what existed before the meter was connected. This is called the loading effect of an instrument and is caused mainly by low sensitivity instruments.

Example 4.8 Figure 4.6 shows a simple series circuit of R_1 and R_2 connected to a 100 V dc source. If the voltage across R_2 is to be measured by voltmeters having

(a) a sensitivity of 1000 Ω/V, and
(b) a sensitivity of 20,000 Ω/V, find which voltmeter will read the accurate value of voltage across R_2. Both the meters are used on the 50 V range.

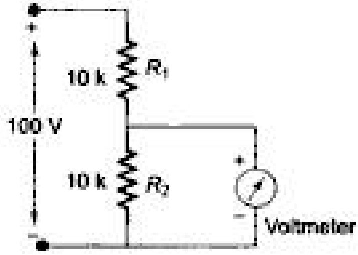

Fig. 4.6 ▬ Example on Loading Effect

Solution Inspection of the circuit indicates that the voltage across the R_2 resistance is

$$\frac{10\ k}{10\ k + 10\ k} \times 100\ V = 50\ V$$

This is the true voltage across R_2.

Case I

Using a voltmeter having a sensitivity of 1000 Ω/V.

It has a resistance of 1000 × 50 = 50 kΩ on its 50 V range.

Connecting the meter across R_2 causes an equivalent parallel resistance given by

$$R_{eq} = \frac{10\ k \times 50\ k}{10\ k + 50\ k} = \frac{500\ M}{60\ k} = 8.33\ k\Omega$$

Now the voltage across the total combination is given by

$$V_1 = \frac{R_{eq}}{R_1 + R_{eq}} \times V$$

$$V_1 = \frac{8.33\ \text{k}}{10\ \text{k} + 8.33\ \text{k}} \times 100\ \text{V} = 45.43\ \text{V}$$

Hence this voltmeter indicates 45.43 V.

Case 2

Using a voltmeter having a sensitivity of 20,000 Ω/V. Therefore it has a resistance of

$$20{,}000 \times 50 = 1000\ \text{k} = 1\ \text{M}\Omega$$

This voltmeter when connected across R_2 produces an equivalent parallel resistance given by

$$R_{eq} = \frac{10\ \text{k} \times 1\ \text{M}}{10\ \text{k} + 1\ \text{M}} = \frac{10^9}{1.01\ \text{M}} = \frac{10\ \text{k}}{1.01} = 9.9\ \text{k}\Omega$$

Now the voltage across the total combination is given by

$$V_2 = \frac{9.9\ \text{k}}{10\ \text{k} + 9.9\ \text{k}} \times 100\ \text{V} = 49.74\ \text{V}$$

Hence this voltmeter will read 49.74 V.

This example shows that a high sensitivity voltmeter should be used to get accurate readings.

Example 4.7 Two different voltmeters are used to measure the voltage across R_b in the circuit of Fig. 4.7.

The meters are as follows.

Meter 1: $S = 1$ kΩ/V, $R_m = 0.2$ k, range 10 V

Meter 2: $S = 20$ kΩ/V, $R_m = 1.5$ k, range 10 V

Calculate (i) voltage across R_b without any meter across it, (ii) voltage across R_b when the meter 1 is used (iii) voltage across R_b when the meter 2 is used, and (iv) error in the voltmeters.

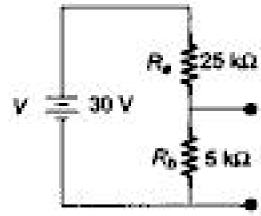

Fig. 4.7

Solution (i) The voltage across the resistance R_b, without either meter connected, is calculated using the voltage divider formula.

$$\text{Therefore,}\ VR_b = \frac{5\ \text{k}}{25\ \text{k} + 5\ \text{k}} \times 30 = \frac{150\ \text{k}}{30\ \text{k}} = 5\ \text{V}$$

(ii) Starting with meter 1, having sensitivity $S = 1$ kΩ/V

Therefore the total resistance it presents to the circuit

$$R_{m_1} = S \times \text{range} = 1\ \text{k}\Omega/\text{V} \times 10 = 10\ \text{k}\Omega$$

The total resistance across R_b is, R_b in parallel with meter resistance R_{m_1}

$$R_{eq} = \frac{R_b \times R_{m_1}}{R_b + R_{m_1}} = \frac{5\text{ k} \times 10\text{ k}}{5\text{ k} + 10\text{ k}} = 3.33\text{ k}\Omega$$

Therefore, the voltage reading obtained with meter 1 using the voltage divider equation is

$$VR_b = \frac{R_{eq}}{R_{eq} + R_a} \times V = \frac{3.33\text{ k}}{3.33\text{ k} + 25\text{ k}} \times 30 = 3.53\text{ V}$$

(iii) The total resistance that meter 2 presents to the circuit is

$$R_{m_2} = S \times \text{range} = 20\text{ k}\Omega/\text{V} \times 10\text{ V} = 200\text{ k}\Omega$$

The parallel combination of R_b and meter 2 gives

$$R_{eq} = \frac{R_b \times R_{m_2}}{R_b \times R_{m_2}} = \frac{5\text{ k} \times 200\text{ k}}{5\text{ k} + 200\text{ k}} = \frac{1000\text{ k} \times 1\text{ k}}{205\text{ k}} = 4.88\text{ k}\Omega$$

Therefore the voltage reading obtained with meter 2, using the voltage divider equation is

$$VR_b = \frac{4.88\text{ k}}{25\text{ k} + 4.88\text{ k}} \times 30 = \frac{4.88\text{ k}}{29.88\text{ k}} \times 30 = 4.9\text{ V}$$

(iv) The error in the reading of the voltmeter is given as:

$$\%\text{ Error} = \frac{\text{Actual voltage} - \text{Voltage reading observed in meter}}{\text{Actual voltage}} \times 100\%$$

$$\therefore \qquad \text{voltmeter 1 error} = \frac{5\text{ V} - 3.33\text{ V}}{5\text{ V}} \times 100\% = 33.4\%$$

$$\text{Similarly voltmeter 2 error} = \frac{5\text{ V} - 4.9\text{ V}}{5\text{ V}} \times 100\% = 2\%$$

Example 4.8 Find the voltage reading and % error of each reading obtained with a voltmeter on (i) 5 V range, (ii) 10 V range and (iii) 30 V range, if the instrument has a 20 kΩ/V sensitivity and is connected across R_b of Fig. 4.8.

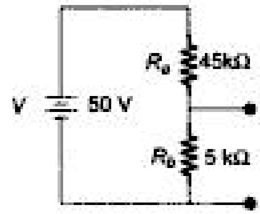

Fig. 4.8

Solution The voltage drop across R_b, without the voltmeter connected is calculated using the voltage equation

$$VR_b = \frac{R_b}{R_a + R_b} \times V = \frac{5\text{ k}}{45\text{ k} + 5\text{ k}} \times 50 = \frac{50 \times 5\text{ k}}{50\text{ k}} = 5\text{ V}$$

On the 5 V range

$$R_m = S \times \text{range} = 20\text{ k}\Omega \times 5\text{ V} = 100\text{ k}\Omega$$

$$\therefore \qquad R_{eq} = \frac{R_m \times R_b}{R_m + R_b} = \frac{100\text{ k} \times 5\text{ k}}{100\text{ k} + 5\text{ k}} = \frac{500\text{ k}}{105\text{ k}} = 4.76\text{ k}\Omega$$

The voltmeter reading is

$$VR_b = \frac{R_{eq}}{R_a + R_{eq}} \times V = \frac{4.76\text{ k}}{45\text{ k} + 4.76\text{ k}} \times 50 = 4.782\text{ V}$$

The % error on the 5 V range is

$$\%\text{ error} = \frac{\text{Actual voltage} - \text{Voltage reading in meter}}{\text{Actual voltage}}$$

$$= \frac{5\text{ V} - 4.782\text{ V}}{5\text{ V}} \times 100 = \frac{0.217\text{ V}}{5\text{ V}} \times 100 = 4.34\%$$

On 10 V range

$$R_m = S \times \text{range} = 20\text{ k}\Omega/\text{V} \times 10\text{ V} = 200\text{ k}\Omega$$

$$\therefore \qquad R_{eq} = \frac{R_m \times R_b}{R_m + R_b} = \frac{200\text{ k} \times 5\text{ k}}{200\text{ k} + 5\text{ k}} = 4.87\text{ k}\Omega$$

The voltmeter reading is

$$V_{R_b} = \frac{R_{eq}}{R_{eq} + R_a} \times V = \frac{4.87\text{ k}}{4.87\text{ k} + 45\text{ k}} \times 50 = 4.88\text{ V}$$

$$\text{The \% error on the 10 V range} = \frac{5\text{ V} - 4.88\text{ V}}{5\text{ V}} \times 100 = 2.34\%$$

On 30 V range

$$R_m = S \times \text{range} = 20\text{ k}\Omega/\text{V} \times 30\text{ V} = 600\text{ k}$$

$$\therefore \qquad R_{eq} = \frac{R_m \times R_b}{R_m + R_b} = \frac{600\text{ k} \times 5\text{ k}}{600\text{ k} + 5\text{ k}} = \frac{3000\text{ k} \times 1\text{ k}}{605\text{ k}} = 4.95\text{ k}$$

The voltmeter reading on the 30 V range

$$V_{R_b} = \frac{R_{eq}}{R_{eq} + R_a} \times V = \frac{4.95\text{ k}}{45\text{ k} + 4.95\text{ k}} \times 50 = 4.95\text{ V}$$

The % error on the 30 V range

$$= \frac{5\text{ V} - 4.95\text{ V}}{5\text{ V}} \times 100 = \frac{0.05}{5\text{ V}} \times 100 = 1\%$$

In the above example, the 30 V range introduces the least error due to loading. However, the voltage being measured causes only a 10% full scale deflection, whereas on the 10 V range the applied voltage causes approximately a one third of the full scale deflection with less than 3% error.

4.7 TRANSISTOR VOLTMETER (TVM)

Direct coupled amplifiers are economical and hence used widely in general purpose low priced VTVM's. Figure 4.9 gives a simplified schematic diagram of a dc coupled amplifier with an indicating meter. The dc input is applied to a range attenuator to provide input voltage levels which can be accommodated by the dc amplifier. The input stage of the amplifier consists of a FET which provides high input impedance to effectively isolate the meter circuit from the circuit under measurement. The input impedance of a FET is greater than 10 MΩ. The bridge is balanced, so that for zero input the dial indicates zero.

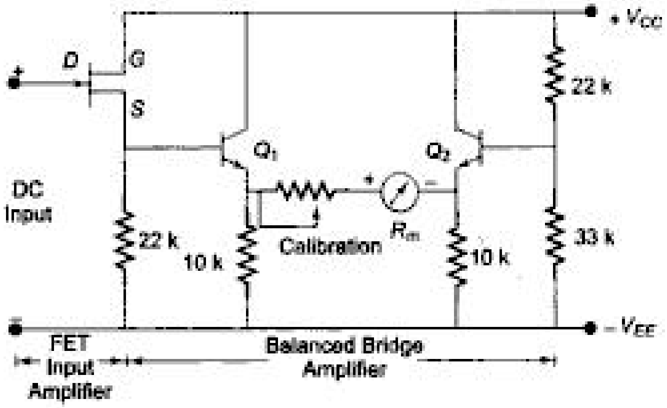

Fig. 4.9 ■ Transistor Voltmeter

The two transistors, Q_1 and Q_2 forms a dc coupled amplifier driving the meter movement. Within the dynamic range of the amplifier, the meter deflection is proportional to the magnitude of the applied input voltage. The input overload does not burn the meter because the amplifier saturates, limiting the maximum current through the meter. The gain of the dc amplifier allows the instrument to be used for measurement of voltages in the mV range. Instruments in the μV range of measurement require a high gain dc amplifier to supply sufficient current for driving the meter movement. In order to avoid the drift problems of dc amplifiers, chopper type dc amplifiers are commonly used in high sensitivity voltmeters.

4.8 CHOPPER TYPE DC AMPLIFIER VOLTMETER (MICROVOLTMETER)

In a chopper type amplifier the dc input voltage is converted into an ac voltage, amplified by an ac amplifier and then converted back into a dc voltage proportional to the original input signal.

The balanced bridge voltmeter has limitations caused by drift problems in dc amplifier. Any fluctuations of voltage supply or variation in the 'Q' characteristics due to ageing or rise in temperature causes a change in the zero setting or balance. This drift in the steady state conditions of a dc amplifier causes the output indications to change as if the signal input had changed. This drift problem limits the minimum voltage that can be measured. To measure small voltages, a chopper type dc amplifier is used.

A chopper amplifier is normally used for the first stage of amplification in very sensitive instruments of a few µV range. In such an amplifier the dc voltage is chopped to a low frequency of 100 – 300 Hz. It is passed through a blocking capacitor, amplified and then passed through another blocking capacitor, in order to remove the dc drift or offset of the amplified signal.

The principle of operation is as given in Fig. 4.10. An ac amplifier which has a very small drift compared to a dc amplifier is used. The chopper may be mechanical or electronic. Photo diodes are used as nonmechanical choppers for modulation (conversion of dc to ac) and demodulation (conversion of ac to dc). Photo conductors have a low resistance, ranging from a few hundreds to a few thousand ohms, when they are illuminated by a neon or incandescent lamp. The photo conductor resistance increases sharply, usually to several Mega ohms when not illuminated.

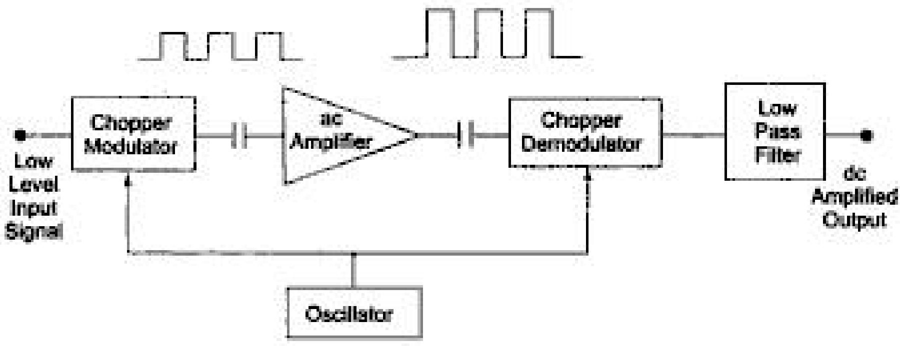

Fig. 4.10 Principle of Operation (Chopper Type Voltmeter)

Figure 4.11 (a) shows a simple circuit for an basic principle of an electronic modulator.

A flashing light source, whose intensity varies from maximum to minimum almost instantaneously, causes the photo diode resistance to change from R_{min} to R_{max} quickly. Therefore the output voltage is an ac, because the photo diode

potentiometer is called zero set and is used for adjusting zero output for zero input conditions.

The two diodes used are for IC protection. Under normal conditions, they are non-conducting, as the maximum voltage across them is 10 mV. If an excessive voltage, say more than 100 mV appears across them, then depending upon the polarity of the voltage, one of the diodes conducts and protects the IC. A μA scale of 50 – 1000 μA full scale deflection can be used as an indicator. R_4 is adjusted to get maximum full scale deflection.

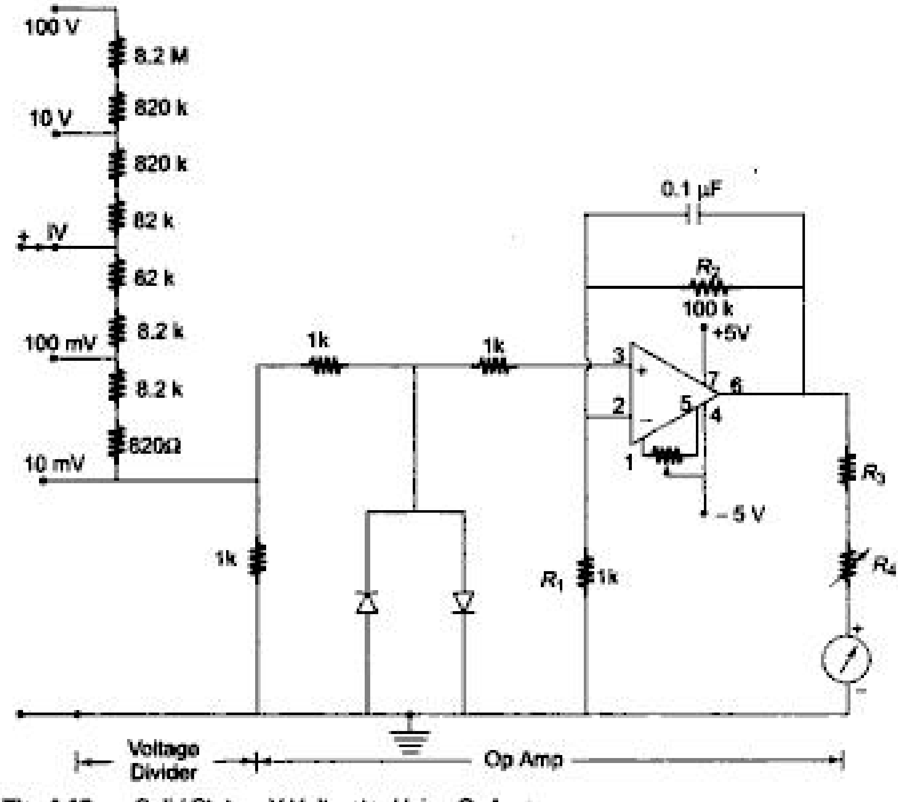

Fig. 4.13 ■ Solid State mV Voltmeter Using OpAmp

4.10 DIFFERENTIAL VOLTMETER

Basic differential measurement

The differential voltmeter technique, is one of the most common and accurate methods of measuring unknown voltages. In this technique, the voltmeter is used to indicate the difference between known and unknown voltages, i.e., an unknown voltage is compared to a known voltage.

Figure 4.14 (a) shows a basic circuit of a differential voltmeter based on the potentiometric method; hence it is sometimes also called a potentiometric voltmeter.

In this method, the potentiometer is varied until the voltage across it equals the unknown voltage, which is indicated by the null indicator reading zero. Under null conditions, the meter draws current from neither the reference source nor the unknown voltage source, and hence the differential voltmeter presents an infinite impedance to the unknown source. (The null meter serves as an indicator only.)

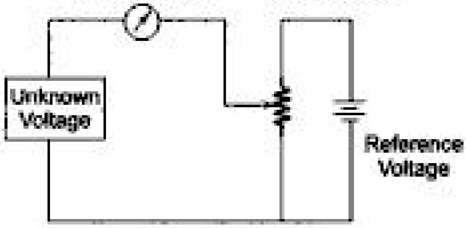

Fig. 4.14 (a) Basic Differential Voltmeter

To detect small differences the meter movement must be sensitive, but it need not be calibrated, since only zero has to be indicated.

The reference source used is usually a 1 V dc standard source or a zener controlled precision supply. A high voltage reference supply is used for measuring high voltages.

The usual practice, however, is to employ voltage dividers or attenuators across an unknown source to reduce the voltage. The input voltage divider has a relatively low input impedance, especially for unknown voltages much higher than the reference standard. The attenuation will have a loading effect and the input resistance of voltmeter is not infinity when an attenuator is used.

In order to measure ac voltages, the ac voltage must be converted into dc by incorporating a precision rectifier circuit. A block diagram of an ac differential voltmeter is shown in Fig. 4.14 (b).

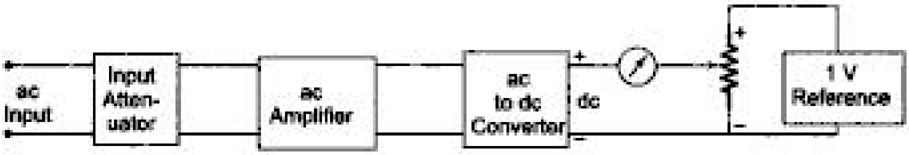

Fig. 4.14 (b) Block Diagram of an ac Differential Voltmeter

4.11 DC STANDARD/DIFFERENCE VOLTMETER

Multifunction laboratory instrument

A basic dc standard differential voltmeter can be operated in different modes. The three basic modes of operation are (i) as a dc voltage standard, (ii) as a dc differential voltmeter, and (iii) as a dc voltmeter (conventional).

1. DC Voltage Standard

A + 1 V dc stable supply is obtained from a temperature controlled reference supply, which is applied to a decimal divider network. With the help of switches on the front panel of the voltmeter, the divider ratios can be controlled (varied),

3. DC Voltmeter

In this mode of operation the instrument is connected as a dc voltmeter. High input impedance to the unknown voltage source is provided by the dc amplifier, which act as a buffer stage.

The input voltage is amplified and the dc output voltage is applied directly to the meter circuit. The meter circuit involves a feedback controlled amplifier and allows a selection of the sensitivity.

4.12 AC VOLTMETER USING RECTIFIERS

Rectifier type instruments generally use a PMMC movement along with a rectifier arrangement. Silicon diodes are preferred because of their low reverse current and high forward current ratings. Figure 4.16 (a) gives an ac voltmeter circuit consisting of a multiplier, a bridge rectifier and a PMMC movement.

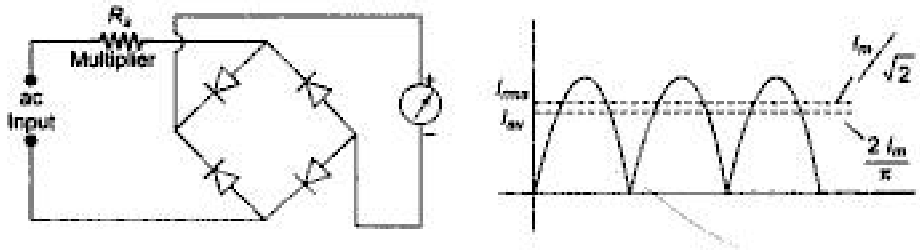

Fig. 4.16 ■ (a) ac Voltmeter (b) Average and RMS Value of Current

The bridge rectifier provides a full wave pulsating dc. Due to the inertia of the movable coil, the meter indicates a steady deflection proportional to the average value of the current (Fig. 4.16 (b)). The meter scale is usually calibrated to give the RMS value of an alternating sine wave input.

Practical rectifiers are non-linear devices particularly at low values of forward current (Fig. 4.16 (c)). Hence the meter scale is non-linear and is generally crowded at the lower end of a low range voltmeter. In this part the meter has low sensitivity because of the high forward resistance of the diode. Also, the diode resistance depends on the temperature.

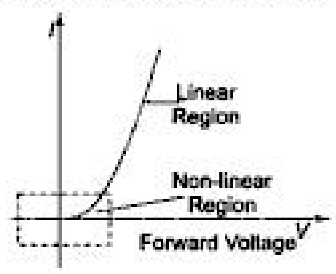

Fig. 4.16 ■ (c) Diode Characteristics (Forward)

The rectifier exhibits capacitance properties when reverse biased, and tends to bypass higher frequencies. The meter reading may be in error by as much as 0.5% decrease for every 1 kHz rise in frequency.

A general rectifier type ac voltmeter arrangement is given in Fig. 4.17.

As $E_{dc} = 0.45 \times E_{rms}$

$\therefore$ The value of the multiplier resistor can be calculated as

$$R_s = \frac{E_{dc}}{I_{dc}} - R_m = \frac{0.45 \times E_{rms}}{I_{dc}} - R_m$$

Example 4.9 Calculate the value of the multiplier resistor for a 10 V rms range on the voltmeter shown in Fig. 4.19.

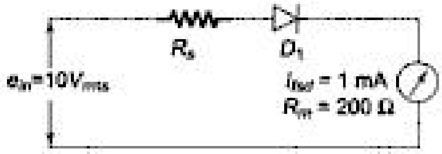

Fig. 4.19

Solution

Method 1 Sensitivity of the meter movement is

$$S_{dc} = 1/I_{fsd} = 1/1 \text{ mA} = 1 \text{ k}\Omega$$

$$R_s = S_{dc} \times \text{range} - R_m = 1 \text{ k}\Omega/\text{V} \times 0.45\, E_{rms} - R_m$$

$$= 1 \text{ k}\Omega/\text{V} \times 0.45 \text{ V} \times 10 \text{ V} - 200\ \Omega$$

$$= 4500 - 200$$

$$= 4.3 \text{ k}\Omega$$

Method 2

$$R_s = \frac{0.45 \times E_{rms}}{1 \text{ mA}} - R_m = \frac{0.45 \times 10}{1 \text{ mA}} - 200$$

$$= 4.5 \text{ k} - 0.2 \text{ k}$$

$$= 4.3 \text{ k}\Omega$$

4.14 AC VOLTMETER USING FULL WAVE RECTIFIER

Consider the circuit shown in Fig. 4.20. The peak value of a 10 V rms signal is

$$E_p = 1.414 \times E_{rms}$$

$$= 1.414 \times 10 = 14.14 \text{ V peak}$$

Average value is

$$E_{av} = 0.636 \times E_{peak}$$

$$= 14.14 \times 0.636 = 8.99 \text{ V}$$
$$\cong 9 \text{ V}$$

Therefore, we can see that a 10 V rms voltage is equal to a 9 V dc for full scale deflection, i.e. the pointer will deflect to 90% of full scale, or

$$\text{Sensitivity (ac)} = 0.9 \times \text{Sensitivity (dc)}$$

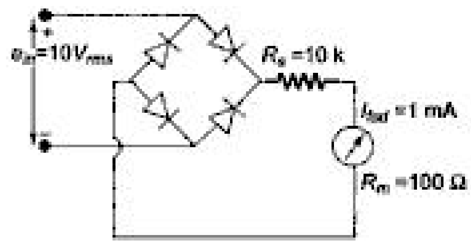

Fig. 4.20 ▬ ac Voltmeter Using Full Wave Rectifier

Example 4.10 Calculate the value of the multiplier resistor for a 10 V rms ac range on the voltmeter in Fig. 4.21

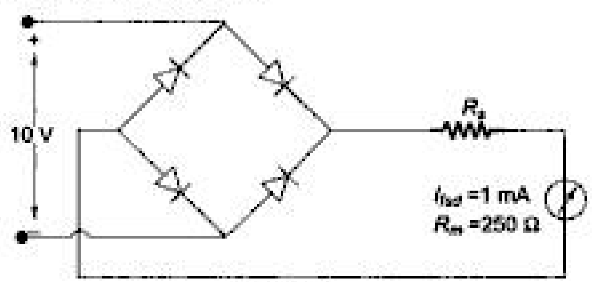

Fig. 4.21

Solution The dc sensitivity is given by

$$S_{dc} = 1/I_{fsd} = 1/1 \text{ mA} = 1 \text{ k}\Omega/\text{V}$$

Therefore AC sensitivity = 0.9 × dc sensitivity

$$S_{ac} = 0.9 \times 1 \text{ k}\Omega/\text{V}$$
$$= 0.9 \text{ k}\Omega/\text{V}$$

The multiplier resistor is given by

$$R_s = S_{ac} \times \text{range} - R_m = 0.9 \text{ k}\Omega/\text{V} \times 10 \text{ V} - 250$$
$$= 900 \times 10 - 250$$
$$= 9000 - 250$$
$$= 8750$$
$$= 8.75 \text{ k}\Omega$$

4.15 MULTIRANGE AC VOLTMETER

Figure 4.22 is circuit for measuring ac voltages for different ranges. Resistances R_1, R_2, R_3 and R_4 form a chain of multipliers for voltage ranges of 1000 V, 250 V, 50 V, and 10 V respectively.

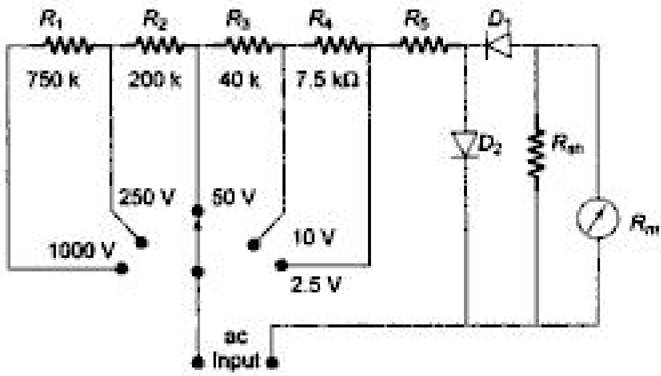

Fig. 4.22 ▬ Multirange ac Voltmeter

On the 2.5 V range, resistance R_5 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.

4.16 AVERAGE RESPONDING VOLTMETER

A simplified version of a circuit used in a typical average responding voltmeters is given in Fig. 4.23.

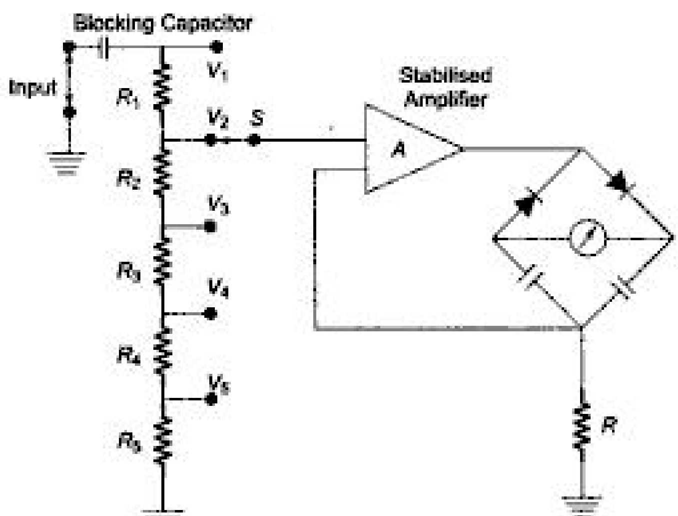

Fig. 4.23 ▬ Block Diagram of Average Responding Voltmeter

circuit under test keeps the capacitor charged to the peak ac voltage. The dc amplifier is used in the peak responding meter to develop the necessary meter current.

The primary advantage of a peak responding voltmeter is that the rectifying diode and the storage capacitor may be taken out of the instrument and placed in the probe when no ac pre-amplification is required. The measured ac signal then travels no farther than the diode. The peak responding voltmeter is then able to measure frequencies of up to 100s of MHz with a minimum of circuit loading. The disadvantage of peak responding voltmeters is the error caused due to harmonic distortion in the input waveforms and limited sensitivity of the instrument because of imperfect diode characteristics.

4.18 TRUE RMS VOLTMETER

Complex waveform are most accurately measured with an rms voltmeter. This instrument produces a meter indication by sensing waveform heating power, which is proportional to the square of the rms value of the voltage. This heating power can be measured by amplifying and feeding it to a thermocouple, whose output voltages is then proportional to the E_{rms}.

However, thermocouples are non-linear devices. This difficulty can be overcome in some instruments by placing two thermocouples in the same thermal environment.

Figure 4.25 shows a block diagram of a true rms responding voltmeter.

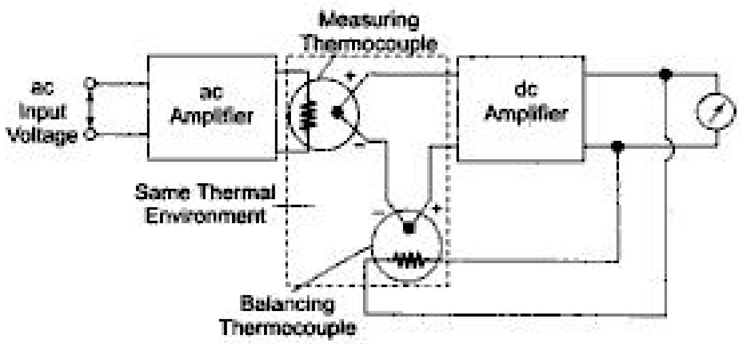

Fig. 4.25 ■■ True RMS Voltmeter (Block Diagram)

The effect of non-linear behaviour of the thermocouple in the input circuit (measuring thermocouple) is cancelled by similar non-linear effects of the thermocouple in the feedback circuit (balancing thermocouple). The two couples form part of a bridge in the input circuit of a dc amplifier.

The unknown ac voltage is amplified and applied to the heating element of the measuring thermocouple. The application of heat produces an output voltage that upsets the balance of the bridge.

The dc amplifier amplifies the unbalanced voltage; this voltage is fed back to the heating element of the balancing thermocouple, which heats the

thermocouple, so that the bridge is balanced again, i.e. the outputs of both the thermocouples are the same. At this instant, the ac current in the input thermocouple is equal to the dc current in the heating element of the feedback thermocouple. This dc current is therefore directly proportional to the effective or rms value of the input voltage, and is indicated by the meter in the output circuit of the dc amplifier. If the peak amplitude of the ac signal does not exceed the dynamic range of the ac amplifier, the true rms value of the ac signal can be measured independently.

4.19 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.

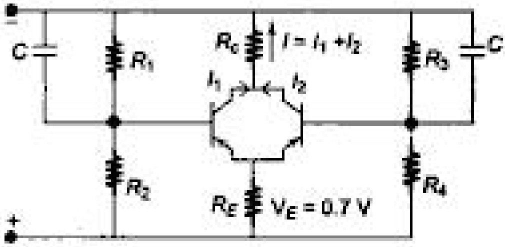

Fig. 4.26 Squaring Device

The basic circuit of Fig. 4.26 employing two transistors is completed by a bridge arrangement in which the dc component is cancelled out. This bridge arrangement is given in Fig. 4.27.

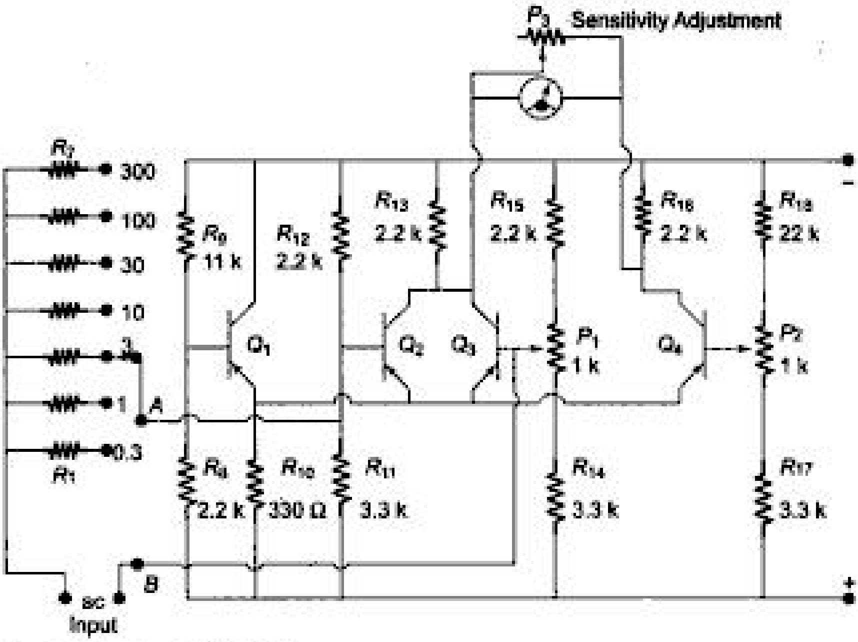

Fig. 4.27 ▬ True RMS Meter

One side of the bridge consists of two parallel connected transistors Q_2 and Q_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 Q_4, 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.

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.

4.20 CONSIDERATIONS IN CHOOSING AN ANALOG VOLTMETER

In choosing an analog voltmeter the following factors are to be considered.

1. Input Impedance

The input impedance or resistance of the voltmeter should be as high as possible. It should always be higher than the impedance of the circuit under measurement to avoid the loading effect, discussed in Section 4.6.

The shunt capacitance across the input terminals also determines the input impedance of the voltmeter. At higher frequencies the loading effect of the meter is noticeable, since the shunt capacitance reactance falls and the input shunt reduces the input impedance.

2. Voltage Ranges

The voltage ranges on the meter scale may be in a 1–3–10 sequence with 10 db separation or a 1.5–5–15 sequence or in a single scale calibrated in decibels. In any case, the scale division should be compatible with the accuracy of the instrument.

3. Decibels

For measurements covering a wide range of voltages, the use of the decibel scale can be very effective, e.g., in the frequency response curve of an amplifier, where the output voltage is measured as a function of the frequency of the applied input voltage.

4. Sensitivity v/s Bandwidth

Noise consists of unwanted frequencies. Since noise is a function of the bandwidth, a voltmeter with a narrow bandwidth picks up less noise than a large bandwidth voltmeter.

In general, an instrument with a bandwidth of 10 Hz–10 MHz has a sensitivity of 1 mV. Some voltmeters whose bandwidth extends up to 5 MHz may have a sensitivity of 100 μV.

5. Battery Operation

A voltmeter (VTVM) powered by an internal battery is essential for field work.

6. AC Current Measurements

Current measurements can be made by a sensitive ac voltmeter and a series resistor.

To summarise, the general guidelines are as follows.

(i) For dc measurement, select the meter with the widest capability meeting the requirements of the circuit.
(ii) For ac measurements involving sine waves with less than 10% distortion, the average responding voltmeter is most sensitive and provides the best accuracy.
(iii) For high frequency measurement (> 10 MHz), the peak responding voltmeter with a diode probe input is best. Peak responding circuits are acceptable if inaccuracies caused by distortion in the input waveform are allowed (tolerated).
(iv) For measurements where it is important to find the effective power of waveforms that depart from the true sinusoidal form, the rms responding voltmeter is the appropriate choice.

4.21 OHMMETER (SERIES TYPE OHMMETER)

A D'Arsonval movement is connected in series with a resistance R_1 and a battery which is connected to a pair of terminals A and B, across which the unknown resistance is connected. This forms the basic type of series ohmmeter, as shown in Fig. 4.28 (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. 4.28 (a)

R_1 = current limiting resistance

R_2 = zero adjust resistance

V = battery

R_m = meter resistance

R_x = unknown resistance

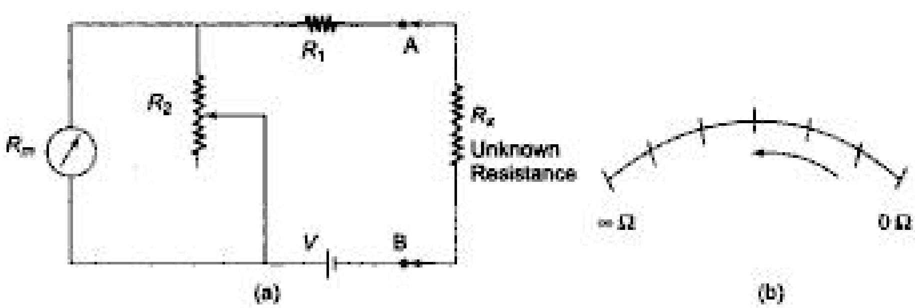

Fig. 4.28 ■ (a) Series Type Ohmmeter (b) Dial of Series Ohmmeter

Therefore $$V_{sh} = V_m$$

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

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

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

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

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

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

Therefore $$R_2 = \frac{I_{fsd} R_m R_h}{V - I_{fsd} R_h} \tag{4.1}$$

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 $$R_1 = R_h - \frac{I_{fsd} R_m R_h}{V} \tag{4.2}$$

Hence, R_1 and R_2 can be determined.

Example 4.11 A 100 Ω basic movement is to be used as an ohmmeter requiring a full scale deflection of 1 mA and internal battery voltage of 3 V. A half scale deflection marking of 2 k is desired. Calculate (i) value of R_1 and R_2, and (ii) The maximum value of R_2 to compensate for a 5% drop in battery voltage.

Solution (i) Using the equations for R_1 and R_2 we have,

$$R_1 = R_h - \frac{I_{fsd} \times R_m \times R_h}{V} \quad \text{and} \quad R_2 = \frac{I_{fsd} \times R_m \times R_h}{V - (I_{fsd} \times R_h)}$$

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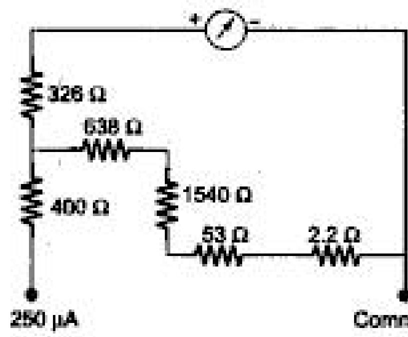

Fig. 4.34 ■■ Micro Ammeter Section of a Multimeter

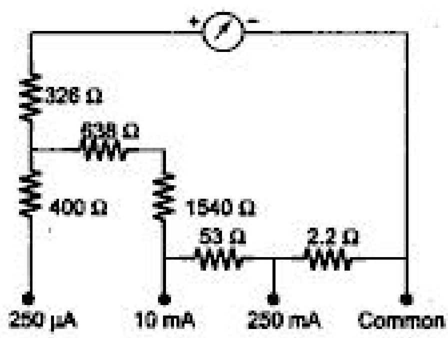

Fig. 4.35 ■■ dc Ammeter Section of a Multimeter

DC Voltmeter

Figure 4.36 shows the dc voltmeter section of a multimeter.

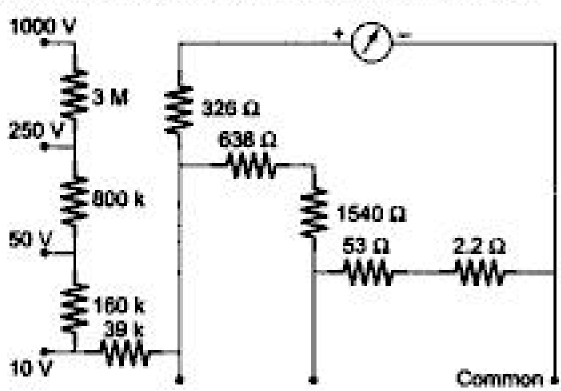

Fig. 4.36 ■■ DC Voltmeter Section of a Multimeter

AC Voltmeter

Figure 4.37 shows the ac voltmeter section of a multimeter. To measure ac voltage, the output ac voltage is rectified by a half wave rectifier before the

value of 100 Ω. Diodes D_1 and D_2 have an average forward resistance of 400 Ω and are assumed to have infinite reverse resistance in the reverse direction. For 10 V ac range, calculate (i) the value of the multiplier, (ii) the voltmeter sensitivity on ac range. (R_s = 1800, S = 225 Ω/V). Refer to Fig. 4.41.

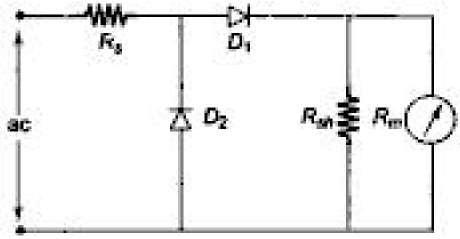

Fig. 4.41

4. The circuit diagram of Fig. 4.42 shows a full wave rectifier ac voltmeter. The meter movement has an internal resistance of 250 Ω and required 1 mA for full scale deflection. The diodes each have a forward resistance of 50 Ω and infinite reverse resistance.
   Calculate:
   (i) the series resistance required for full scale meter deflection when 25 V rms is applied to the meter terminals.
   (ii) the ohms per volt rating of this ac voltmeter.

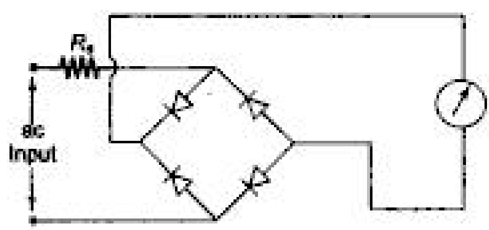

Fig. 4.42

5. A series ohmmeter uses a 50 Ω basic movement requiring a full scale deflection of 1 mA. The internal battery voltage is 3 V. The desired scale marking for half scale deflection is 2000 Ω.
   Calculate
   (i) values of R_1 and R_2
   (ii) maximum value of R_2 to compensate for a 10% drop in battery.
6. A series type ohmmeter is designed to operate with a 6 V battery. The meter movement has an internal resistance of 2 kΩ and requires a current of 100 μA for full scale deflection. The value of R_1 is 49 k.
   (i) Assuming the battery voltage has fallen to 5.9 V, calculate the value of R_2 required to "0" the meter.
   (ii) Under the condition mentioned in (i), an unknown resistance is connected to the meter, causing a 60% deflection. Calculate the value of the unknown resistance.

ramp has reached zero value. The ground comparator compares the ramp with ground. When the ramp voltage equals zero or reaches ground potential, the ground comparator generates a stop pulse. The output pulse from this comparator closes the gate. The time duration of the gate opening is proportional to the input voltage value.

In the time interval between the start and stop pulses, the gate opens and the oscillator circuit drives the counter. The magnitude of the count indicates the magnitude of the input voltage, which is displayed by the readout. Therefore, the voltage is converted into time and the time count represents the magnitude of the voltage. The sample rate multivibrator determines the rate of cycle of measurement. A typical value is 5 measuring cycles per second, with an accuracy of ± 0.005% of the reading. The sample rate circuit provides an initiating pulse for the ramp generator to start its next ramp voltage. At the same time a reset pulse is generated, which resets the counter to the zero state.

Any DVM has a fundamental cycle sequence which involves sampling, displaying and reset sequences.

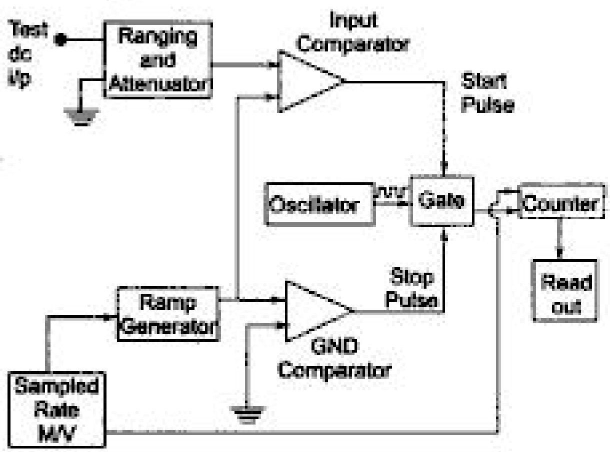

Fig. 5.2 ■ Block Diagram of Ramp Type DVM

Advantages and Disadvantages

The ramp technique circuit is easy to design and its cost is low. Also, the output pulse can be transmitted over long feeder lines. However, the single ramp requires excellent characteristics regarding linearity of the ramp and time measurement. Large errors are possible when noise is superimposed on the input signal. Input filters are usually required with this type of converter.

DUAL SLOPE INTEGRATING TYPE DVM (VOLTAGE TO TIME CONVERSION)

In ramp techniques, superimposed noise can cause large errors. In the dual ramp technique, noise is averaged out by the positive and negative ramps using the process of integration.

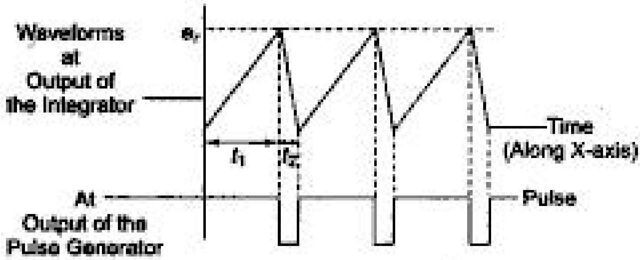

Fig. 5.7

The voltage-frequency conversion can be considered to be a dual slope method, as shown in Fig. 5.7.

Referring to Eq. 5.3 we have

$$e_i = \frac{e_r\, t_2}{t_1}$$

But in this case e_r and t_2 are constants.

Let $$K_2 = e_r\, t_2$$

$\therefore$ $$e_i = K_2\left(\frac{1}{t_1}\right) = K_2\,(f_0)$$

The output frequency is proportional to the input voltage e_i. This DVM has the disadvantage that it requires excellent characteristics in linearity of the ramp. The ac noise and supply noise are averaged out.

An integrator contains a 100 kΩ and 1 μF capacitor. If the voltage applied to the integrator input is 1 V, what voltage will be present at the output of the integrator after 1 s.

Using the equation

$$e_o = \frac{e_i \times t_1}{RC} = \frac{1 \times 1\,\text{s}}{100\,\text{k} \times 1\,\mu\text{F}} = \frac{1}{0.1} = 10\ \text{V}$$

Now if a reference voltage is applied to the integrator of the above example at time t_1 is 5 V in amplitude, what is the time interval of t_2?

Using the equation

$$\frac{e_i \times t_1}{RC} = \frac{e_r \times t_2}{RC}$$

Therefore, $$t_2 = \frac{e_i}{e_r} \times t_1$$

$\therefore$ $$t_2 = \frac{1 \times 1}{5} = 0.2\ \text{s}$$

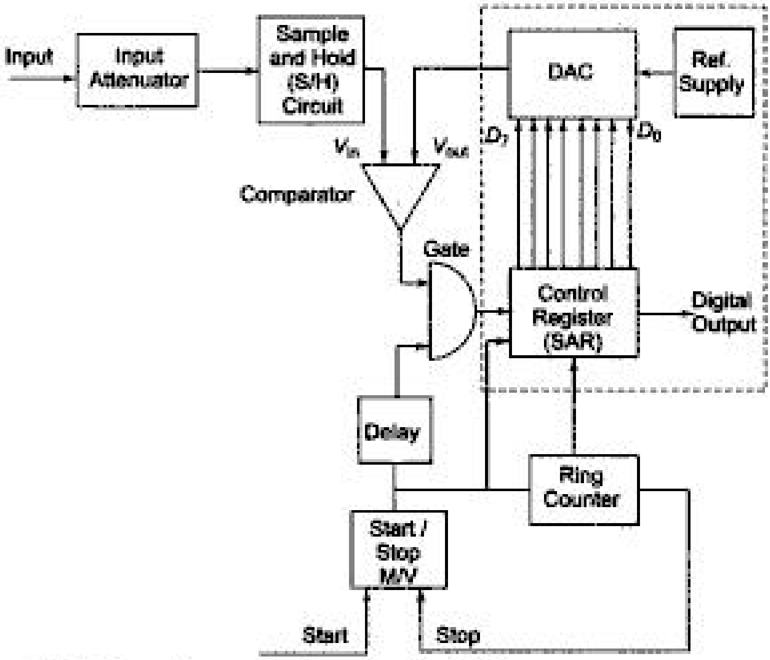

Fig. 5.10 ■ Successive Approximation DVM

At the beginning of the measurement cycle, a start pulse is applied to the start-stop multivibrator. This sets a 1 in the MSB of the control register and a 0 in all bits (assuming an 8-bit control) its reading would be 10000000. This initial setting of the register causes the output of the D/A converter to be half the reference voltage, i.e. 1/2 V. This converter output is compared to the unknown input by the comparator. If the input voltage is greater than the converter reference voltage, the comparator output produces an output that causes the control register to retain the 1 setting in its MSB and the converter continues to supply its reference output voltage of 1/2 V_{ref}.

The ring counter then advances one count, shifting a 1 in the second MSB of the control register and its reading becomes 11000000. This causes the D/A converter to increase its reference output by 1 increment to 1/4 V, i.e. 1/2 V + 1/4 V, and again it is compared with the unknown input. If in this case the total reference voltage exceeds the unknown voltage, the comparator produces an output that causes the control register to reset its second MSB to 0. The converter output then returns to its previous value of 1/2 V and awaits another input from the SAR. When the ring counter advances by 1, the third MSB is set to 1 and the converter output rises by the next increment of 1/2 V + 1/8 V. The measurement cycle thus proceeds through a series of successive approximations. Finally, when the ring counter reaches its final count, the measurement cycle stops and the digital output of the control register represents the final approximation of the unknown input voltage.

Sensitivity of Digital Meters

Sensitivity is the smallest change in input which a digital meter is able to detect. Hence, it is the full scale value of the lowest voltage range multiplied by the meter's resolution.

Sensitivity $S = (fs)_{min} \times R$

where $(f_S)_{min}$ = lowest full scale of the meter

R = resolution expressed as decimal

Example 5.3 What is the resolution of a 3½ digit display on 1 V and 10 V ranges?

Solution Number of full digits is 3. Therefore, resolution is $1/10^n$ where $n = 3$. Resolution $R = \frac{1}{10^3} = \frac{1}{1000} = 0.001$

Hence the meter cannot distinguish between values that differ from each other by less than 0.001 of full scale.

For full scale range reading of 1 V, the resolution is $1 \times 0.001 = 0.001$ V.

For full scale reading of 10 V range, the resolution is $10\text{ V} \times 0.001 = 0.01$ V.

Hence on 10 V scale, the meter cannot distinguish between readings that differ by less than 0.01 V.

Example 5.4 A 4½ digit voltmeter is used for voltage measurements.

(i) Find its resolution
(ii) How would 12.98 V be displayed on a 10 V range?
(iii) How would 0.6973 be displayed on 1 V and 10 V ranges.

Solution

(i) Resolution $= \frac{1}{10^n} = \frac{1}{10^4} = 0.0001$

where the number of full digits is $n = 4$

(ii) There are 5 digit places in 4½ digits, therefore 12.98 would be displayed as 12.980.

Resolution on 1 V range is $1\text{ V} \times 0.0001 = 0.0001$

Any reading up to the 4th decimal can be displayed.

Hence 0.6973 will be displayed as 0.6973.

(iii) Resolution on 10 V range $= 10\text{ V} \times 0.0001 = 0.001$ V

Hence decimals up to the 3rd decimal place can be displayed.

Therefore on a 10 V range, the reading will be 0.697 instead of 0.6973.

3. There is a good repeatability in switching instants in the presence of noise and interference. This is because the ramp approaches the point at which the comparator operates always the same side and always the same rate.

Disadvantages

Noise and interference cannot be suppressed.

Review Questions

1. State the advantages of a DVM over an analog meter.
2. What are the operating and performance characteristics of a DVM?
3. How are DVMs classified?
4. Explain the operating principle of a Ramp type DVM.
5. Explain the basic principle of a digital voltmeter.
6. Explain, with the help of a neat circuit diagram, the working of a dual slope DVM.
7. What are the advantages of dual slope over Ramp type DVMs?
8. Explain the principle of a successive approximations type DVM.
9. What is the advantage of a SAR type DVM over other types of DVM?
10. What are the two basic DVM circuits used for measuring voltages?
11. Define sensitivity of a digital meter.
12. Describe the term overrange and half digit.
13. What is a sample-hold circuit?
14. What is the advantage of using a sample hold circuit?

Practice Problems

1. The lowest range on a 4½ digit DVM is 10 mV full scale. What is the sensitivity of this meter?
2. A 3½ digit voltmeter is used for measuring voltage.
   (i) Find the resolution of the instrument.
   (ii) How would a voltage of 14.42 be displayed on 10 V range?
   (iii) How would be a reading 14.42 be displayed on 100 V range?
3. A 3½ digit DVM has an accuracy of ±0.5% of reading ±1 digit.
   (i) What is the possible error, in volts, when the instrument is reading 5 V on the 10 V range?
   (ii) What is the possible error, in volts, while reading 0.10 V on the 10 V range?

Further Reading

1. A.J. Bouwens, *Digital Instrumentation*, McGraw-Hill, 1986.
2. K.J. Dean, *Digital Instruments*, Chapman and Hall, 1965.
3. E.O. Doebelin, *Measurements Systems: Applications and Design*, 4th Edition, McGraw-Hill, 1990.

applied to the A/D converter, thereby producing an indication of the value of the unknown resistance.

6.2.1 Digital Panel Meters (DPM)

Digital panel meters are available in a very wide variety of special purpose functions. They have a readout range from the basic 3 digit (999 counts, accuracy of ± 0.1% of reading, ± 1 count) to high precision 4¾ digit ones (± 39,999 counts, accuracy ± 0.005% of reading ± 1 count). Units are available to accept inputs such as dc voltage (from microvolts range to ± 20 volts) ac voltage (for true rms measurement), line voltage, strain gauge bridges (meter provides bridge excitation), RTDs (meter provides sensor excitation), thermocouples of many types (meter provides cold junction compensation and linearisation) and frequency inputs, such as pulse tachometers.

Figure 6.3 shows some details of a high precision unit with an input resistance of $10^9\ \Omega$, ± 0.00250% resolution (10 µV), and ± 0.005% of reading ± 1 count accuracy, which uses a dual slope A/D conversion with automatic zero. The sampling rate is 2.5 per second when it is free running and a maximum of 10 per second when it is externally triggered.

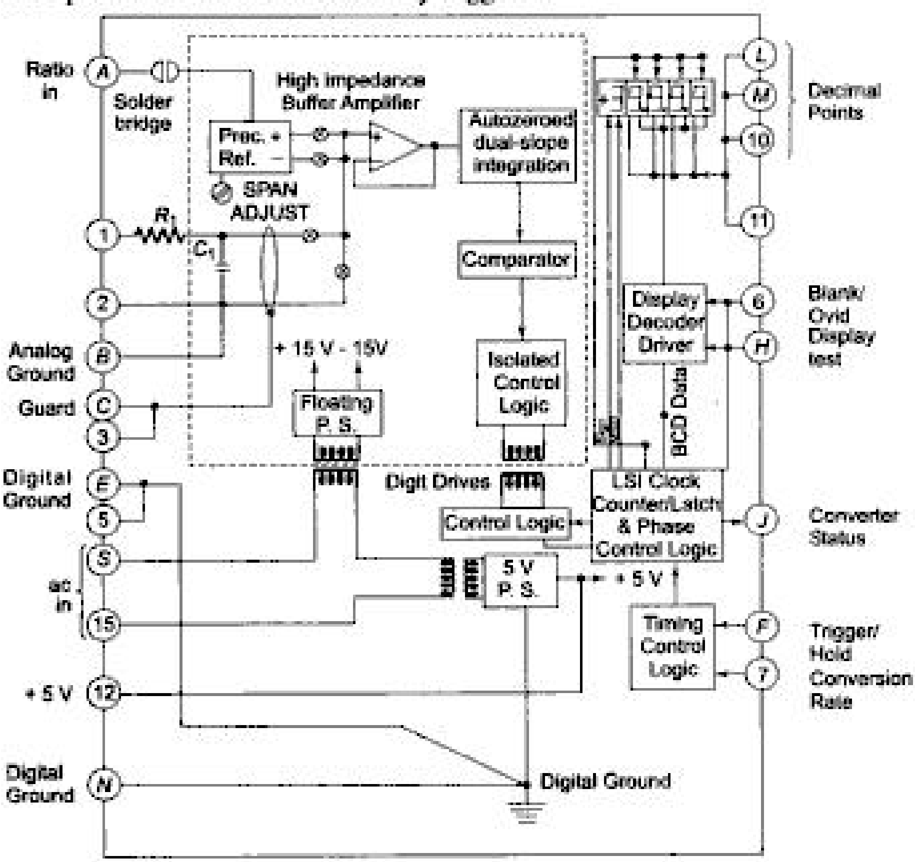

Fig. 6.3 ■ High Precision Digital Panel Meter

the gating signal, is applied to input *B* of the main gate thereby enabling the gate.

Now the pulses from the unknown frequency source pass through the main gate to the counter and the counter starts counting. This same pulse from the START gate is applied to the set input of F/F–1, changing its state from 0 to 1. This disables the START gate and enables the STOP gate. However, till the main gate is enabled, pulses from the unknown frequency continue to pass through the main gate to the counter.

The next pulse from the time base selector passes through the enabled STOP gate to the set input terminal of F/F–2, changing its output back to 1 and $\bar{Y} = 0$. Therefore the main gate is disabled, disconnecting the unknown frequency signal from the counter. The counter counts the number of pulses occurring between two successive pulses from the time base selector. If the time interval between this two successive pulses from the time base selector is 1 second, then the number of pulses counted within this interval is the frequency of the unknown frequency source, in Hertz.

The assembly consisting of two F/Fs and two gates is called a gate control F/F. The block diagram of a digital frequency meter is shown in Fig. 6.7.

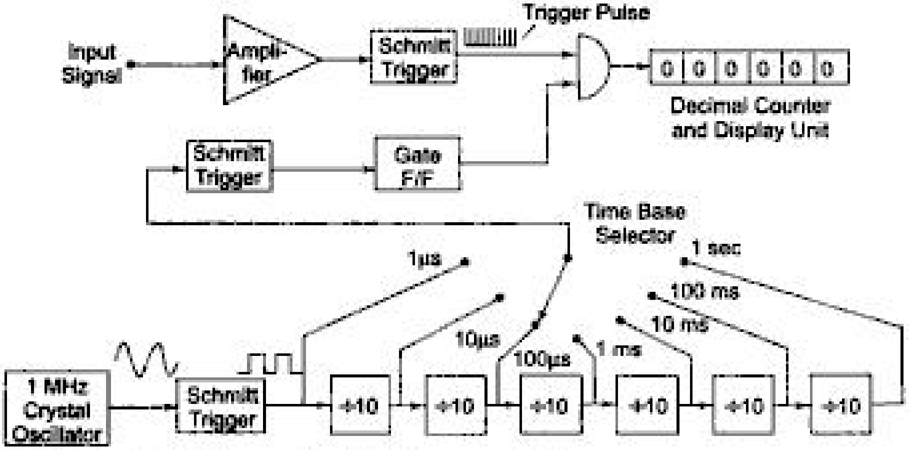

Fig. 6.7 Block Diagram of a Digital Frequency Meter

The input signal is amplified and converted to a square wave by a Schmitt trigger circuit. In this diagram, the square wave is differentiated and clipped to produce a train of pulses, each pulse separated by the period of the input signal. The time base selector output is obtained from an oscillator and is similarly converted into positive pulses.

The first pulse activates the gate control F/F. This gate control F/F provides an enable signal to the AND gate. The trigger pulses of the input signal are allowed to pass through the gate for a selected time period and counted. The second pulse from the decade frequency divider changes the state of the control F/F and removes the enable signal from the AND gate, thereby closing it. The decimal counter and display unit output corresponds to the number of input

6.4.3 Ratio and Multiple Ratio Measurement

The ratio measurement involves the measurement of the ratio of two frequencies. The measurement in effect is a period measurement. A low frequency is used as gating signal while the high frequency is the counted signal. Hence the low frequency takes the place of the time base. The block diagram for the ratio measurements are multiple ratio is shown in Fig. 6.11.

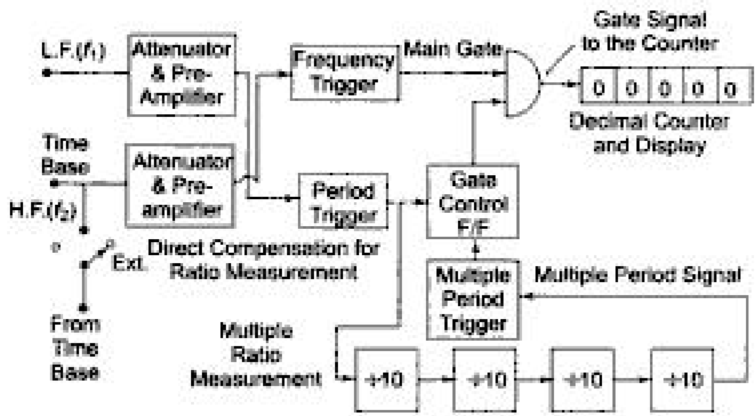

Fig. 6.11 ▬ Block Diagram for Ratio and Multiple Ratio Measurement

The number of cycles of high frequency signal f_1 which occur during the period of lower frequency signal f_2 are counted and displayed by the decimal counter and display unit. In multiple ratio measurements the period of low frequency signal is extended by a factor of 10,100, etc. by using DDAs.

6.5 UNIVERSAL COUNTER

All measurements of time period and frequency by various circuits can be assembled together to form one complete block, called a Universal Counter Timer.

The universal counter uses logic gates which are selected and controlled by a single front panel switch, known as the function switch. A simplified block diagram is shown in Fig. 6.12.

With the function switch in the frequency mode, a control voltage is applied to the specific logic gate circuitry. Hence, the input signal is connected to the counted signal channel of the main gate.

The selected output from the time base dividers is simultaneously gated to the control F/F, which enables or disables the main gate. Both control paths are latched internally to allow them to operate only in proper sequence.

When the function switch is on the period mode, the control voltage is connected to proper gates of the logic circuitry, which connects the time base signals to the counted signal channel of the main gate. At the same time the logic circuitry connects the input to the gate control for enabling or disabling

The outputs of the F/F B and D are high (equal to binary 1) after 10 pulses have been applied to the counter. Therefore, the output signal of the decade counter is 1010. This output has to be reset on the very next pulse which is done by the use of an AND gate that resets all F/F's to 0, when the outputs of B and D are 1. The waveform shown in Fig. 6.13 (b) shows the pulse train applied to the trigger input (clock) of the decade counter (shown in Fig. 6.13(a)) and the output waveform of each F/F.

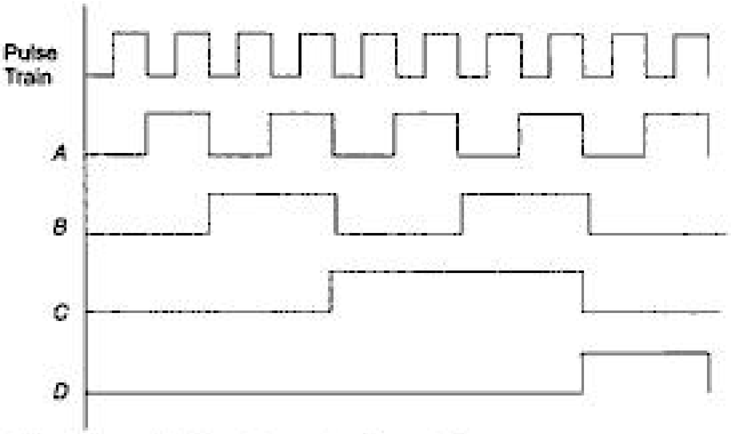

Fig. 6.13 ■ (b) Waveforms of a Decade Counter

At the beginning all the F/Fs are reset to 0000. The clock pulse is applied to the trigger input T of the F/F. Since this is a negative edged triggered F/F, at the negative edge or falling edge of the trigger input the F/F A will toggle, and hence the output of F/F A changes to level 1; all other F/Fs undergo no change. The outputs from the F/Fs will be 0001. At the next clock pulse the F/F A will toggle back to 0, and the output of F/F A falls from 1 to 0 and is applied to the T input of the next F/F B, toggling it. The output of the F/F B changes to 1 and the output of the decade counter goes to 0010.

Similarily, as the clock progresses, the F/F toggles in a straight sequence up to 10 (binary 1010). On the very next pulse the AND gate is enabled, which makes the reset input of F/F B high. As soon as the clock pulse arrives, all F/Fs are reset to 0 and the output of the decade counter goes back to 0000. Therefore, by using the AND gate the counter is reset at the tenth pulse.

If some indicator device, such as a lamp or LED has to be driven, the signal must be encoded in the decimal system. This can be done by the use of AND gates. The output of the F/Fs is applied to the AND gates. The AND gates inputs are set to a unique set of conditions that occur only once during the ten trigger pulses. Therefore, each of the 10 lights is ON for only one particular pulse, which allows us to determine at a glance how many pulses have been counted. An F/F divides its input frequency by two. It can be seen from the that the F/F acts as a frequency divider.

Large scale integration (LSI) has made it possible to incorporate the entire decade counter divider circuit with binary to decimal encoding in one or more IC's.

6.7 ELECTRONIC COUNTER

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.

6.7.1 Totalising

In the totalising mode, as shown in Fig. 6.14, 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.

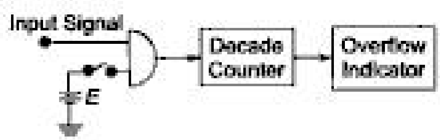

Fig. 6.14 Block Diagram of the Totalising Mode of an Electronic Counter

6.7.2 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. 6.15, in place of the dc voltage source. This technique is referred to as gating the counter. A block diagram of an electronic counter operating in the frequency mode is shown in Fig. 6.15. The frequency of the input signal is computed as

$$f = \frac{N}{t}$$

where f = frequency of the input signal

N = pulse counted

t = duration of the gate pulse

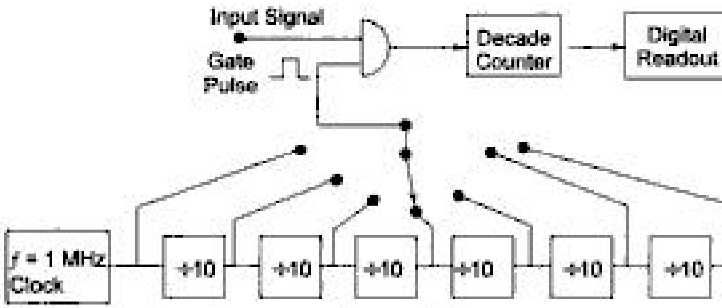

Fig. 6.15 ■ Block Diagram of Electronic Counter Frequency Mode

6.7.3 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 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. 6.16.

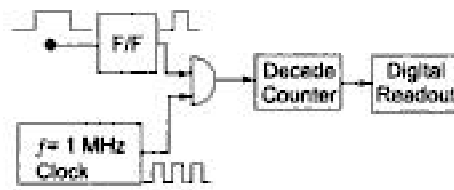

Fig. 6.16 ■ Block Diagram of Electronic Counter in Period Mode

6.7.4 Period Mode

In some applications, it is desirable to measure the period of the signal rather than its frequency. Since the period is the reciprocal of the frequency, it can easily be measured by using the input signal as a gating pulse and counting the clock pulses, as shown in Fig. 6.16.

The period of the input signal is determined from the number 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

$$T = \frac{N}{f}$$

where N = pulse counted

f = frequency of the clock

6.7.5 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. 6.17.

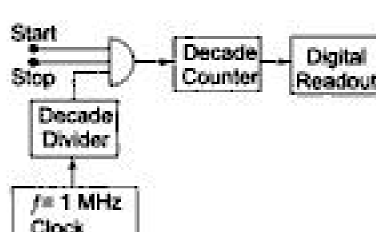

Fig. 6.17 ■ Block Diagram of Electronic Counter in Time Interval Mode

6.9 DIGITAL TACHOMETER

The technique employed in measuring the speed of a rotating shaft is similar to the technique used in a conventional frequency counter, except that the selection of the gate period is in accordance with the rpm calibration.

Let us assume, that the rpm of a rotating shaft is R. Let P be the number of pulses produced by the pick up for one revolution of the shaft. Therefore, in one minute the number of pulses from the pick up is $R \times P$. Then, the frequency of the signal from the pick up is $(R \times P)/60$. Now, if the gate period is G s the pulses counted are $(R \times P \times G)/60$. In order to get the direct reading in rpm, the number of pulses to be counted by the counter is R. So we select the gate period as $60/P$, and the counter counts

$$\frac{(R \times P \times 60)}{60 \times P} = R \text{ pulses}$$

and we can read the rpm of the rotating shaft directly. So, the relation between the gate period and the number of pulses produced by the pickup is $G = 60/P$. If we fix the gate period as one second (G = 1 s), then the revolution pickup must be capable of producing 60 pulses per revolution.

Figure 6.19 shows a schematic diagram of a digital tachometer.

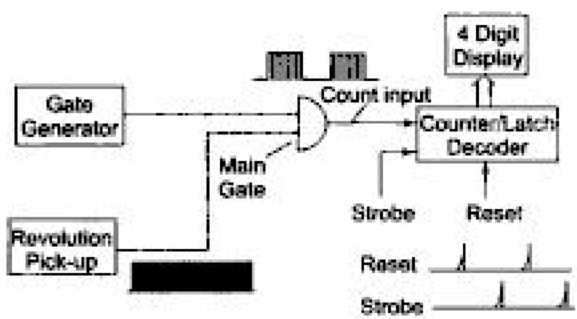

Fig. 6.19 ■ Basic Block Diagram of a Digital Tachometer

6.10 DIGITAL pH METER

The measurement of hydrogen ion activity (pH) in a solution can be accomplished with the help of a pH meter. For those unfamiliar with the terminology, a very brief review is included.

pH is a quantative measure of acidity. If the pH is less than 7, the solution is acidic (the lower the pH, the greater the acidity). A neutral solution has a pH of 7 and alkaline (basic) solutions have a pH greater than 7.

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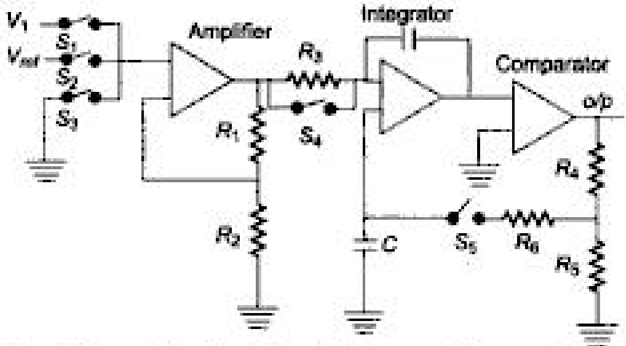

Fig. 6.24 ▬ Simplified Circuit Diagram of Automatic Zeroing Circuit that can be Used With Dual Slope ADC

Before the real measurement is made, switches S_3, S_4 and S_5 are closed, say for 50 ms, thus grounding the input, giving the integrator a short RC time, and connecting the output of the comparator to capacitor C. This capacitor is now charged by the offset voltages to the amplifier, the integrator and the comparator. When switches S_3, S_4 and S_5 are opened again to start the real measurement, the total offset voltage of the circuit (equal to zero error) is stored in this capacitor, and the real input voltage is measured correctly.

6.11.1 Fully Automatic Digital Instrument

A multimeter with automatic polarity indication, automatic zero correction and automatic ranging (of course coupled with automatic decimal point indication) only needs a signal applied to its input, and a command as to what quantity (V_{dc}, V_{ac}, I or R) to measure; it does all the rest itself.

The digital part of a typical instrument is organised so as to produce a display or a digital output signal, as shown in Fig. 6.25. Before a measurement can

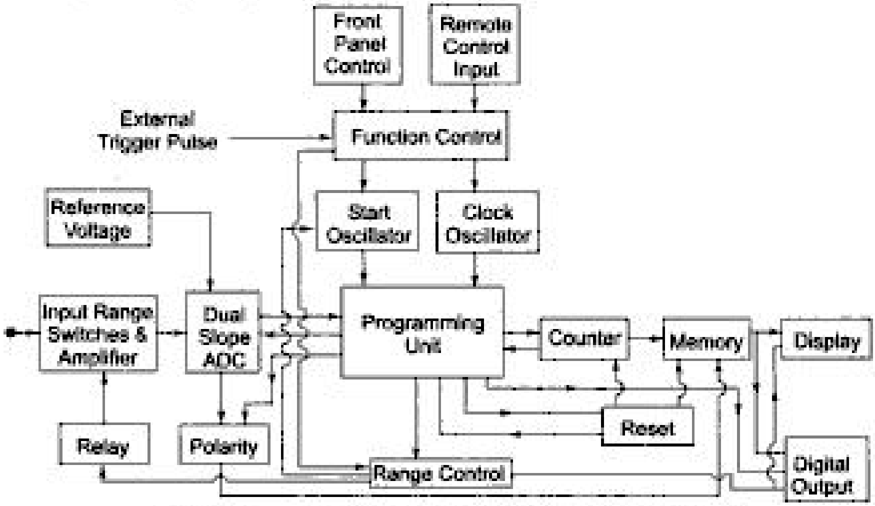

Fig. 6.25 ▬ Block Diagram of an Automatic Instrument

turned on and routed to the counter. When the discharge portion of the cycle is completed, the display is updated and the value of the capacitor is readout. By selecting the proper reference frequency and charging currents, one can obtain a direct digital display of the value of the capacitance.

Be sure to properly shield the leads and keep them short for low capacity measurements, since the 50 Hz hum can cause some slight instability.

6.14 MICROPROCESSOR-BASED INSTRUMENTS

Digital instruments are designed around digital logic circuits without memory. The use of microprocessors as an integral part of measuring instruments has given rise to a whole new class of instruments, called intelligent instruments.

Figure 6.28 shows a block diagram of a microprocessor based impedance measuring instrument. The operation makes interface with the instrument via the IEEE 488 bus to allow control by, or to make the measurement available to, a large external computer system. The timing clock signal and the ac test signal are provided by frequency division of the oscillator signal.

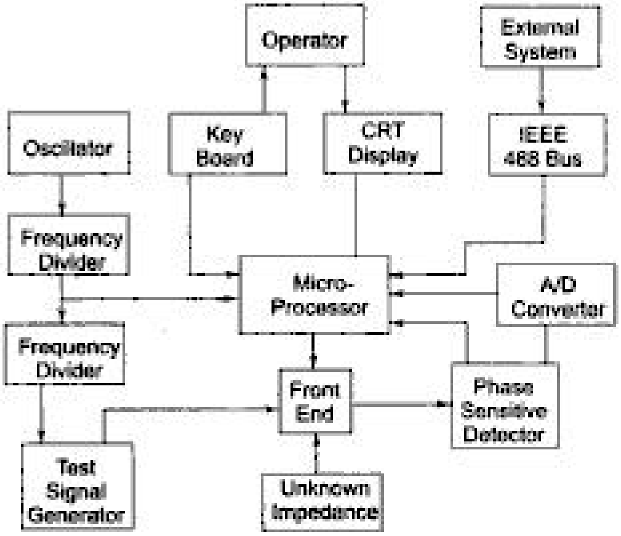

Fig. 6.28 ■■ Block Diagram of a μp (Microprocessor) Based Instrument

The front end circuit applies the test signal to the unknown impedance and an standard impedance provides an output signal, proportional to the voltage across each, to the phase sensitive detector. Signal transfer is controlled by the microprocessor. The phase sensitive detector, which is also controlled by the microprocessor, converts the ac inputs of the impedance in vector form to a dc output. The A/D converter provides the digital data,which is used by the microprocessor to compute the value of the unknown impedance. This is then displayed on the CRT or sent as output to the IEEE 488 bus.

7.2 BASIC PRINCIPLE

7.2.1 Electron Beam

To understand the principle of an oscilloscope, let us consider a torch which is focussed on a piece of cardboard (held perpendicular to the torch). The light beam will make a bright spot where it strikes the cardboard or screen. Hold the torch still, the spot remains still, move the torch, the spot also moves. If the movement is slow, the eye can follow the movement, buf if it is too fast for the eye to follow, persistence of vision causes the eye to see the pattern traced by the spot. Hence when we wave the torch from side to side, a horizontal line is traced; we can similarly have a vertical line or a circle. Hence, if the torch is moved in any manner at a very rapid rate, light would be traced, just like drawing or writing.

A similar action takes place in the CRT of an oscilloscope. The torch is replaced by an electron gun, the light beam by a narrow electron beam, and the cardboard by the external flat end of a glass tube, which is chemically coated to form a fluorescent screen. Here the electron gun generates the beam which moves down the tube and strikes the screen. The screen glows at the point of collision, producing a bright spot.

When the beam is deflected by means of an electric or magnetic field, the spot moves accordingly and traces out a pattern.

The electron gun assembly consists of the indirectly heated cathode with its heater, the control grid, and the first and second anodes.

The control grid in the CRT is cylindrical, with a small aperture in line with the cathode. The electrons emitted from the cathode emerge from this aperture as a slightly divergent beam. The negative bias voltage applied to the grid, controls the beam current. The intensity (or brightness) of the phosphorescent spot depends on the beam current. Hence this control grid bias knob is called or labelled as intensity.

The diverging beam of electrons is converged and focussed on the screen by two accelerating anodes, which form an electronic lens. Further ahead of the grid cylinder is another narrow cylinder, the first anode. It is kept highly positive with respect to the cathode. The second anode is a wider cylinder following the first. Both the cylinders have narrow apertures in line with the electron beam. The second anode is operated at a still higher positive potential and does most of the accleration of the beam. The combination of the first anode cylinder and the wider second anode cylinder produces an electric field that focuses the electron beam on the screen, as a lens converges a diverging beam of light.

The electronic lens action is controlled by the focus control. If this control is turned to either side of its correct focussing position, the spot on the screen becomes larger and blurred. Bringing it back to its correct position brightens and concentrates the spot. With this proper focus, the small spot can be deflected to produce sharp narrow lines that trace the pattern on the CRT screen.

CRT FEATURES

Electrostatic CRTs are available in a number of types and sizes to suit individual requirements. The important features of these tubes are as follows.

1. Size

Size refers to the screen diameter. CRTs for oscilloscopes are available in sizes of 1, 2, 3, 5, and 7 inches. 3 inches is most common for portable instruments.

For example a CRT having a number 5GP1. The first number 5 indicates that it is a 5 inch tube.

Both round and rectangular CRTs are found in scopes today. The vertical viewing size is 8 cm and horizontal is 10 cm.

2. Phosphor

The screen is coated with a fluorescent material called phosphor. This material determines the colour and persistence of the trace, both of which are indicated by the phosphor.

The trace colours in electrostatic CRTs for oscilloscopes are blue, green and blue green. White is used in TVs, and blue-white, orange, and yellow are used for radar.

Persistence is expressed as short, medium and long. This refers to the length of time the trace remains on the screen after the signal has ended.

The phosphor of the oscilloscope is designated as follows.

P1 — Green medium
P2 — Blue green medium
P5 — Blue very short
P11 — Blue short

These designations are combined in the tube type number. Hence 5GP1 is a 5 inch tube with a medium persistence green trace.

Medium persistence traces are mostly used for general purpose applications.

Long persistence traces are used for transients, since they keep the fast transient on the screen for observation after the transient has disappeared.

Short persistence is needed for extremely high speed phenomena, to prevent smearing and interference caused when one image persists and overlaps with the next one.

P11 phosphor is considered the best for photographing from the CRT screen.

3. Operating Voltages

The CRT requires a heater voltage of 6.3 volts ac or dc at 600 mA.

Several dc voltages are listed below. The voltages vary with the type of tube used.

(i) Negative grid (control) voltage – 14 V to – 200 V.
(ii) Positive anode no. 1 (focusing anode) – 100 V to – 1100 V
(iii) Positive anode no. 2 (accelerating anode) 600 V to 6000 V

triggered scopes is that the recurrent sweep locks at the frequency of the input signal, while the triggered scope displays a trace for a specific period of time. Hence, the triggered scope is ON during a specific time interval and will display a waveform or a segment of waveform (e.g. a one shot waveform) regardless of the signal frequency. Hence transients or single clamped oscillations can be observed on the screen.)

Most triggered scopes use a convenient feature of calibrating the sweep speed, in time per cm or division. Sweep frequency is the reciprocal of the time period.

5. Intensity Modulation

In some applications an ac signal is applied to the control electrode of the CRT. This causes the intensity of the beam to vary in step with signal alternations. As a result, the trace is brightened during the +ve half cycles and diminished or darkened during –ve half cycles. This process, is called intensity modulation or Z-axis modulation (in contrast to *X*-axis for horizontal and *Y*-axis for vertical). It produces bright segments or dots on the trace in response to positive peak or dim segments or holes in response to negative peaks.

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

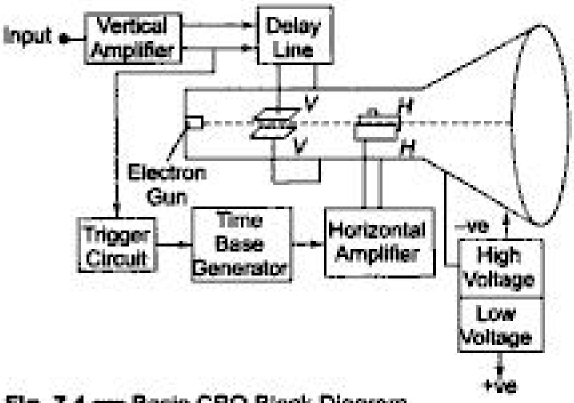

Fig. 7.4 ■ Basic CRO Block Diagram

The function of the various blocks are as follows.

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 antiphase 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.

7.7 HORIZONTAL DEFLECTING SYSTEM

The horizontal deflecting system consist of a Time Base Generator and an output amplifier.

7.7.1 Sweep 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 C_T changes exponentially through R_T. The UJT emitter voltage V_E rises towards V_{BB} and when V_E reaches the peak voltage V_P, as shown in Fig. 7.9, the emitter to base '1' (B_1) diode becomes forward biased and the UJT triggers ON. This provides a low resistance discharge path and the capacitor discharges rapidly. The emitter voltage V_E reaches the minimum value rapidly and the UJT goes OFF. The capacitor recharges and the cycle repeats.

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.

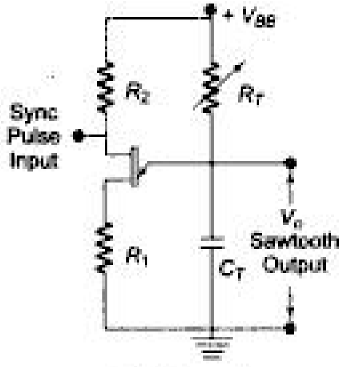

Fig. 7.8 ■■■ Continuous Sweep

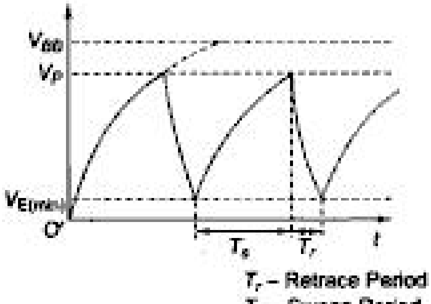

Fig. 7.9 ■■■ Sawtooth Output Waveform

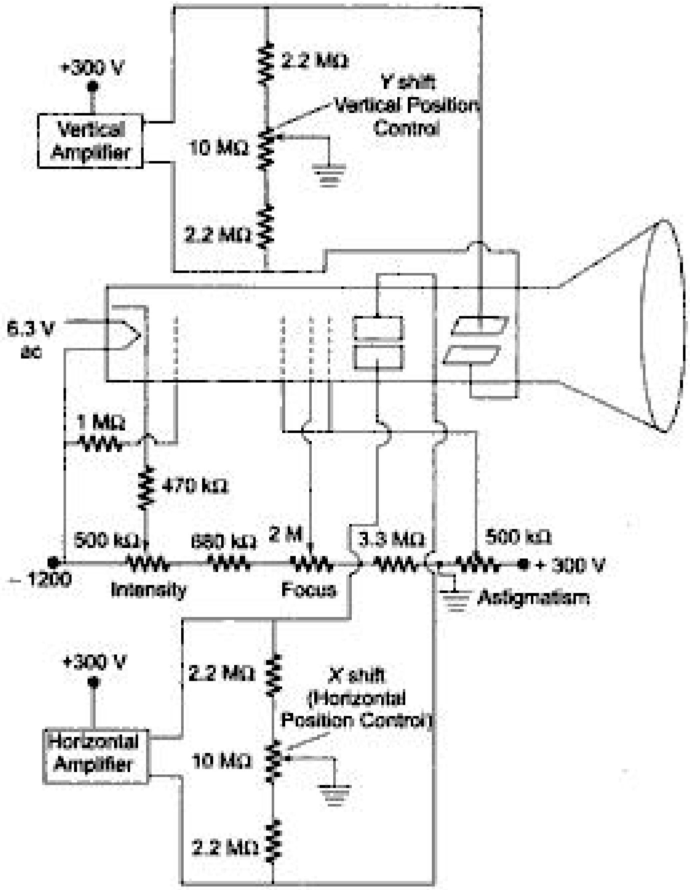

Fig. 7.16 Typical CRT Connections

2. *Focus* The focusing anode potential is adjusted with respect to the first and final accelerating anodes. This is done by the 2 MΩ 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 centre 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 centre position, the two vertical plates have the same potential.

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

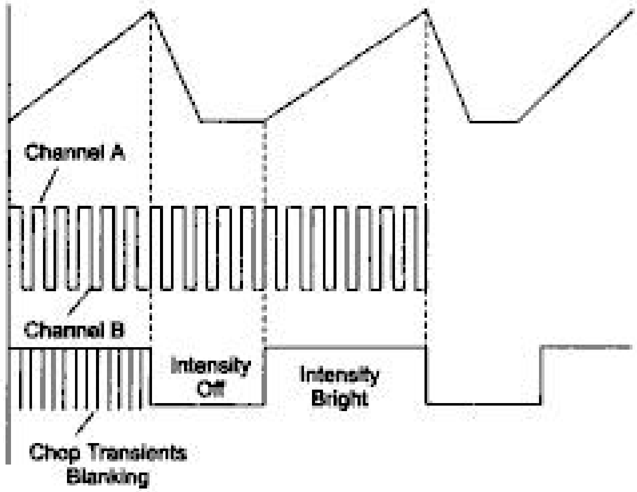

Fig. 7.19 ■ (c) Time Relation of a Dual-Channel Vertical Amplifier in Chop Mode

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

7.15.1 Dual Trace Oscilloscope (0–15 MHz) Block Description

Y-Channels

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

As the transistors are the balanced pre-amplifier stage, they share the same IC block. The resulting stabilisation provides a measure of correction to reduce

7.16 ELECTRONIC SWITCH

The electronic switch is a device that enables two signals to be displayed simultaneously on the screen by a single gun CRT. The basic block diagram of an electronic switch is shown in Fig. 7.22.

Each signal is applied to a separate gain control and gate stage. The gates stage are alternately biased to cut off by square wave signals from the square wave generator. Therefore only one gate stage is in a condition to pass its signal at any given time.

The outputs of both stages are applied directly to the oscilloscope input.

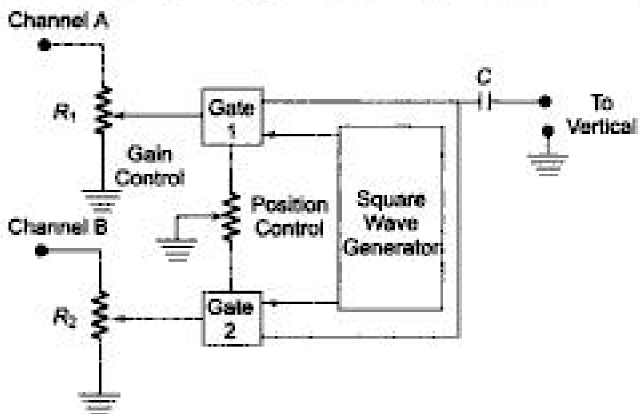

Fig. 7.22 Basic Block Diagram of an Electronic Switch

R_1 and R_2 are gain controls used to adjust the amplitudes of Channels A and B.

In the circuit diagram of Fig. 7.23, Q_1 and Q_2 are the amplifiers and Q_3 and Q_4 the switches. Input signal 1 is applied to Q_1 through gain control R_1, and input signal 2 is applied to Q_2 through gain control R_2. The square wave genera-

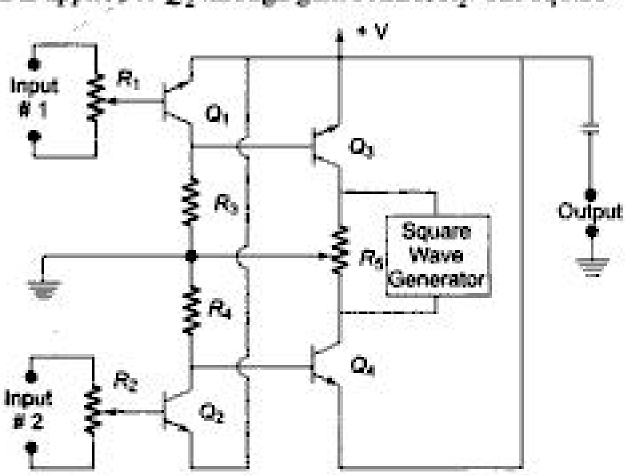

Fig. 7.23 Electronic Switch

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

Below the first crossover a net negative charge results, since the impinging electrons do not have sufficient energy to force an equal number to be emitted. In order to store a trace, assume that the storage surface is uniformly charged and write gun (beam emission gun) will hit the storage target. Those areas of the storage surface hit by the deflecting beam lose electrons, which are collected by the collector mesh. Hence, the write beam deflection pattern is traced on the storage surface as a positive charge pattern. Since the insulation of the dielectric material is high enough to prevent any loss of charge for a considerable length of time, the pattern is stored. To view, the stored trace, a flood gun is used when the write gun is turned off. The flood gun, biased very near the storage mesh potential, emits a flood of electrons which move towards the collector mesh, since it is biased slightly more positive than the deflection region. The collimator, a conductive coating on the CRT envelope with an applied potential, helps to align the flood electrons so that they approach the storage target perpendicularly. When the electrons penetrate beyond the collector mesh, they encounter either a positively charged region on the storage surface or a negatively charged region where no trace has been stored. The positively charged areas allow the electrons to pass through to the post accelerator region and the display target phosphor. The negatively charged region repels the flood electrons back to the collector mesh. Thus the charge pattern on the storage surface appears reproduced on the CRT display phosphor just as though it were being traced with a deflected beam.

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

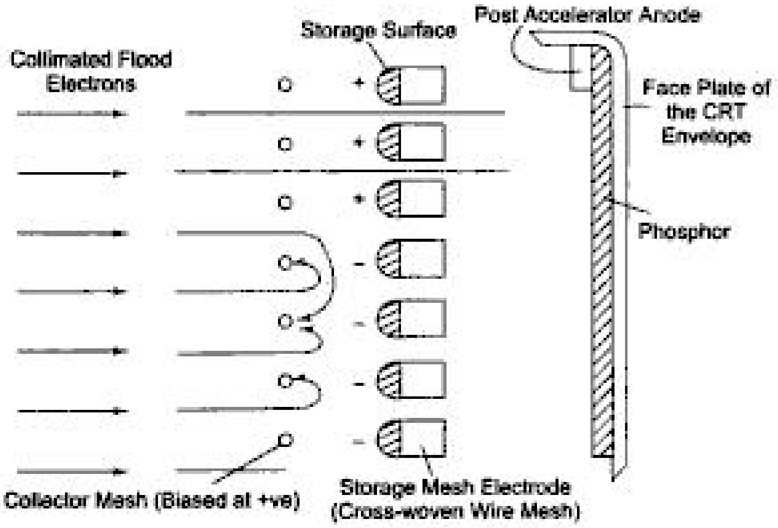

Fig. 7.28 ■■ Display of Stored Charged Pattern on a Mesh-storage

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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.

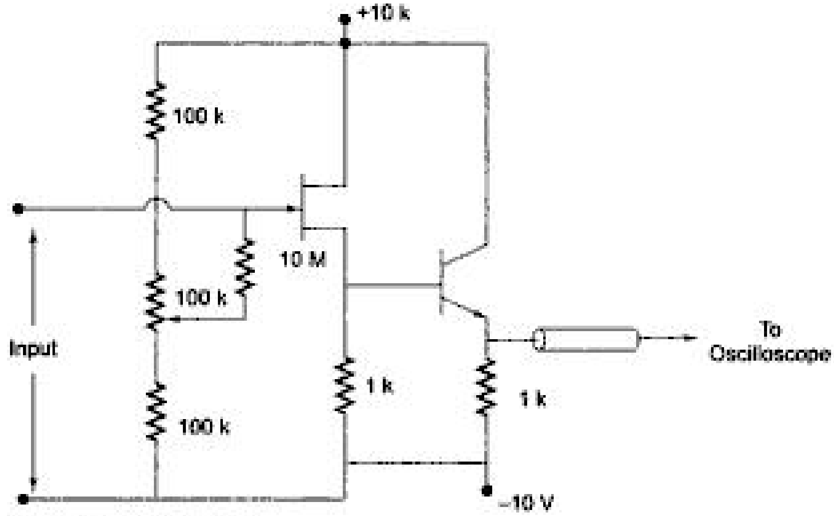

Fig. 7.46 ■ FET Probe

7.29 ATTENUATORS

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.

7.29.1 Uncompensated Attenuators

The circuit diagram shown in Fig. 7.47 gives a resistive divider attenuator connected to an amplifier with a 10 pf input capacitance. If the input impedance of the amplifier is high, the input impedance of the attenuator is relatively constant, immaterial of the switch setting of the attenuator.

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7.31 DELAYED SWEEP

Many oscilloscopes of laboratory quality include a delayed sweep feature. This feature increases the versatility of the instrument by making it possible to magnify a selected portion of an undelayed sweep, measure waveform jitter or rise time, and check pulse time modulation, as well as many other applications.

Delayed sweep is a technique that adds a precise amount of time between the trigger point and the beginning of the scope sweep. When the scope is being used in the sweep mode, the start of the horizontal sweep can be delayed, typically from a few μs to perhaps 10 seconds or more. Delayed sweep operation allows the user to view a small segment of the waveform, e.g. an oscillation or ringing that occurs during a small portion of a low frequency waveform.

The most common approaches used by oscilloscpe manufacturers for delayed sweep operations are, the following.

1. Normal triggering sweep after the desired time delay, which is set from the panel controls.
2. A Delay Plus Trigger mode, where a visual indication, such as light, indicates that the delay time has elapsed and the sweep is ready to be triggered.
3. Intensified sweep, where the delayed sweep acts as a positional magnifier.

7.32 DIGITAL STORAGE OSCILLOSCOPE (DSO)

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

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

(Units with built in hard copy plotters are particularly useful, since they can serve as digital scope high speed recorders, tabular printers and *X*–*Y* plotters, all in one unit, with computing power and an 8½" × 11" paper/ink printout.)

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

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

The basic advantage of digital operation is the storage capability, the stored waveform can be repetitively read out, thus making transients appear

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8. Curve Tracer:

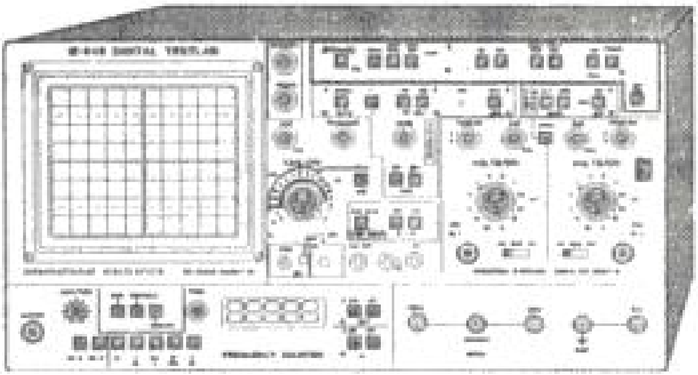

Fig. 7.53 ■ 8 in 1 Digitest Lab[IE-549] [*Courtesy*: International Electronics Ltd.] [Marketed: Signetics Electronics Ltd.]

Test semiconductors like Transistors, FET's, Diodes, etc. You can check for selected parameters and obtain matched pairs of devices for production and service.

7.34 OSCILLOSCOPE OPERATING PRECAUTIONS

In addition to the general safety precautions, the following specific precautions should be observed when operating any type of oscilloscope. Most of the precautions also apply to recorders.

1. Always study the instruction manual of any oscilloscope with which you are not familiar even if you have had considerable experience with oscilloscopes.
2. Use the procedure of Section 7.35 to place the oscilloscope in operation. It is a good practice to go through the procedures each time the oscilloscope is used. This is especially true when the oscilloscope is used by other persons. The operator cannot be certain that position, focus and (especially) intensity control are at safe positions and the oscilloscope CRT could be damaged by switching on immediately.
3. As for any cathode ray tube device (such as a TV receiver), the CRT spot should be kept moving on the screen. If the spot must remain in one position, keep the intensity control as low as possible.
4. Always keep the minimum intensity necessary for good viewing.
5. If possible, avoid using the oscilloscope in direct sunlight or in a brightly lighted room. This will permit a low intensity setting. If the oscilloscope must be used in bright light, use the viewing hood.
6. Make all measurements in the centre area of the screen; even if the CRT is flat, there is a chance of reading errors caused by distortion at the edges.

CHAPTER

8 Signal Generators

8.1 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.

There are various types of signal generator but several requirements are common to all types.

1. The frequency of the signal should be known and stable.
2. The amplitude should be controllable from very small to relatively large values.
3. Finally, the signal should be distortion-free

The above mentioned requirements vary for special generators, such as function generators, pulse, and sweep generators.

Various kinds of signals, at both audio and radio frequencies, are required at various times in an instrumentation system. In most cases a particular signal required by the instrument is internally generated by a self-contained oscillator. The oscillator circuit commonly appears in a fixed frequency form (e.g. when it provides a 1000 c/s excitation source for an ac bridge). In other cases, such as in a Q-meter, oscillators in the form of a variable frequency arrangement for covering Q-measurements over a wide range of frequencies, from a few 100 kHz to the MHz range, are used.

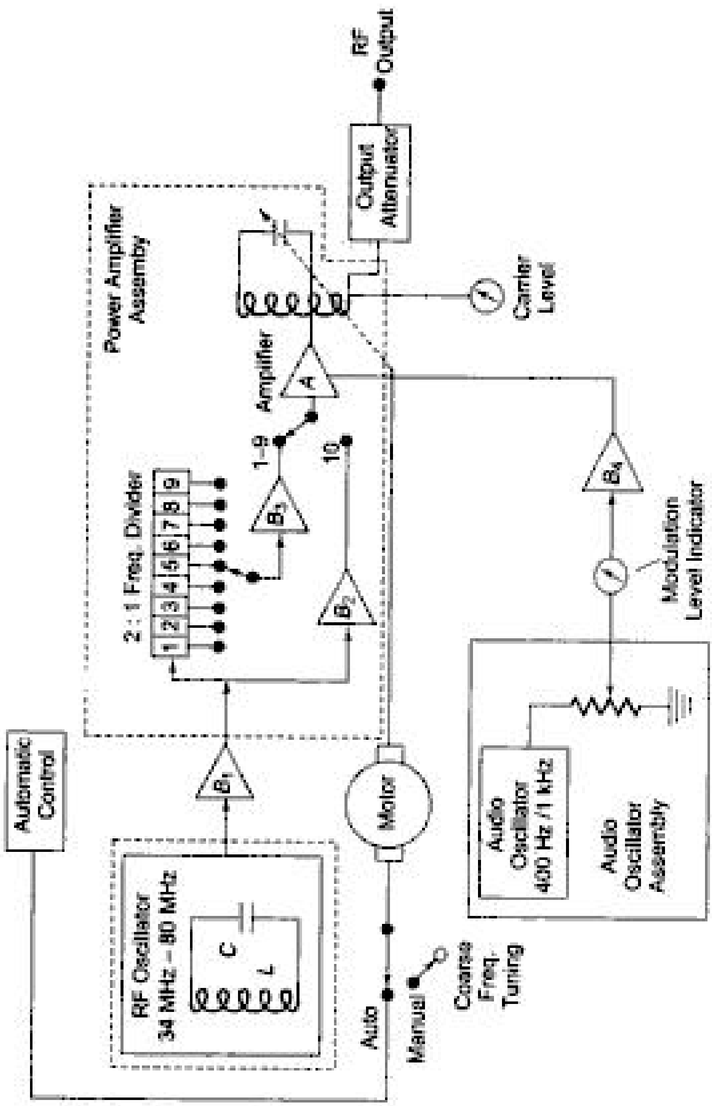

Fig. 8.3 ▬ Modern Signal Generator

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.

8.9 SQUARE AND PULSE GENERATOR (LABORATORY TYPE)

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

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

A square wave generator has a 50% duty cycle.

8.9.1 Requirements of a Pulse

1. The pulse should have minimum distortion, so that any distortion, in the display is solely due to the circuit under test.
2. The basic characteristics of the pulse are rise time, overshoot, ringing, sag, and undershoot.
3. The pulse should have sufficient maximum amplitude, if appreciable output power is required by the test circuit, e.g. for magnetic core memory. At the same time, the attenuation range should be adequate to produce small amplitude pulses to prevent over driving of some test circuit.
4. The range of frequency control of the pulse repetition rate (PRR) should meet the needs of the experiment. For example, a repetition frequency of 100 MHz is required for testing fast circuits. Other generators have a pulse-burst feature which allows a train of pulses rather than a continuous output.

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

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

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

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

8.12 TV SWEEP GENERATOR

An RF generator, when used for alignment and testing of the RF and IF stages of a TV receiver, permits recording of circuit performance at one frequency at a time. Therefore, plotting the total response curve point by point over the entire channel bandwidth becomes a laborious process and takes a long time. To overcome this difficulty, a special RF generator, known as a sweep generator, is used. It delivers RF output voltage at a constant amplitude which sweeps across a range of frequencies and continuously repeats at a predetermined rate.

The sweep generator is designed to cover the entire VHF and UHF range. Any frequency can be selected as the centre frequency by a dial on the front panel of the instrument.

Frequency sweep is obtained by connecting a varactor diode across the HF oscillator circuits. A modified triangular voltage at 50 Hz is used to drive the varactor diode. Thus the frequency sweeps on either side of the oscillator centre frequency, at the rate of driving voltage frequency. The amplitude of the driving voltage applied across the varactor diodes can be varied to control maximum frequency deviation on either side of the carrier frequency. This is known as the sweep width and can be adjusted to the desired value, up to a maximum of about ± 15 MHz. A width control is provided for this procedure.

Alignment Procedure

The output of the sweep generator is connected to the input terminals of the tuned circuit under test.

The frequency and sweep width dials are adjusted to a sweep range which lies in the pass-band of the circuit. With an input signal of constant amplitude, the output voltage varies in accordance with the frequency gain characteristics

picture tube screen of a normally operated colour receiver, these bars appear as shown in Fig. 8.15.

Only 10 colour bars are shown in the screen, because one of the bursts occurs at the same time as the H-sync pulse and is thus eliminated. The adder, while gating the crystal oscillator output, also combines H-sync, V-sync and blanking pulses to the oscillator output. The composite colour video signal available at the output of the adder can be fed directly to the chrominance band-pass amplifier in the TV receiver. This signal is usually AM modulated with the carrier of either channel 3 or 4.

The main technical specifications of a colour bar pattern generator are as follows.

Test signals

1. 8 bars, linearised, grey scale
2. Cross-hatch pattern
3. 100% white pattern (with burst)
4. Red pattern (50% saturated)
5. Standard colour bar with white reference, 75% contrast (internally changeable to full bars).

Video carrier

1. VHF B-III (170 MHz - 230 MHz)
2. UHF B-IV (470 MHz - 600 MHz)

RF Output

>> 100 mV peak to peak (75 Ω impedance)

Video Modulation

Amplitude modulation (negative)

Sound carrier

Frequency – 5.5 MHz (or 6 MHz by internal adjustment)
Modulation – Frequency modulation
Internal signal – 1 kHz sine wave.
FM Sweep 40 kHz on 5.5 MHz
Chroma-PAL-G and I standards

Power

115 – 230 V; 50 – 60 Hz, 6 W

Dimension

23 × 11 × 21 cm – ($w \times h \times d$)

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advantage of this type of oscillator is that a stable continuous output covering the entire AF range can be realised by simple variation of the tuning capacitor in one of the oscillators.

In the circuit given in Fig. 8.21, the voltages obtained from two RF oscillators operating at slightly different frequencies are combined and applied to a mixer circuit. The difference frequency current that is thus produced represents the desired oscillations. The practical value of a BFO arises from the fact that a small or moderate percentage variation in the frequency of one of the individual oscillators (such as can be obtained by the rotation of the shaft controlling a variable tuning capacitor) varies the beat or difference output continuously from a few c/s to throughout the entire AF or video frequency range. At the same time, the amplitude of the difference frequency output is largely constant as frequency is varied. The principal factors involved in the performance of a BFO are the frequency stability of individual oscillators, the tendency of the oscillators to synchronise at very low difference frequencies, the wave shape of the difference frequency output, and the tendency for spurious beat notes to be produced.

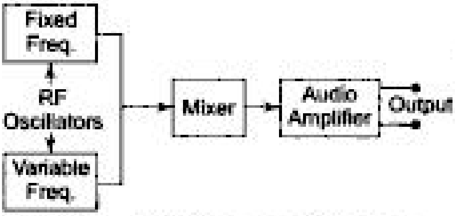


Fig. 8.21 ■■■ Beat Frequency Oscillator

Frequency stability of the individual oscillators is important, because a slight change in their relative frequency would cause a relatively large change in the difference frequency. To minimise the drift of the difference frequency with time, the individual oscillators should have high inherent frequency stability with respect to changes in temperature and to supply voltage variations, and they should be as alike electrically, mechanically and thermally, as possible.

In this way, frequency changes are minimised and the frequency changes that do take place tend to be the same in each of the individual oscillators and so have little effect on the difference in their frequencies.

The two RF oscillators must be completely isolated from each other. If coupling of any type exists between them, they will synchronise when the difference is small. Hence, low values of difference frequency are impossible to obtain, and in addition cause interaction between the oscillators that results in a highly distorted wave shape.

(To ensure low distortion, one of the voltages applied to the mixer, preferably the one derived from the fixed frequency oscillator, should be considerably smaller than the voltage derived from the other oscillator, and preferably free of harmonics.)

BFOs are commonly affected with spurious beat notes, sometimes called whistles. These effects are usually the result of cross-modulation in the AF amplifier between high order RF harmonics generated by the mixer. These spurious whistles often appear when the output frequency is high.

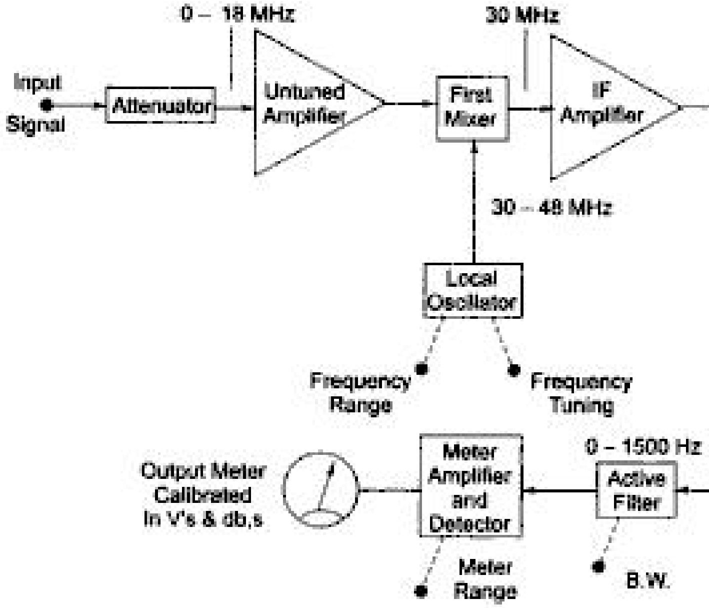


Fig. 9.4 ■■ RF Heterodyne Wave Analyzer

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

9.5 HARMONIC DISTORTION ANALYZER

9.5.1 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

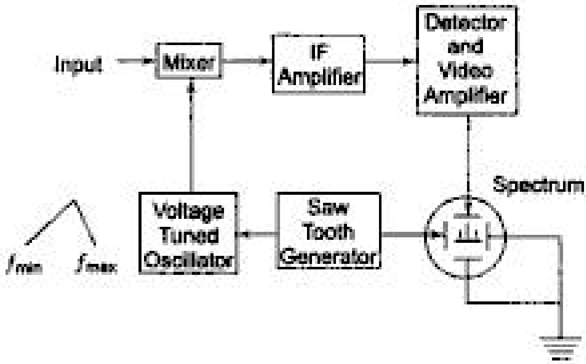


Fig. 9.9 (b) Spectrum Analyzer

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

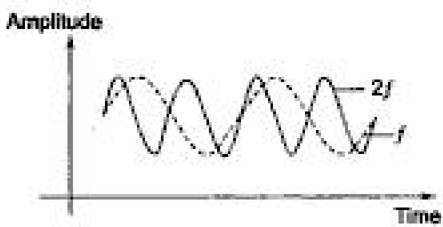


Fig. 9.10 Test Wave Seen on Ordinary CRO

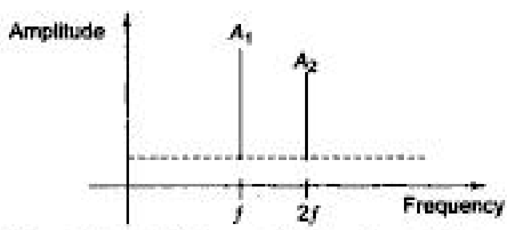


Fig. 9.11 Display on the Spectrum CRO

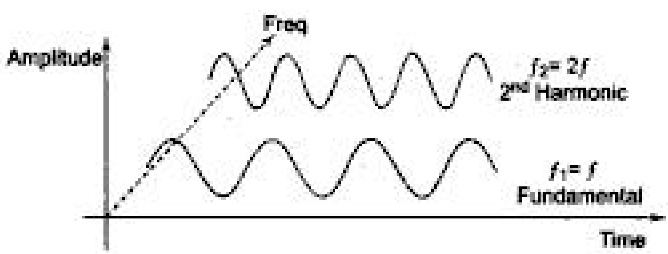


Fig. 9.12 Test Waveform as Seen on X-Axis (Time) and Z-Axis (Frequency)

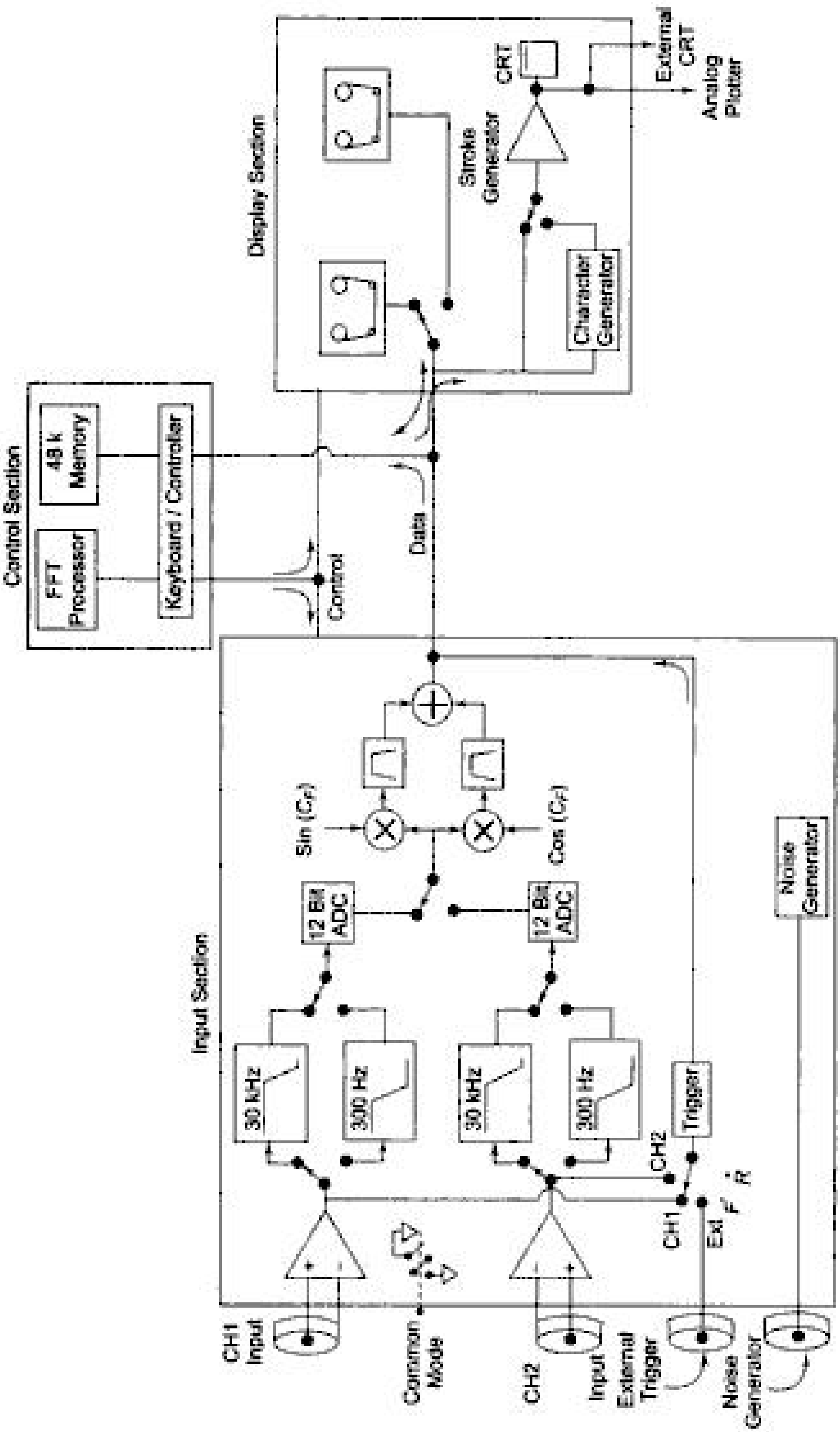
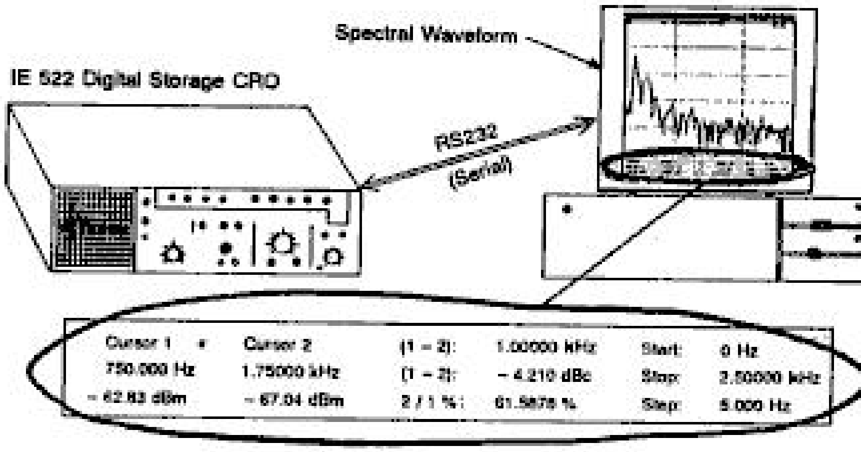


Fig. 9.15 Block Diagram of a Digital Signal Analyzer



Cursor 1 and Cursor 2 Amplitudes / Frequencies / Freq Difference / Amplitude Diff / Harmonic Content Ratio etc.are displayed and will be computed dynamically as the cursors are moved. The "START" and "STOP" frequency denote the min and max frequency range of the display. The STOP frequency can range from 1 Hz to 10 MHz. Thus the minimum STEP or frequency resolution possible is 0.002 Hz. Display can be in Lin/Log. Horizontal Zoom level is 500.

Fig. 9.18 Set-up of FFT Spectrum Analysis

Review Questions

1. What is the difference between a wave analyzer and a harmonic distortion analyzer?
2. Explain with the help of a block diagram, the working of a harmonic distortion analyzer.
3. Explain with the help of a block diagram the working of a spectrum analyzer.
4. Where are spectrum analyzers commonly used?
5. Draw the circuit diagram and explain the working of a heterodyne type wave analyzer.
6. What is meant by the distortion factor? How can this factor be measured? Explain with the help of a block diagram.
7. Explain any one application of a distortion factor meter.
8. Explain the front panel control and applications of a distortion factor meter in trouble shooting.
9. With the help of a block diagram, explain an AF wave analyzer.
10. Compare a Wien bridge harmonic distortion analyzer to a bridged-T type harmonic distortion analyzer.
11. State the applications of a spectrum analyzer.

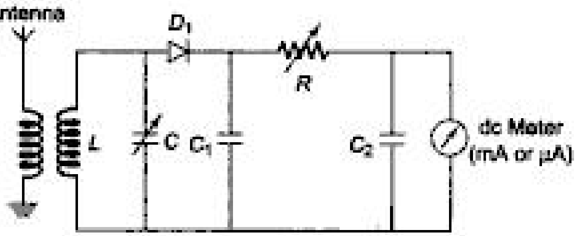


Fig. 10.2 ■ (a) Field Strength Meter

The field strength measurement should be made at a distance of several wavelengths from the transmitting antenna, to avoid misleading readings when the pickup is obtained from a combination of radiation field with the induction field close to the transmitter. To enable the wavemeter combination to act as a field strength meter, greater sensitivity can be easily obtained with the addition of a transistor dc amplifier, as shown in Fig. 10.2(b). (The coil L is held near an oscillating circuit to provide loose coupling, and the capacitor C is tuned to resonance. When the dial of the variable capacitor is calibrated in terms of frequency, the unit becomes very useful as a rough frequency meter. Since the wavemeter is tuned to resonance, it will absorb the greatest amount of energy, and cause a detectable change in an indicating meter of the transmitter.)

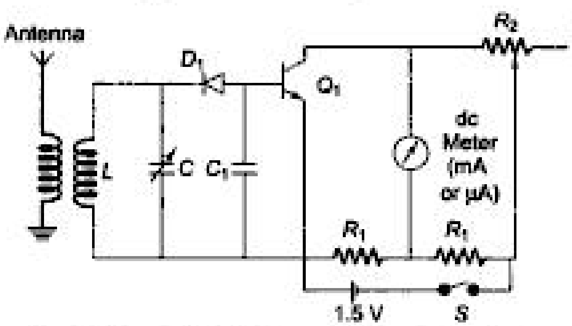


Fig. 10.2 ■ (b) Field Strength Meter (Transistor)

The transistor provides ample current gain, so that satisfactory sensitivity is obtained. The transistor is connected in a common emitter configuration. With no signal being received, the quiescent current is balanced out by the back up current, through the variable resistor R_2. This zero balance should be checked at intervals, since the quiescent current is sensitive to temperature changes.

The collector current through the meter provides an indication of the strength of the RF wave being picked up. This current is not strictly proportional to the field strength, because of the combined non-linearities of the semiconductor diode and transistor. However, the response is satisfactory for the relative comparison of field strength.

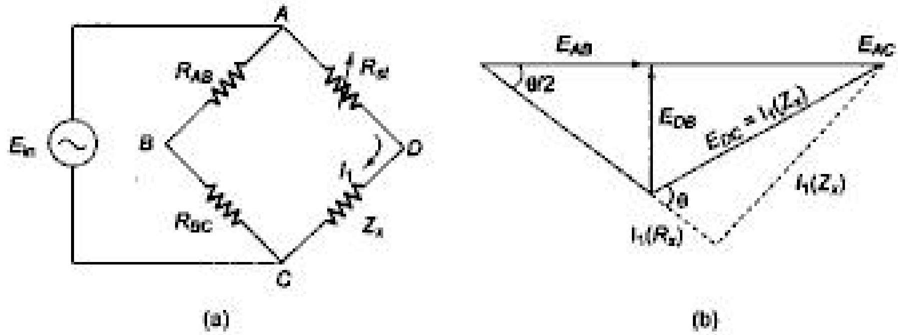


Fig. 10.5 ■ (a) Vector Impedance Method (b) Vector Diagram

The phase angle θ of the impedance Z_x can be obtained from the reading of the voltage at points B and D, that is, E_{DB}. The deflection of the meter will be found to vary with the Q of the unknown impedance Z_x. The VTVM ac voltage reading will vary from 0 V, when the phase angle of 0° ($Q = 0$) to the maximum voltage, with an angle of 90° (Q = infinite). The angle between the voltages E_{AB} and E_{AD} is half the phase angle θ, since E_{AD} is made equal to E_{DC}.

$$\frac{\theta}{2} = \tan \frac{E_{DB}}{E_{AB}}$$

Since E_{AB} is known to be half the known input voltage E_{in}, the voltmeter reading of E_{DB} can be interpreted in terms of $\theta/2$, and hence the phase angle θ of the unknown Z_x can be determined.

While this method for obtaining both Z and θ is approximate because of the crowding caused by the non-linear relation, it is useful for obtaining a first approximation. A commercial vector impedance meter is used for greater accuracy.

10.6.1 Commercial Vector Impedance Meter

A commercial instrument that measures impedance directly in the polar form, giving the magnitude of Z in ohms, at a phase angle θ, requires only one balancing control for both values.

It measures any combination of R, L and C, and includes not only pure resistive, capacitive or inductive elements but also complex impedances. Since the determination of magnitude and angle requires only one balance control, the awkward condition of sliding balance, frequently encountered when measuring low Q reactors with conventional bridge circuits, which necessitates so much successive adjustments, is avoided.

Measurements of impedances ranging from 0.5 – 100,000 Ω can be made over the frequency range from 30 Hz to 40 kHz, when supplied by an external oscillator. Internally generated frequencies of 60 Hz, 400 Hz or 1 kHz are available. At these internal frequencies and external frequencies up to 20 kHz, the readings have an accuracy of ± 1% for the magnitude of Z and ± 2% for θ.

10.7.1 Factors that May Cause Error

1. At high frequencies the electronic voltmeter may suffer from losses due to the transit time effect. The effect of R_{sh} is to introduce an additional resistance in the tank circuit, as shown in Fig. 10.8.

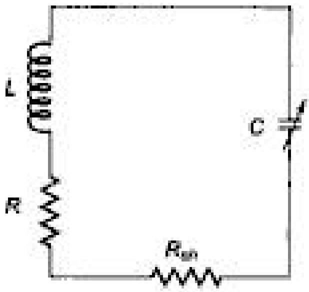


Fig. 10.8 ■ Effect of R_{sh} on Q

$$Q_{act} = \frac{\omega L}{R} \text{ and } Q_{obs} = \frac{\omega L}{R + R_{sh}}$$

$$\therefore \quad \frac{Q_{act}}{Q_{obs}} = \frac{R + R_{sh}}{R} = 1 + \frac{R_{sh}}{R}$$

$$\therefore \quad Q_{act} = Q_{obs}\left(1 + \frac{R_{sh}}{R}\right)$$

where Q_{act} = actual Q

Q_{obs} = observed Q

To make the Q_{obs} value as close as possible to Q_{act}, R_{sh} should be made as small as possible. An R_{sh} value of 0.02 – 0.04 Ω introduces negligible error.

2. Another source of error, and probably the most important one, is the distributed capacitance or self capacitance of the measuring circuit. The presence of distributed or stray capacitances modifies the actual Q and the inductance of the coil. At the resonant frequency, at which the self capacitance and inductance of the coil are equal, the circuit impedance is purely resistive—this characteristic can be used to measure the distributed capacitance.

One of the simplest methods of determining the distributed capacitance (C_s) of a coil involves the plotting of a graph of $1/f^2$ against C in picofarads.

The frequency of the oscillator in the Q meter is varied and the corresponding value of C for resonance is noted. $1/f^2$ is plotted against C in picofarads, as shown in Fig. 10.9(a). The straight line produced to intercept the X-axis gives the value of C_s, from the formula given on the next page. The value of the unknown inductance can also be determined from the equation.

$$L = \frac{\text{slope}}{4\pi^2}\text{, therefore slope} = 4\pi^2 L$$

and
$$f = \frac{1}{2\pi\sqrt{L(C + C_s)}}$$

Therefore
$$\frac{1}{f_2} = 4\pi^2 L(C + C_s)$$

Referring to Fig. 10.10(a), the unknown impedance is shorted or otherwise not connected and the tuned circuit is adjusted for resonance at the oscillator frequency. The value of Q and C are noted. The unknown impedance is then connected, the capacitor is varied for resonance, and new values Q' and C' are noted.

From part 1, we have $$\omega L = 1/\omega C \tag{10.3}$$

From part 2, we have $$\omega L + X_x = \frac{1}{\omega C'} \tag{10.4}$$

Subtracting Eq. (10.4) from Eq. (10.3), we have

$$X_x = \frac{1}{\omega C'} - \frac{1}{\omega C} = \frac{1}{\omega C}\left(\frac{C - C'}{C'}\right) = \frac{1}{\omega}\left(\frac{C - C'}{CC'}\right)$$

Since $R' = R + R_x$, $R_x = R' - R$, where R is the resistance of the auxillary coil.

$$R_x = R' - R = \frac{\omega L}{Q'} - \frac{\omega L}{Q} = \omega L\left(\frac{Q - Q'}{QQ'}\right)$$

The unknown impedance Z_x can be calculated from the equation

$$Z_x = R_x + j\,X_x$$

A positive value of X_x indicates inductive reactance and a negative value indicates capacitive reactance.

If Z_x is considerably greater than X_L, the unknown impedance is shunted across the coil and the capacitor, as shown in Fig. 10.10(b).

Y_x represents the shunt admittance of the unknown impedance. It consists of two shunt elements, conductance G_x and susceptance B_x. In this method, Y_x is disconnected and the capacitor C is tuned to the resonant value. At the oscillator frequency, the values of Q and C are noted. With Y_x connected, the capacitor is tuned again for resonance at the oscillator frequency and the new values Q' and C' are noted.

Hence $$Y_x = G_x + jB_x$$

and $$B_x = \omega C - \omega C'$$

also $$G_x = \frac{1}{\omega L}\left(\frac{Q - Q'}{QQ'}\right)$$

Therefore $$Y_x = \frac{Q - Q'}{\omega LQQ'} + j\omega\,(C - C')$$

The accuracy with which the reactance can be determined by the method of substitution is quite high. Error may mainly be because

(i) C' cannot be accurately determined since the resonance curve may be flat due to additional resistance, and

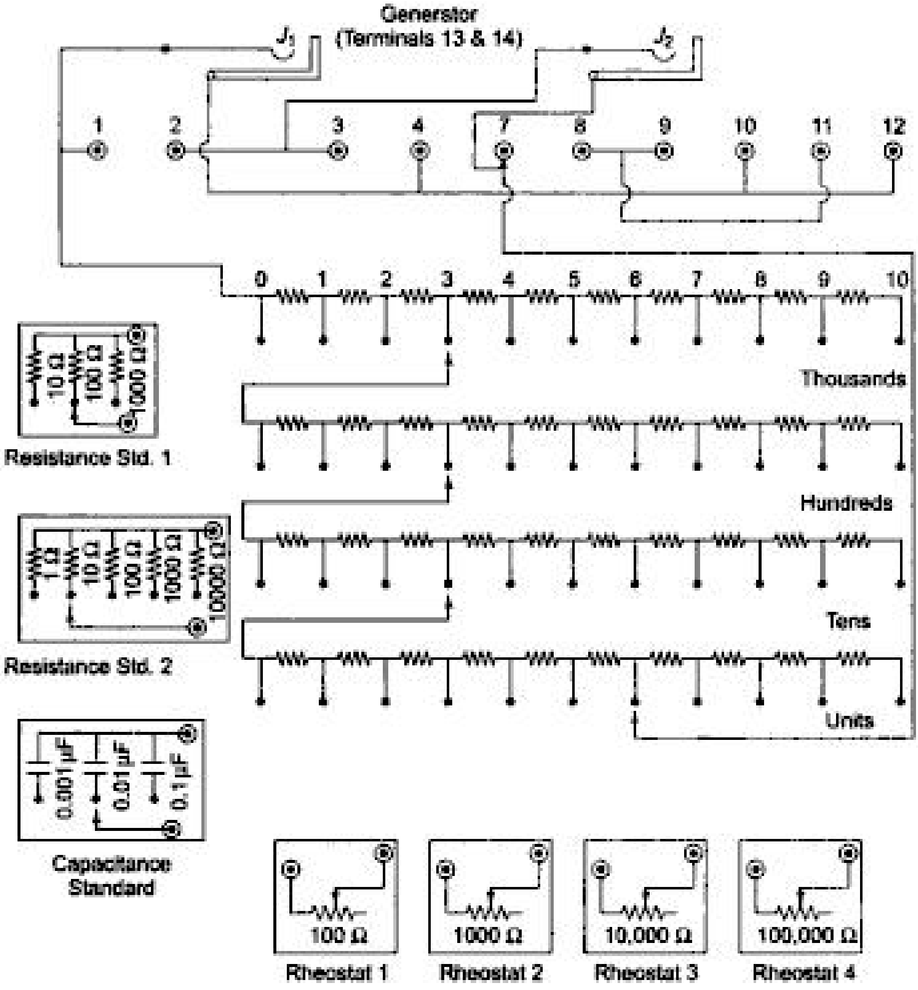


Fig. 10. 13 ■ (b) Complete Circuit of the Skeleton Bridge and Accessories

By proper arrangement of the bridge arms, the Wheatstone's bridge shown in Fig. 10.14(a) may be set up for resistance measurement (ac and dc), a comparison circuit shown in Fig. 10.14(b) for measurement of *C*, and a Maxwell's circuit shown in Fig. 10.14(c) for the measurement of inductance *L*.

The skeleton bridge permits resistance measurements from 0.001 Ω to 11.11 MΩ, capacitance measurements from 1 pf (if stray capacitance permits) to 1111 μF and inductance measurements from 1 μH (if stray inductance and capacitance permit) to 111.1 H.

The complete circuit of an LCR bridge is shown in Fig. 10.15 (kit type bridge).

A wide range of resistance (ac and dc), inductance and capacitance measurements can be done using a Kit type impedance bridge.

This bridge measures inductance (*L*) from 1 μH – 100 *H*, capacitance (*C*) from 10 μμF – 100 μF, resistance (*R*) from 0.01 Ωs – 10 MΩ, dissipation factor (*D*) from 0.001 – 1 and *Q* from 1 – 1000. Resistance, capacitance and inductance units are read directly on the same dial scale, graduated 0 – 1, and are multiplied by settings of a multiplier switch.

Referring to Fig. 10.15, six inductance ranges are provided

(i) 10 – 100 μH	(ii) 50 μH – 10 mH
(iii) 0.5 – 100 mH	(iv) 5 mH – 1 H
(v) 50 mH – 10 H	(vi) 0.5 – 100 H

These ranges include all common inductances of coils of all types employed in electronics.

Also eight resistance ranges are provided.

(i) 0.01 – 1 Ω	(ii) 0.05 – 10 Ω
(iii) 0.5 – 100 Ω	(iv) 5 – 1000 Ω
(v) 50 – 10,000 Ω	(vi) 500 – 100,000 Ω
(vii) 5,000 – 1 MΩ	(viii) 50,000 – 10 MΩ

There are six capacitance ranges provided:

(i) 10 – 1000 μμF	(ii) 50 μμF – 0.01 μF
(iii) 0.0005 – 0.1 μF	(iv) 0.005 – 1 μF
(v) 0.05 – 10 μF	(vi) 0.5 – 100 μF

The two pole, eight position Multiplier Switch sets the bridge to the desired *R*, *C* or *L* range. This switch cuts the various precision resistors, R_1 to R_9 in or out of the circuit. The dial settings of the multiplier switch show the various *R*, *C* and *L* factors by which the settings of the main control dial must be multiplied to obtain the correct value of the component under test.

The function of the Detector Switch is to connect an appropriate null detector across the bridge output terminals. When this switch is thrown to its external position, the two terminals labelled external detector are connected across the bridge output, and an external null detector may be connected to these terminals. (Satisfactory external detectors are high resistance headphones, ac VTVMs, oscilloscopes, sensitive centre zero dc galvanometers, etc.). The galvanometer is used only in resistance measurements when the internal 6 V battery (or a higher voltage external battery) is used to power the bridge.

When the detector switch is thrown to its galvanometer position, the self contained centre zero (100 – 0 – 100) dc microammeter is connected, as a dc null detector across the bridge output. When the detector switch is thrown to its shunted galvanometer position, the microammeter is connected across the bridge output, but in parallel with the 100 Ω resistor R_{10}. This resistor decreases the microammeter sensitivity and acts to prevent meter damage when an unknown resistance is first checked.

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but can be used with any parallel "Z". The basic circuit of a typical RX meter is shown in Fig. 10.16.

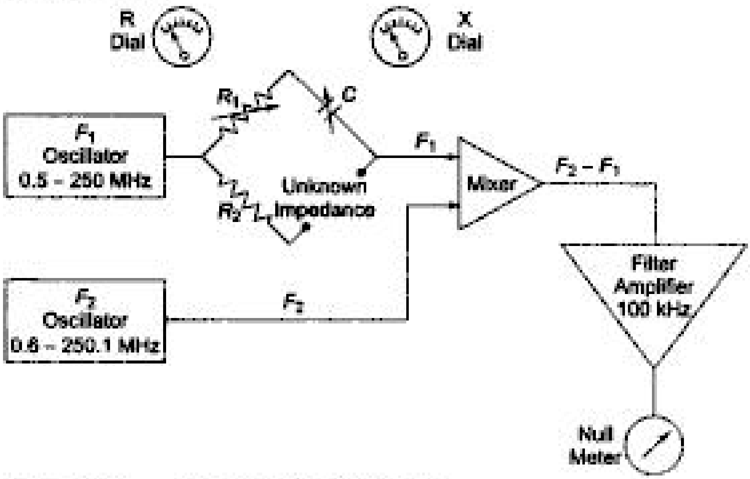

Fig. 10.16 ■■ Basic Circuit of R-X Meter

As shown in Fig. 10.16, there are two variable frequency oscillators that track each other at frequencies 100 kHz apart. The output of a 0.5 – 250 MHz oscillator, F_1 is fed into a bridge. When the impedance network to be measured is connected across one arm of the bridge, the equivalent parallel resistance and reactance (capacitive or inductive) unbalances the bridge and the resulting voltage is fed to the mixer. The output of the 0.6 – 250.1 MHz oscillator F_2, tracking 100 kHz above F_1, is also fed to the mixer.

This results in a 100 kHz difference frequency proportional in level to the bridge unbalance. The difference frequency signal is amplified by a filter amplifier combination and is applied to a null meter. When the bridge resistive and reactive controls are nulled, their respective dials accurately indicate the parallel impedance components of the network under test. For example, if balance is achieved with 50 Ω of resistance and 300 Ω of reactance, the network under test has the same values.

10.10 AUTOMATIC BRIDGES

The bridges discussed so far require that the controls be adjusted for balance after each capacitor (or other devices being tested) is connected to the bridge. In effect, they are manual. In recent years a number of automatic bridges have been developed. These bridges provide an automatic readout without adjustment of balance controls.

In some cases, the automatic bridges also provide a Binary Coded Digital (BCD) readout to external equipment. Automatic bridges are similar in operation to digital meters. To understand their operation, it is necessary to understand logic and digital circuit methods.

There is a definite relationship between alpha and beta, so that either may be calculated when the other is known.

$$\alpha = \frac{\beta}{1+\beta} \quad \text{and} \quad \beta = \frac{\alpha}{1-\alpha}$$

The test circuit for measuring beta is similar to that for measuring dc gain (see Fig. 10.20). The primary difference is that the beta measurement requires an ac signal at the transistor base. The proper values of either beta or alpha are given on the manufacturer's data sheet. The measured values should match these fairly closely, if the transistor is good.

10.11.5 Four Terminal Parameter Test (Hybrid Parameters)

A transistor may be considered as a four terminal network in order to determine the relationships between input and outputs. These relationships are referred to as hybrid (*h*) parameters, which are referred to in data sheets and on test instrument.

Hybrid parameters are very useful in determining the quality of a transistor. The four terminal network is shown in Fig. 10.21(a).

With this arrangement, there are two currents and two voltages to consider. If the two currents are considered as dependent variables, the resulting parameters are short-circuited parameters, and they are measured in mhos. When the two voltages are considered as dependent variables, the resulting parameters are open-circuit parameters, and they are measured in ohms. Hybrid (*h*) parameters are obtained by using one current and one voltage as dependent variables. The designations for the four *h* parameters are as follows.

h_i – input impedance with output shorted

h_r – reverse voltage ratio with input open

h_f – forward current gain with output shorted

h_o – output admittance with input open

The unit of measure for h_i is ohms, and for h_o is mhos. There are no units for h_f and h_r, since they are ratios.

The *h* parameters can be applied to any of the three basic amplifier configurations. An additional subscript letter is generally used to designate the type of configuration. Subscript *b* indicates common-base, *e* designates common-emitter and *c* denotes a common-collector.

The *h* parameter designations for a common emitter are h_{ie}, h_{re}, h_{fe}, and h_{oe}. Alpha for a common base circuit is equal to h_{fb} and beta in a common emitter is equal to h_{fe}.

The tester circuit for obtaining *h* parameters is illustrated in Fig. 10.21(b). G_1 is a calibrated current generator and G_2 is a calibrated voltage generator. The ac meter is used to indirectly measure current. The switches are four ganged sections of a five position rotary switch.

The lower the pH value, the more acidic the solution. Increasing pH values above 7.0, indicate increasing alkalinity.

Usually the pH is measured by immersing a special glass electrode and reference electrode into the solution. There are two types of methods used to measure the pH, the colorimetric method and the electrical method.

The colorimetric method is based on the assumption that if an indicator has the same colour in two solutions, then the pH of both solutions is the same. However, in practice this assumption does not hold good always, since the colour developed depends not only on the pH but also on other factors.

The electrical method is the most popular and is based upon a measurement of the electrode potential. The principle of this method is that when an electrode is immersed in the solution, a potential arises at the electrode solution boundary known as the electrode potential. This electrode potential, at a given temperature, depends upon the concentrations of ions of the electrolyte which exist in the solution. The electrode potential (in volts) of a metal immersed in a solution with ions of the same metal can be expressed by the following relation.

$$E = E_o + \frac{0.0001982\,(273 + t)}{n} \log_{10} a$$

where E_o = potential of the electrode, when its active-ion concentration in the solution is equal to unity.

t = temperature in degree centigrade

n = valency of the ion

a = active concentration of the ions of the metal in gram-equivalents per litre

In practice, only the potential difference can be measured and so the pH always has two elements; a measuring element, the potential of which depends on the concentration of the hydrogen ions, and a comparison element, the potential of which must remain constant. Two such elements connected electrically form a galvanic system, and by measuring the emf of this system we can drive the active concentration of the hydrogen ions in the solution under investigation.

The various electrodes used for pH measurements are as follows.

1. Hydrogen electrode
2. Calomel electrode
3. Quinhydrone and antimony electrodes
4. Glass electrodes

We now give some of the electrical methods used for measuring pH.

10.13.1 pH Measurement Using Hydrogen Electrode

The hydrogen electrode comparises a platinum plate covered with platinum black kept in a hydrogen element, where gaseous hydrogen at atmospheric pressure acts directly on this plate.

9. What are the features of a Kit type LCR bridge?
10. On what principle does the RX meter operate? Explain.
11. Explain the operation of an automatic bridge.
12. How can a transistor tester be used for the measurement of the following?
    (i) Faulty transistor
    (ii) I_{cbo}
    (iii) I_{ceo}
    (iv) Beta gain
    (v) Hybrid parameters
13. Explain in details the working of a Megger. State its applications.
14. What do you understand by pH?
15. How can pH be measured? State the different methods of pH measurement.
16. What is the necessity of using a thermocompensator for pH measurements?

Practice Problems

1. Determine the distributed stray capacitances for the following data
   First measurement $f_1 = 4$ MHz and $C_1 = 3.3$ kpf
   Second measurement $f_2 = 3f_1 = 12$ MHz and $C_2 = 1000$ pf
   Also calculate the value of inductance.
2. The distributed capacitance was found to be 20 pf by use of a Q meter. The first resonance occurred at $C_1 = 300$ pf and f_1 was half the second resonance frequency. Determine the value of C_2 and f_2 at the second resonance (given $L = 40\ \mu$H).

Further Reading

1. *Handbook of Electronic Measurements*, Vols. I & II, Polytechnic Institute of Brooklyn, 1956. (Microwave Research Institute)
2. John D. Lenk, *Handbook of Electronic Meters, Theory and Applications*, Prentice-Hall, 1980.
3. Rugus, D. Turner, *Basic Electronics Test Instruments*, Rinehart Books, 1953.
4. Vestor Robinson, *Handbook of Electronic Instrumentation, Testing and Troubleshooting*, D.B. Taraporevala Sons & Co, 1979.
5. Miles, Retter Sander (jr), *Electronic Meters Techniques and Troubleshooting*, Reston Publishing Co, 1977.
6. John D. Lenk, *Handbook of Electronic Test Equipment*, Prentice-Hall, 1971.

Therefore, the voltage between *a* and *b* is the difference between E_a and E_b, which represents Thévenin's equivalent voltage.

$$E_{th} = E_{ab} = E_a - E_b = \frac{E \times R_3}{R_1 + R_3} - \frac{E \times R_4}{R_2 + R_4}$$

Therefore $$E_{ab} = E\left(\frac{R_3}{R_1 + R_3} - \frac{R_4}{R_2 + R_4}\right)$$

Thévenin's equivalent resistance can be determined by replacing the voltage source *E* with its internal impedance or otherwise short-circuited and calculating the resistance looking into terminals *a* and *b*. Since the internal resistance is assumed to be very low, we treat it as 0 Ω. Thévenin's equivalent resistance circuit is shown in Fig. 11.3.

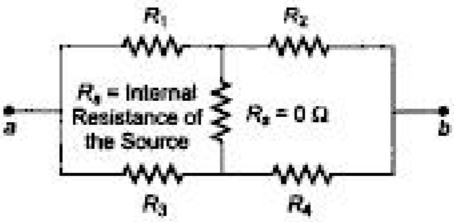

Fig. 11.3 ■ Thévenin's Resistance

The equivalent resistance of the circuit is $R_1//R_3$ in series with $R_2//R_4$ i.e. $R_1//R_3 + R_2//R_4$.

$$\therefore \qquad R_{th} = \frac{R_1 R_3}{R_1 + R_3} + \frac{R_2 R_4}{R_2 + R_4}$$

Therefore, Thévenin's equivalent circuit is given in Fig. 11.4. Thévenin's equivalent circuit for the bridge, as seen looking back at terminals *a* and *b* in Fig. 11.2, is shown in Fig. 11.4.

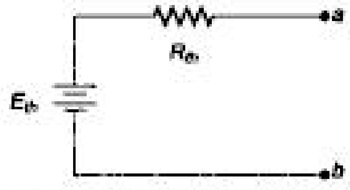

Fig. 11.4 ■ Thévenin's Equivalent

If a galvanometer is connected across the terminals *a* and *b* of Fig. 11.2, or its Thévenin equivalent Fig. 11.4 it will experience the same deflection at the output of the bridge. The magnitude of current is limited by both Thévenin's equivalent resistance and any resistance connected between *a* and *b*. The resistance between *a* and *b* consists only of the galvanometer resistance R_g. The deflection current in the galvanometer is therefore given by

$$I_g = \frac{E_{th}}{R_{th} + R_g} \qquad (11.5)$$

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galvanometer. In the case of high resistance measurements in mega ohms, the Wheatstones bridge cannot be used.

Another difficulty in Wheatstone's bridge is the change in resistance of the bridge arms due to the heating effect of current through the resistance. The rise in temperature causes a change in the value of the resistance, and excessive current may cause a permanent change in value.

11.9 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 Wheatstone'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 1 Ω. In low resistance measurement, the resistance of the leads connecting the unknown resistance to the terminal of the bridge circuit may affect the measurement.

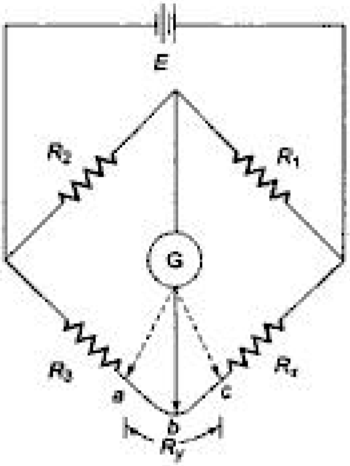

Fig. 11.10 Kelvin's Bridge

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 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 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

$$\frac{R_{cb}}{R_{ab}} = \frac{R_1}{R_2} \tag{11.6}$$

and the usual balance equations for the bridge give the relationship

$$(R_x + R_{cb}) = \frac{R_1}{R_2}\,(R_3 + R_{ab}) \tag{11.7}$$

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

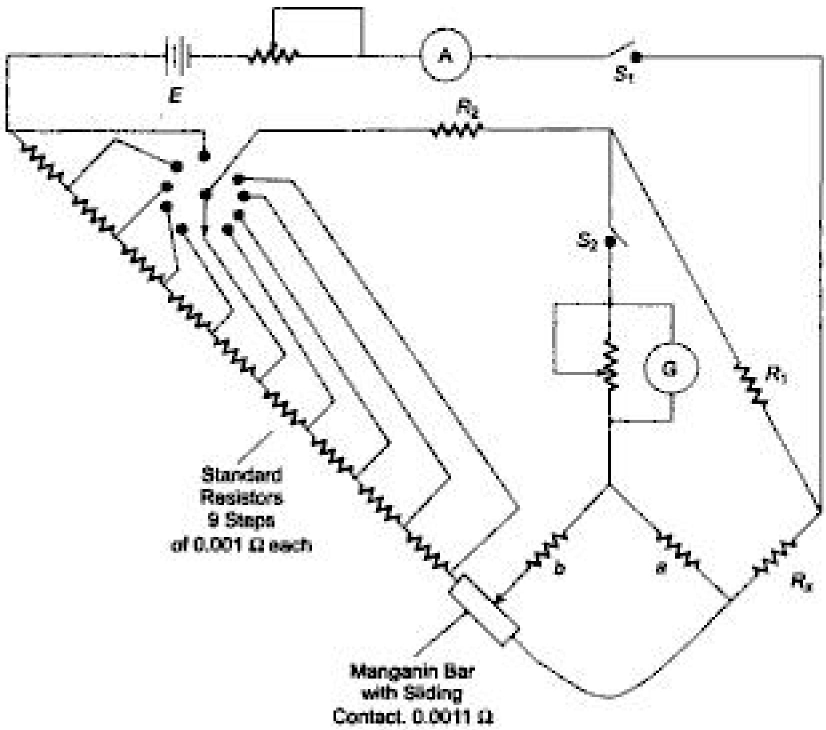

Fig. 11.13 ▬ Practical Kelvin's Bridge

11.5 BRIDGE CONTROLLED CIRCUITS

Whenever a bridge is unbalanced, a potential difference exists at its output terminal. The potential difference causes current to flow through the detector (say, a galvanometer) when the bridge is used as part of a measuring instrument. When the bridge is used as an error detector in a control circuit, the potential difference at the output of the bridge is called an error signal, as in Fig. 11.14.

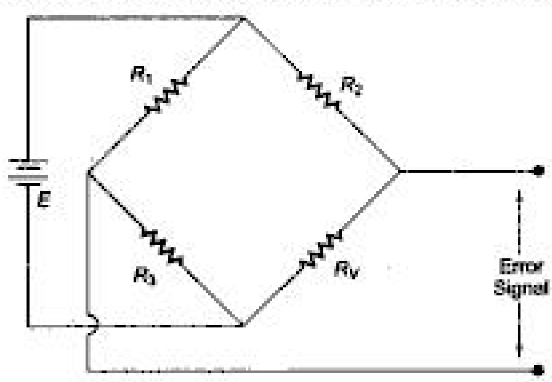

Fig. 11.14 ▬ Wheatstone's Bridge Error Detector with Resistance R_v Sensitive to Some Physical Parameters

easiest method of measurement and requires only one measurement circuit to obtain various results. Specifically, one quantity can be measured in terms of another, or several others with completely different dimensions, and the desired results calculated with the microprocessor.

(One such microprocessor-based instrument is the General Radio model 1658RLC digibridge.)

Such intelligent instruments represent a new era in impedance measuring instruments. The following are some features of these instruments.

1. Automatically measures *R*, inductance *L*, capacitance *C*, dissipation factor *D* and storage factors for inductors *Q*.
2. 0.1% basic accuracy
3. Series or parallel measurement mode
4. Autoranging
5. No calibration required
6. Ten bins for component sorting/binning (equivalent, binary number)
7. Three test speeds
8. Three types of display-programmed bin limits, measured values or bin number.

Most of these features are available because of the use of a microprocessor, e.g. the component sorting/binning feature is achieved by programming the microprocessor.

When using the instrument in this mode, bins are assigned a tolerance range. When a component is measured, a digital readout (bin number) indicating the proper bin for that component is displayed on the keyboard control panel.

11.8 AC BRIDGES

Impedances at AF or RF are commonly determined by means of an ac Wheatstone bridge. The diagram of an ac bridge is given in Fig. 11.17. This bridge is similar to a dc bridge, except that the bridge arms are impedances. The bridge is excited by an ac source rather than dc and the galvanometer is replaced by a detector, such as a pair of headphones, for detecting ac. When the bridge is balanced,

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

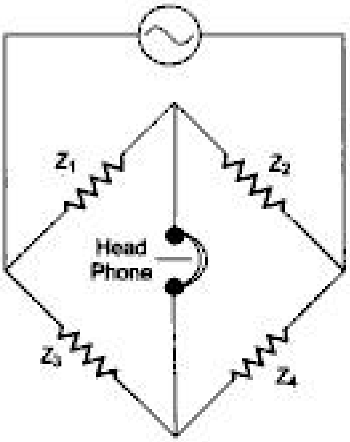

Fig. 11.17 ■ ac Wheatstone's Bridge

where Z_1, Z_2, Z_3 and Z_4 are the impedances of the arms, and are vector complex quantities that possess phase angles. It is thus necessary to adjust both the

Equating real terms and imaginary terms we have

$$R_x = \frac{R_2 R_3}{R_1} \text{ and } L_x = C_1 R_2 R_3 \tag{11.15}$$

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

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

The Maxwell bridge using a fixed capacitor has the disadvantage that there 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).

Example 11.7 A Maxwell bridge is used to measure an inductive impedance. The bridge constants at balance are

$$C_1 = 0.01\ \mu\text{F},\ R_1 = 470\ \text{k}\Omega,\ R_2 = 5.1\ \text{k}\Omega, \text{ and } R_3 = 100\ \text{k}\Omega.$$

Find the series equivalent of the unknown impedance.

Solution We need to find R_x and L_x.

$$R_x = \frac{R_2 R_3}{R_1} = \frac{100\ \text{k} \times 5.1\ \text{k}}{470\ \text{k}} = 1.09\ \text{k}\Omega$$

$$L_x = R_2 R_3 C_1$$

$$= 5.1\ \text{k} \times 100\ \text{k} \times 0.01\ \mu\text{f}$$

$$= 5.1\ \text{H}$$

The equivalent series circuit is shown in Fig. 11.22

Fig. 11.22

11.12 HAY'S BRIDGE

The Hay bridge, shown in Fig. 11.23, differs from Maxwell's bridge by having a resistance R_1 in series with a standard capacitor C_1 instead of a parallel. For

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$$Z_3 = -j/\omega C_3$$

$$Y_1 = 1/R_1 + j\,\omega C_1$$

as $$Z_x = Z_2 Z_3 Y_1$$

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

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

Equating the real and imaginary terms, we get

$$R_x = \frac{R_2 C_1}{C_3} \qquad [11.20(a)]$$

and $$C_x = \frac{R_1}{R_2} C_3 \qquad [11.20(b)]$$

The dial 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 contangent of the phase angle.

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

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 100 pf – 1 µf, 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.

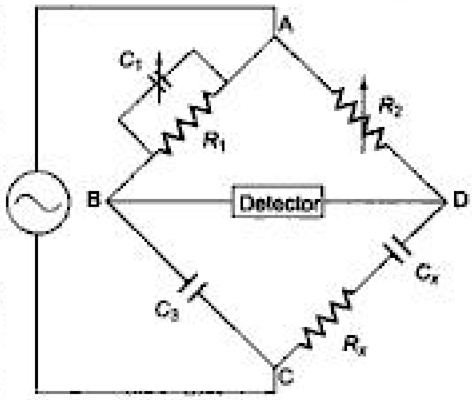

Fig. 11. 26

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.

themselves, become significant. This introduces an error in the measurement, when small values of capacitance and large values of inductance are measured.

An effective method of controlling these capacitances, is to enclose the elements by a shield and to ground the shield. This does not eliminate the capacitance, but makes it constant in value.

Another effective and popular method of eliminating these stray capacitances and the capacitances between the bridge arms is to use a Wagner's ground connection. Figure 11.28 shows a circuit of a capacitance bridge. C_1 and C_2 are the stray capacitances. In Wagner's ground connection, another arm, consisting of R_w and C_w forming a potential divider, is used. The junction of R_w and C_w is grounded and is called Wagner's ground connection. The procedure for adjustment is as follows.

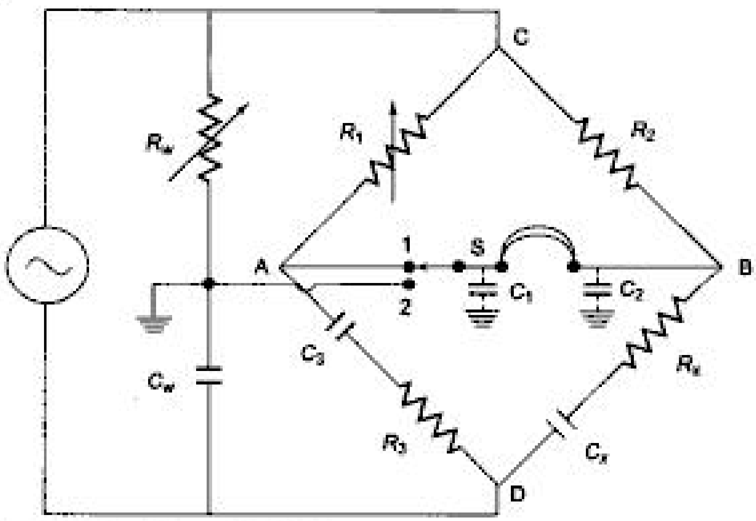

Fig. 11.28 ▬ Wagner's Earth Connection

The detector is connected to point 1 and R_1 is adjusted for null or minimum sound in the headphones. The switch S is then connected to point 2, which connects the detector to the Wagner ground point. Resistor R_w is now adjusted for minimum sound. When the switch 'S' is connected to point 1, again there will be some imbalance. Resistors R_1 and R_3 are then adjusted for minimum sound and this procedure is repeated until a null is obtained on both switch positions 1 and 2. This is the ground potential. Stray capacitances C_1 and C_2 are then effectively short-circuited and have no effect on the normal bridge balance.

The capacitances from point C to D to ground are also eliminated by the addition of Wagner's ground connection, since the current through these capacitors enters Wagner's ground connection.

The addition of the Wagner ground connection does not affect the balance conditions, since the procedure for measurement remains unaltered.

Practice Problems

1. Calculate the value of R_x in a Wheatstone bridge if
   (i) $R_1 = 400\ \Omega$, $R_2 = 5$ k, $R_3 = 2$ k
   (ii) $R_1 = 10$ k, $R_2 = 40$ k, $R_3 = 15.5$ k
   (iii) $R_1 = 5$ k, $R_2 = 40$ k, $R_3 = 10\ \Omega$
2. What resistance range must resistor R_3 have in order to measure unknown resistor in the range 1 – 100 kΩ using a Wheatstone bridge? Given $R_1 = 1$ k and $R_2 = 10$ k.
3. Calculate the value of R_x in Fig. Ex. 11.12, $R_a = 1600\ R_b$, $R_1 = 800\ R_b$ and $R_1 = 1.25\ R_2$.
4. Calculate the current through the galvanometer in the circuit diagram of Fig. 11.30.
5. If the sensitivity of the galvanometer in the circuit of Fig. 11.31 is 10 mm/μA, determine its deflection.

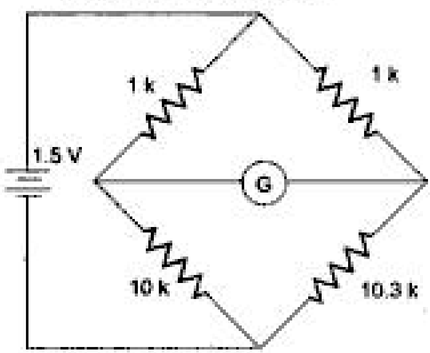

Fig. 11.30

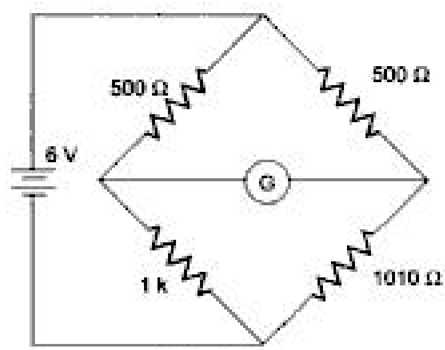

Fig. 11.31

6. A balanced ac bridge has the following constants.
   Arm AB – $R = 1$ k in parallel with $C = 0.047$ μF
   Arm BC – $R = 2$ k in series with $C = 0.047$ μF
   Arm DC – unknown
   Arm DA – $C = 0.25$ μF.
   The frequency of the oscillator is 1 kHz. Determine the constants of arm CD.
7. A bridge is balanced at a frequency of 1 kHz and has the following constants.
   Arm AB – 0.2 μF pure capacitor
   Arm BC – 500 Ω pure resistance
   Arm CD – unknown
   Arm DA – $R = 600\ \Omega$ in parallel with $C = 0.1$ μF.
   Derive the balance condition and find the constants of arm CD, considered as a series circuit.
8. A 1000 Hz bridge has the following constants
   Arm AB – $R = 1$ k in parallel with $C = 0.25$ μF
   Arm BC – $R = 1$ k in series with $C = 0.25$ μF
   Arm CD – $L = 50$ mH in series with $R = 200\ \Omega$
   Arm DA – unknown

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CHAPTER

12 Recorders

12.1 INTRODUCTION

A recorder is a measuring instrument that displays a time-varying signal in a form easy to examine, even after the original signal has ceased to exist.

Recorders generally provide a graphic recod of variations in the quantity being measured, as well as an easily visible scale on which the indication is displayed.

The variety of recording instruments in the central monitoring and control stations of many industrial and utility plants is proof of their importance in industrial work. They provide a continuous, written record of the changes taking place in the quantity being measured. This chart record may be scaled off in electrical values (mV/mA) or in terms of some non-electrical quantity, such as temperature or pressure.

Many recording instruments include an additional provision for some sort of controlling action. If the control function is the primary one, the measuring instrument is called a controller.

The recorder usually provides an instantaneous indication for monitoring at the same time as it makes a graphic record.

Electronic recording instruments may be divided into three groups.

The easiest type is simply a meter having an indicating needle and a writing pen attached to the needle. If a strip of paper is pulled at a constant velocity under the writing pen (at a 90° angle to the direction of pen motion), the moving pen plots the time function of the signal applied to the meter. A highly special designed D'Arsonval movement is used to drive the writing pen. This type is called a *galvanometer recorder*.

Another recorder is the null or *potentiometric recorder*, operating on a self-balancing comparison basis by servomotor action. This recorder is basically a voltage responsive positional servo system using a motor to move a writing

Example 12.2 If the frequency of a signal to be recorded with a strip-chart recorder is 20 Hz, what must be the chart speed used to record one complete cycle on 5 mm of recording paper?

Solution Given frequency = 20 Hz and time base = 5 mm

Period = 1/frequency = 1/20 = 0.05 s

$$\text{Period} = \frac{\text{time base}}{\text{chart speed}}, \quad \text{therefore} \quad 0.05 = \frac{5\ \text{mm/cycle}}{\text{chart speed}}$$

$$\text{Chart speed} = \frac{5\ \text{mm}}{\text{cycle}} \times \frac{1}{0.05\ \text{s/cycle}}$$

$$= \frac{5 \times 100}{5}\ \text{mm/s} = 100\ \text{mm/s}$$

There are basically two types of strip chart recorders, the (i) galvanometer type, and the (ii) null type (potentiometric).

12.3 GALVANOMETER TYPE RECORDER

The D'Arsonval movement used in moving coil indicating instruments can also provide the movement in a galvanometer recorder.

The D'Arsonval movement consists of a moving coil placed in a strong magnetic field, as shown in Fig. 12.2(a).

In a galvanometer type recorder, the pointer of the D'Arsonval movement is fitted with a pen-ink (stylus) mechanism.

The pointer deflects when current flows through the moving coil. The deflection of the pointer is directly proportional to the magnitude of the current flowing through the coil.

As the signal current flows through the coil, the magnetic field of the coil varies in intensity in accordance with the signal. The reaction of this field with the field of the permanent magnet causes the coil to change its angular position. As the position of the coil follows the variation of the signal current being recorded, the pen is accordingly deflected across the paper chart.

The paper is pulled from a supply roll by a motor driven transport mechanism. Thus, as the paper moves past the pen and as the pen is deflected, the signal waveform is traced on the paper.

The recording pen is connected to an ink reservoir through a narrow bore tube. Gravity and capillary action establish a flow of ink from the reservoir through the tubing and into the hollow of the pen.

Galvanometer type recorders are well suited for low frequency ac inputs obtained from quantities varying slowly at frequencies of upto 100 c/s, or in special cases up to 1000 c/s.

Because of the compact nature of the galvanometer unit (or pen motor) this type of recorder is particularly suitable for multiple channel operation. Hence it

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Modulation of the current in the recording head by the signal to be recorded linearly modulates the magnetic flux in the recording gap. As the tape moves under the recording head, the magnetic particles retain a state of permanent magnetisation proportional to the flux in the gap. The input signal is thus converted to a spatial variation of the magnetisation of the particles on the tape. The reproduce head detects these changes as changes in the reluctance of its magnetic circuit which induce a voltage in its winding. This voltage is proportional to the rate of change of flux. The reproduce head amplifier integrates the signal to provide a flat frequency characteristics.

Since the reproduce head generates a signal which is proportional to the rate of change of flux, the direct recording method cannot be used down to dc. The lower limit is around 100 Hz and the upper limit for direct recording, around 2 MHz. The upper frequency limit occurs when the induced variation in magnetisation varies over a distance smaller than the gap in the reproduce head.

The signal on an exposed tape can be retrieved and played out at any time by pulling the tape across the magnetic head, in which a voltage is induced.

It is possible to magnetise the tape longitudinally or along either of the other two main axis, but longitudinal magnetisation is the best choice.

Figure 12.10(b) shows simply how the tape is magnetised. If a magnetic field is applied to any one of the iron oxide particles in a tape and removed, a residual flux remains. The relationship between the residual flux and the recording field is determined by the previous state of magnetisation and by the magnetisation curves of the particular magnetic recording medium.

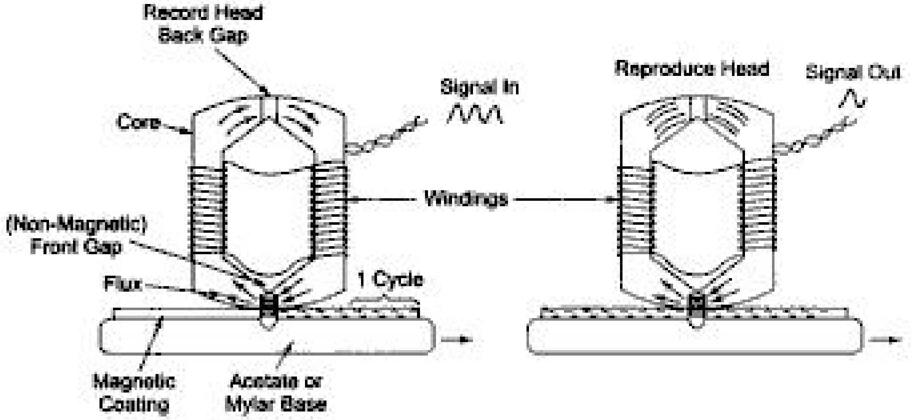

Fig. 12.10(b) ▬ Magnetisation of Tape

A simple magnetic particle on the tape might have the $B - H$ curve shown in Fig. 12.10(c) where H is the magnetising force and B the flux density in the particle.

Consider the material with no flux at all, i.e. the condition at point 0.

Now if the current in the coil of the recording head [Fig. 12.10(b)] is increased from 0 in a direction that gives positive values of H, the flux density

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Disadvantages

1. FM recording is extremely sensitive to tape speed fluctuations.
2. FM recording circuitry is more complicated than that of direct recording systems.
3. FM system has a limited frequency response.
4. It requires a high tape speed.
5. It requires a high quality of tape transport and speed control.

Pulse Duration Modulation

Pulse width modulation is also called pulse duration modulation (PDM). In this system, the amplitude and the starting time of each pulse is kept fixed, but the width of the pulse is made proportional to the amplitude of the signal at that instant. This type of system is mostly used for Digital recording.

DIGITAL DATA RECORDING

Digital magnetic tapes are often used as storage devices in digital data processing applications. Digital tape units are of two types, incremental and synchronous.

Incremental digital recorders are commanded to step ahead (increment) for each digital character to be recorded. Input data may be at a relatively slow, or even discontinuous rate. In this way, each character is equally and precisely spaced along the tape.

In a synchronous digital recorder, the tape moves at a constant speed (about 75 cm/s) while a large number of data characters are recorded. The data inputs are at precise rates, up to tens of thousands of characters per second. The tape is rapidly brought up to speed, recording takes place, and the tape is brought to a fast stop. In this way a block of characters (a record) is written with each character spaced equally along the tape. Blocks of data are usually separated from each other by an erased area on the tape called the record gap. The synchronous tape unit starts and stops the tape for each block of data to be recorded.

Characters are represented on magnetic tape by a coded combination of 1-bit in appropriate tracks across the tape width. The recording technique used in most instrumentation tape recorders is the industry accepted IBM format of Non-Return Zero (NRZ) recording.

In this system the tape is magnetically saturated at all times in either the positive or the negative direction.

The NRZ method uses the change in flux direction on the tape to indicate 1 bit, and no change in flux direction to indicate 0 bit. This method is illustrated in Fig. 12.12, where the binary numbr 11101011 is represented by a flux pattern in the NRZ system.

The simplest method of coding the recording head field is to reverse its direction.

8. Charts speed expressed in inches or centimeters per second, per min. or per hour.

12.13 POTENTIOMETRIC RECORDER (MULTIPOINT)

12.13.1 Principle of Operation

The thermocouple or millivolt signal is amplified by a non-inverting MOSFET, chopper stabilised, feedback amplifier. This configuration has a very high input impedance and the current passing through the signal source is a maximum of 0.5 nA (without broken sensor protection). With the use of span control, the output signal is adjusted to 5 V (nominal), for an input signal change, e.g. to full scale deflection of the pen.

The pre-amplifier output signal is then compared with a reference voltage picked off the measuring slide wire, which is energised by a stabilised power supply, and the difference amplified by a servo amplifier, whose output drives a linear motor. The motor carriage carries the indicating pointer pen and the sliding contact on the slide wire.

The motor itself consists of a coil assembly, travelling in a magnetic field (Fig. 12.14). The servo amplifier drives the carriage in the appropriate direction, to reduce the difference signal to zero.

An input filter circuit reduces any spurious signals picked up by the input leads. The B–E junctions of the transistor are used for overload protection.

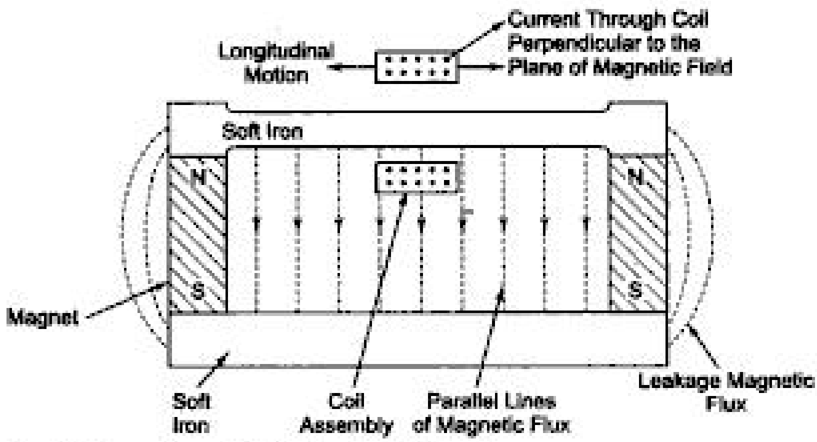

Fig. 12.14 Linear Motor Operating Principle

In multipoint versions of the recorder, a signal selector switch is driven by a synchronous motor. The pen changeover and dotting action are actuated by a second synchronous motor (Fig. 12.15). The pen operation is electrically synchronised to the rotation of the signal selector switch—should they get out of step, the pen motor stops at a predetermined point and restarts only when the signal selector switch has rotated to its correct alignment. The linear motor is

driven from a synchronous motor having a speed of 10 rpm via an intermittent motor. Each signal is sampled for a period of 3 or 6 seconds, depending on the switch motor fitted.

A second synchronous motor (10 rpm – 24 V ac) is mounted and fitted with cams and microswitches (Fig. 12.15).

The cam at the extreme end actuates the pen lifting (and dotting) bar and initiates the pen dotting. As the stylus lifts off the paper, a pawl and ratchet system in the pen head rotates the stylus and ink well to the next point.

A synchronising microswitch, mounted under the pen head, is operated by a pip on the stylus shaft. The contacts are open while the pen stylus is at initial point 1.

Fitted to the shaft of the dotting motor is a second cam, which operates a second microswitch in the synchronising circuit. The contact switches are open for a period of 0.3 – 0.4s, once in each revolution of the dotting motor, which rotates once during the sampling period of each print, i.e. 6s.

The third synchronising microswitch is operated by the projection on the side of the plastic intermittent advance gear on the same shaft of the signal switch. The contact of this microswitch closes for a period of 0.5 – 0.6s once in each revolution of the signal switch, i.e. once every 72s for a 6s sampling.

When the recorder goes out of synchronisation, if the cams and pen stylus are set correctly, the dotting motor will continue operating until the stylus comes around to the initial point. At this point the pen microswitch opens, as does the dotting microswitch. The dotting motor then stops.

The signal selector switch motor operates continuously, and when the microswitch operated by this motor closes, the dotting starts again.

(Note: The closing time of the signal selector microswitch is slightly more than the open time of the dotting motor microswitch, ensuring that the dotting motor microswitch be closed again before the signal selector switch motor microswitch opens.)

12.13.5 Multiple Recorders (6 Point Recorders)

The controller consists of a high gain opamp in comparator configuration, with one input from the pre-amplifier and another from the set point potentiometer. The output of the comparator is connected to the Schmitt trigger via both high and low control microswitches, operated by control cams, as shown in Fig. 12.17.

The Schmitt trigger circuit maintains the relay state after the input is disconnected, i.e. while the signal selector switches scan the other signal input. The control microswitch ensures that the relay does not change state during signal changeover, while the pre-amplifier input is open-circuit. Once the relay gets energised, it remains in that state via its own (normally open) contacts and through the Reset button.

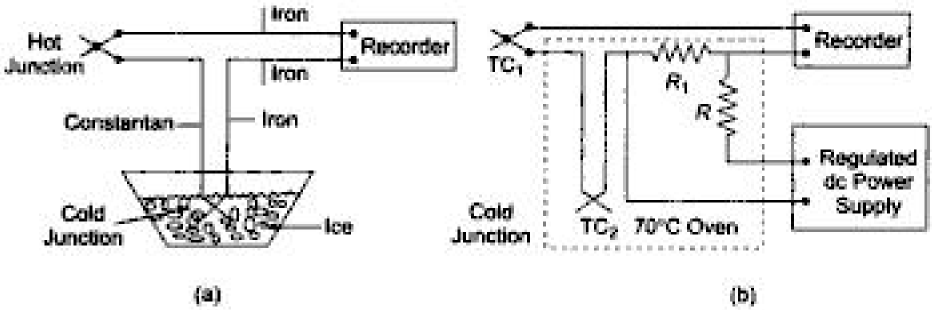

Fig. 12.19 ■ (a) Basic Circuit used to Record Thermocouple Voltage
(b) Basic Circuit with Artificial Reference Junction Voltage used to Measure Thermocouple Voltage

A thermocouple (discussed in Sec. 3.6) is made by joining two dissimilar metals. A potential difference, which is proportional to the temperature, exists across the junctions. This potential difference has an almost linear relationship with the temperature and is very repeatable.

Elaborate tables of temperature versus potential difference have been developed for certain pairs of metals that are used for commercial thermocouples. These tables allow one to determine the hot junction temperature when the cold junction or reference junction temperature is 0°C. If the reference temperature is not 0°C, correction factors may be used.

However, it is usually convenient to maintain the reference junction at 0°C or to develop an artificial reference junction emf by using a circuit as shown in Fig. 12.19(b).

Thermocouple TC_2 is maintained at 70°C by the oven. The emf developed by TC_2 is balanced out by the voltage drop across R, due to current flowing from the regulated dc power supply, until the total emf is equl to the emf of TC_2 at 0°C.

(The two metals connected to the recorder terminal are of the same metal.)

2. Sound Level Recording

It is frequently desirable to obtain a record of the sound level over a period of time, near highways, airports, hospitals, schools or residence.

This can be done with an ordinary microphone and a strip-chart recorder, provided the output signal from the microphone is of sufficient amplitude to drive the recorder.

A better setup for obtaining sound level data is to use a sound level meter and a strip chart recorder, as shown in Fig. 12.20.

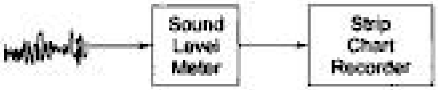

Fig. 12.20 ■ Setup for Measuring Sound Level as a Function of Time

3. Recording Amplifier Drift

Transistor amplifiers are sensitive to temperature changes. Temperature changes causes the bias voltage of the transistor to change, thereby changing

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

Advantages of Electrical Transducers

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

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

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

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

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In each of these cases, the element moved by the pressure change is made to cause a change in resistance. This resistance change can be made part of a bridge circuit and then taken as either ac or dc output signal to determine the pressure indication.

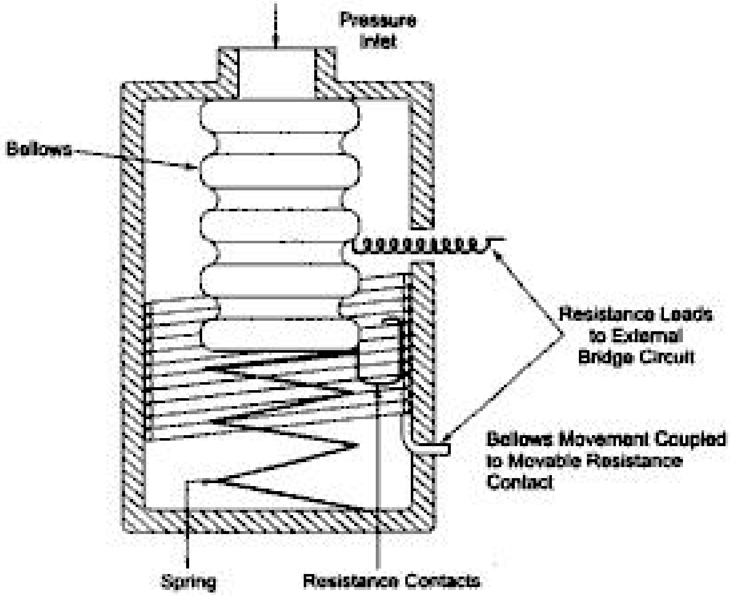

Fig. 13.1(d) ■■ Resistance Pressure Transducer

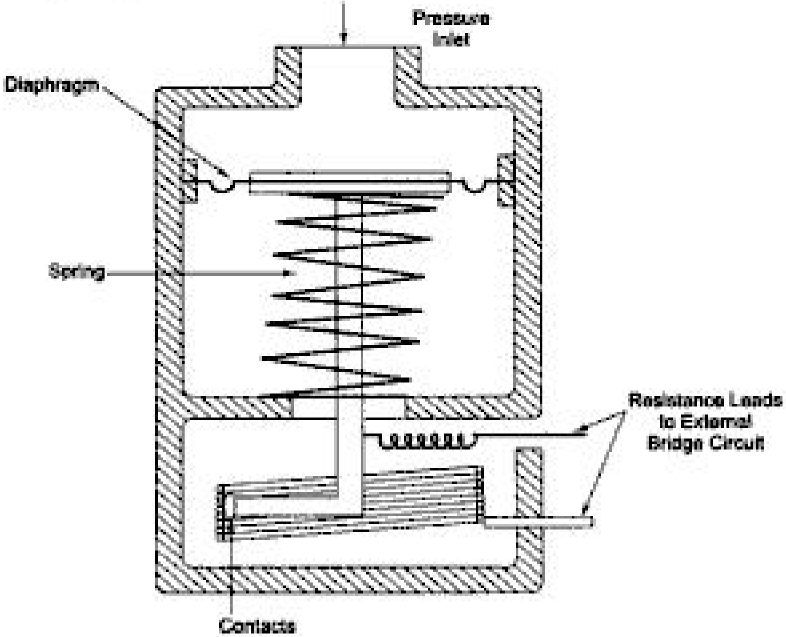

Fig. 13.1(e) ■■ Sensitive Diaphragm Moves the Resistance Contact

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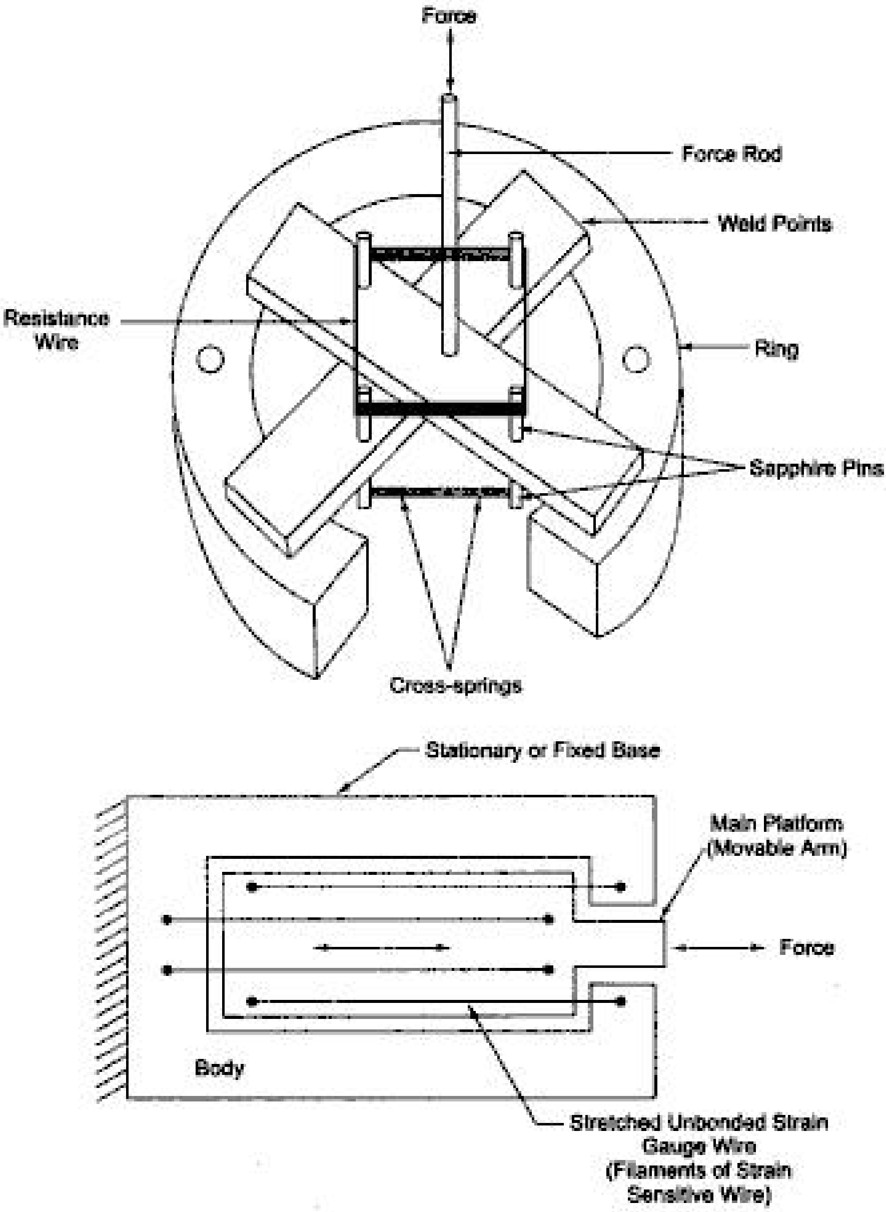

Fig. 13.3 ■ Unbonded Strain Gauge

2. 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

Solution Given:

$$K = \frac{\Delta R / R}{\Delta l / l}$$

Therefore, $\Delta R = K\, R\, \Delta l / l$

$$\Delta R = 2 \times 130 \times 1 \times 10^{-6} = 260\ \mu\Omega$$

The initial resistance value R of a strain gauge is typically around 120 Ω and the gauge factor may be from (for Nickel) – 12 to + 6. A gauge factor of 2 is reasonable for most strain gauges. Semiconductor gauge have higher sensitivities.

The strain gauge is normally used in a bridge arrangement in which the gauge forms one arm of the bridge. The bridge may be ac or dc actuated. A simple dc arrangement is shown in Fig. 13.5. Only one of the gauges is an active element, producing an output proportional to the strain. The other (dummy) gauge is not strained, but simply balances the bridge (compensation). Since the resistance of the fine wire element is sensitive to temperature as well as stress variation, any change in temperature will cause a change in the bridge balance conditions. This effect can cause error in the strain measurement (thereby affecting the accuracy). Hence, when temperature variations are significant, or when unusual accuracy is required, some compensation must be used. The dummy gauge accomplishes this, because it is placed in the same temperature environment as the active gauges, but not subjected to strain. Consequently, the temperature causes the same change of resistance in the two strain gauges and the bridge balance is not affected by the temperature.

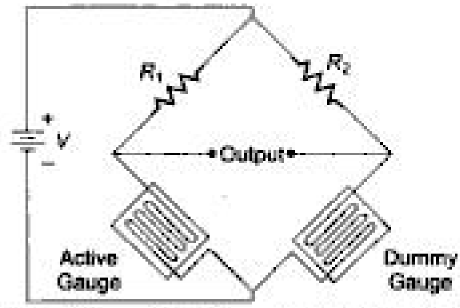

Fig. 13.5 ▬ Strain Gauge Used in Bridge Arrangement

If the two resistors R_1 and R_2 have negligible temperature coefficients, the bridge retains its balance under conditions of no-strain, at any temperature within its operating range.

(However, one of the two gauges in mounted so that its sensitivity direction is at right angles to the direction of strain.)

The resistance of this dummy gauge is not affected by the deformation of the material and it therefore acts like a passive resistance, with regard to strain measurement.

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.

Advantages of Semiconductor Strain Gauge

1. Semiconductor strain gauges have a high gauge factor of about + 130. This allows measurement of very small strains, of the order of 0.01 micro strain.
2. Hysteresis characteristics of semiconductor strain gauges are excellent, i.e. less than 0.05%.
3. Life in excess of 10×10^6 operations and a frequency response of 10^{12} Hz.
4. Semiconductor strain gauges can be very small in size, ranging in length from 0.7 to 7.0 mm.

Disadvantages

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

13.7 RESISTANCE THERMOMETER*

The resistance of a conductor changes when its temperature is changed. This property is utilised for the measurement of temperature. The resistance thermometer is an instrument used to measure electrical resistance in terms of temperature, i.e. it uses the change in the electrical resistance of the conductor to determine the temperature.

The main part of a resistance thermometer is its sensing element. The characteristics of the sensing element determines the sensitivity and operating temperature range of the instrument.

* Also refer Sec. 13.20.2 (RTD's)

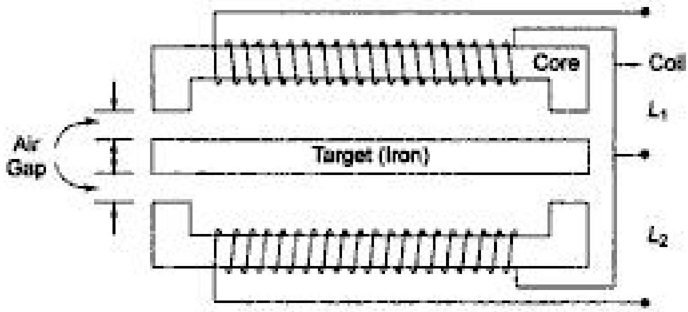

Fig. 13.18 Inductive Transducer Differential Output (Reluctance Principle)

13.11 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.

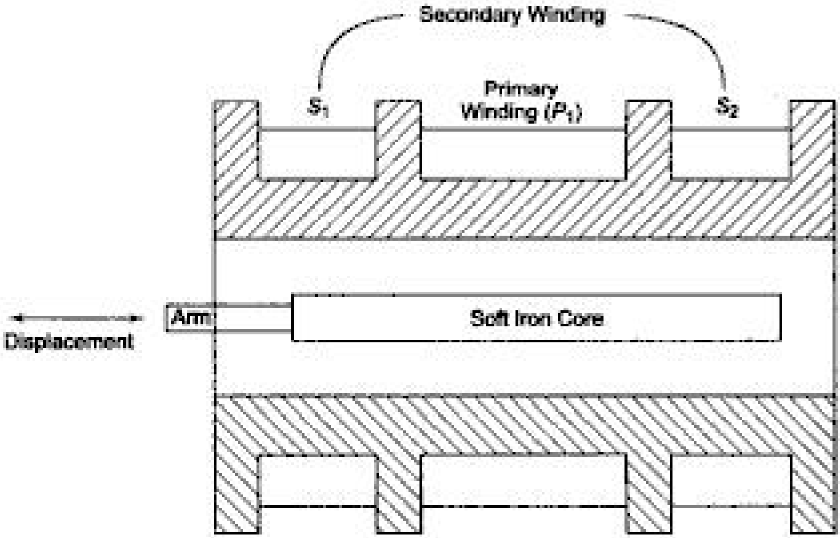

Fig. 13.19 Construction of a Linear Variable Differential Transducer (LVDT)

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

An movable soft iron core slides within the hollow former and therefore affects the magnetic coupling between the primary and the two secondaries.

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

Disadvantages

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

Example 13.5 An ac LVDT has the following data.
Input = 6.3 V, Output = 5.2 V, range ± 0.5 in. Determine
(i) Calculate the output voltage vs core position for a core movement going from + 0.45 in. to – 0.30 in.
(ii) The output voltage when the core is – 0.25 in. from the centre.

Solution

(i) 0.5 in. core displacement produces 5.2 V, therefore a 0.45 in. core movement produces (0.45 × 5.2)/0.5 = 4.68 V.
Similarly a – 0.30 in. core movement produces

$$(-0.30 \times -5.2)/(-0.5) = -3.12\ \text{V}$$

(ii) – 0.25 in. core movement produces

$$(-0.25 \times -5.2)/(-0.5) = -2.6\ \text{V}$$

13.12 PRESSURE INDUCTIVE TRANSDUCER

A simple, arrangement, wherein a change in the inductance of a sensing element is produced by a pressure change, is given in Fig. 13.22.

Here the pressure acting on a movable magnetic core causes an increase in the coil inductance corresponding to the acting pressure. The change in inductance can again be made on the basis of an electrical signal, using an ac bridge.

An advantage of the inductive type over the resistive type is that no moving contacts are present, thereby providing continuous resolution of the change, with no extra friction load imposed on the measuring system.

In a slightly modified form, this principle is used to obtain a change in mutual inductance between magnetically coupled coils, rather than in the self inductance of a single coil. When a change in an induced voltage is involved,

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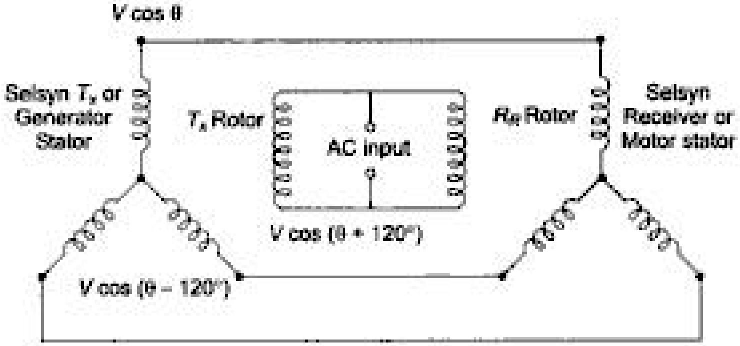

Fig. 13.25 Torque Selsyn

The rotor of both units are excited through slip rings by an ac source at a convenient frequency.

If the receiver rotor is in the same relative position with reference to stator windings as the transmitter, the inductive coupling is identical and no stator current flows between the two units.

If transmitter rotor is shifted from this null position, voltages induced in the two stator will be the difference and a current starts to flow. This current flow produces a torque in the receiver which causes the receiver rotor to move into alignment with the new transmitter rotor position and the previous null position is obtained. Hence the receiver always follow the angular motion in accordance with that of the transmitter. Its accuracy is limited by the friction of the receiver bearings and calibration of its dial face.

13.12.3 Control Synchro

When larger amounts of power or torque and greater accuracy are required control synchros are used.

These devices are used for providing and handling control signals to a servo amplifier when more power and accurate angular displacement of a large load are required. The control synchros are not designed to handle any mechanical load.

The Control Transformer (CT) develops an ac rotor output voltage that is proportional to the relative shaft angles between synchro transmitter and control transformer. The devices are normally connected as shown in Fig. 13.26.

The two most common control synchro are Control Transmitter (CX) and Control Transformer (CT).

The output of the CX (transmitter) is fed to the stator of CT (transformer). The CT is a high impedance version of the torque receiver with its rotor aligned at 90° to that of transmitter (TR).

In a control system, when the shaft angle of the CX equals that of CT shaft angle, a minimum and null voltage will appear on the rotor terminals R_1 and R_2 of the CT. Any variation from this null will produce a signal in CT rotor whose phase will depend in which direction it is moved off the null.

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obtained. This makes the load cell sensitive to very small values of applied stress, as well as to extremely heavy loads.

13.15 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. 13.31.

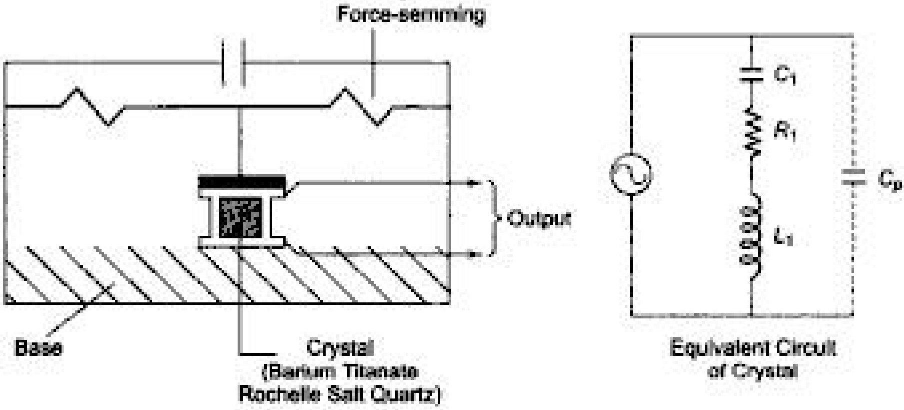

Fig. 13.31 ■ Piezo Electric Transducer

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

$$E = \frac{Q}{C_p}$$

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

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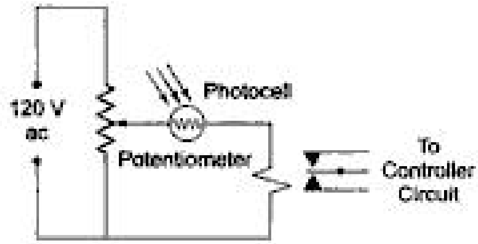

Fig. 13.34 Photo Cell and Relay Control Circuit

When the photocell has the appropriate light shining on it, its resistance is low and the current through the relay is consequently high enough to operate the relay. When the light is interrupted, the resistance rises, causing the relay current to decrease enough to de-energise the relay.

Example 13.7 The relay of Fig. Ex. 13.7(a) is to be controlled by a photo-conductive cell with the characteristics shown in Fig. Ex. 13.7(b). The potentiometer delivers 10 mA at a 30 V setting when the cell is illuminated with about 400 l/m^2 and is required to be de-energised when the cell is dark. Calculate (i) the required series resistance, and the (ii) dark current level.

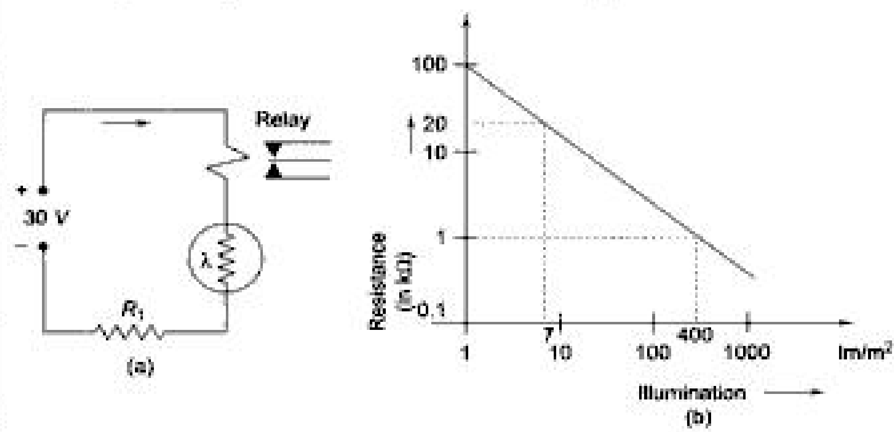

Fig. Ex. 13.7

Solution

(i) The cell resistance at 400 l/m^2 is 1 kΩ.

$$\text{Therefore,} \quad I = \frac{30\ V}{R_1 + R_{cell}} \quad \text{i.e.} \quad R_1 = \frac{30\ V}{I} - R_{cell}$$

$$= \frac{30\ V}{10\ \text{mA}} - 1\ \text{k} = 3\ \text{k} - 1\ \text{k} = 2\ \text{k}\Omega$$

Referring to Fig. 13.39, it can be seen that one of the RTD leads L_1 is in the arm of the bridge with R_T and a second lead L_2 is in the adjacent arm with R_3.

When the bridge is balanced, all the bridge arm resistance are equal, hence same current flows in all the bridge arms. The same current flows through both these leads L_1 and L_2 under balance conditions, therefore the voltage drop across them will be identical and being in the adjacent arms will effectively cancel out. Hence the effect of the lead wire is eliminated.

The third lead L_3, is connected in the output circuit of the bridge and has no effect on the bridge ratios or balance. Hence when the bridge is balanced no current flows through L_3 and therefore has no effect on the bridge balance. This method gives very good accuracy if the lead resistances are matched.

Four Lead RTD Connection

The three lead RTD gives sufficient accuracy for most of the industrial applications. However, when a higher degree of accuracy and precision is required, a four lead RTD connection is used.

The four lead RTD is the most expensive type, especially when long four wire extension leads are needed to connect to the instrumentation. However the four lead RTD can offer the greatest accuracy if the instrumentation is properly designed. Four lead RTDs are widely used in laboratory work, where highest precision is required.

To select a 100 Ω Platinum RTD, the information given in Table 13.2 is helpful.

Table 13.2

1. Temperature range	200°C–850°C
2. Temperature coefficient in %°C at 25°C	$\alpha = 0.39$
3. Construction	Wire wound or thin film deposited platinum
4. Self heating	0.02°C–0.75°C/mV (typical)
5. Lead wire	Copper two, three or four depending on the system
6. Lead resistance compensation	Use three or four wire lead systems
7. Accuracy	± 0.6 at 100°C
8. Resolution	0.29–0.39 Ω/°C
9. Drift	Approximately 0.01–0.1°C per year

13.20.3 Platinum Thin Film Sensors

Platinum thin film sensors are manufactured by a very thin layer of platinum in suitable pattern to achieve smaller dimension and higher resistance, on a ceramic base. The deposition of layers and introduction of patterns are obtained using different methods.

Type 'E' Thermocouple units use Chromel alloy as the positive electrode and constantan alloy as the negative electrode.

Type 'S' Thermocouple produces the least output voltage but can be used over greatest temperature range.

Type 'T' shown in Fig. 13.44, uses copper and constantan.

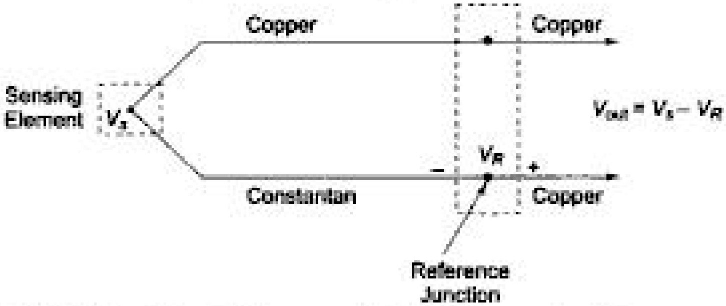

Fig. 13.44 ■ A Type T Thermocouple with Reference Junction

Copper used, is an element and constantan used is an alloy of nickel and copper. The copper side is positive and constantan side is negative. Assuming copper wires used to connect the thermocouple to the next stage (circuit), a second Copper-Constantan junction is (formed) produced. This junction is called as the reference junction. It generates a Seebeck voltage that opposes the voltage generated by the sensing junction. If both junctions are at the same temperature, the output voltage V_{out} will be zero. If the sensing junction is at a higher temperature, V_{out} will be proportional to the difference between the two junction temperature. The temperature cannot be derived directly from the output voltage alone. It is subjected to an error caused by the voltage produced by the reference junction. This can be overcome by placing the reference junction in an ice bath to keep it at a known temperature. This process is called as *cold junction compensation* as shown in Fig.13.45(a). The reference voltage is maintained at 0 °C. The reference voltage is now predictable from the calibration curve of the type 'T' thermocouple.

When copper is not one of thermocouple metal then four junction circuit is formed. The type 'J' thermocouple uses iron and constantan as the two elements shown in Fig.13.45(b). When it is connected to copper wires, two iron copper junctions result. These junctions present no additional difficulties because of the *isothermal block* used. This block is made of material that is a poor conductor of electricity but a good conductor of heat. Both Iron–Copper junctions will be at the same temperature and generate the same Seeback voltage and hence these two voltages will cancel. Cold junction compensation is also used as the Reference junction in this case.

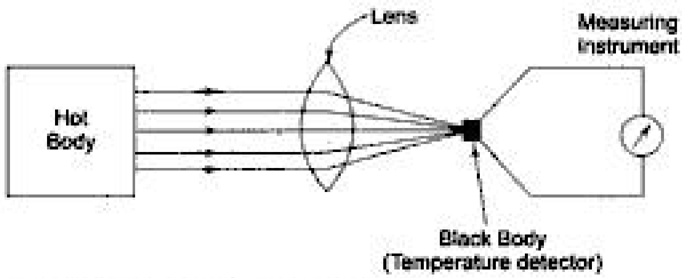

Fig. 13.54 Basic Principle of Pyrometer

detector is blackened and it absorbs all or almost all radiation falling on it (if the temperature is very small compared with that of hot body, then

$$q = 5.72 \times 10^{-8} \times T^4 \text{ w/m}^2$$

Therefore, the heat received by the detector is proportional to the fourth power of the absolute temperature of the hot body.

Radiation pyrometers are of two types.

1. Total Radiation Pyrometers
2. Infrared Pyrometers

Both of these are discussed in the following sections.

13.20.10 Total Radiation Pyrometer (TRP)

The total radiation pyrometer receives virtually all the radiation from a hot body and focuses on a hot body and focuses on a sensitive temperature transducer such as thermocouple, bolometer, thermopile, etc. Total radiation includes both visible and infrared radiation.

The total radiation pyrometer consists of a radiation receiving element and a measuring device to indicate the temperature directly. Figure 13.55 shows a mirror type radiation pyrometer.

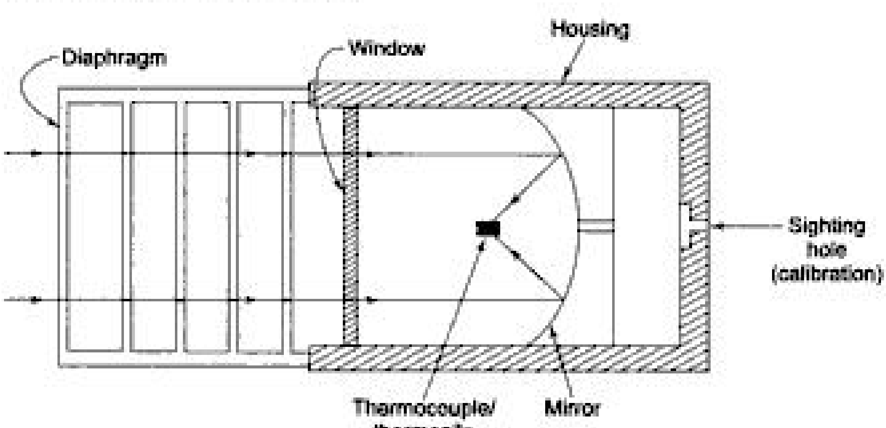

Fig.13.55 Total radiation pyrometer

The length L is the distance between the electrodes and equals the pipe diameter. As liquid passes through the pipe section, it also passes through the magnetic field set up by the magnet coils, thus inducing a voltage in the liquid, which is detected by a pair of electrodes mounted on the pipe wall. The amplitude of the induced voltage is proportional to the velocity of the flowing liquid. The magnetic coils may be excited by either ac or dc voltage. Currently, pulsating dc in which magnetic coils are periodically energised is used.

Magnetic flow meters are available in sizes from 2.54 – 2540 mm in diameter, with an accuracy range of ± 0.5 to ± 2%. The measurement taken by these meters are independent of viscosity, density, temperature and pressure. (The range of such meters may be 30 :1, but normally a 20:1 range is accepted.)

A modern design of magnetic flowmeter is one which can be inserted into the line through couplings. It consists of electrodes mounted on each side of a probe and magnetic coils which are also integral to the probe. The probe can be mounted on pipes of diameters 152.4 mm and above can easily be mounted for open channel flow.

Advantages of Magnetic Flowmeter

1. It can handle slurries and greasy materials.
2. It can handle corrosive fluids.
3. It has very low pressure drop.
4. It is totally obstructionless.
5. It is available in large pipe sizes and capacity as well as in several construction materials.
6. It is capable of handling low flows (with minimum size, less than 3.175 mm inside diameter) and very high volume flow rate (with sizes as large as 3.04 m).
7. It can be used as bidirectional meter.

Disadvantage of Magnetic Flowmeter

1. It is relatively expensive.
2. It works only with fluids which are adequate electrical conductors.
3. It is relatively heavy, especially in larger sizes.
4. It must be full at all times.
5. It must be explosion proof when installed in hazardous electrical areas.

13.26 TURBINE FLOWMETER

The turbine flowmeter is used for the measurement of liquid gas and gases of very low flow rate. It works on the principle of turbine. It consists of a multibladed rotor (called turbine wheel) which is mounted 90° to the axis of the flowing liquid as shown in Fig. 13.60.

8. List three types of temperature transducers and describe the applications of each.
9. What is the difference between a thermocouple and a thermistor?
10. Explain how to use a potentiometric transducer.
11. Describe the operation of a piezo-electric transducer.
12. Name different types of photo-electric transducers.
13. What is the difference between photo-emissive, photo-conductive and photo-voltaic transducers?
14. Give the difference between a self generating and a passive inductive transducer.
15. Explain the operation of a photo-multiplier.
16. What is the advantage of using differential output rather than a single output for measuring displacement?
17. List four types of electrical pressure transducers and describe one application of each type.
18. What is a load cell? Where is it used?
19. Under what condition is a dummy strain gauge used? What is the function of the gauge?
20. What is an LVDT? Where is it used?
21. Explain the operating principle of an LVDT.
22. Describe the principle of operation of a pressure transducer employing each of the following principles.
    (i) Resistive transducer
    (ii) Inductive transducer
    (iii) Capacitive transducer
23. What is the effect of temperature changes on a strain gauge?
24. State the most common method of temperature compensation for overcoming the above difficulty.
25. Distinguish between bonded and unbonded strain gauges.
26. Describe the essential difference between a variable reluctance type of transducer and an LVDT.
27. State the applications of a solar cell.
28. Describe the principle of operation of an accelerometer.
29. State the main advantages and disadvantages of semiconductor strain gauges compared to a metallic wire strain gauge.
30. What are the advantages of using a foil type strain gauge.
31. Compare a magnetic flowmeter with a turbine flowmeter.
32. How can the thickness of a sheet material be measured?
33. What is the operating principle of a beta gauge?
34. What are the various scanning modes of a beta gauge?
35. Define temperature.
36. List various types of temperature transducers and describe the applications of each.
37. Differentiate between thermistor and thermocouple.
38. Explain the working principle of a resistance temperature detector.
39. State the different elements used as a sensor in RTD. Explain each in brief.
40. Explain the operation of two wire RTD.
41. Describe the different techniques used to eliminate the lead wire effect of RTD connection in a Bridge circuit.
42. Explain the operation of thin film RTD.

Excitation is needed only for passive transducers, because they do not generate their own voltage or current. It is essential for passive transducers like strain guage, potentiometers, resistance thermometers, and inductive or capactive transducers to be excited from an external source.

Active transducers such as thermocouples, piezo-electric crystal and inductive pickups etc. do not require an external excitation because they produce their own voltages only by the application of physical quantities. However these signals are at a low level, and require amplification.

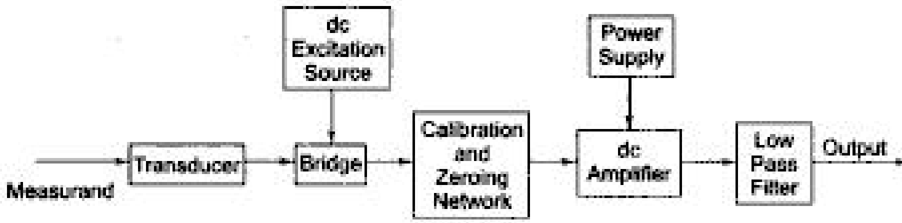

Fig. 14.2 ▬ DC Signal Conditioning System

The excitation source may be ac or dc. A simple dc system is shown in Fig. 14.2.

The strain guage (resistance transducer) constitutes one or more arm of the Wheatstone's bridge, which is excited by the dc source. The bridge can be balanced by using a potentiometer and can also be calibrated to indicate the unblanced condition. The dc amplifier should have the following characteritics.

1. Its input stage may be a balanced differential inputs giving a high CMRR.
2. It should have extremely good thermal and long term stability.
3. Easy to calibrate at low frequency.
4. Able to recover from an over load condition, unlike an ac system.

The main disadvantage of a dc amplifier is the problem of drift. Hence low frequency spurious signals are available as data at the output and to avoid this low drift of a dc amplifier, special low drift dc amplifiers are used.

The dc amplifiers is followed by a low-pass filter, which is used to eliminate high frequency components or noise from the data signals.

In order to overcome the problem of drift in the dc systems, ac systems are used. Figure 14.3 shows a circuit of an ac system using carrier type ac signal conditioning system.

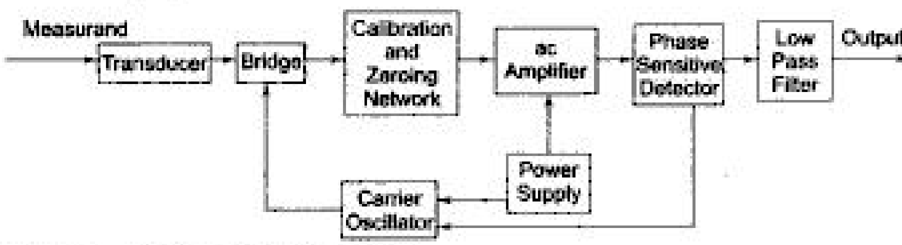

Fig. 14.3 ▬ AC Signal Conditioning System

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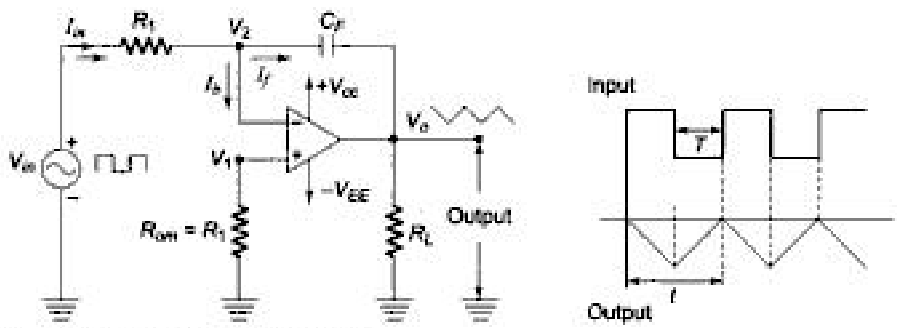

Fig. 14.9 ■ Interator using OpAmps

flows into the opamp, the input current is constant and equals $I_{in} = V_{in}/R_1$. Approximately all the current goes to the capacitor C_F. As $C = Q/V$ or $V = Q/C$ and since a constant current is flowing into the capacitor, the charge Q increases linearly. This means that the capacitor voltage increases linearly. Because of the phase reversal of the opamp, the output voltage is a negative ramp. At the negative pulse period of the input signal, the direction of the charging current is opposite, hence the output is an increasing ramp.

An integrator circuit is obtained by using a basic inverting amplifier configuration and by replacing the feedback resistor R_F by a capacitor C_F. The expression for the output voltage V_o can be obtained by using Kirchhoff's current equation.

$I_{in} = I_f + I_b$, since I_b is negligible, $I_{in} \cong I_f$. The current through the capacitor is given by

$$I_f = C_F \frac{dV_c}{dt}$$

But $$I_{in} = \frac{(V_{in} - V_2)}{R_1}$$

As $$I_{in} \cong I_f$$

$$\therefore \quad \frac{V_{in} - V_2}{R_1} = C_F \frac{dV_c}{dt} = C_F \frac{d(V_2 - V_o)}{dt}$$

But $$V_1 \cong V_2 \cong 0$$

therefore $$\frac{V_{in}}{R_1} = -\,C_F \frac{dV_o}{dt}$$

The output voltage can be obtained by integrating both sides with respect to time, hence

$$\int_0^t \frac{V_{in}}{R_1} = -C_F \int_0^t \frac{dV_o}{dt}$$

Solution

(i) To design a differentiator, we follow the steps outlined above.

(a) $f_a = 800$ Hz (the highest frequency) and $f_a = 1/(2\pi C_1 R_F)$

Let $C_1 = 0.1\ \mu F$,

then $R_F = \dfrac{1}{2\pi C_1 f_a} = \dfrac{1}{2 \times 3.14 \times 0.1 \mu F \times 800\ Hz} = 1.98\ k\Omega$

Let $R_F = 2.2\ k\Omega$

(b) $f_b = 20 \cdot f_a = 20 \times 800 = 16$ kHz and $f_b = \dfrac{1}{2\pi R_1 C_1}$

$$\therefore \quad R_1 = \frac{1}{2\pi C_1 f_b} = \frac{1}{1 \times 3.14 \times 0.1\ \mu F \times 16 \times 1000}$$

$$= 99.5\ \Omega$$

Let $R_1 = 100\ \Omega$

Since $R_1 C_1 = R_F C_F$,

$$C_F = \frac{R_1 C_1}{R_F}$$

$$= \frac{100 \times 0.1 \times 10^{-6}}{2200}$$

$$= 0.0045\ \mu F$$

Let $C_F = 0.0047\ \mu F$

$$R_{om} = R_1 // R_F = 2.2\ k // 100$$

$$= 95.6 \Omega$$

(but 100 ohms can be used)

The complete circuit is shown in Fig 14.15.

(ii) Since $V_p = 2V$

and $f = 800$ Hz, the input voltage is $V_{in} = V_p \sin \omega t$

$$V_{in} = 2\ V \sin (2\pi\ 800) t$$

As $\quad V_o = -R_F C_1 \dfrac{dV_{in}}{dt} = -R_F C_1 \dfrac{d}{dt} (V_p \sin \omega t)$

$\therefore \quad V_o = -R_F C_1 \times Vp(\omega) \cos \omega t$

$\therefore \quad V_o = -2.2\ k \times 0.1\ \mu F \times 2 \times 2 \times 3.142 \times 800 \times \cos \omega t$

$\therefore \quad V_o = -2.21 \cos \omega t$

$\quad V_o = -(2.21) \cos [2\pi\ 800 t]$

The waveform is as shown in Fig. 14.16.

$$e_5 = e_4 - e_3 \tag{14.13}$$

where $e_{cm} + e_1$ is the input to amplifier A_1.
and $e_{cm} + e_2$ is the input to amplifier A_2
If $R_2 = R_3$, the output voltage is given by

$$e_5 = \left(1 + \frac{2R_2}{R_1}\right) \times (e_2 - e_1) \tag{14.14}$$

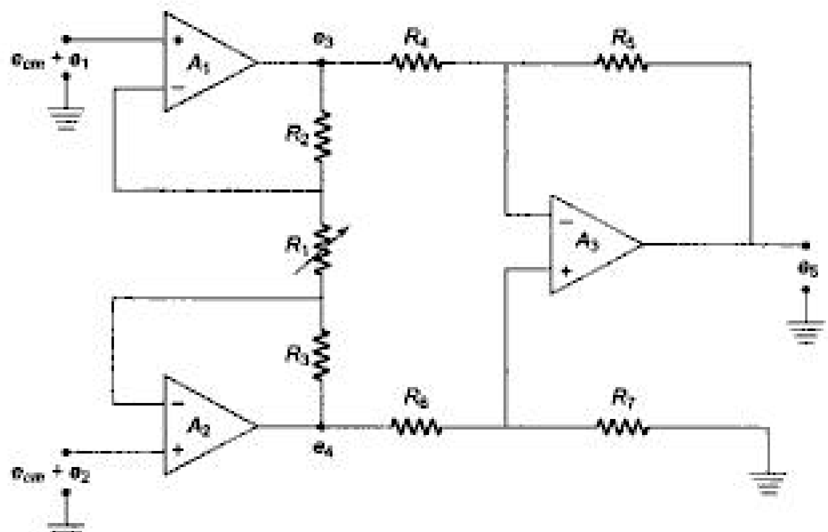

Fig. 14.23(a) Instrumentation Amplifier

The input amplifiers A_1 and A_2 act as input buffers with unity gain for common mode signals e_{cm} and with a gain of $(1 + 2R_2/R_1)$ for differential signals.

A high input impedance is ensured by the non-inverting configuration in which they operate. The common mode (CM) rejection is achieved by the following stage which is connected as a differential amplifier. The optimum common mode rejection can be obtained by adjusting R_6 or R_7 ensuring that $R_5/R_4 = R_7/R_6$.

The amplifier A_3 can also be made to have some nominal gain for the whole amplifier by an appropriate selection or R_4, R_5, R_6, and R_7.

The drift errors of the second stage add to the product of the drift errors of the first amplifier and first stage gain. Hence, it is necessary that the gain in the first stage be enough to prevent the overall drift performance from being significantly affected by the drift in the second stage. The drift problem of instrumentation amplifiers can be improved if amplifiers A_1 and A_2 have offset voltages which tends to track the temperature.

The gain of an instrumentation amplifier can be varied by changing R_1 alone. A high gain accuracy can be obtained by using precision metal film resistors for all the resistances.

resistance transducers are thermisistors, photoconductor cells, and strain gauges.

14.4.1 Temperature Indicators Using Thermistor

The Thermistor is a relative passive type of temperature resistance transducer. They are basically semiconductors.

In many respects, a thermistor resembles a conventional resistor. It is usually a two-terminal device. It has resistance as its fundamental property. It is generally installed and operated in the manner of an ordinary resistor. But its great difference is that it has a negative temperature coefficient (NTC) or positive temperature coefficient (PTC) type. Most thermistors exhibit an NTC characteristic. An NTC type is one in which its resistance decreases with increase in temperature. The temperature coefficient is expressed in ohms/°C.

Since it is a THERMally sensitive resISTOR, it has a high temperature coefficient of resistance and is therefore well suited for temperature measurement and control.

If in the bridge circuit of Fig. 14.25 the transducer used is a thermistor, the circuit can thus be used as a temperature indicator. The output meter is then calibrated in °C or °F. The bridge is balanced initially at a desired reference condition. As the temperature varies, the resistance of the thermistor also changes, unbalancing the bridge, which in turn produces a meter deflection at the output. By selecting the appropriate gain for the differential instrumentation amplifier, the meter can be calibrated to read a desired temperature. In this circuit, the meter movement (deflection) depends on the amount of unbalance in the bridge, which is caused by a change in the value of thermistor resistance ΔR. The change ΔR for the thermistor can be determined as follows.

$$\Delta R = \text{temperature coefficient of resistance} \; [\text{final temperature} - \text{reference tamperature}]$$

If the meter in this circuit is replaced by a relay, and if the output of the differential instrumentation amplifier drives the relay that controls the current in the heat-generating circuit, a temperature controller can be formed. A properly designed circuit should energise a relay when the temperature of the thermistor drops below a desired value, causing the heater unit to turn on.

Example 14.3 In the circuit of Fig. 14.25, $R_1 = 2.2$ k, $R_F = 10$ k, $R_A = R_B = R_C = 120$ k, $E = +5$ V, and Opamp supply voltage = ± 15 V. The transducer is a thermistor with the following specifications.

$R_T = 120$ K at a reference temperature of 25°C

temperature coefficient of resistance – 1 k/°C or 1%/°C

Determine the output voltage at 0 °C and 100 °C.

Solution At 25°C, $R_A = R_B = R_C = 120$ k

14.6.2 Magnetic Modulator

The most reliable substitutes for electromechanical choppers are magnetic modulators. These devices reach a null stability as low as 10 μV, but their response time is often less than 2 Hz and the ambient temperature range is restricted. The 3-leg saturable reactor, shown in Fig. 14.32 falls within the category of magnetic modulator devices. A magnetic modulator is based on the principle of saturation. If dc product is applied to windings L_1 and L_2, the core will be saturated according to the B–H loop characteristics.

As shown in Fig. 14.32, L_2 is the ac excitation winding and $L_1 - L_3$ are the dc winding.

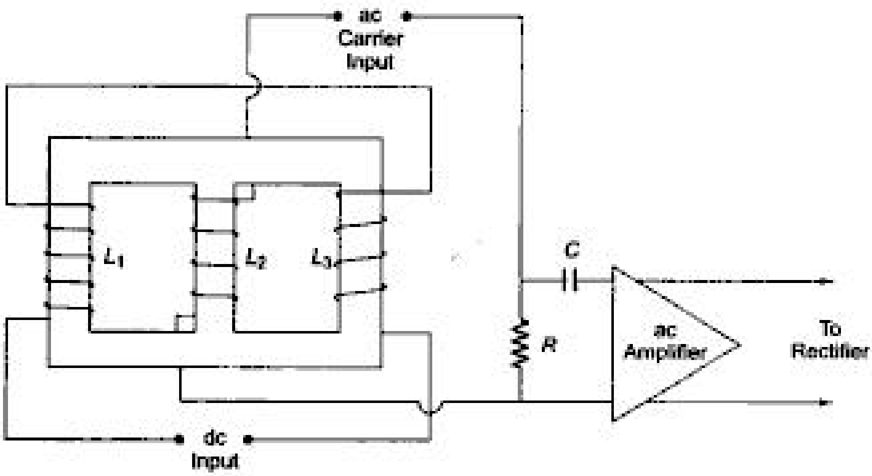

Fig. 14.32 ■■ Magnetic Modulator

A given degree of magnetic saturation causes a change of inductance in L_2. If no dc voltage is applied to the reactor, the impedance of L_2 will set the value of a given ac current flowing through it. Now if dc voltage is applied, it causes an increase in the core saturation changing the L_2 impedance characteristics which in turn causing a change in ac current seen by the follow-up ac amplifier. The dc excitation windings are connected in Buck type configurations. This configuration prevents the ac current to enter the dc windings by transformer action.

14.6.3 Diode Bridge Modulator

Figure 14.33 shows a silicon diode ring modulator with an associated ac coupled dc amplifier. The amplifier itself has a gain of 65 db and a flat response within ± 1 db, from 8 Hz to 80 kHz. Precautions are taken to safeguard the amplifier against sudden surge voltages having an active magnitude above the supply voltage of 9 V dc by using a 10 V zener diode as a guard element.

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defined for $n = -\infty$ to ∞, that is, a sampled complex exponential with radian frequency ω. The output of the system having impulse response $\{h(k)\}$ can be written as

$$y(n) = \sum_{k=-\infty}^{\infty} h(k)\, e^{j(n-k)\omega} = e^{jn\omega} \sum_{k=-\infty}^{\infty} h(k)\, e^{-jk\omega} \tag{15.74}$$

Let

$$H(e^{j\omega}) = \sum_{k=-\infty}^{\infty} h(k)\, e^{-jk\omega} \tag{15.75}$$

we can write

$$y(n) = e^{jn\omega} H(e^{j\omega}) \tag{15.76}$$

The function $H(e^{j\omega})$, which is called the frequency response of the system, describes the change in phase and amplitude of the input exponential, provided the series for $H(e^{j\omega})$ converges. $H(e^{j\omega})$ is in general a complex number, and can therefore be represented in terms of its real and imaginary parts.

$$H(e^{j\omega}) = HR(e^{j\omega}) + i\, HI(e^{j\omega}) \tag{15.77}$$

or in terms of its magnitude and phase

$$H(e^{j\omega}) = |H(e^{j\omega})|\, e^{j \arg H(e)^{j\omega}} \tag{15.78}$$

In this representation the phase can be substituted by the group delay, defined as the negative of the first derivative of the phase with respect to ω.

15.19.1 1-D Linear Systems Described by the Difference Equation

A very important class of linear shift invariant systems is the one described by the following equation

$$y(n) = \sum_{k=0}^{N-1} a(k)\, x(n-k) = \sum_{k=0}^{M-1} b(k)\, y(n-k) \tag{15.79}$$

where $x(n)$ are the samples of the input sequence, $y(n)$ are the samples of the output sequence, and $a(k)$ and $b(k)$ are coefficients which define the system.

In general, of course, a digital filter is not uniquely specified by the difference Eq. (15.79), that is, to any solution of Eq. (15.79) we can add a component which satisfies the homogeneous difference equation (the difference equation with the LHS equal to 0) so that the overall sum satisfies Eq. (15.79).

Therefore, as with difference equations in continuous time, it is necessary to specify the initial conditions of the system. These initial conditions must be such that the system is linear and recursive.

For recursivity of the system, it is necessary that any output samples be computable from a knowledge of previously computed samples or from initial

$m = 0, 1, ..., 2N - 1$, when N is even, a and b are equal to the 1 in the Butterworth case.

Thus when the parameters of the design, N, ω_c and ε are known in the Chebyschev case, the coefficients of the filter can be obtained by computing the pole positions by means of either Eqs (15.102) or (15.103).

The problem is now to investigate the relationship between the order x of the filter N, the pass band deviation δ, and the transition bandwidth Δf, defined by the cutoff frequency f_c and the frequency f_a at which the squared magnitude frequency response is less than or equal to $1/A^2$.

Let us now consider the three types of design specifications.

In the first case (Δf and δ fixed), the design procedure has to start with the evaluation of the order of the filter necessary to meet the specifications in terms of the desired attenuation, transition bandwidth and pass band deviation.

The pass band deviation can be controlled in the case of Chebyschev filters be ε. In any case, having defined f_c and f_a (i.e. transition bandwidth), the desired value $1/A^2$ of $|H(e^{j\omega})|^2$ at f_a and ε in the Chebyschev case, it is possible to determine N iteratively, starting from a first order filter and increasing the order of the filter to the point where the attenuation at f_a is greater than the desired value. At this point the design is completely determined.

In the second case (N and Δf fixed), the design is completely determined for the Butterworth filter case by obtaining the value of the attenuation at f_a directly.

In the third case (N and δ fixed), the filter is completely specified and the transition band width is directly obtainable during the design procedure.

A computer program is presented which designs Butterworth and Chebyschev filters by means of the above relation. It also computes the coefficients of their cascade structure. The inputs to the program are the critical frequencies f_c and f_a, the values of the desired attenuation of the filters at f_a and the value of the maximum pass band ripple if a Chebyschev filter is to be designed. The order of the filter is computed iteratively.

Two examples of the filter design with this program are shown in Figs 15.40 (a) and (b).

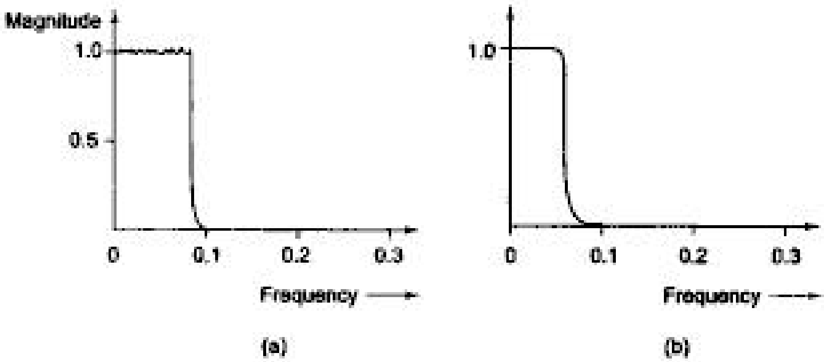

Fig. 15.40 (a) Example of IIR Chebyschev Filter ($N = 12$, $f_c/f_s = 0.1$)
(b) Example of IIR Butterworth Filter $N = 8$, $f_c/f_s = 0.05$

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where ε – field strength

P_r – load power

G – antenna power gain in terms of the receiving antenna.

This arrangement requires that the signal generator be calibrated in terms of the power that it delivers to a terminated co-axial line, instead of in terms of the voltage that it develops across a resistance.

16.6 MEASUREMENT OF SENSITIVITY

The sensitivity of a radio receiver is its ability to amplify weak signals. It is often defined in terms of the voltage that must be applied to the receiver input terminals to give a standard output power, measured at the output terminals. For AM broadcast receivers, many of the relevant quantities have been standardised. Hence 30% modulation by a 400 Hz sine wave is used and the signal is applied to the receiver through a standard coupling network, known as a dummy antenna.

The standard output is 50 mW; for all types of receivers the loud speaker is replaced by a load resistance of equal value.

Sensitivity is often expressed in μ volts or in decibles below 1 V, and measured at three points along the tuning range when a production receiver is lined up. It can be seen from the sensitivity curve in Fig. 16.4, that sensitivity varies over the tuning band. At 1000 Hz, this particular receiver has a sensitivity of 12.7 μ V or – 98 db V (db below 1 V).

The most important factors for determining the sensitivity of a superheterodyne receiver are the gains of the IF and RF amplifiers.

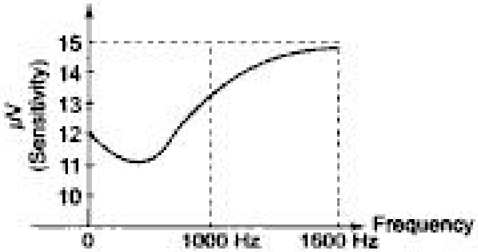

Fig. 16.4 ■ Sensitivity Curve

16.7 MEASUREMENT OF SELECTIVITY

The selectivity of a receiver is its ability to reject (adjacent) unwanted signals. It is expressed as a curve, such as the one in Fig. 16.5, which shows the attenuation that the receiver offers to signals at frequencies near the one to which it is tuned. Selectivity is measured at the end of a sensitivity test under

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The important factors that decide the configuration and sub systems of the data acquisition system are as follows.

1. Accuracy and resolution
2. Number of channels to be monitored
3. Analog or digital signal
4. Single channel or multichannel
5. Sampling rate per channel
6. Signal conditioning requirements of each channel
7. Cost

The various general configurations include the following.

1. Single channel possibilities
   - (i) Direct conversion
   - (ii) Pre-amplification and direct conversion
   - (iii) Sample and hold, and conversion
   - (iv) Pre-amplification, signal conditioning and any of the above
2. Multi channel possibilities
   - (i) Multiplexing the outputs of single channel converters
   - (ii) Multiplexing the output of sample-hold circuits
   - (iii) Multiplexing the inputs of sample-hold circuits
   - (iv) Multiplexing low level data

17.2 OBJECTIVE OF A DAS

1. It must acquire the necessary data, at correct speed and at the correct time.
2. Use of all data efficiently to inform the operator about the state of the plant.
3. It must monitor the complete plant operation to maintain on-line optimum and safe operations.
4. It must provide an effective human communication system and be able to identify problem areas, thereby minimising unit availability and maximising unit through point at minimum cost.
5. It must be able to collect, summarise and store data for diagnosis of operation and record purpose.
6. It must be able to compute unit performance indices using on-line, real-time data.
7. It must be flexible and capable of being expanded for future requirements.
8. It must be reliable, and not have a down time greater than 0.1%.

17.3 SIGNAL CONDITIONING OF THE INPUTS

Since all the data that have to be acquired, do not generally originate from identical sources, signal conditioning becomes necessary in some cases.

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Metal wire bolometers are referred to as barreters. They have a positive temperature coefficient of resistance and are generally operated at bias powers which heat to 100 – 200°C. (They consist of short lengths of Wollaston wire whose external silver sheath has been removed by etching or deplating, so as to expose the extremely thin noble metal core, usually consisting of platinum or platinum alloy. Wire diameters range from approximately 1 – 3 microns and wire lengths range from as short as feasible to about 2.5 mm. The resistance of the deplated portion is selected so that the bolometer presents a good match to the RF line when properly biased with low power.)

Since the dc and RF resistances are nearly the same, the resistance value is generally close to the characteristic impedance.

Thermistor elements for RF measurements are usually minute beads of a ceramic like semiconductor mixture of metallic oxides having a large negative temperature coefficient of resistivity.

Two fine platinum or platinum alloy wires are embedded in the bead, which is then sintered and coated with a film of glass. The beads are sometimes enclosed in a glass envelope.

20.6 BOLOMETER MOUNT

The bolometer support consists of a thin mica disc on one side of which silver electrodes are sprayed. Silver painted holes through the mica connect the (lower) outer electrode to a circular electrode on the opposite side. Between the centre and outer electrodes are mounted two short (1 mm) lengths of deplated Wollaston wires of 1 micron diameter, each measuring 100Ω at dc with normal bias power. The mica disc is clamped in the holder, as shown in Fig. 20.1, so that the upper electrode makes contact with the metal case, while the other two electrodes are insulated from a co-axial line by a thin mica sheet which provides the bypass capacitor necessary to complete the RF circuit, and to place two wires in RF parallel across the line.

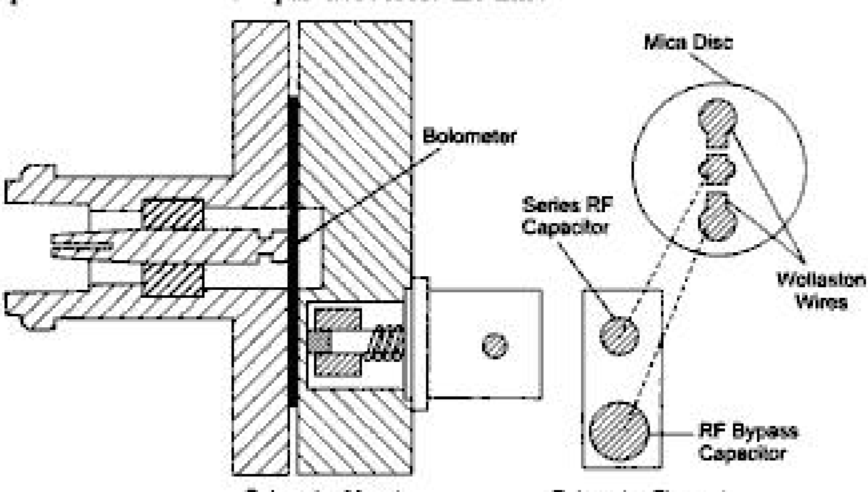

Fig. 20.1 ■ Schematic View of Bolometer Mount and Bolometer Element

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