CHAPTER 1

Instrumentation

Introduction to syllabus

- Introduction to instrumentation system
- Signal Measurement
- Physical variables and transducers
- Signal Conditioning and processing
- Data Transmission and
- Output device
- Data Acquisition system

Introduction to instrumentation system

- Components of instrumentation and their function
- Basic concepts of Transducers
- Signal condition and transmission
- Types of signals in instrumentation

Instrumentation system

- An instrumentation system is a collection of devices and software that work together to measure and record physical or electrical parameters such as temperature, pressure, flow rate, voltage, current, and other variables. The main purpose of an instrumentation system is to monitor and control a process or system in real-time.

- An instrumentation system typically consists of sensors or transducers that convert physical or electrical quantities into electrical signals, signal conditioning circuits that amplify, filter, or otherwise modify the signals, data acquisition systems that digitize and store the signals, and control systems that use the data to adjust the process or system.

- Instrumentation systems are used in a wide variety of applications, including industrial process control, scientific research, environmental monitoring, and medical diagnostics. They are essential tools for ensuring safety, quality, and efficiency in many fields.

What is instrumentation system?

- Definition: A collection of devices and software that work together to measure and record physical or electrical parameters
- Purpose: Monitor and control a process or system in real-time
- Examples: Industrial process control, scientific research, environmental monitoring, medical diagnostics

Components of an Instrumentation System

- Sensors or transducers: Convert physical or electrical quantities into electrical signals
- Signal conditioning circuits: Amplify, filter, or modify the signals
- Data acquisition systems: Digitize and store the signals
- Control systems: Use the data to adjust the process or system

Functional block/Components of instrumentation system

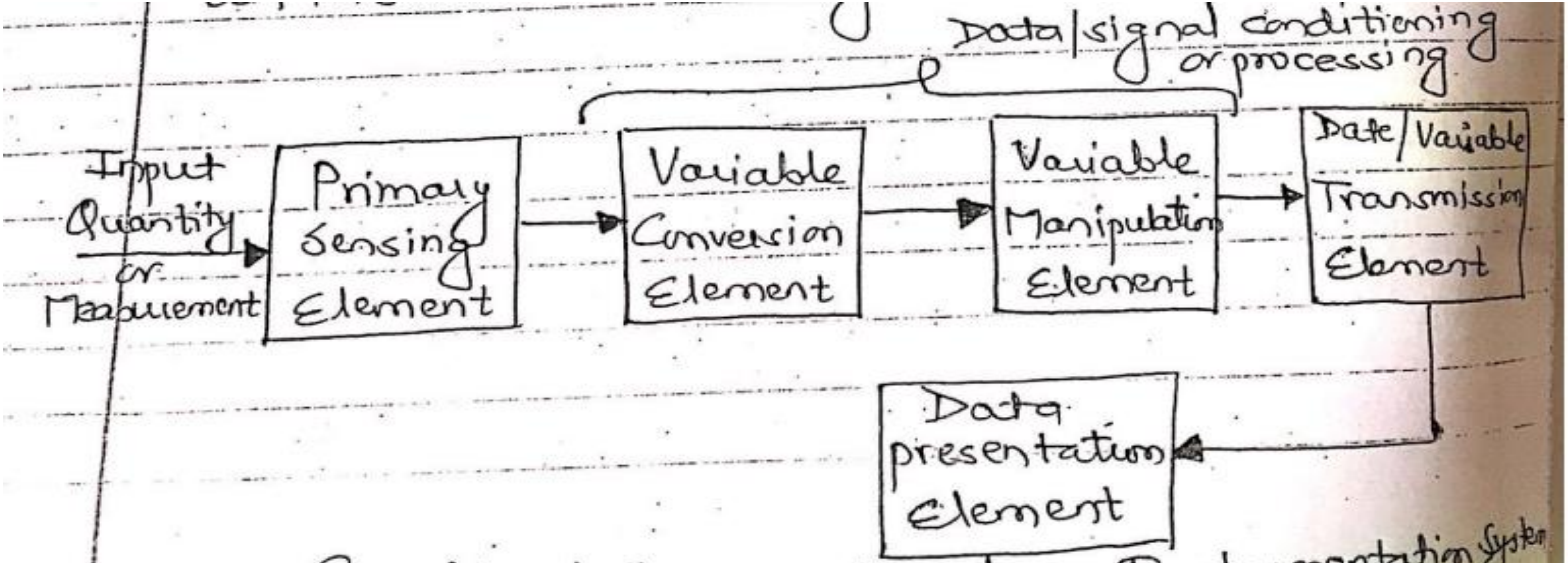


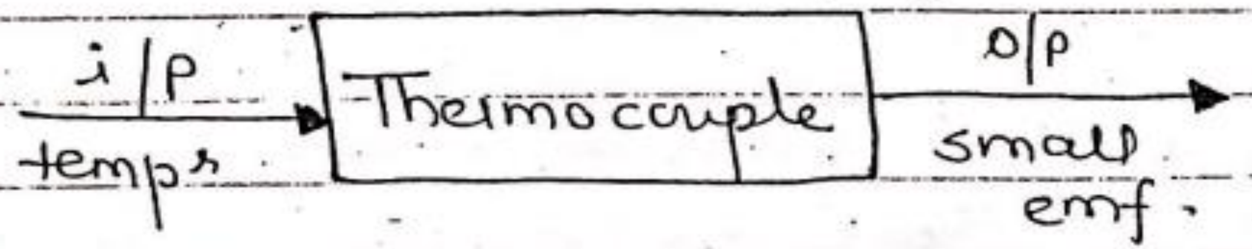
Fig: Functional Components of an Instrumentation System

Any instrumentation system or Measurement system is developed for unison of diverse devices to perform the measurement tasks. According to the functional block-diagram of instrumentation system; the various functions of the components can be explained as given below.

a) Primary Sensing Element :→

The first contact of the measured is occured in this section of the block diagram. The primary sensing unit has the signal sensors or the transducers. These transducers help to convert the variable being measured to the suitable form of energy and the rest of the measurement system capable to give a value to the input variable.

e.g. :→ Thermocouple, which has input as temperature and output as the small emf. LVDT, strain guage etc.



(b) Variable Conversion Element :→

The output of the primary sensing element (or the first stage of instrumentation system) may be electrical signal of any form. It may be a voltage, current, a frequency or some other electrical parameter. Sometimes this output is not suited to the system. For the instrument to perform the desired function, it may be necessary to convert this output to some other suitable form while preserving the information content of the original signal.

e.g:→
Variable conversion involves, Analog to digital conversion, digital to analog conversion, AC to dc or dc to ac conversion, frequency to voltage conversion etc.

May instruments do not need any variable conversion element, while others need more than one variable conversion element

(c) Variable Manipulation Element:→
The function of this element is to manipulate the signal presented to it preserving the original nature of the signal. Manipulation here means only a change in numerical value of the signal. Signal amplification and attenuation task is performed in the variable manipulation element/unit of the

instrumentation system.

The combined form of variable conversion and variable manipulation is known as the signal conditioning element. The signal conditioning may be linear and non-linear.

* <u>Linear</u> :→ amplification, attenuation, Integration, Differentiation, addition, subtraction etc.
* <u>Non-linear</u> :→ Modulation, demodulation/ detection, sampling, filtering, chopping and clipping etc.

(d) **Data / Signal Transmission Element** :→

The elements of an instrumentation systems are actually physically separated, it becomes necessary to transmit data from one unit to another. The element that performs this function is called a data transmission element. Data transmission is done either through wire line or wire-less transmission medias. The signal conditioning and transmission stage is commonly known as Intermediate stage of the instrumentation system & their position may be interchanged in the block-diagram.

(e) Data Presentation Element :→

The information about the quantity under measurement has to be conveyed to the personnel handling the instrument or the system for monitoring, control, or analysis purposes. The information conveyed must be in a form intelligible to the personnel or to the intelligent instrumentation system. This function is done by data presentation element.

The data presentation element may

be video display unit (VDU) or the recorder (e.g :- X-Y plotter strip-chart recorder) or data may be transmitted to any control circuit so that it can be compared with required value.

Types of Sensors

- Temperature sensors: Thermocouples, RTDs, thermistors
- Pressure sensors: Strain gauges, piezoelectric sensors, capacitive sensors
- Flow sensors: Turbine flow meters, ultrasonic flow meters, mass flow meters
- Voltage/current sensors: Hall effect sensors, current transformers, shunt resistors

Signal Conditioning Circuits

- Purpose: Prepare the sensor signal for processing by the data acquisition system
- Examples: Amplifiers, filters, signal converters

Data Acquisition Systems

- Purpose: Digitize and store the signals from the sensors
- Examples: Data loggers, oscilloscopes, data acquisition cards

Control Systems

- Purpose: Use the data from the sensors to adjust the process or system
- Examples: PID controllers, PLCs, microcontrollers

Applications of Instrumentation Systems

- Industrial process control: Manufacturing, chemical processing, power generation
- Scientific research: Physics, chemistry, biology
- Environmental monitoring: Air quality, water quality, weather
- Medical diagnostics: Blood glucose monitoring, blood pressure monitoring, electrocardiography

Types of Signals in Instrumentation

Analog Signals

- Definition: A continuous signal that varies in amplitude or frequency over time
- Examples: Voltage, current, temperature, pressure

Digital Signals

- Definition: A discrete signal that represents data in binary form (0s and 1s)
- Examples: Logic signals, serial data, Ethernet packets

Pneumatic Signals

- Definition: A signal that uses air pressure to transmit information
- Examples: Pneumatic valves, pressure regulators, pneumatic actuators

Optical Signals

- Definition: A signal that uses light to transmit information
- Examples: Fiber-optic communication, optical sensors, optical encoders

Radio Signals

- Definition: A signal that uses radio waves to transmit information
- Examples: Wireless communication, radio telemetry, GPS signals

Unit and standard of measurement

1. Length:
- \- Meter (m)
- \- Centimeter (cm)
- \- Kilometer (km)
- \- Inch (in)
- \- Foot (ft)
- \- Yard (yd)

2. Mass:
- \- Kilogram (kg)
- \- Gram (g)
- \- Pound (lb)
- \- Ounce (oz)

- Time:
  - Second (s)
  - Minute (min)
  - Hour (hr)
  - Day (day)
- Temperature:
  - Celsius (°C)
  - Fahrenheit (°F)
  - Kelvin (K)
- Electric Current:
  - Ampere (A)
- Amount of Substance:
  - Mole (mol)
- Luminous Intensity:
  - Candela (cd)

Gross Error

Gross Error The gross error occurs due to the human mistakes in reading or using the instruments. These errors cover human mistakes like in reading, calculating and recordings etc. It sometimes occurs due to incorrect adjustments of instruments. The complete elimination of gross errors is impossible, but we can minimize them by the following ways:

- 1. It can be avoided by taking care while reading and recording the measurement data.
- 2. Taking more than one reading of same quantity. At least three or more reading must be taken by different persons.

Systematic Error

A systematic error is divided in three different categories: instrumental errors, environmental errors and observational errors.

1. Instrumental Errors

The instrument error generate due to instrument itself. It is due to the inherent shortcomings in the instruments, misuse of the instruments, loading effects of instruments. For example in the D' Arsonval movement friction in bearings of various moving components may cause incorrect readings. There are so many kinds of instrument errors, depending on the type of instrument used. Instrumental errors may be avoided by

(a) Selecting a suitable instrument for the particular measurement application

(b) Applying correction factors after determining the amount of instrumental error

(c) Calibrating the instruments against a standard.

2. Environmental Errors

Environmental errors arise as a result of environmental effects on instrument. It includes conditions in the area surrounding the instrument, such as the effects of changes in temperature, humidity, barometric pressure or of magnetic or electrostatic fields. For example when making measurements with a steel rule, the temperature when the measurement is made might not be the same as that for which the rule was calibrated. Environmental errors may be avoided by

(a) Using the proper correction factor and information supplied by the manufacturer of the instrument.

(b) Using the arrangement which will keep the surrounding condition constant like use of air condition, temperature controlled enclosures etc.

(c) Making the new calibration under the local conditions.

3. Observational Errors These errors occur due to carelessness of operators while taking the reading. There are many sources of observational errors such as parallax error while reading a meter, wrong scale selection, the habits of individual observers etc. To eliminate such observational errors, one should use the instruments with mirrors, knife edged pointers, etc. Now a day’s digital display instruments are available, which are much more versatile.

Random Error

- These errors are due to unknown causes and occur even when all systematic errors have been accounted for.
- In some experiments some random errors usually occur, but they become important in high-accuracy work. These errors are due to friction in instrument movement, parallax errors between pointer and scale, mechanical vibrations, hysteresis in elastic members etc.
- When we measure a volume or weight, you observe a reading on a scale of some kind. Scales by their very nature are limited to fixed increments of value, indicated by the division marks. The actual quantities we are measuring, in contrast, can vary continuously. So there is an inherent limitation in how finally we can discriminate between two values that fall between the marked divisions of the measuring scale.
- The same problem remains if we substitute an instrument with a digital display. There will always be some point at which some value that lies between smallest divisions must arbitrarily toggle between two numbers on the readout display. This introduces an element of randomness into the value we observe, even if the true value remains unchanged. These errors are of variable magnitude and sign and do not obey any known law. The presences of random errors become evident when different results are obtained on repeated measurements of one and the same quantity

Probability of Error

The probability of errors refers to the likelihood that an error will occur in a particular process or system. In the context of instrumentation and measurement, the probability of errors is an important concept to consider because it can affect the accuracy and reliability of the measurements.

There are several factors that can contribute to the probability of errors in a measurement process, including:

1. Human error: Mistakes made by the operator or technician performing the measurement, such as misreading the instrument or recording the wrong data.
2. Instrument error: Inaccuracies or drift in the instrument being used to make the measurement.
3. Environmental factors: Changes in temperature, humidity, or other environmental conditions that can affect the measurement.
4. Sample error: Variations or inconsistencies in the sample being measured.

The probability of errors can be expressed in terms of statistical measures such as mean, standard deviation, and confidence interval. These measures can help to quantify the degree of uncertainty or error in a measurement.

To minimize the probability of errors, it is important to follow best practices for measurement and instrumentation, including calibration, regular maintenance and inspection of instruments, and proper training of personnel. Using redundant or backup systems can also help to reduce the impact of errors and improve overall measurement accuracy and reliability.

Absolute Error

- Absolute Error

Measurement is the process of comparing an unknown quantity with an accepted standard quantity. Absolute error may be defined as the difference between the measured value of the variable and the true value of the variable.

dA = Am – A

where,

dA = absolute error

Am = expected value

A = measured value

Relative Error

- Relative Error

The relative error is the ratio of absolute error to the true value of the quantity to be measured. Mathematically, the relative error can be expresses as,

Relative error e_r = Absolute error /true value = $\delta A/ A$

when absolute error is negligible $dA = e_o$, then $A_m = A$

Relative limiting error $e_r = e_o /A_m = dA/A_m$

Percentage error = $e_r \times 100 = e_o /A_m \times 100$

It may be carefully noted that relative error is the ratio of absolute error and original value, where absolute error is the difference between original value and approximated value

% Error = Absolute value /Expected value ×100

$= \delta A/ A *100 = (A_m - A)/A_m \times 100$

- The normal distribution is characterized by two parameters: the mean and the standard deviation. The mean represents the center of the distribution, while the standard deviation describes the spread or variability of the distribution.

THANKYOU

1.3 Introduction to errors and uncertainties in the measurement of performance parameters

1.3.1

Errors and uncertainties in the measurement of performance parameters are inevitable in any experimental or measurement process. These errors and uncertainties arise due to various factors and can affect the accuracy and reliability of the results obtained. Understanding and quantifying these errors and uncertainties is crucial for assessing the validity of measurements and interpreting their significance.

Errors refer to the differences between the measured value and the true value of a parameter. They can be categorized into systematic errors and random errors.

1. Systematic errors: These errors are consistent and repeatable, causing measurements to consistently deviate from the true value in the same direction. Systematic errors can result from faulty instruments, calibration issues, or flawed experimental procedures. They can lead to biased results and affect the overall accuracy of the measurements. Examples include zero errors, parallax errors, or inaccuracies in instrument readings.

2. Random errors: Random errors, also known as indeterminate or statistical errors, occur unpredictably and can cause measurements to vary in both directions around the true value. They arise from limitations in the precision of instruments, variations in environmental conditions, or inherent fluctuations in the system being measured. Random errors can be minimized through repeated measurements and statistical analysis, such as calculating the mean or standard deviation.

Uncertainties, on the other hand, express the degree of confidence or reliability associated with a measurement. They provide a range of values within which the true value of a parameter is expected to lie. Uncertainties arise due to various factors and can be categorized as follows:

1. Instrument uncertainties: These uncertainties arise from the limitations and inaccuracies of the measuring instrument itself. They depend on factors such as instrument resolution, precision, and sensitivity. Manufacturers often provide specifications and uncertainties associated with their instruments.

2. Measurement uncertainties: These uncertainties arise from the limitations of the measurement process and the techniques employed. They can include uncertainties introduced by the experimenter, the experimental setup, the calibration procedures, and the methods used to extract and analyze the data.

3. Natural uncertainties: Some measurements are inherently uncertain due to the nature of the physical phenomenon being measured. These uncertainties can arise from fluctuations, noise, or inherent variability in the system being studied. They are often assessed using statistical methods and can be reduced through appropriate experimental design and data analysis techniques.

To quantify uncertainties, various methods are employed, such as error propagation, statistical analysis, and calibration procedures. The estimation and reporting of uncertainties are crucial for scientific rigor, enabling comparisons between different measurements and ensuring the traceability and reproducibility of results.

In summary, errors and uncertainties in the measurement of performance parameters are an inherent part of experimental work. Understanding and quantifying these errors and uncertainties are essential for evaluating the reliability and significance of measurements and ensuring accurate interpretation of results.

1.3.2 Static performance parameters

Static performance parameters are used to evaluate the characteristics and quality of measurement devices or systems. Here is an explanation of each parameter:

1. Accuracy: Accuracy refers to the closeness of a measured value to the true or reference value. It quantifies the systematic error in a measurement and indicates how well a measurement device or system can provide results that are close to the actual value.

2. Precision: Precision relates to the degree of repeatability or reproducibility of a measurement. It measures the random error or variability in repeated measurements of the same quantity. A high precision indicates that measurements have low random errors and exhibit consistent and tight clustering around the mean value.

3. Resolution: Resolution is the smallest incremental change or the smallest detectable difference that a measurement system can detect. It indicates the ability to distinguish between small changes in a quantity. For example, a device with high resolution can detect fine details or small changes in a signal.

4. Threshold: Threshold refers to the minimum value of a physical quantity that a measurement system can detect or respond to. It represents the lower limit below which the measurement system may not provide reliable or accurate readings.

5. Sensitivity: Sensitivity is a measure of how much the output of a measurement system changes in response to a change in the input or measured quantity. It indicates the responsiveness or the ability to detect small variations in the input signal. High sensitivity means that even small changes in the input result in noticeable changes in the output.

6. Linearity: Linearity refers to the degree to which the relationship between the input and output of a measurement system follows a straight line. A linear system produces output that is directly proportional to the input. Deviations from linearity indicate non-linear behavior, which can introduce measurement errors.

7. Hysteresis: Hysteresis is a phenomenon observed when the output of a measurement system does not follow the same path during increasing and decreasing values of the input. It represents a lag or memory effect in the system. Hysteresis can introduce errors and cause discrepancies in measurements when the input changes direction.

8. Dead band: Dead band refers to a range of input values within which a measurement system does not respond or provide any output. It represents a zone of non-responsiveness or insensitivity in the system, typically around a certain threshold value.

9. Backlash: Backlash is a mechanical term that describes the play or clearance in a mechanical system. In the context of measurement, it refers to the amount of movement or displacement required to overcome the initial static resistance before a measurement is registered. Backlash can introduce errors and affect the accuracy of measurements.

10. Drift: Drift refers to the change in the output of a measurement system over time while the input remains constant. It represents a systematic shift or deviation in the measurement, often caused by environmental factors, aging, or instability in the system components. Drift can affect the accuracy and reliability of long-term measurements.

11. Span: Span refers to the range between the lowest and highest values that a measurement system can accurately measure or detect. It represents the full-scale capability of the system.

These static performance parameters provide valuable information about the quality and limitations of measurement devices or systems, allowing users to assess their suitability for specific applications and to understand the potential sources of errors or uncertainties in measurements.

1.3.3 Impedance loading and matching

Impedance loading and impedance matching are concepts related to the electrical impedance of a device or a circuit and how it interacts with other components in a system

1. Impedance Loading: Impedance loading refers to the effect of connecting a load to a source or output device, which can affect the performance and characteristics of the source. When a load is connected, it forms a parallel circuit with the source impedance. The load impedance can alter the voltage and current distribution in the circuit, affecting the overall behavior and operation of the source.If the load impedance is significantly different from the source impedance, it can cause impedance mismatch, leading to a degraded signal transfer, loss of power, or distortion. It is important to consider the impedance characteristics of both the source and the load to ensure proper matching for efficient and reliable signal transmission.

2. Impedance Matching: Impedance matching is the process of optimizing the electrical impedance between a source and a load to maximize power transfer and minimize signal reflections or losses. The goal of impedance matching is to minimize the impedance mismatch

between the source and the load, reducing the amount of reflected signal and improving the overall efficiency of the system.

By matching the impedance, the voltage and current signals can flow smoothly between the source and the load without significant reflections or distortions. This is particularly important in applications such as transmission lines, antennas, audio systems, and amplifiers, where efficient signal transfer is crucial.

Impedance matching can be achieved through various techniques, such as using impedance matching transformers, attenuators, transmission line stubs, or resonant circuits. These techniques help to adjust the impedance levels and ensure a smooth transition of signals between the source and the load, optimizing the performance of the system.

In summary, impedance loading refers to the effect of connecting a load to a source, which can impact the performance of the source. Impedance matching, on the other hand, is the process of optimizing the impedance between a source and a load to maximize power transfer and minimize signal losses or reflections. Proper impedance matching is important for efficient signal transmission and minimizing the degradation of the system's performance.

Diploma in Electrical and Instrumentation Engg. IVth Semester 2019-20	BEE - 401 Electrical Measurement and Measuring Instrument Unit-3 Notes	Teacher: Mr. Uvais Mustafa

1. Classification of Resistances:

Classification of Resistances from the point of view of measurement is as follows:

i. Low Resistances:

All the resistances of the order of 1 ohm and under are classified as Low Resistances.

ii. Medium Resistances:

All the resistances which are more than 1 ohm but less than 100,000 ohm are classified as medium.

iii. High Resistances:

Resistances of the order of 100,000 ohm and above are classified as high resistances.

2. Measurement of Medium Resistances:

The different methods for the measurement of medium resistances are as under:

(i) Ammeter Voltmeter method
(ii) Substitution method
(iii) Wheatstone Bridge method
(iv) Ohmmeter method

Out of these four methods, our course here is concerned with only Ammeter-Voltmeter method.

i. Ammeter-Voltmeter Method:

This method is very popular since the instruments required for this test are usually available in the laboratory. The two types of connections employed for Ammeter-Voltmeter method are shown in Figs. (a) and (b). In both the cases, if reading of ammeter and voltmeter are taken, then the measured value of resistance (R_m) is given by

$$R_m = \frac{Voltmeter\ Reading}{Ammeter\ Reading} = \frac{V}{I}$$

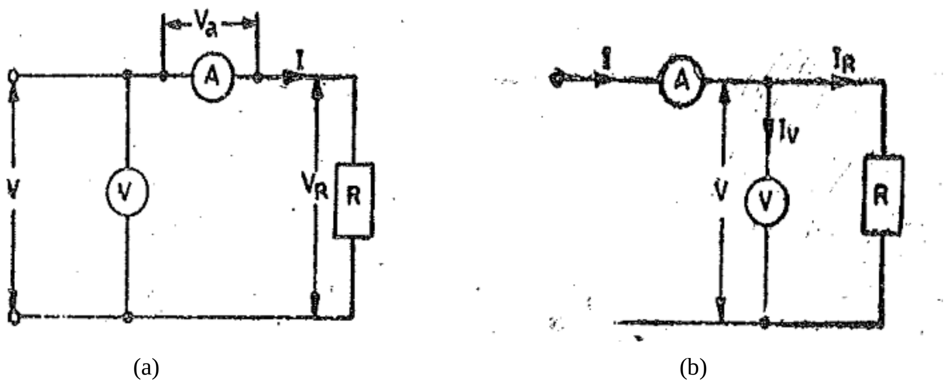


Figure 1 Two Configurations of Ammeter-Voltmeter Method

Circuit of Fig. 1(a): In this circuit the ammeter measures the true value of the current through the resistance but the voltmeter does not measure the true voltage across the resistance. The voltmeter

indicates the sum of the voltages across the ammeter and the resistance.
Let R_a be the resistance of the ammeter, then voltage across ammeter, $V_a = I.R_a$
Now measured value of resistance, $R_{m1} = V/I = (V_R+V_a)/I$

$$= (I.R+I.R_a)/I = R+R_a$$

Thus, true value of resistance, $R = R_{m1} - R_a$

$$= R_{m1}[1-(R_a/R_{m1})]$$

Thus the measured value of resistance is more than the true value.
Thus, relative error, $\varepsilon_r = (R_{m1} - R)/R = R_a/R$
From the expression of the relative error, it is clear that the relative error would be small if the true value of resistance i.e. R is much larger than the ammeter resistance Ra. Thus this configuration is used for the measurement of higher resistance.

Circuit of Fig. 1(b): In this circuit the voltmeter measures the true value of voltage but the ammeter measures the sum of currents through the resistance and the voltmeter.
Let Rv be the resistance of the voltmeter
Current through the voltmeter, $I_v = \frac{V}{R_v}$
Measured value of resistance, $R_{m2} = \frac{V}{I} = \frac{V}{I_R+I_v} = \frac{V}{V/_R+V/_{R_v}} = \frac{R}{1+R/_{R_v}}$
True value of Resistance, $R = \frac{R_{m2}R_v}{R_v-R_{m2}} = R_{m2}(\frac{1}{1-R_{m2}/_{R_v}})$
From the above equation it is clear that the measured value of resistance, R_{m2} is equal to the true value of resistance only if the voltmeter resistance is infinite.
Relative error, $\varepsilon_r = \frac{R_{m2}-R}{R}$

3. Measurement of Low Resistance:

The methods used for measurement of medium resistances are unsuitable for measurement of low resistances i.e. resistances having a value under 1 Ω. The reason is that the resistance of leads and contacts, though small, are appreciable in comparison in the case of low resistances. For example a contact resistance of 0.002 Ω causes a negligible error when a resistance of 100 Ω is being measured but the same contact resistance would cause an error of 10% if a low resistance of the value of 0.02 Ω is measured. Hence special types of construction and techniques have to be used for the measurement of low resistances in order to avoid serious errors occurring on account of the factors mentioned above.

Low resistances are constructed with four terminals as shown in Fig 2. One pair of terminals CC' (called the current terminals) is used to lead current to and from the resistor. The voltage drop is measured between the other two terminals PP', called the potential terminals. The voltage V, indicated in Fig. 2, is thus I_R times the resistance R between terminals PP' and does not include any contact resistance drop that may be present at the current terminals CC'.

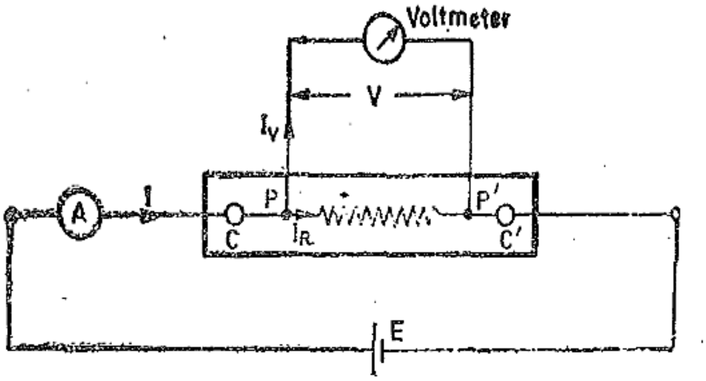
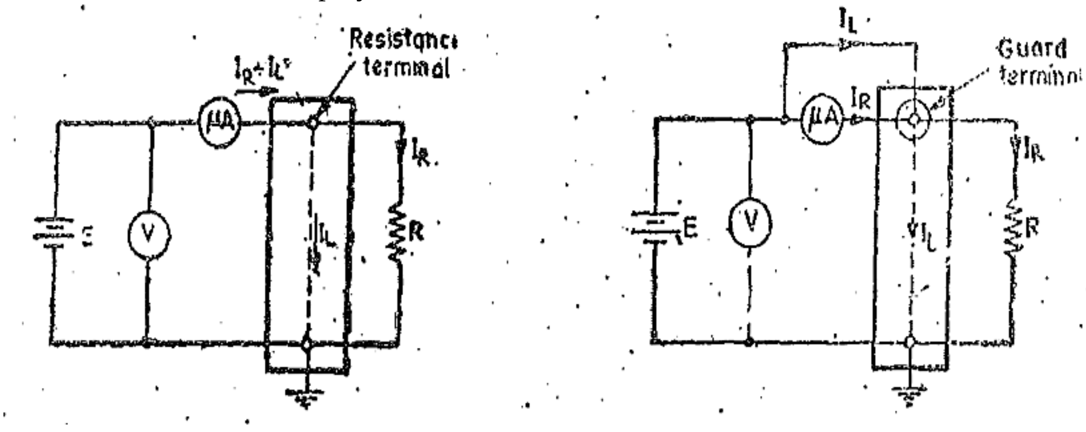


Figure 2 Construction and Measurement of Low Resistance

4. Measurement of High Resistance

High resistances of the order of hundreds or thousands of mega-ohm are often encountered in electrical equipment, and frequently must be measured. Since the resistances under measurement have high values, very small currents are encountered in the measurement circuits. This aspect leads to several difficulties. The insulation resistance of the resistor may be comparable with the actual value of the resistor. Thus leakage currents are produced. These leakage currents are of comparable magnitude to the current being measured and must be eliminated from the measurement. Leakage currents no doubt introduce errors, but they generally vary from day to day, depending upon the humidity conditions and therefore cause additional unpredictable complications. High accuracy is rarely required in such measurements, hence simple circuits are used. To remove the leakage current problem, Guard Circuits are employed.



(a) (b)

Figure 3 Measurement of High Resistance

Some form ·of guard circuits are generally used to eliminate the errors caused by leakage currents over insulation. Fig. 3 illustrates the operation of a guard circuit. In Fig 3 (a), a high resistance mounted on a piece of insulating material is measured by the ammeter-voltmeter method. The micro-ammeter measures the sum of the current through the resistor (I_R) and the current through the leakage path around the resistor (I_L). The measured value of resistance computed from the readings indicated on the voltmeter and the micro-ammeter, will not be true value but will be in error. In Fig. 3 (b) a guard terminal has been added to resistance terminal block. The guard terminal surrounds the resistance terminal entirely and is connected to the battery side of the micro-ammeter. The ·leakage current I_L, now bypasses the micro-ammeter which then indicates the current I_R through the resistor and thus allows the correct determination of the resistance value from the readings of voltmeter and micro-ammeter. The guard terminal and resistance terminal are almost at the same potential and thus there will be no flow of current between them. This method of measuring the High Resistances is also called as Direct Deflection Method.

5. Ohm-meter

The OHMMETER is an instrument which measures resistance of a quantity. Resistance in the electrical sense means the opposition offered by a substance to the current flow in the device. Every device has a resistance, it may be large or small and it increases with temperature for conductors, however for semiconducting devices the reverse is true. Ohmmeter is made from the PMMC instrument so the construction of this is similar as discussed in UNIT-1.

There are different types of ohmmeter

(i) Series Type Ohmmeter

(ii) Shunt Type Ohmmeter

(iii) Multi Range Ohmmeter

i. Series Type Ohmmeter:

The series type ohmmeter consists of a current limiting resistor R_1, Zero adjusting resistor R_2, EMF source E, Internal resistance of PMMC instrument R_m and the resistance to be measured R.

When there is no resistance to be measured, current drawn by the circuit will be maximum and the meter will show a deflection. By adjusting R_2 the meter is adjusted to a full scale current value since the resistance will be zero at that time. The co-responding pointer indication is marked as zero. Again when the terminal AB is opened it provides very high resistance and hence almost zero current will flow through the circuit. In that case the pointer deflection is zero which is marked at very high value for resistance measurement. So a resistance between zeros to a very high value is marked and hence can be measured. So, when a resistance is to be measured, the current value will be somewhat less than the maximum and the deflection is recorded and accordingly resistance is measured. This method is good but it possess certain limitations such as the decrease in potential of the battery with its use so adjustment must be made for every use. The meter may not read zero when terminals are shorted, these types of problem may arise which is counteracted by the adjustable resistance connected in series with the battery.

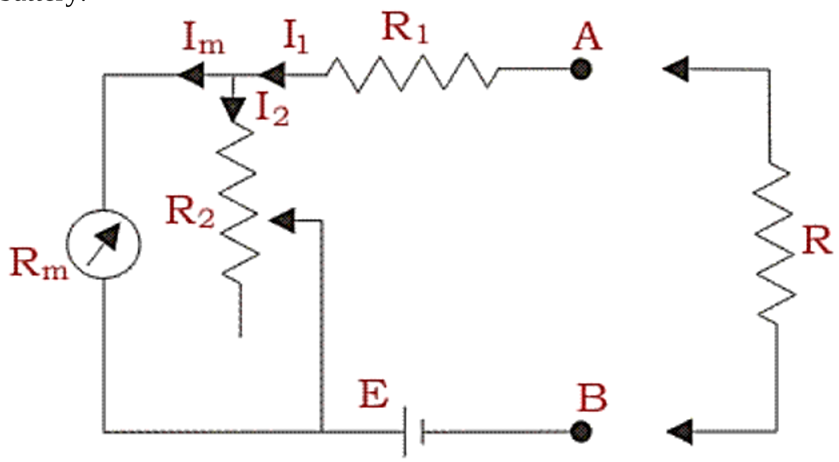


Figure 4 Series Type Ohmmeter

ii. Shunt Type Ohmmeter:

In this type of meters we have a battery source and an adjustable resistor is connected in series with the source. We have connected the meter in parallel to the resistance which is to be measured. There is a switch by the use of which we can on or off the circuit. The switch is opened when it is not in use. When the resistance to be measured is zero, the terminals A and F are shorted so the current through the meter will be zero. The zero position of the meter denotes the resistance to be zero. When the resistance connected is very high, then a small current will flow the terminal AF and hence full scale current is allowed to flow through the meter by adjusting the series resistance connected with the battery. So, full scale deflection measures very high resistance. When the resistance to be measured is connected between A and F, The pointer shows a deflection by which we can measure the resistance values.

In this case also, the battery problem may arise which can be counteracted by adjusting the resistance. The meter may have some error due to its repeated use also.

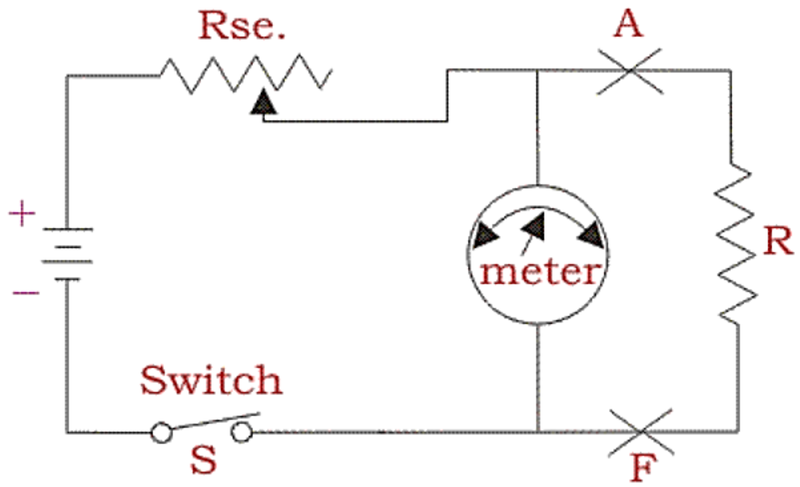


Figure 5 Shunt Type Ohmmeter

iii. Multi Range Ohmmeter :

This instrument provides the reading up to a very wide range. In this case we have to select the range switch according to our requirement. An adjuster is provided so that we can adjust the initial reading to be zero. The resistance to be measured is connected in parallel to the meter. The meter is adjusted so that it shows full scale deflection when the terminals in which the resistance connected is full scale range through the range switch. When the resistance is zero or short circuit, there is no current flow through the meter and hence no deflection. Suppose we have to measure a resistance under 1 ohm, then the range switch is selected at 1 ohm range at first. Then that resistance is connected in parallel and the corresponding meter deflection is noted. For 1 ohm resistance it shows full scale deflection but for the resistance other than 1 ohm it shows a deflection which is less than the full load value and hence resistance can be measured. This is the most suitable method of all the ohmmeters as we can get accurate reading in this type of meters. So this meter is most widely used now days.

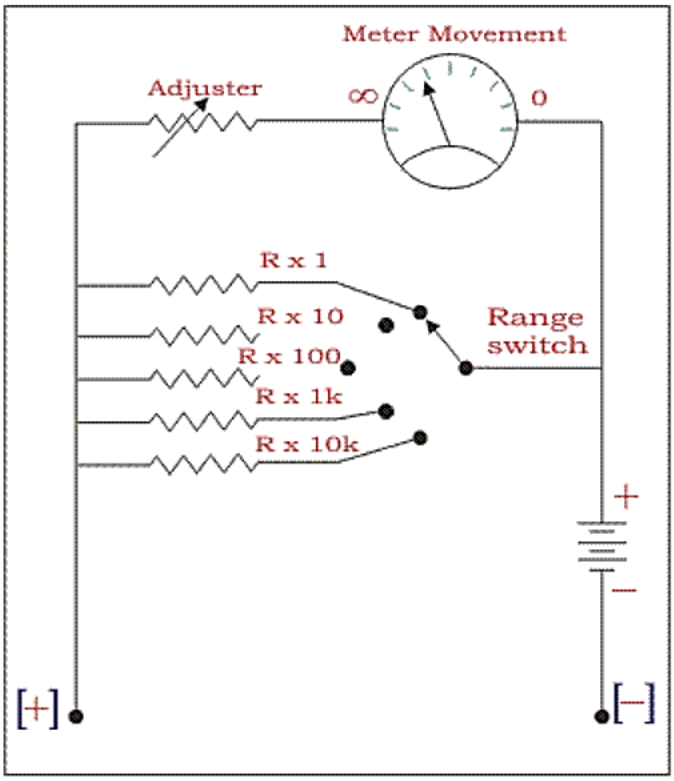


Figure 6 Multi Range Ohmmeter

1.3 Introduction to errors and uncertainties in the measurement of performance parameters

1.3.1

Errors and uncertainties in the measurement of performance parameters are inevitable in any experimental or measurement process. These errors and uncertainties arise due to various factors and can affect the accuracy and reliability of the results obtained. Understanding and quantifying these errors and uncertainties is crucial for assessing the validity of measurements and interpreting their significance.

Errors refer to the differences between the measured value and the true value of a parameter. They can be categorized into systematic errors and random errors.

1. Systematic errors: These errors are consistent and repeatable, causing measurements to consistently deviate from the true value in the same direction. Systematic errors can result from faulty instruments, calibration issues, or flawed experimental procedures. They can lead to biased results and affect the overall accuracy of the measurements. Examples include zero errors, parallax errors, or inaccuracies in instrument readings.

2. Random errors: Random errors, also known as indeterminate or statistical errors, occur unpredictably and can cause measurements to vary in both directions around the true value. They arise from limitations in the precision of instruments, variations in environmental conditions, or inherent fluctuations in the system being measured. Random errors can be minimized through repeated measurements and statistical analysis, such as calculating the mean or standard deviation.

Uncertainties, on the other hand, express the degree of confidence or reliability associated with a measurement. They provide a range of values within which the true value of a parameter is expected to lie. Uncertainties arise due to various factors and can be categorized as follows:

1. Instrument uncertainties: These uncertainties arise from the limitations and inaccuracies of the measuring instrument itself. They depend on factors such as instrument resolution, precision, and sensitivity. Manufacturers often provide specifications and uncertainties associated with their instruments.

2. Measurement uncertainties: These uncertainties arise from the limitations of the measurement process and the techniques employed. They can include uncertainties introduced by the experimenter, the experimental setup, the calibration procedures, and the methods used to extract and analyze the data.

3. Natural uncertainties: Some measurements are inherently uncertain due to the nature of the physical phenomenon being measured. These uncertainties can arise from fluctuations, noise, or inherent variability in the system being studied. They are often assessed using statistical methods and can be reduced through appropriate experimental design and data analysis techniques.

To quantify uncertainties, various methods are employed, such as error propagation, statistical analysis, and calibration procedures. The estimation and reporting of uncertainties are crucial for scientific rigor, enabling comparisons between different measurements and ensuring the traceability and reproducibility of results.

In summary, errors and uncertainties in the measurement of performance parameters are an inherent part of experimental work. Understanding and quantifying these errors and uncertainties are essential for evaluating the reliability and significance of measurements and ensuring accurate interpretation of results.

1.3.2 Static performance parameters

Static performance parameters are used to evaluate the characteristics and quality of measurement devices or systems. Here is an explanation of each parameter:

1. Accuracy: Accuracy refers to the closeness of a measured value to the true or reference value. It quantifies the systematic error in a measurement and indicates how well a measurement device or system can provide results that are close to the actual value.

2. Precision: Precision relates to the degree of repeatability or reproducibility of a measurement. It measures the random error or variability in repeated measurements of the same quantity. A high precision indicates that measurements have low random errors and exhibit consistent and tight clustering around the mean value.

3. Resolution: Resolution is the smallest incremental change or the smallest detectable difference that a measurement system can detect. It indicates the ability to distinguish between small changes in a quantity. For example, a device with high resolution can detect fine details or small changes in a signal.

4. Threshold: Threshold refers to the minimum value of a physical quantity that a measurement system can detect or respond to. It represents the lower limit below which the measurement system may not provide reliable or accurate readings.

5. Sensitivity: Sensitivity is a measure of how much the output of a measurement system changes in response to a change in the input or measured quantity. It indicates the responsiveness or the ability to detect small variations in the input signal. High sensitivity means that even small changes in the input result in noticeable changes in the output.

6. Linearity: Linearity refers to the degree to which the relationship between the input and output of a measurement system follows a straight line. A linear system produces output that is directly proportional to the input. Deviations from linearity indicate non-linear behavior, which can introduce measurement errors.

7. Hysteresis: Hysteresis is a phenomenon observed when the output of a measurement system does not follow the same path during increasing and decreasing values of the input. It represents a lag or memory effect in the system. Hysteresis can introduce errors and cause discrepancies in measurements when the input changes direction.

8. Dead band: Dead band refers to a range of input values within which a measurement system does not respond or provide any output. It represents a zone of non-responsiveness or insensitivity in the system, typically around a certain threshold value.

9. Backlash: Backlash is a mechanical term that describes the play or clearance in a mechanical system. In the context of measurement, it refers to the amount of movement or displacement required to overcome the initial static resistance before a measurement is registered. Backlash can introduce errors and affect the accuracy of measurements.

10. Drift: Drift refers to the change in the output of a measurement system over time while the input remains constant. It represents a systematic shift or deviation in the measurement, often caused by environmental factors, aging, or instability in the system components. Drift can affect the accuracy and reliability of long-term measurements.

11. Span: Span refers to the range between the lowest and highest values that a measurement system can accurately measure or detect. It represents the full-scale capability of the system.

These static performance parameters provide valuable information about the quality and limitations of measurement devices or systems, allowing users to assess their suitability for specific applications and to understand the potential sources of errors or uncertainties in measurements.

1.3.3 Impedance loading and matching

Impedance loading and impedance matching are concepts related to the electrical impedance of a device or a circuit and how it interacts with other components in a system

1. Impedance Loading: Impedance loading refers to the effect of connecting a load to a source or output device, which can affect the performance and characteristics of the source. When a load is connected, it forms a parallel circuit with the source impedance. The load impedance can alter the voltage and current distribution in the circuit, affecting the overall behavior and operation of the source.If the load impedance is significantly different from the source impedance, it can cause impedance mismatch, leading to a degraded signal transfer, loss of power, or distortion. It is important to consider the impedance characteristics of both the source and the load to ensure proper matching for efficient and reliable signal transmission.

2. Impedance Matching: Impedance matching is the process of optimizing the electrical impedance between a source and a load to maximize power transfer and minimize signal reflections or losses. The goal of impedance matching is to minimize the impedance mismatch

between the source and the load, reducing the amount of reflected signal and improving the overall efficiency of the system.

By matching the impedance, the voltage and current signals can flow smoothly between the source and the load without significant reflections or distortions. This is particularly important in applications such as transmission lines, antennas, audio systems, and amplifiers, where efficient signal transfer is crucial.

Impedance matching can be achieved through various techniques, such as using impedance matching transformers, attenuators, transmission line stubs, or resonant circuits. These techniques help to adjust the impedance levels and ensure a smooth transition of signals between the source and the load, optimizing the performance of the system.

In summary, impedance loading refers to the effect of connecting a load to a source, which can impact the performance of the source. Impedance matching, on the other hand, is the process of optimizing the impedance between a source and a load to maximize power transfer and minimize signal losses or reflections. Proper impedance matching is important for efficient signal transmission and minimizing the degradation of the system's performance.

Measurement of hygrometer (Humidity)

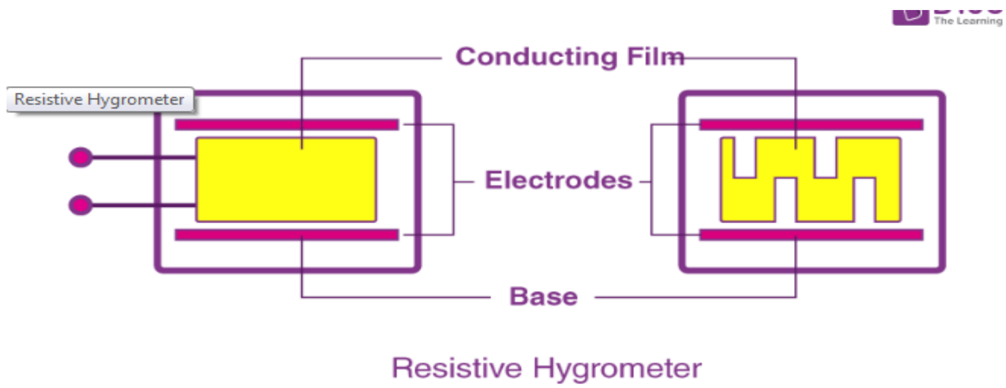
A hygrometer is a specially designed apparatus that calculates relative humidity in an open or enclosed area.

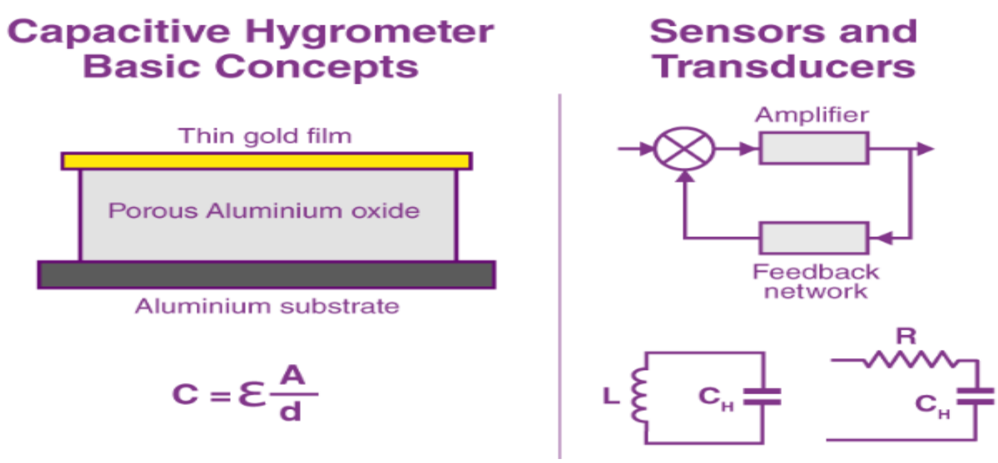
Humidity can also be explained as air humidity or relative humidity, which is stated as the quantity of water vapor in the atmosphere. The population of water molecules in the atmosphere relies on multiple factors, including the air's temperature. Warm air usually is much more humid than cold air. When the atmosphere temperature drops, the highest amount of water the air can sustain decreases.

Electrical Hygrometer

An electrical hygrometer measures humidity by analysing the variation in electrical resistance of a fine layer of a semiconductor device. On the other hand, other hygrometers detect variations in transparency, weight or volume of substances that respond to humidity. Predominantly there are two types of electrical hygrometers- Resistive Hygrometer and Capacitive Hygrometer.

The calculation of an electrical hygrometer is rooted in changes in capacitance or resistance. The device usually possesses a sensor to measure variations in an on-chip layer of semiconductor (eg-lithium chloride).





Hygrometer Uses

A hygrometer helps to calculate moisture content in the air or enclosed areas. This is essential in manufacturing industries, hospitals, museums, agricultural fields, food preservation, meteorology, etc.

Hygrometers are frequently used in pharmaceutical storage and manufacturing systems. Most pharmaceutical products are hygroscopic; therefore, variation in humidity could alter their chemical compositions.

Electronic devices like ACs make use of electrical hygrometers. Humidity sensors (smart hygrometers) are vital parts of devices that function on temperature, pressure and humidity.

pH meter is an instrument used to measure acidity or alkalinity of a solution - also know as pH. pH is the unit of measure that describes the degree of acidity or alkalinity. It is measured on a scale of 0 to 14.

The quantitative information provided by the pH value expresses the degree of the activity of an acid or base in terms of hydrogen ion activity. The pH value of a substance is directly related to the ratio of the hydrogen ion [H+] and the hydroxyl ion [OH-] concentrations.

Measurement of Blood Pressure: Blood pressure refers to the force exerted by circulating blood against the walls of blood vessels. It is an important physiological parameter that provides information about the cardiovascular health of an individual. Blood pressure is typically measured using a device called a sphygmomanometer. There are two main types of sphygmomanometers: mercury-based and electronic (digital) sphygmomanometers.

1. Mercury-based Sphygmomanometer:

The traditional mercury-based sphygmomanometer consists of the following components:

- Cuff: The cuff is wrapped around the upper arm and inflated to occlude the brachial artery temporarily.

- Manometer: The manometer is a vertical glass tube filled with mercury. It is connected to the cuff and has a scale that measures pressure in millimeters of mercury (mmHg).

- Stethoscope: A stethoscope is used to listen to the blood flow sounds (Korotkoff sounds) in the brachial artery.

The process of measuring blood pressure using a mercury-based sphygmomanometer involves the following steps:

1. The cuff is wrapped around the upper arm, with its lower edge about 2.5 cm above the elbow joint.

2. The cuff is inflated by pumping air using a rubber bulb or an electric pump until the pressure is higher than the expected systolic blood pressure.

3. The pressure in the cuff is gradually released by opening a valve, allowing blood flow through the brachial artery.

4. While deflating the cuff, a healthcare professional uses a stethoscope to listen for two distinct sounds called Korotkoff sounds. The first sound represents the systolic blood pressure (maximum pressure during heart contraction), and the disappearance of sound represents the diastolic blood pressure (minimum pressure during heart relaxation).

5. The corresponding pressure on the manometer when the first sound is heard is the systolic blood pressure, and the pressure when the sound disappears is the diastolic blood pressure.

2. Electronic (Digital) Sphygmomanometer:

Digital sphygmomanometers have become increasingly popular due to their ease of use and digital display. They work based on the oscillometric principle and consist of the following components:

- Cuff: Similar to the mercury-based sphygmomanometer, a cuff is wrapped around the upper arm.

- Pressure Sensor: The pressure sensor measures the fluctuations in pressure within the cuff.

- Microprocessor: A microprocessor controls the inflation and deflation of the cuff, as well as calculates and displays the blood pressure readings.

The process of measuring blood pressure using an electronic sphygmomanometer involves the following steps:

1. The cuff is wrapped around the upper arm in the same manner as with the mercury-based sphygmomanometer.

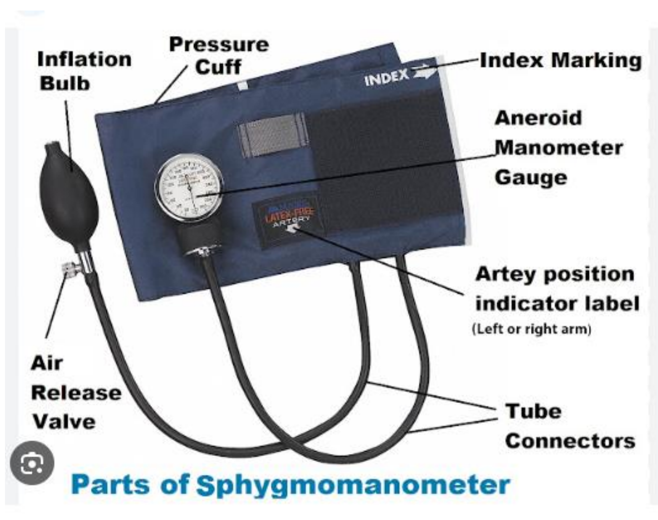
2. The user presses a button to initiate the measurement. The cuff automatically inflates to a predetermined pressure and then gradually deflates.

3. As the cuff deflates, the pressure sensor detects the oscillations in pressure caused by the blood flow in the brachial artery.

4. The microprocessor analyzes the oscillations and calculates the systolic and diastolic blood pressure based on algorithms and preset calibration data.

5. The calculated blood pressure readings are displayed digitally on the device's screen.

It's important to note that accurate blood pressure measurement requires proper cuff size, correct placement, and following the recommended guidelines for the specific sphygmomanometer being used. It is advisable to consult healthcare professionals for guidance on proper blood pressure measurement techniques and device usage.



Measurement of Myoelectric Potentials

The measurement of myoelectric potentials, also known as electromyography (EMG), involves capturing and analyzing the electrical activity generated by muscles during contraction or movement. EMG systems typically consist of the following components:

1. Surface Electrodes: Surface electrodes are placed on the skin over the muscle of interest to detect the electrical signals. These electrodes are typically made of conductive materials, such as silver/silver chloride (Ag/AgCl), and are designed to establish a good electrical connection with the skin.

2. Pre-Amplifier: The electrical signals captured by the surface electrodes are very weak, so a pre-amplifier is used to amplify the signals and make them suitable for further processing. The pre-amplifier helps to increase the amplitude of the signals while minimizing interference and noise.

3. Amplifier: The amplified signals from the pre-amplifier are further amplified using an amplifier. The amplifier provides gain control to adjust the signal amplification according to the specific requirements of the measurement.

4. Analog-to-Digital Converter (ADC): The amplified analog signals are converted into digital signals using an ADC. The ADC samples the analog signals at a high rate and quantizes them into digital values that can be processed by a computer or other digital devices.

5. Signal Processing and Analysis: The digitized EMG signals undergo various processing and analysis techniques to extract meaningful information. This can include filtering to remove noise or unwanted frequencies, rectification to convert the signals into absolute values, and further analysis techniques such as time-domain or frequency-domain analysis.

6. Display or Recording: The processed EMG signals can be displayed in real-time on a computer screen or recorded for offline analysis. The display may show the amplitude or frequency characteristics of the EMG signals, allowing researchers or clinicians to visualize and interpret the muscle activity.

The working principle of an EMG system involves the following steps:

1. Surface Electrode Placement: The surface electrodes are placed on the skin over the muscle of interest. The electrodes detect the electrical potentials generated by the muscle fibers during contraction.

2. Signal Detection: When the muscle contracts or moves, the motor units within the muscle fibers produce electrical potentials. The surface electrodes capture these potentials as voltage changes on the skin surface.

3. Amplification: The weak electrical signals captured by the surface electrodes are amplified using a pre-amplifier and an amplifier to increase their amplitude and make them detectable for further processing.

4. Conversion to Digital Signals: The amplified analog signals are converted into digital signals using an ADC. This conversion allows the signals to be processed and analyzed by digital devices such as computers.

5. Signal Processing: The digitized EMG signals undergo various processing techniques, including filtering, rectification, and further analysis methods to extract meaningful features or characteristics of the muscle activity.

6. Display or Recording: The processed EMG signals can be displayed in real-time or recorded for later analysis and interpretation. This allows researchers, clinicians, or therapists to assess muscle function, diagnose abnormalities, evaluate muscle performance, or monitor changes over time.

It's important to note that the specific construction and working principles of an EMG system may vary depending on the manufacturer and the intended application. However, the general principles outlined above are commonly employed in most EMG systems for the measurement of myoelectric potentials.

1.9 Calibration and errors in transducers

Calibration is an essential process in transducer measurements to ensure accuracy and reliability. It involves comparing the output of a transducer with known reference standards or a calibration standard to determine any systematic errors and establish a calibration curve or equation for the transducer.

Here are some key aspects of calibration and potential sources of error in transducer measurements:

1. Calibration Standards: Calibration standards are devices or instruments with known and traceable measurement values. These standards should have a higher accuracy and precision than the transducer being calibrated. The transducer's output is compared to the calibration standard's values to determine the calibration error.

2. Calibration Procedure: The calibration procedure typically involves applying known input values to the transducer and measuring its output. This is done at multiple points across the measurement range to establish a calibration curve or equation. The calibration procedure should be performed under controlled conditions, following established protocols and standards.

3. Systematic Errors: Systematic errors arise from consistent biases in the transducer's measurements, resulting in a consistent shift or deviation from the true value. These errors can occur due to factors such as sensor drift, nonlinearity, hysteresis, temperature effects, or voltage or current supply variations. Calibration helps identify and correct for these systematic errors by establishing correction factors or curves.

4. Random Errors: Random errors are fluctuations or uncertainties in the measured values that occur due to various factors, such as noise, environmental conditions, electrical interference, or signal processing limitations. Calibration cannot completely eliminate random errors, but it helps determine the measurement uncertainty associated with the transducer's output.

5. Calibration Accuracy and Uncertainty: The accuracy of a calibrated transducer refers to its deviation from the true value. Calibration uncertainty quantifies the confidence interval within which the true value lies. The calibration process should aim to minimize uncertainty by considering various factors like the accuracy of calibration standards, measurement techniques, environmental conditions, and the transducer's specifications.

6. Traceability: Traceability ensures that the calibration standards and processes are linked to national or international measurement standards. Traceability provides a documented chain of comparisons that establishes the accuracy and reliability of the calibration results.

7. Regular Calibration Maintenance: Transducers may drift or change their characteristics over time due to aging, environmental factors, or usage. Regular calibration maintenance is essential to monitor and correct for such changes, ensuring the transducer's ongoing accuracy and reliability.

It's important to note that proper calibration should be performed by qualified personnel using appropriate calibration equipment and procedures. Calibration intervals should be determined based on the transducer's specifications, application requirements, and any applicable industry standards or regulations.

Moving iron instrument for the measurement of Voltage and current

Construction

Moving-iron instruments are generally used to measure alternating voltages and currents. In moving-iron instruments the movable system consists of one or more pieces of specially-shaped soft iron, which are so pivoted as to be acted upon by the magnetic field produced by the current in coil.

There are two types of measuring iron instruments. They are:

1) Repulsion type
2) Attraction Type

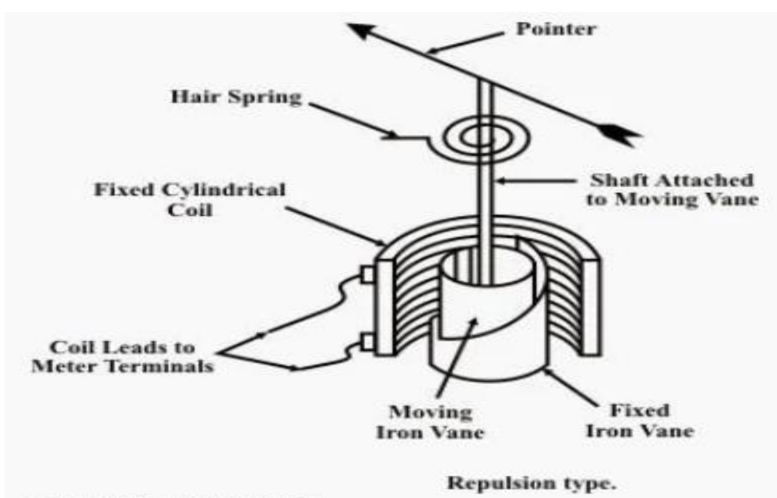
Construction:

The brief description of different components of a moving-iron instrument is given below:

- **Moving element:** a small piece of soft iron in the form of a vane or rod.
- **Coil:** to produce the magnetic field due to current flowing through it and also to magnetize the iron pieces.
- **In repulsion type**, a **fixed** vane or rod is also used and magnetized with the same polarity.
- **Control torque** is provided by spring or weight (gravity).
- **Damping torque** is normally pneumatic, the damping device consisting of an air chamber and a moving vane attached to the instrument spindle.
- **Deflecting torque** produces a movement on an aluminum pointer over a graduated scale.

Operating Principle

The deflecting torque in any moving-iron instrument is due to forces on a small piece of magnetically 'soft' iron that is magnetized by a coil carrying the **operating current**. In repulsion type moving–iron instrument consists of two cylindrical soft iron vanes mounted within a fixed current-carrying coil.



One iron vane is held fixed to the coil frame and other is free to rotate, carrying with it the pointer shaft. Two irons lie in the magnetic field produced by the coil that consists of only few turns if the instrument is an ammeter or of many turns if the instrument is a voltmeter.

Current in the coil induces both vanes to become magnetized and repulsion between the similarly magnetized vanes produces a proportional rotation

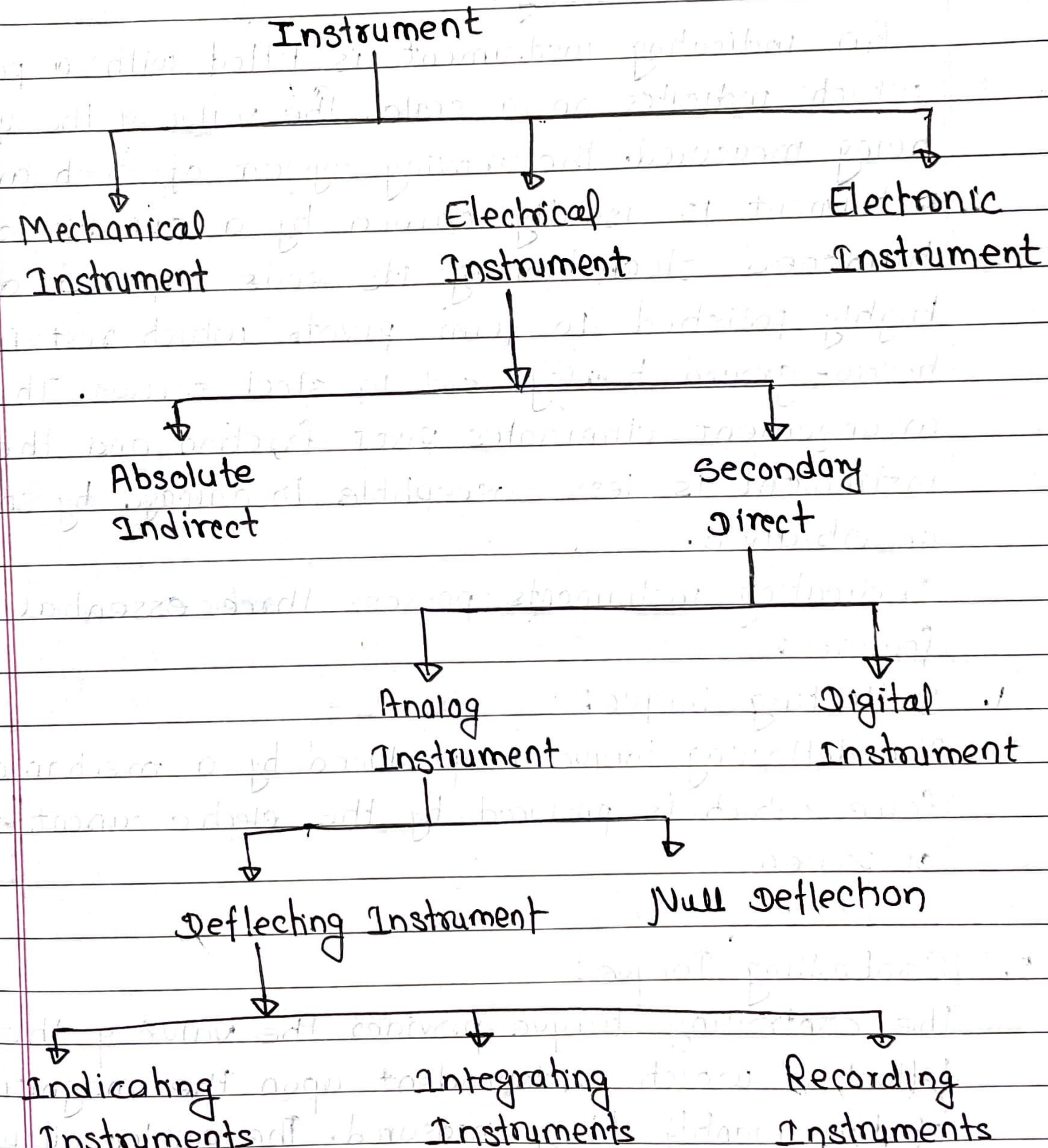
The deflecting torque is proportional to the square of the current in the coil, **making the instrument reading is a true 'RMS' quantity**. Rotation is opposed by a hairspring that produces the restoring torque. Only the fixed coil carries load current, and it is constructed so as to withstand high transient current.

10. Instrumentation and Control

Electrical Measurements

Classification, working, and applications of indicating, recording and integrating instruments for electrical measurements,

The electrical instrument is used for measuring electrical quantities like current, voltage, power etc.



Indicating Instrument:

The instrument which indicates the instantaneous value of the electrical quantity being measured at the time at which it is being measured is called indicating instrument. Their indicators are given by pointers moving over calibrated scale.

Examples: Ammeter, wattmeter, voltmeters etc.

Construction & working:

An indicating instrument is fitted with a pointer which indicates on a scale, the value of the quantity being measured. The moving system of such an instrument is usually carried by a spindle of hardened steel, having its ends tapered and highly polished to form pivots which rest in hollow-ground bearings, set in steel screws. This arrangement eliminates pivot friction and the instrument is less susceptible to damage by shock or vibration.

Indicating instruments possess three essential features:

1. **Deflecting Torque:**

The deflecting torque is produced by a mechanical force which is produced by the electric current, voltage or power.

2. **Controlling Torque:**

The controlling torque provides the value of the deflection which is dependent upon the magnitude of the quantity being measured. The pointer attains steady position when the controlling torque becomes equal to the opposing torque (i.e. deflecting torque).

3. Damping Torque
The damping torque enables to prevent oscillation of the moving system and makes the latter to reach its final position quickly.

Ammeter

An ammeter must have a very low resistance (ideally it has zero internal resistance).

Why ammeter is connected in series?
Ammeter is always connected in series with the circuit because it has low internal resistance. The current to be measured in the circuit should not be practically affected by the ammeter. In series connection, the same current flows through all the components, and ammeter will be able to measure that current.
If the internal resistance of an ammeter is very low, then
a) The whole measured current passes through an ammeter
b) Low voltage drop occurs across an ammeter
c) Low power loss occurs in an ammeter

Types of Ammeter:

Depending on the constructing principle, there are mainly:

1. Permanent Magnet Moving Coil (PMMC) ammeter [DC]
2. Moving Iron (MI) Ammeter [DC|AC]
3. Electrodynamometer type Ammeter [DC|AC]
4. Rectifier type Ammeter

PMMC Ammeter:

Introduction: The instruments which use the permanent magnet for creating the stationary magnetic field between which the coil moves is known as the permanent magnet moving coil or PMMC instrument. It operates on the principle that the torque is exerted on the moving coil placed in the field of the permanent magnet.

The PMMC instrument gives the accurate results for DC measurement.

Construction:

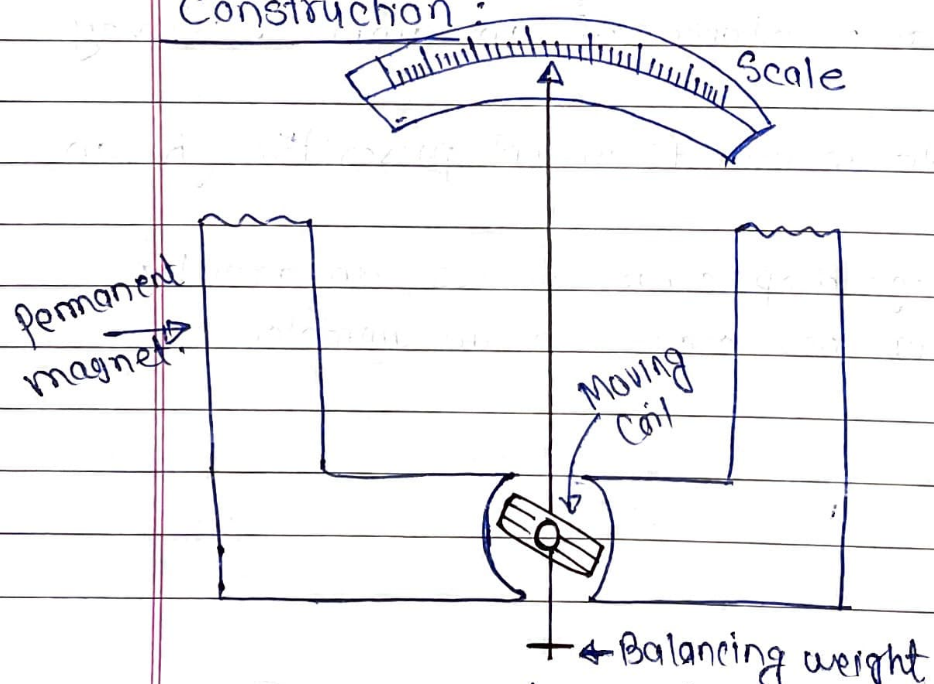


Fig. Front view (vertical view)

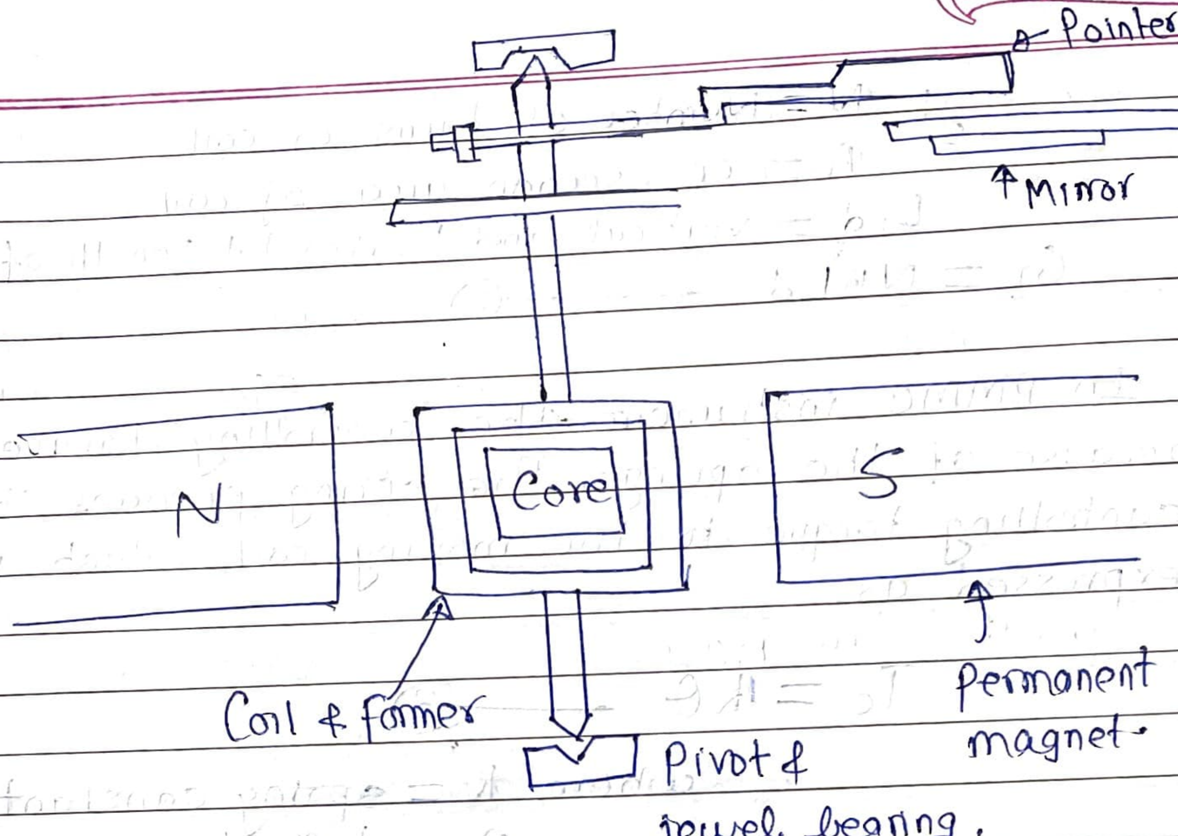


Fig. crosssection view of PMMC

The moving coil and permanent magnet are the main parts of the PMMC instrument.
It consists of moving coil, permanent magnet, pointer and scale and spring system (balancing weight).
The moving coil is the current carrying part of the instrument which is freely moved between the stationary magnetic field of the permanent magnet. According to Fleming's Left hand rule, when a current carrying conductor is placed in between a uniform magnetic field, it experiences a force (torque).

The deflecting torque is given by

$$T_d = BINA = BINLd \quad \text{--- (1)}$$

where,

B = flux density in the air gap

I = current through the coil

N = Number of turns of coil
A = cross-section area of coil
L, d = vertical and horizontal length of the side

$$G = NBLd \quad \text{——— (2)}$$

In PMMC instrument, the controlling torque is because of the springs. The spring provides the controlling torque to the moving coil which is expressed as,

$$T_c = K\theta \quad \text{——— (3)}$$

where, K = spring constant
θ = deflection angle

For final deflection, (steady state condition)

$$T_c = T_d$$

$$K\theta = GI$$

$$\theta = \frac{GI}{K} \quad \text{——— (4)}$$

$$I = \frac{K}{G}\theta \quad \text{——— (5)}$$

Eq^n (4) shows that the deflection torque is directly proportional to the current passing through the coil.

The pointer is linked with the moving coil. The pointer notices the deflection of the coil, and the magnitude of their deviation is shown on the scale.

Moving Iron (MI) Ammeter

- Cheap
- simple in construction
- Accurate at fixed power supply frequency
- can be used for both AC or DC

There are two types of moving iron instruments:

① Attraction Type MI instrument
② Repulsion Type MI instrument

① Attraction Type MI instrument

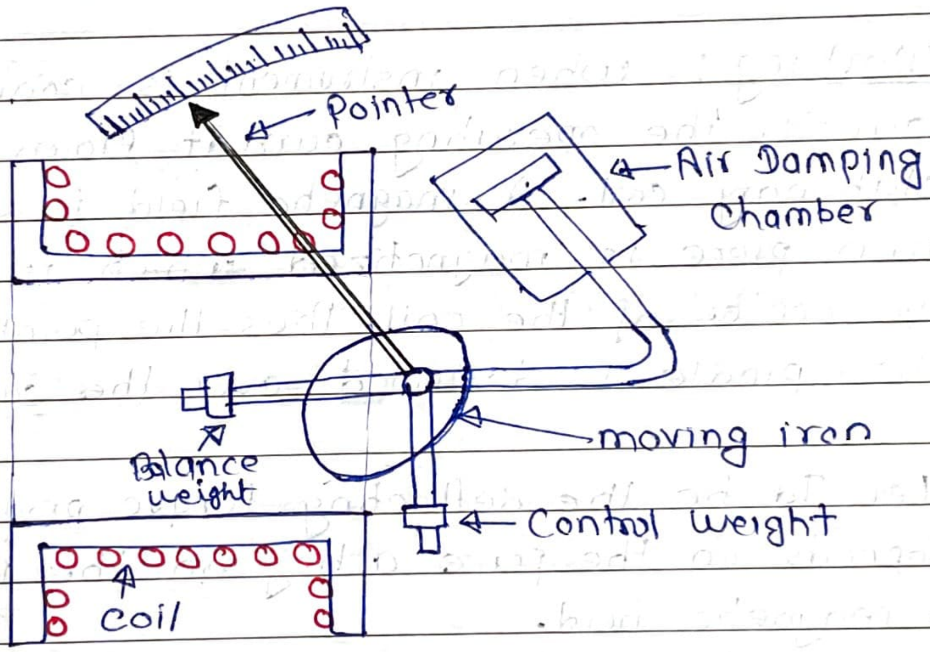
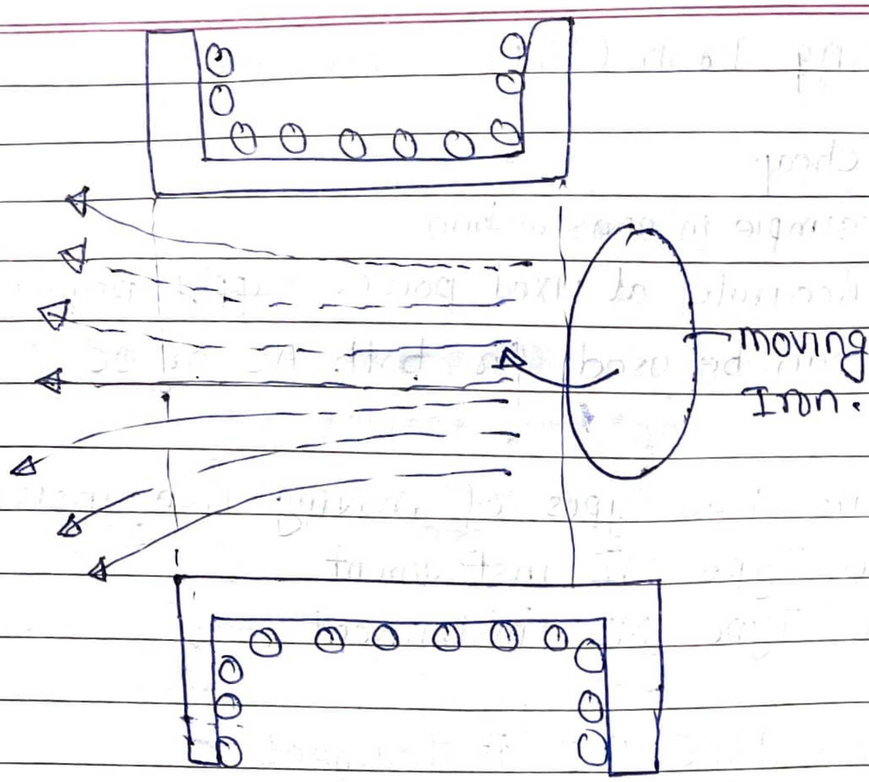


Fig. Attraction type MI Instrument

<u>Principle</u>: when a soft iron piece is placed in a magnetic field of current carrying coils, it is attracted towards the centre of coil.



Working: when instrument is connected to the circuit, the operating current flows through the stationary coil. A magnetic field is setup and soft iron piece is magnetized which is attracted towards the center of the coil. Thus, the pointer attached to the spindle is deflected over the calibrated scale.

Let Td be the deflecting torque produced which depends on the force acting on the iron piece in a magnetic field.

Force acting on iron piece is given by,

$F \propto m H$ where, —— (I)

m = Pole strength

H = magnetic field intensity produced by coil.

$m \propto H$ —— (II)

~~$F \propto I^2$~~

$$F \propto H^2 \quad \text{——— (III)}$$

we know, $H = \frac{NI}{l}$ 10.

$$H \propto I$$

$$\therefore F \propto I^2 \quad \text{——— (IV)}$$

since, $T_d \propto F$, hence,

$$\boxed{T_d \propto I^2}$$

And, $T_c = k\theta$

$$\boxed{T_c \propto \theta}$$

For final deflection (steady state condition)

$$T_c = T_d$$

$$\theta = I^2$$

$$\boxed{\theta \propto I^2}$$

Hence, the deflection torque is directly proportional to the square of the current passing through the coil.

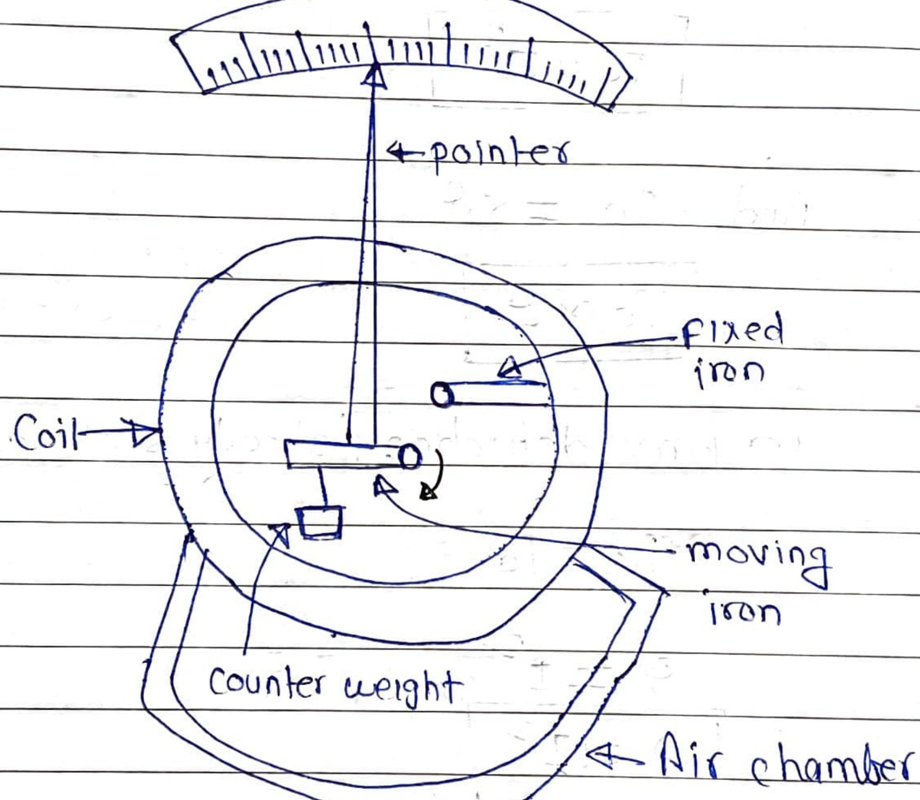
The pointer is attached to the moving iron which deflects over a graduated scale.

The air damping chamber is provided with the instrument for an air friction damping.

A The damping is the phenomenon through which the amplitude of the oscillation decreases. The moving iron instrument uses the air friction damping while the moving coil instrument uses the eddy current damping system.

27 Repulsive Type MI Instrument

Principle: "Repulsive type force acts when two similarly magnetised iron pieces are placed together."



A pointer is attached to the moving iron.

working: when the instrument is connected to the circuit, the operating current flows through the coil. A magnetic field is set up along the axis of coil. The magnetic field magnetises both the iron pieces similarly (same polarities).

A force of repulsion acts between the two irons and the moving iron moves away (repels) from the fixed iron.
Thus, the pointer attached to the spindle deflects over the calibrated scale.

The deflecting torque produced by two similarly magnetised iron bars is proportional to the pole strength of both bars ie.

$T_d \propto m_1 \cdot m_2$

$m_1 \propto H$

$m_2 \propto H$

$\therefore T_d \propto H^2$

we know, $H = \frac{NI}{l}$ $\Rightarrow H \propto I$

$\boxed{T_d \propto I^2}$

Now, $T_c = K\theta$

$\boxed{T_c \propto \theta}$

At equilibrium cond^n,

$T_c = T_d$

$\boxed{\therefore \theta \propto I^2}$ Hence, the deflection torque is proportional to the square of the current.

Date
Page

Difference Between Moving Coil and Moving Iron Instrument:

Definition

⇒ The instrument which uses the soft iron core for measuring the current or voltage is known as the moving iron instrument. It works on the principle that the iron attracts towards the magnet. The magnetic field induces because of the electromagnet and the iron piece is placed between this field. The force of attraction acting on the soft iron core and the magnitude of the force depends on the strength of the magnetic field.

⇒ The instrument in which the coil rotates between the magnetic field of the permanent magnet is known as the moving coil instrument. It works on the principle that the force acting on the coil places between the magnetic field of the permanent magnet. And because of this magnetic field, the coil rotates.

⇒ The moving iron instrument uses the soft iron piece as a rotating element. whereas the moving coil instrument uses the coil as a rotating element

⇒ The working principle of the MI instrument depends on magnetism. whereas working principle of MC instrument is similar to the working principle of dc motor.

⇒ 4. MI is less accurate compared to MC.

⇒ MI uses the air friction damping while MC uses the eddy current damping system. The damping is the phenomenon through which the amplitude of the oscillations decreases.

⇒ MI consumes more power as compared to MC.

⇒ MI is used for measuring both DC and AC whereas MC is used for the DC measurement.

⇒ In MI, the gravity or spring provides the controlling torque to the instrument. Whereas, in MC, the spring provides the controlling torque to the moving coil instrument.

⇒ The deflection of MI is proportional to the square of the current whereas the deflection of MC is proportional to the current.

⇒ MI can be used as an ammeter
voltmeter
wattmeter

MC can be used as an ammeter
voltmeter
galvanometer
ohm ~~watt~~meter

#

Voltmeter

A voltmeter must have a very high resistance (ideally it has infinite internal resistance.)

Why voltmeter is connected in parallel?

→ The voltmeter constructs in such a manner that their internal resistance always remains high. If it is connected in series with the circuit, it minimises the current which flows because of the measured voltage, which disturbs the reading of the voltmeter.

→ The voltmeter always connects in parallel with the circuit so that the same voltage drop occurs across it. The very high resistance of the voltmeter is combined with the impedance of the element across which it is connected. Hence, the overall impedance of the system is equal to the impedance that the element had. Thus, no obstruction occurs in the circuit because of the voltmeter and the meter gives the correct reading.

Types of Voltmeter:

Depending on the constructing principle, there are mainly

1. Permanent magnet moving coil (PMMC) Voltmeter ~~ammeter~~
2. Moving Iron (MI) voltmeter
3. Electrodynamic Voltmeter
4. Rectifier Type Voltmeter
5. Induction Type Voltmeter

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Applications of PMMC:

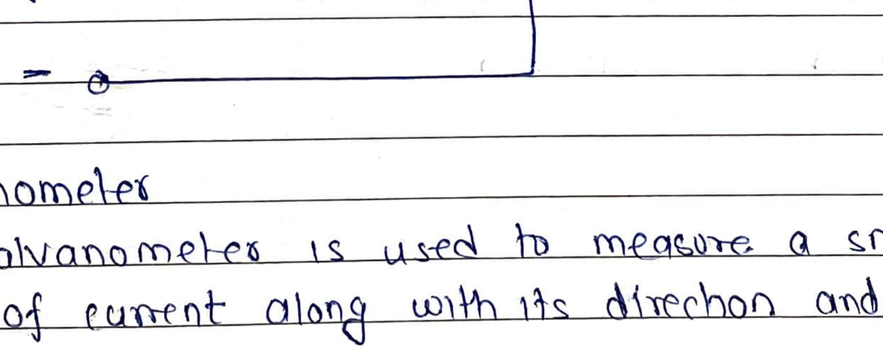
It can be used as:

① Ammeter:

When PMMC is used as an ammeter, a shunt resistor is connected across the moving coil. The shunt resistance will have suitable low resistance so that only small part of the main current flows through the coil. The value of the shunt resistor depends on the current range of the device is going to measure.

② Voltmeter:

When PMMC is used as a voltmeter, a series high resistance is connected in series with the moving coil.



③ Galvanometer

The galvanometer is used to measure a small value of current along with its direction and strength.

④ Ohmmeter

The Ohmmeter is used to measure the resistance of the electric circuit by applying a voltage to a resistance with the help of battery.

Applications of MI Instrument:

(1) Ammeter

- Instrument always connected in series with the circuit and carries the current to be measured
- The current flowing through the coil produces the desired deflecting torque.
- It should have low resistance as it is connected in series.

(2) Voltmeter

- Instrument always connected in parallel with the circuit
- The current flowing through the operating coil of the meter produces deflecting torque.
- It should have high resistance.

Wattmeter

A wattmeter is essentially an inherent combination of an ammeter and a voltmeter and therefore, consists of two coils known as current coil and pressure coil (voltage coil). The operating torque in wattmeter is produced due to interaction of fluxes on account of current in current and pressure coils.

The current coil is generally inserted in series with the line carrying current to be measured and the pressure coil in series with the high non-inductive resistance R, is connected across the load or supply terminal.

Generally the DC wattage power measurement is done by the arrangement of voltmeter and ammeter but in case of ac power measurement wattmeter is used.

For ac quantity, the wattmeter reading is proportional to the product of current flowing through its current coil (I), potential difference across potential coil (V) and cosine of the phase angle between voltage and current ($\cos\phi$).

i.e. $P = VI\cos\phi$

The wattmeter indicates the power lost either in current coil (CC) or in pressure coil (PC) in addition to load power. Normally, the power lost in current coil (CC) or in pressure coil (PC) is very small as compared with that measured power and therefore neglected.

The general connection of wattmeter for 1ϕ wattage power measurement is shown below:

Wattmeter

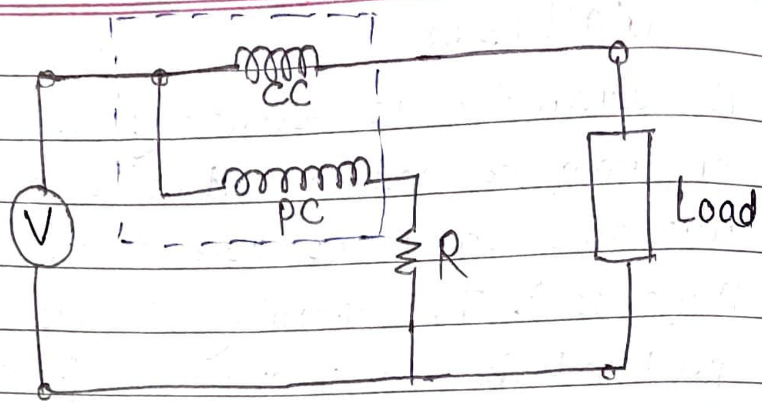


fig. 1ϕ wattmeter connection

Types of Wattmeter :-

Two types of wattmeter:

1. Electrodynamometer or Dynamo type wattmeter
2. Induction Type Wattmeter

1. Electrodynamometer Type Wattmeter :

Construction :

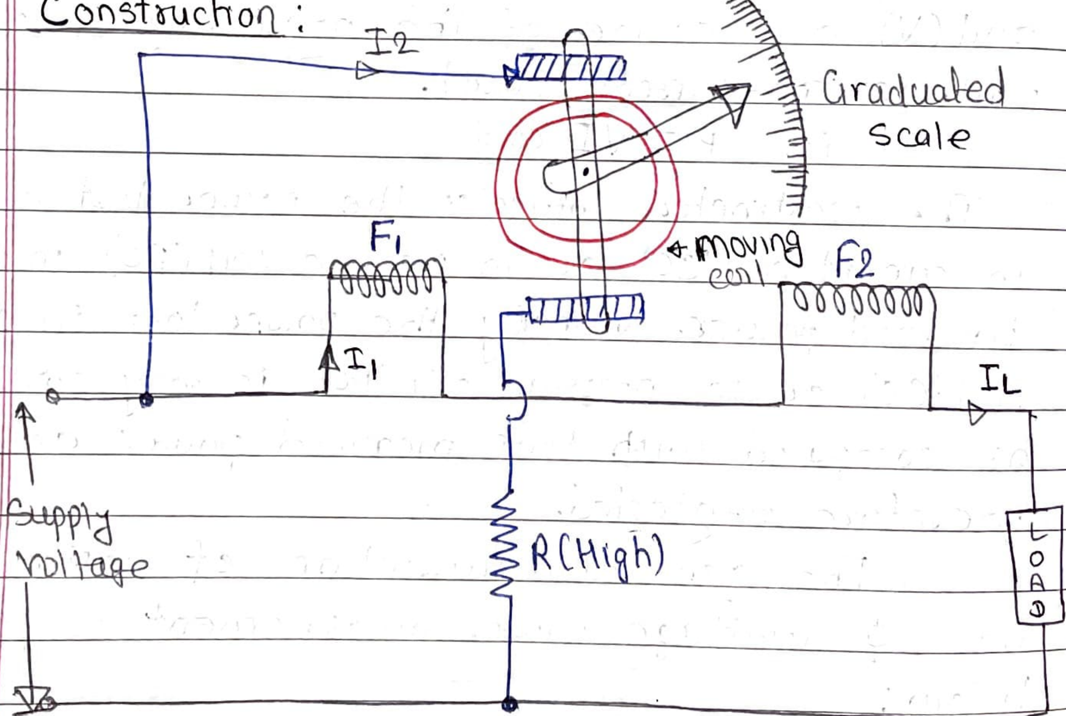


Fig (a) Construction of Electrodynamometer type wattmeter

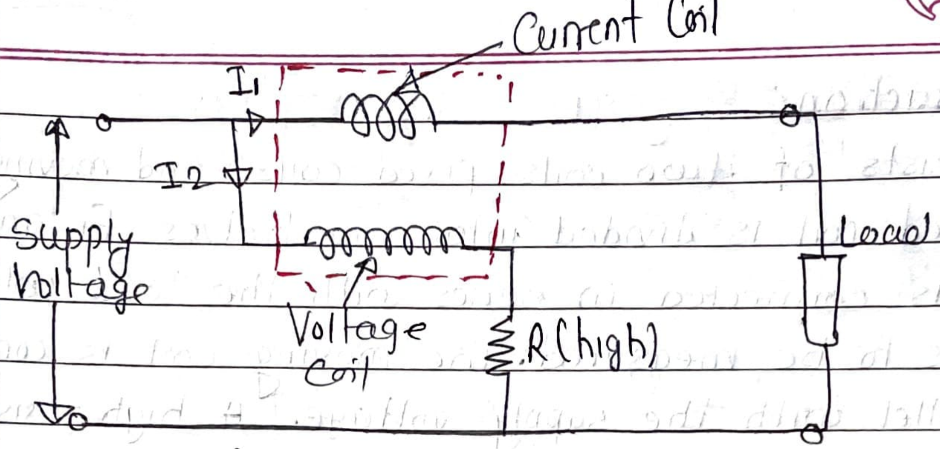


Fig (b) Equivalent circuit of Dynamometer type wattmeter

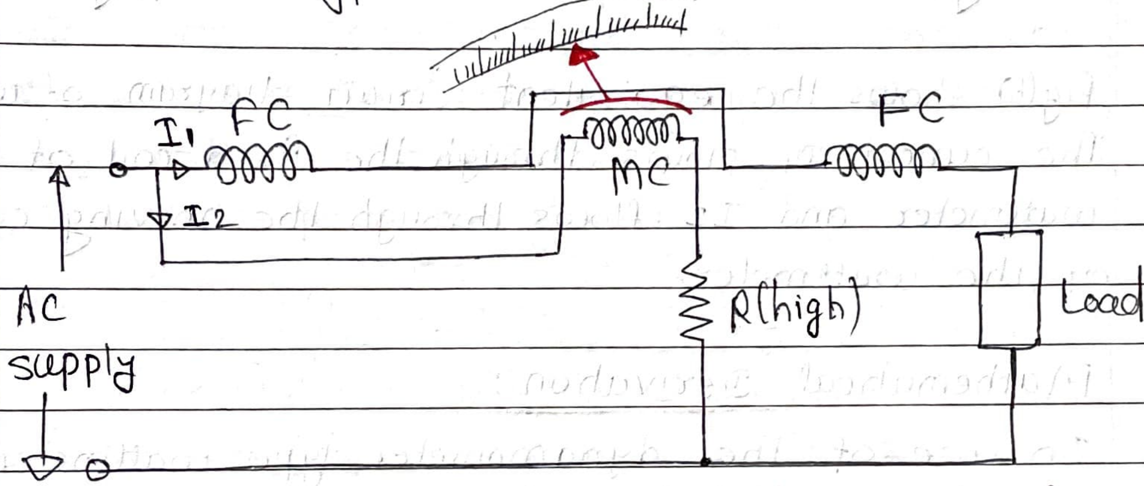


Fig (c) Alternate equivalent circuit of Dynamometer type wattmeter

Working Principle

Dynamometer type wattmeter operates on the principle that when a current carrying coil is under magnetic field, then it experiences a deflecting torque.

In this wattmeter, the operating magnetic field is produced, not by a permanent magnet but by another fixed coil. So when a current carrying moving coil is placed in the magnetic field produced by a current carrying fixed coil, a force is exerted on the moving coil and the deflection takes place.

Construction:

fig ⓐ It consists of two coils: fixed coils and moving coil. The fixed coil is divided into two halves F_1 and F_2 which is connected in series with the load whose power is to be measured. The moving coil is connected in parallel with the supply voltage. A high resistance R is connected in series with moving coil, as moving coil is connected across the supply voltage.

Fig ⓑ shows the equivalent circuit diagram of wattmeter. The current I_1 flows through the fixed coil of the wattmeter and I_2 flows through the moving coil of the wattmeter.

Mathematical Derivation:

In case of the dynamometer type wattmeter, there is no iron core, so the field strength and hence the flux density is proportional to the current I_1 and is given by:

$$B = K I_1 \quad \text{——— (1)}$$

So the fixed coils F_1 and F_2 are responsible for producing the required magnetic field.

Now, when the current flows through the moving coil, it experiences the deflecting torque and moves to show deflection.

The deflecting torque produced is given by,

$$T_d \propto B I_2 \quad \text{——— (2)}$$

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Since, $I_2 \propto KV$ and $B \propto KI_1$

$\therefore T_d \propto I_1 V$ —— (3)

$T_d = K V I_1$

$\boxed{T_d = K * \text{power}}$ —— (4)

In case of dc circuit, the power is given by the product of voltage and current. Hence, eq^n (4) shows that, the deflecting Torque (T_d) is directly proportional to the product of voltage and current ie.

$\boxed{T_d \propto V I_1}$

Now, consider the case of AC, then

$T_d \propto v * i_1 \Rightarrow T_d = K v i_1$

where,
v = instantaneous value of voltage across moving coil
i_1 = instantaneous value of current

$\therefore$ Mean deflecting Torque (T_m) $\propto$ avg value of $v * i_1$

Let $v = V_m \sin\theta$ and $i_1 = I_m \sin(\theta - \phi)$

$$\text{Avg value of } v*i = \frac{1}{2\pi}\int_0^{2\pi} V_m \sin\theta * I_m \sin(\theta-\phi)\, d\theta$$

$$P_{avg} = \frac{V_m I_m}{2*2\pi}\int_0^{2\pi} 2\sin\theta * \sin(\theta-\phi)\, d\theta$$

$$2\sin A \sin B = \cos(A-B) - \cos(A+B)$$

$$P_{avg} = \frac{V_m I_m}{4\pi} \int_0^{2\pi} \left[\cos\phi - \cos(2\theta-\phi)\right] d\theta$$

$$= \frac{V_m I_m}{4\pi} \left\{ \int_0^{2\pi} \cos\phi \, d\theta - \int_0^{2\pi} \cos(2\theta-\phi)\, d\theta \right\}$$

$$= \frac{V_m I_m}{4\pi} \left\{ \left(\theta\cos\phi\right]_0^{2\pi} - \left[\frac{\sin(2\theta-\phi)}{2}\right]_0^{2\pi} \right\}$$

$$= \frac{V_m I_m}{4\pi} \left[2\pi * \cos\phi - \cancel{\frac{\sin(4\pi-\phi)}{2}}^{0} + \cancel{\frac{\sin(-\phi)}{2}}^{0} \right]$$

If $\theta \approx$ very small then
$\sin\theta$ & will be negligible.

$$P_{avg} = \frac{V_m I_m}{4\pi} * 2\pi * \cos\phi = \frac{V_m I_m}{2} \cos\phi$$

$$P_{avg} = V_{rms} I_{rms} \cos\phi$$

as, $T_m \propto P_{avg}$

$$\boxed{\therefore T_m = V_{rms} I_{rms} \cos\phi}$$

Hence, in case of ac supply, the deflecting Torque is proportional to the active power in the ckt.

The graduated type wattmeter is more or less uniform because the deflection is proportional to the average power.

Advantages of Electrodyngmometer Wattmeter:

1. used for both DC and ac
2. high accuracy of measurement, if design is carefully done.
3. low power consumption
4. Light in weight compared to induction type
5. short uniform scale to be provided

Disadvantages of Electrodynamometer Wattmeter:

1. Provides the deflection for average torque
2. Accuracy depends on design
3. comparatively weaker working torque.

② Induction Type Wattmeter :-

Induction type wattmeter belongs to the family of induction type measuring instrument. Since the induction phenomenon can only happen in the alternating current system, this instrument only measures AC power. For that reason, an induction wattmeter differs from a dynamometer wattmeter. Because dynamometer type wattmeter can measure both AC and DC power.

Construction:

→ It consists of two laminated electro-magnets known as shunt electromagnet and series electromagnet.

→ The series magnet is excited by the load current flowing through the current coils. So the flux produced by this electromagnet is directly proportional to the current in the circuit.

→ The shunt magnet is excited by the current proportional to the voltage across the load flowing through the voltage coil. Thus, the current proportional to the voltage of the circuit produces another flux in this electromagnet.

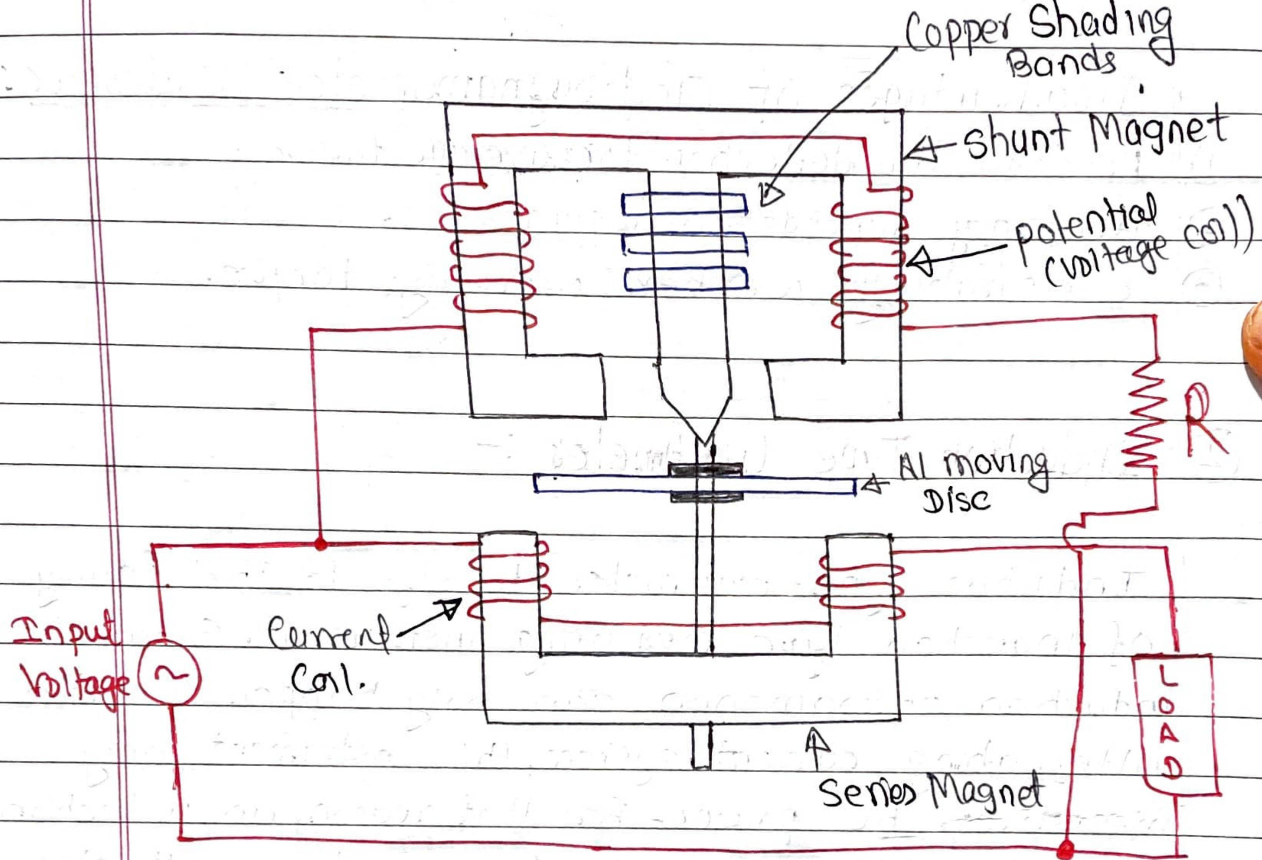


Fig. Induction Type wattmeter.

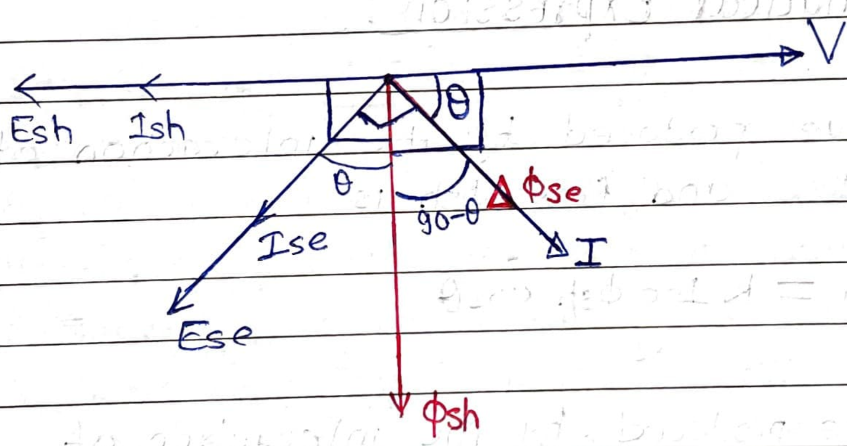
→ In this type, the shunt electromagnet has three limbs. Here, two side limbs hold the voltage coil and the central limb holds the copper rings. On the other hand, the series electromagnet has two limbs. Both of the two limbs hold the current coil.

→ The lightweight circular aluminum disc is placed in between these two electromagnets. Fluxes of the electromagnets produce two eddy currents in the disc. The interaction between eddy currents with the fluxes produces deflecting torque in the instrument.

There are two or three copper rings fitted on the central limb of the shunt electromagnet. Due to this arrangement, the flux created by the shunt magnet lags 90 degree behind the circuit voltage.

The instrument is provided with spiral springs for controlling torque and with permanent magnet for damping torque.

Working Principle :



Let V = circuit voltage

I = circuit current

θ = angle between V and I

ϕ_{se} = flux created by the series electromagnet

This flux will be in phase with the I.

ϕ_{sh} = flux created by the shunt electromagnet

Ideally, the flux ϕ_{sh} lags behind circuit voltage, V by 90°.

$\phi_{se} \rightarrow E_{se} \rightarrow I_{se}$

$\phi_{sh} \rightarrow E_{sh} \rightarrow I_{sh}$

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The flux ϕ_{se} of series electromagnet induces emf E_{se} in the disc. This emf causes the eddy current I_{se} in the disc. Let us assume that the disc is fully resistive. Hence the eddy current I_{se} caused by induced emf E_{se} will be in phase with that emf. So, I_{se} also lags the current I by $90°$.

$\therefore$ angle betn ϕ_{se} and $I_{se} = 90°$

The flux ϕ_{sh} of shunt electromagnet induces emf E_{sh} in the disc. This emf causes the eddy current I_{sh} in the disc. Let us assume that the disc is fully resistive. Hence, the eddy current I_{sh} caused by induced emf E_{sh} will be in phase with that emf. So I_{sh} also lags the flux ϕ_{sh} by $90°$

Mathematical Expression:

The torque produced by the interaction of current I_{se} and flux ϕ_{sh} is

$$T_1 = K I_{se} \phi_{sh} \cos\theta$$

The torque produced by the interaction of current I_{sh} and flux ϕ_{se} is

$$T_2 = K I_{sh} \phi_{se} \cos(180° - \theta)$$

The resultant deflecting torque is,

$$T_d = T_1 - T_2$$

$$= K I_{se} \phi_{sh} \cos\theta - K I_{sh} \phi_{se} \cos(180° - \theta)$$

$$= K [I_{se} \phi_{sh} \cos\theta + I_{sh} \phi_{se} \cos\theta]$$

$$T_d = K[K_1 VI \cos\theta + K_2 VI \cos\theta]$$

$$= K VI \cos\theta (K_1 + K_2)$$

$$\therefore \boxed{T_d \propto VI \cos\theta}$$

Hence, the deflection torque in induction wattmeter is proportional to the ac power to be measured.

Advantages:

1. Having uniform and long scale
2. Free from the stray field and mutual inductance in the coils
3. Has a good damping behaviour.
4. Stronger working Torque

Disadvantages:

1. used for only AC power measurement, not for DC
2. Bulkies and occupying higher weight
3. Power consumption is more as compared to dynamometer type wattmeter
4. It is less accurate since the order of operation depends on the frequency and tempr.

Integrating Instrument :

The instrument which measure the consumption of total quantity of electricity, energy etc during a particular period of ~~type~~ time is called integrating instrument. These instruments totalize events over a specific period of time. No indication of the rate or variation or the amount at a particular instant are available from them. Some widely used integrating instruments are: Ampere-hour meter, energy meter or kilowatthour (kwh) meter, kilovoltampere-hour (KVARh) meter etc.

Energy Meter :

Energy meter are integrating instruments used to measure quantity of electrical energy supplied to a load for a particular period of time. These are also known as the kilowatthour (kwh) meter.

Types of Energy Meter :

There are following types of energy meters:

1. Electrolytic Energy Meters
2. Clock - Energy meters
3. Motor - Energy meters

Electrolytic Meters :

The operation of these meters depends on electrolytic action.

Clock meters

They function as in clock mechanism.

Motor Meters:

They are working as if they are small electric motors. The motor meters can also be further divided into:

ⓐ Mercury motor meters
ⓑ Commutator motor meters
ⓒ Induction motor type enerey meters.

Among these all, the induction type meter are the most common form of ac enerey meters met within work by domestic and industrial application.

Single phase Induction Type Enerey Meters:-

The construction of enerey meter consist of mainly four parts:

1. Driving System
2. Moving System
3. Braking System
4. Registering System

① Driving System:

The electromagnet is the main component of the driving system. It is a temporary magnet which is excited by the current flow through their coil. The core of the electromagnet is made up of silicon steel lamination.

The driving system consists of two electromagnets

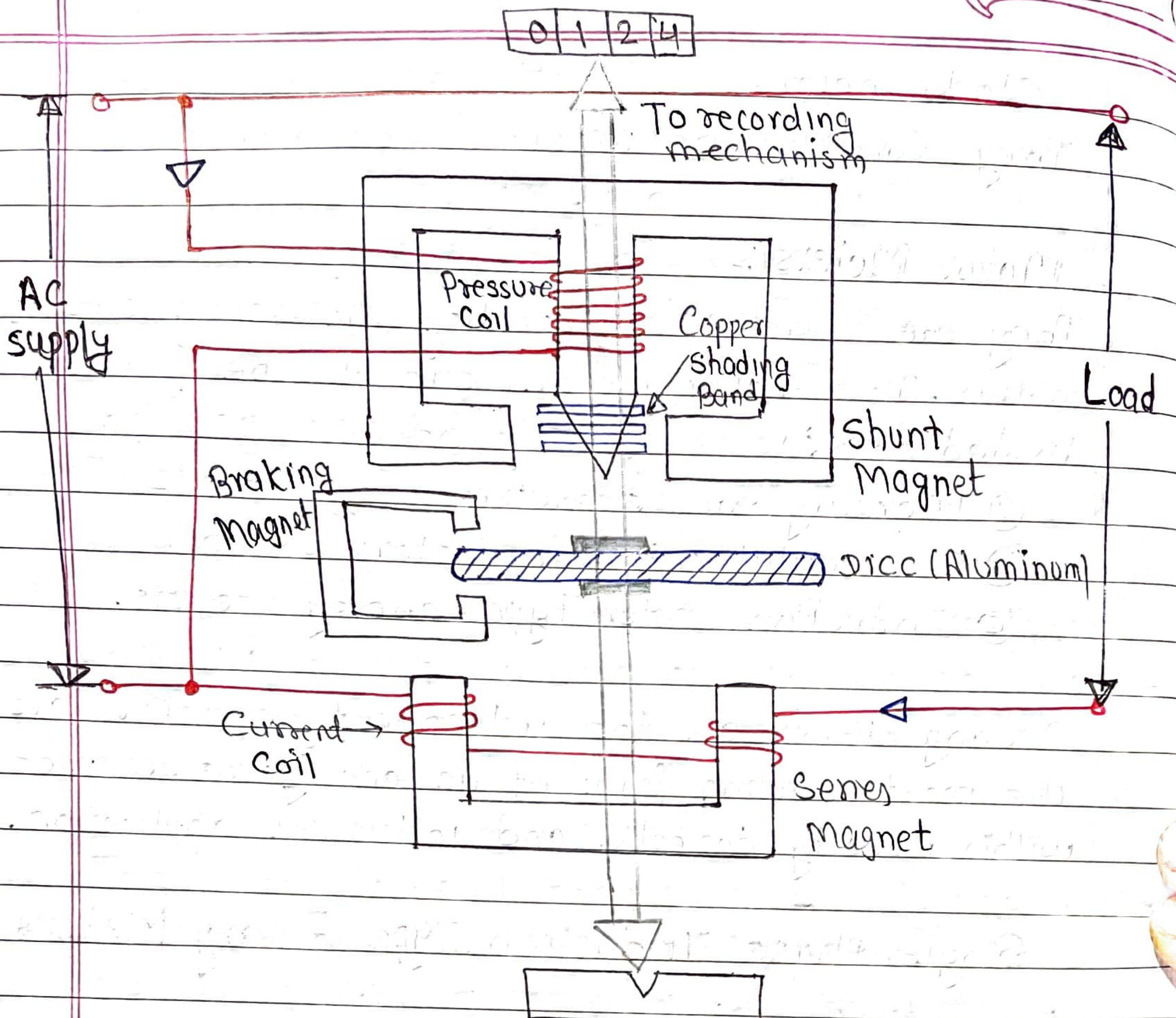


Fig. Induction Type Energy Meter

The upper one is called the shunt electromagnet. The lower one is called the series electromagnet.

The series electromagnet is excited by the load current flow through the current coil. The coil of the shunt electromagnet is directly connected with the supply and carry the current proportional to the shunt (supply) voltage.
The centre limb of the magnet has the copper band. These bands are adjustable. The main function of the copper band is to align the flux produced by the shunt magnet in such

a way that it is exactly perpendicular to the supplied voltage.

② Moving System:
The moving system consists of an aluminium disc mounted on the shaft of the alloy. The disc is placed in the air gap of the two electromagnets. The eddy current is induced in the disc because of the change of the magnetic field. The eddy current is cut by the magnetic flux. The interaction of the flux and the disc induces the deflecting torque.

③ Braking System:
The permanent magnet is used for reducing the rotation of the aluminum disc. The aluminium disc induces the eddy current because of their rotation. The eddy current cut the magnetic flux of the permanent magnet and hence produces the braking torque.
The braking torque opposes the movement of the disc, thus reduces their speed. The permanent magnet is adjustable due to which the braking torque is also adjusted by shifting the magnet to the other radial position.

④ Registration (counting mechanism)
The main function of the registration or counting mechanism is to record the number of rotations of the aluminium disc. Their rotation is directly proportional to the energy consumed by the loads in the kilowatt hour.

The rotation of the disc is transmitted to the pointers of the different dial for recording the different readings. The reading in kwh is obtained by multiply the number of rotations of the disc with the meter constant.

Working of the Energy Meter:

The energy meter has the aluminium disc whose rotation determines the power consumption of the load. The disc is placed between the air gap of the series and shunt electromagnet. The shunt magnet has the pressure coil, and the series magnet has the current coil.

The pressure coil creates the magnetic field because of the supply voltage, and the current coil produces it because of the current.

The field induces by the voltage coil is lagging by 90° on the magnetic field of the current coil because of which eddy current induced in the disc. The interaction of the eddy current and the magnetic field causes torque, which exerts a force on the disc. Thus, the disc starts rotating.

The force on the disc is proportional to the current and voltage of the coil. The permanent magnet controls their rotation. The permanent magnet opposes the movement of the disc and equalises it on the power consumption.

The cyclometer counts the rotation of the disc.

Power Factor Meter :

On measuring the current, voltage and power in ac circuit, its power factor can be calculated from the relationship,

$$\cos\phi = \frac{P}{VI}$$

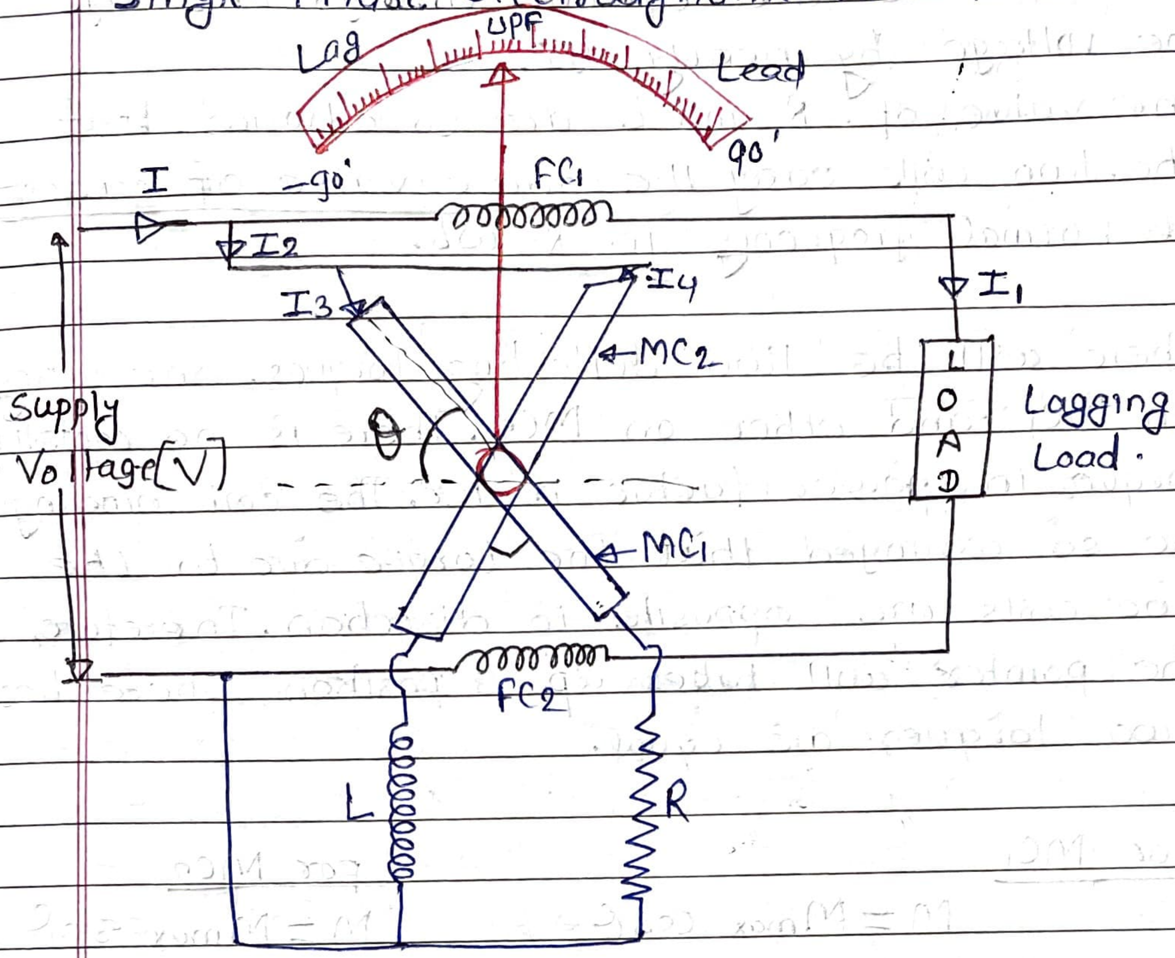
The power factor meter measures the power factor of a transmission line. It determines the types of load using on the line, and it also calculates the losses occur on it.

Types of Power Factor Meter:
The power factor meters is of two types: They are,

1. Electrodynamometer Type
   - ✓ Single phase electrodynamometer
   - ✓ Three phase electrodynamometer

2. Moving Iron Type Meter
   - ✓ Rotating Iron Magnetic Field
   - ✓ Number of Alternating field.

Single Phase Electrodynamometer Power Factor Meter



Construction

It consists of two fixed coils (current coil) connected in series ie. FC1 and FC2, which carry the load current. The magnetic field of the coil is directly proportional to the current flowing through the coil.

The meter also has two identical moving coils (pressure coils) MC1 and MC2, which are pivoted on the spindle. ~~The moving coil MC1 is highly resistive~~ The moving coil MC1 is connected with pure resistor R in series while the moving coil MC2 is connected with pure inductor L in series. Hence the current through MC1 is in phase with the

circuit while the current through MC_2 lags the voltage by nearly 90°.
The value of R and L are so adjusted that the two coils carry the same value of current at normal frequency i.e. $R = \omega L$.

There will be two deflecting torques, one acting on MC_1 and other on MC_2. There is no controlling torque in power factor meter. The coil windings are so arranged that the torque due to the two coils are opposite in direction. Therefore, the pointer will takes up a position where these two torques are equal.

For MC_1

$$M = M_{max} \cos\theta$$

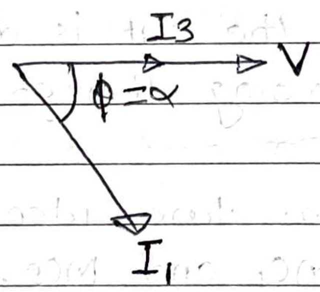
$$\frac{dM}{d\theta} = -M_{max} \sin\theta$$

For MC_2

$$M = M_{max} \sin\theta$$

$$\frac{dM}{d\theta} = M_{max} \cos\theta$$

For Highly Resistive coil MC_1:

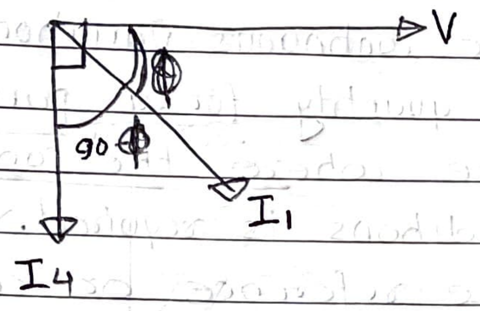


$$\therefore Td_1 = I_1 I_3 \cos\alpha \cdot \frac{dM}{d\theta}$$

$$Td_1 = I_1 I_3 \cos\phi \, (-M_{max} \sin\theta)$$

$$\boxed{Td_1 = M_{max} I_1 I_3 \sin\theta \cos\phi}$$

For Highly Inductive coil MC2:



$$T_{d2} = I_1 I_4 \cos(90-\phi) \cdot \frac{dM}{d\theta}$$

$$= I_1 I_4 \cos(90-\phi) \cdot M_{max} \cos\theta \cdot$$

$$\boxed{T_{d2} = M_{max} I_1 I_4 \cos\theta \sin\phi}$$

At balanced condition:

$$T_{d1} = T_{d2}$$

also assume $I_3 = I_4$

$$M_{max} I_1 I_3 \sin\theta \cos\phi = M_{max} I_1 I_4 \cos\theta \sin\phi$$

$$\tan\theta = \tan\phi$$

$$\boxed{\theta = \phi}$$

Therefore, the deflection of the instrument is the measure of the phase angle 'ϕ' of the circuit. The scale of the instrument can be calibrated in directly in terms of power factor.

Current transformer

The **Current Transformer** (C.T.), is a type of “instrument transformer” that is designed to produce an alternating current in its secondary winding which is proportional to the current being measured in its primary

Fig: LV CT application

Fig: HV CT application

Fig: Clamp meter

Operation

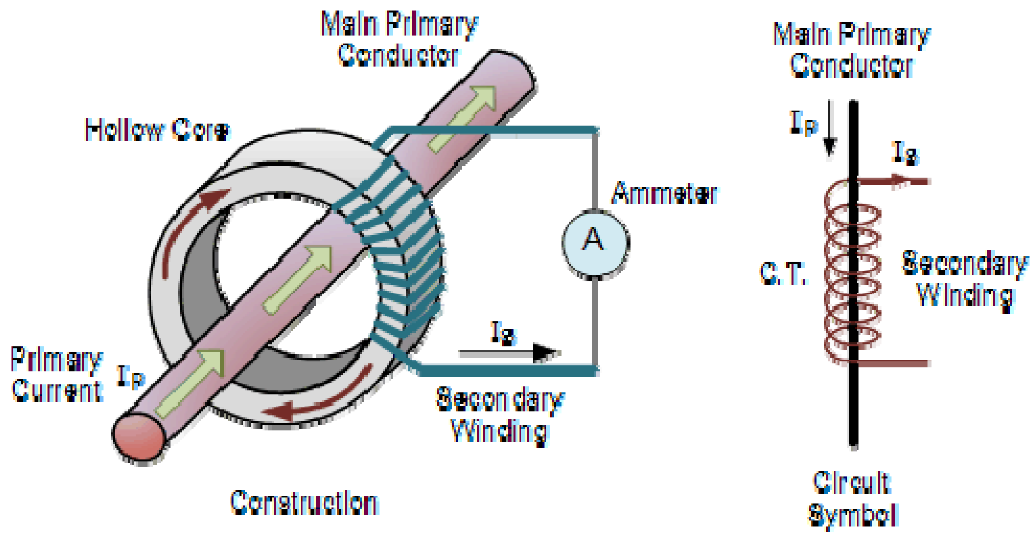
A CT functions with the same basic working principle of electrical power transformer, but here is some difference. In an electrical power transformer or other general purpose transformer, primary current varies with load or secondary current. In case of CT, primary current is the system current and this primary current or system current transforms to the CT secondary, hence secondary current or burden current depends upon primary current of the current transformer.

In a power transformer, if load is disconnected, there will be only magnetizing current flow in the primary. The primary of the power transformer takes current from the source proportional to the load connected with secondary. But in case of CT, the primary is connected in series with power line. So current through its primary is nothing but the current flows through that power line. The primary current of the CT, hence does not depend upon whether the load or burden is connected to the secondary or not or what is the impedance value of burden. Generally CT has very few turns in primary where as number of turns in secondary is large in number.

Due to this type of arrangement, the current transformer is often referred to as a “series transformer” as the primary winding, which never has more than a very few turns, is in series with the current carrying conductor.

The secondary winding may have a large number of coil turns wound on a laminated core of low-loss magnetic material which has a large cross-sectional area so that the magnetic flux density is low using much smaller cross-sectional area wire, depending upon how much the current must be stepped down. This secondary winding is usually rated at a standard 1 Ampere or 5 Amperes for larger ratings. The product of voltage and current on the secondary side when the CT is supplying the instrument or relay with its maximum rated value of current is known as

rated burden and is measured in volt-amperes (VA). Generally the VA ratings ranges from 5 to 150 VA.



Generally current transformers and ammeters are used together as a matched pair in which the design of the current transformer is such as to provide a maximum secondary current corresponding to a full-scale deflection on the ammeter. In most current transformers an approximate inverse turns ratio exists between the two currents in the primary and secondary windings. This is why calibration of the CT is generally for a specific type of ammeter.

Most current transformers have a standard secondary rating of 5 amps with the primary and secondary currents being expressed as a ratio such as 100/5. It means when 100 amps is flowing in the primary conductor it will result in 5 amps flowing in the secondary winding, or one of 500/5 will produce 5 amps in the secondary for 500 amps in the primary conductor, etc.

By increasing the number of secondary windings, N2, the secondary current can be made much smaller than the current in the primary circuit being measured because as N2 increases, I2 goes down by a proportional amount. In other words, the number of turns and the current in the primary and secondary windings are related by an inverse proportion.

$$\text{T.R.} = n = \frac{N_P}{N_S} = \frac{I_S}{I_P}$$

From which we get:

$$\text{secondary current, } I_S = I_P\left(\frac{N_P}{N_S}\right)$$

As the primary usually consists of one or two turns whilst the secondary can have several hundred turns, the ratio between the primary and secondary can be quite large. For example, assume that the current rating of the primary winding is 100A. The secondary winding has the standard rating of 5A. Then the ratio between the primary and the secondary currents is 100A-to-5A, or 20:1. In other words, the primary current is 20 times greater than the secondary current.

It should be noted however, that a current transformer rated as 100/5 is not the same as one rated as 20/1 or subdivisions of 100/5. This is because the ratio of 100/5 expresses the "input/output current rating" and not the actual ratio of the primary to the secondary currents. Also note that the number of turns and the current in the primary and secondary windings are related by an inverse proportion.

Example

A bar-type current transformer which has 1 turn on its primary and 160 turns on its secondary is to be used with a standard range of ammeters that have an internal resistance of 0.2Ω's. The ammeter is required to give a full scale deflection when the primary current is 800 Amps. Calculate the maximum secondary current and secondary voltage across the ammeter.

Secondary Current:

$$I_S = I_P\left(\frac{N_P}{N_S}\right) = 800\left(\frac{1}{160}\right) = 5A$$

Voltage across Ammeter:

$$V_S = I_S \times R_A = 5 \times 0.2 = 1.0\,\text{Volts}$$

We can see above that since the secondary of the current transformer is connected across the ammeter, which has a very small resistance, the voltage drop across the secondary winding is only 1.0 volts at full primary current. If the ammeter is removed, the secondary winding becomes open-circuited and the transformer acts as a step-up transformer due to the very large increase in magnetizing flux in the secondary core. This results in a high voltage being induced in the secondary winding equal to the ratio of: Vp(Ns/Np) being developed across the secondary winding.

So for example, assume our current transformer from above is connected to a 480 volt three-phase power line. Therefore:

$$T.R. = n = \frac{V_P}{V_S} = \frac{N_P}{N_S}$$

$$\therefore\ V_S = V_P\left(\frac{N_S}{N_P}\right) = 480\left(\frac{160}{1}\right) = 76{,}800V \text{ or } 76.8kV$$

This 76.8kV is why a current transformer should never be left open-circuited or operated with no-load attached when the main primary current is flowing through it. If the ammeter is to be removed, a short-circuit should be placed across the secondary terminals first to eliminate the risk of shock.

Types of CT

There are three basic types of current transformers:

Bar type

- This type of current transformer uses the actual cable or bus-bar of the main circuit as the primary winding, which is equivalent to a single turn. They are fully insulated from the high operating voltage of the system and are usually bolted to the current carrying device.

Fig: Bar type

Fig: Wound type

Fig: Window type

Wound type

- Wound CTs have a primary and secondary winding like a normal transformer. The transformers primary winding is physically connected in series with the conductor that carries the measured current flowing in the circuit. The magnitude of the secondary current is dependent on the turns ratio of the transformer.

Window type

- They are constructed with no primary winding and are installed around the primary conductor. The electric field created by current flowing through the conductor interacts with the CT core to transform the current to the appropriate secondary output. Window CTs can be of solid or split core construction. The primary conductor must be disconnected when installing solid window CTs. However, split core CTs can be installed around the primary conductor without disconnecting the primary conductor

Handheld Current Transformers

There are many specialized types of current transformers now available. Popular and portable types which can be used to measure circuit loading are called “clamp meters” as shown

Clamp meters open and close around a current carrying conductor and measure its current by determining the magnetic field around it, providing a quick measurement reading usually on a digital display without disconnecting or opening the circuit.

As well as the handheld clamp type CT, split core current transformers are available which has one end removable so that the load conductor or bus bar does not have to be disconnected to install it. These are available for measuring currents from 100 up to 5000 amps, with square window sizes from 1″ to over 12″ (25-to-300mm).

Standard ratios

The most common CT secondary full-load current is 5 amps which matches the standard 5 amp full-scale current rating of switchboard indicating devices, power metering equipment, and protective relays. CT's with a 1 amp full-load value and matching instruments with a 1 amp full-range value are also available. Many new protective relays are programmable for either value. The secondary current of 0.1 amp is also used in some cases for static relays. Primary current rating ranges from 10 amp to 3000 amp or more.
CT ratios are expressed as a ratio of the rated primary current to the rated secondary current.
For example, a 300:5 CT will produce 5 amps of secondary current when 300 amps flow through the primary. As the primary current changes the secondary current will vary accordingly. With 150 amps through the 300 amp rated primary, the secondary current will be 2.5 amps (150 : 300 = 2.5 : 5). When the rated primary amps is exceeded, which is usually the case when a fault occurs on the system, the amount of secondary current will increase but, depending on the magnetic saturation in the CT, the output may not be exactly proportional.

Application

Current transformers are used extensively for measuring current and monitoring the operation of the power grid. Multiple CTs are installed for various uses. For example, protection devices and metering may use separate CTs to provide isolation between metering and protection circuits, and allows current transformers with different characteristics (accuracy, overload performance) to be used for the devices.

Knee Point Voltage of Current Transformer

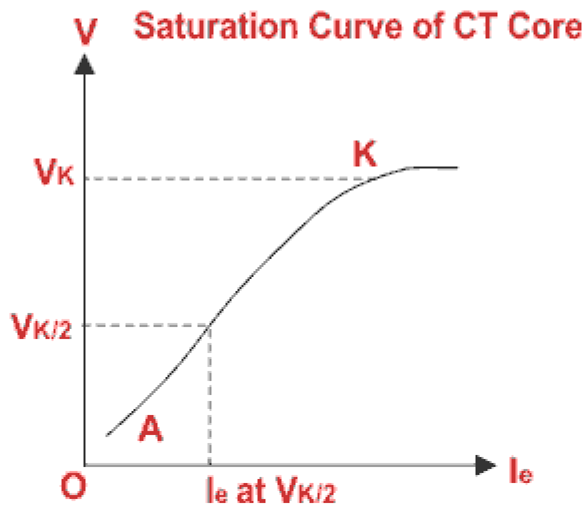
This is the significance of saturation level of a CT core mainly used for protection purposes. The sinusoidal voltage of rated frequency applied to the secondary terminals of current transformer, with other winding being open circuited, which when increased by 10% cause the exiting current to increase 50%.

The EMF induced in the CT secondary windings is

$$E_2 = 4.44\varphi f T_2$$

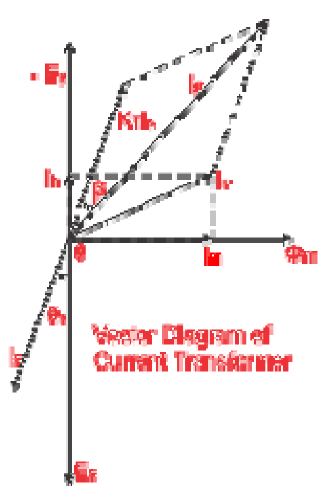
Where, **f** is the system frequency, **φ** is the maximum magnetic flux in Wb. $\mathbf{T_2}$ is the number of turns of the secondary winding. The flux in the core, is produced by excitation current $\mathbf{I_e}$. We have a non-liner relationship between excitation current and magnetizing flux. After certain value of excitation current, flux will not further increase so rapidly with increase in excitation current. This non-liner relation curve is also called **B - H** curve. Again from the equation above, it is found that, secondary voltage of a current transformer is directly proportional to flux **φ**. Hence one typical curve can be drawn from this relation between secondary voltage and excitation current as shown below.

It is clear from the curve that, linear relation between **V** & $\mathbf{I_e}$ is maintained from point **A** & **K**. The point **'A'** is known as **'ankle point'** and point **'K'** is known as **'Knee Point'**.



Accuracy class and errors

Errors in a CT can be understood with following phasor diagram



I_s - Secondary current.
E_s - Secondary induced emf.
I_p - Primary current.
E_p - Primary induced emf.
K_T - Turns ratio = Numbers of secondary turns/number of primary turns.
I_0 - Excitation current.
I_m - Magnetizing component of I_0.
I_w - Core loss component of I_0.
Φ_m - Main flux.

Accuracy class is determined by the value of errors. There are two types of errors in a CT

(i) Current ratio error and (ii) Phase angle error

Current ratio error

From above passer diagram it is clear that primary current I_p is not exactly equal to the secondary current multiplied by turns ratio, i.e. $K_T I_s$. This difference is due to the primary current is contributed by the core excitation current. The **error in current transformer** introduced due to this difference is called current error of CT or sometimes **ratio error in current transformer**. .

$$\text{Hence, the percentage current error} = \frac{|I_p| - |K_T.I_s|}{I_p} \text{ X } 100\ \%$$

Where; I_P = Primary current; K_T = Turn ratio; I_S = Secondary current

Phase angle error

For an ideal CT the angle between the primary and reversed secondary current vector is zero. But for an actual CT there is always a difference in phase between two due to the fact that primary current has to supply the component of the exiting current. The angle between the above two phases in termed as **phase angle error in current transformer** or CT. Here in the pharos diagram it is β. The phase angle error is usually expressed in minutes.

Limits of error for measuring CTs

Accuracy class	Permissible current ration error in % at % rated current				Permissible phase angle error in min. at % rated current			
	5	20	100	120	5	20	100	120
0.1	± 0.4	± 0.2	± 0.1	± 0.1	± 15	± 8	± 5	± 5
0.2	± 0.75	± 0.35	± 0.2	± 0.2	± 30	± 15	± 10	± 10
0.5	± 1.5	± 0.75	± 0.5	± 0.5	± 90	± 45	± 30	± 30
1.0	± 3.0	± 1.5	± 1.0	± 1.0	± 180	± 90	± 60	± 60

Limits of error for protection CTs

Accuracy class	Permissible current ratio error in % at rated primary current	Permissible phase displacement in min. at rated primary current	Permissible composite error at rated accuracy limit primary current in percentage
5p	± 1.0	± 60	5
10p	± 3.0	-	10
15p	± 5.0	-	15

Potential Transformer

Fig: Medium voltage PT

Fig: HV PT in application

Potential transformer or **voltage transformer** gets used in electrical power system for stepping down the system voltage to a safe value which can be fed to low ratings meters and relays. Commercially available relays and meters used for protection and metering, are designed for low voltage.

Operation

A **voltage transformer theory** or **potential transformer theory** is just like a theory of general purpose step down transformer. Primary of this transformer is connected across the phase and ground. Just like the transformer used for stepping down purpose, potential transformer i.e. PT has lower turns winding at its secondary. The system voltage is applied across the terminals of primary winding of that transformer, and then proportionate secondary voltage appears across the secondary terminals of the PT.

Application

The potential transformers are used to

(i) feed instruments to measure the voltage level

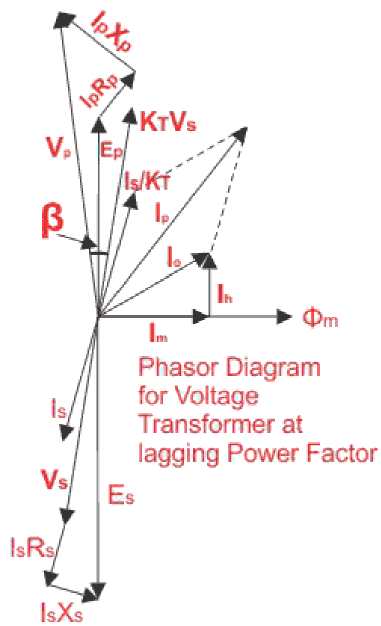
(ii) feed relay to protect the power system components from undesirable voltage fluctuations

(iii) safely isolating secondary control circuitry from the high voltages.

Standard ratios

The secondary voltage of the PT is generally 110 V. In an ideal **potential transformer** or **voltage transformer**, when rated burden gets connected across the secondary; the ratio of primary and secondary voltages of transformer is equal to the turns ratio and furthermore, the two terminal voltages are in precise phase opposite to each other. But in actual transformer, there must be an error in the voltage ratio as well as in the phase angle between primary and secondary voltages.
The errors in potential transformer or voltage transformer can be best explained by phasor diagram below.

Errors in PT or Potential Transformer or VT or Voltage Transformer



I_s - Secondary current. E_s - Secondary induced emf. V_s - Secondary terminal voltage. R_s - Secondary winding resistance. X_s - Secondary winding reactance. I_p - Primary current. E_p - Primary induced emf. V_p - Primary terminal voltage. R_p - Primary winding resistance. X_p - Primary winding reactance. K_T - Turns ratio = Numbers of primary turns/number of secondary turns. I_0 - Excitation current. I_m - Magnetizing

Voltage Error or Ratio Error in Potential Transformer (PT) or Voltage Transformer (VT)

The difference between the ideal value V_p/K_T and actual value V_s is the voltage error or ratio error in a potential transformer, it can be expressed as,

$$\boxed{\%\ \text{voltage error} = \frac{V_p - K_T.V_s}{V_p} \text{X } 100\ \%}$$

Phase Error or Phase Angle Error in Potential or Voltage Transformer

The angle 'β' between the primary system voltage V_p and the reversed secondary voltage vectors $K_T.V_s$ is the phase error.

Characteristics of potential transformer

Accuracy class	Permissible voltage ratio error (%)	Permissible phase angle error (min)
0.2	± 0.2	± 10
0.5	± 0.5	± 20
1.0	± 1.0	± 40
3.0	± 3.0	± 120
5.0	± 5.0	± 300

Digital DAS

Digital data acquisition systems are used when the physical process being monitored is slowly varying (narrow bandwidth) and when accuracy and low per-channel cost is required. Digital data acquisition systems range in complexity from single-channel dc voltage measuring and recording systems to sophisticated automatic multichannel systems that measure a large number of input parameters, compare against preset limits or conditions, and perform computations and decisions on the input signal. Digital acquisition systems are in general more complex than analog systems, both in terms of the instrumentation involved and the volume and complexity of input data they can handle.

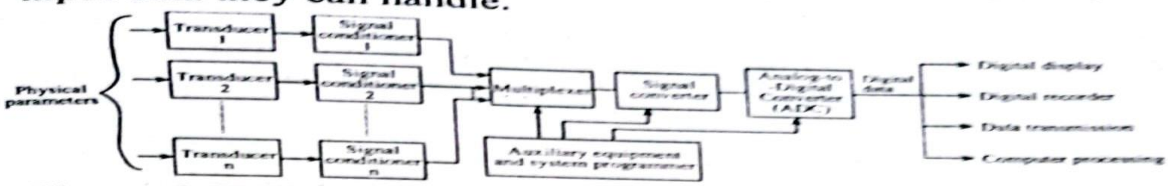


Figure 6.10 Block diagram of a digital data acquisition system.

A digital data acquisition system typically consists of the following elements:

i. Transducer
ii. Signal conditioner
iii. Multiplexer
iv. **Signal converter**

   Signal converter translates the analog signals to a form acceptable by the analog-to-digital converter (ADC). An example of a signal converter is an amplifier for amplifying low-level voltages produced by transducers.

v. **Auxiliary equipment**

   This contains devices for system programming functions and digital data processing. Some of the typical functions done by the auxiliary equipments are linearization and limit comparison of signals.

vi. **Analog-to-digital (A/D) converter**

   It converts the analog voltage to its equivalent digital form.

After the digital data is generated, digital information are recorded on punched cards, perforated paper tapes, type written pages, floppy discs, or a combinations of these systems.

6.6 Communication System

In broad sense, the term "*communication*" refers to the sending, receiving, and processing of information by electronic means.

Communication system is a system designed to send information from a source generating that information to one (point-to-point communication) or more (broadcasting) receivers of that information. A communication system transmits information (voice, data, video) from one place to another, whether separated by a few kilometres or by transoceanic distances. Communication systems may be broadly divided into two types: *analog communication systems* and *digital communication systems.*

1. General Communication system

The general communication system comprises of the following components:

i. Transmitter

This portion processes the message signal into a form suitable for transmission over the channel. Such an operation is called modulation.

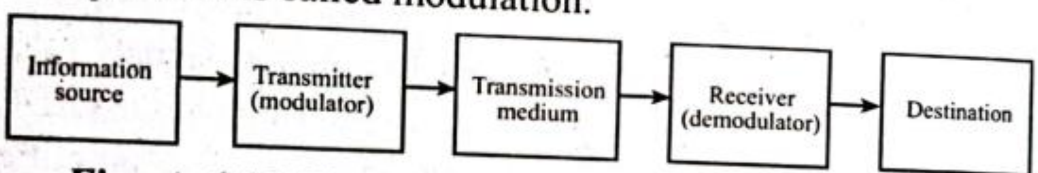


Figure 6.11 *Block diagram of a general communication system.*

ii. Transmission medium

The function of the transmission medium is to provide a physical connection between the transmitter output and the receiver input. The transmission medium can consist of a pair of wires, a coaxial cable, or a radio link through free space.

iii. Receiver

This portion processes the received signal to get message signal. Such an operation is called demodulation.

2. Optical Fibre Communication System

Optical Fibre

It is a flexible optically transparent fibre, usually made of glass or plastic, through which light can be transmitted by successive total internal reflections. Optical fibre consists of three parts namely protective layer, cladding, and core. The refractive index of the core is greater than that of the cladding.

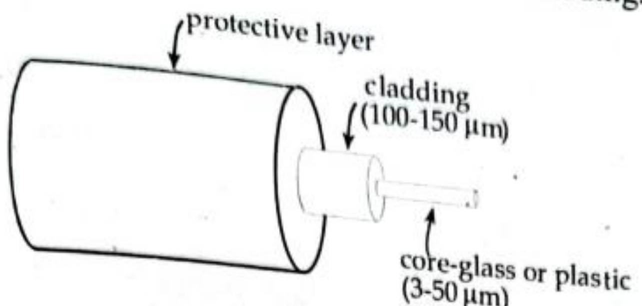


Figure 6.12 Optical fibre.

In optical fibre communication system, the transmission medium is optical fibre. Figure 6.13 shows the elements of an optical fibre communication system.

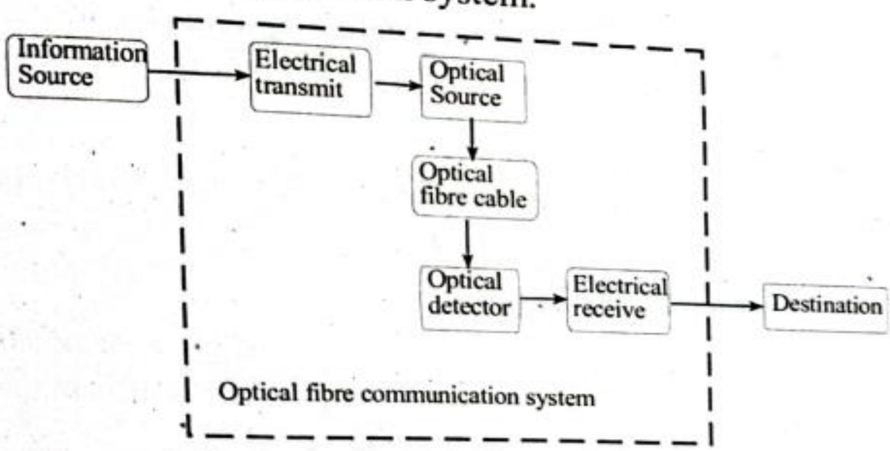


Figure 6.13 Functional block diagram of an optical fibre communication system.

The information source provides an electrical signal to a transmitter comprising an electrical stage which drives an optical source to give modulation of the light wave carrier. Put simply, modulation is the process of imposing information on a light wave. The optical source which provides the electrical-optical conversion may be either a semiconductor laser or light-emitting diode (LED). The transmission medium consists of an optical fibre cable and the receiver consists of an optical detector which drives a further electrical stage and hence, provides demodulation of the optical carrier. Photodiodes (p-n, p-i-n or avalanche) and, in some instances, phototransistors and photoconductors and utilized for the detection of the optical signal and the optical-electrical conversion. Thus, there is a requirement for electrical interfacing at either end of the optical link and at present, the signal processing is usually performed electrically.

The optical carrier may be modulated using either an analog or digital information signal. Analog modulation involves the variation of the light emitted from the optical source in a continuous manner. With digital modulation, however, discrete changes in the light intensity are obtained (i.e., on-off pulses).

Advantages of optical fibre communication:

i. **Enormous potential bandwidth**

   Optical fibre communication system provides a bandwidth of around 100 GHz.

ii. **Small size and weight**

   Optical fibres are far smaller and much lighter than corresponding copper cables.

iii. Electrical isolation

Optical fibres are fabricated from glass or plastic polymer and are therefore insulators. As a result, optical fibres do not exhibit any electrical hazards.

iv. Immunity to interference

Optical fibres are free from electromagnetic interference (EMI).

v. Signal security

The light from optical fibres does not radiate significantly and therefore they provide a high degree of signal security.

iv. Low transmission loss

The losses in optical fibre are as low as 0.2 dB km^{-1}. Thus, it requires wider repeater spacing.

vii. Ruggedness and flexibility

Optical fibres have very high tensile strengths.

viii. System reliability and ease of maintenance

Few repeaters are needed and also the life time of the optical components is around 20 to 30 years. These factors make optical fibre to have higher system reliability and make the maintenance easier and cheaper.

easier and cheaper.

ix. Potential low cost

The glass which is used for the fabrication of optical fibre is extracted from sand. So, optical fibre communication offers the potential for low cost communication in comparison with the copper conductors.

Disadvantages:

i. Joining fibre is difficult and expensive.

ii. Fibre is not as mechanically robust as copper wire.

iii. High investment cost.

Communication means transmission of data.

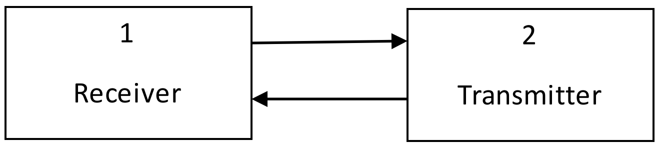


Fig: Communication

Series and parallel transmission are two different methods of connecting multiple devices or components in a communication or electrical system.

1. Series Transmission: In series transmission, the devices or components are connected in a linear sequence, where the output of one device is connected to the input of the next device, and so on. The data or signal passes through each device in a sequential manner. If one device fails or is disconnected, the entire transmission may be disrupted.

Key characteristics of series transmission in communication:

- Sequential data flow: Data or signals travel through each channel one after another.

- Dependency on previous channels: The output of one channel serves as the input for the next channel.

- Vulnerability to channel failure: If one channel fails, the entire communication may be interrupted.

Advantages of series transmission:

- Simplicity: It is relatively simple to implement, especially in systems with a small number of devices.

- Cost: It can be cost-effective for certain applications since fewer transmission lines are required.

Disadvantages of series transmission:

- Reliability: If one device fails, the entire transmission can be affected, leading to a loss of data or signal.

- Speed: The data transmission speed may be limited by the slowest device in the series.

- Flexibility: It can be challenging to add or remove devices without interrupting the transmission.

2. Parallel Transmission: In parallel transmission, each device or component is connected to a separate transmission line, and data or signals are sent simultaneously across all lines. Each line carries a different part of the data, allowing for faster transmission compared to series transmission. Additionally, if one device or line fails, the others can still function independently.

Key characteristics of parallel transmission in communication:

- Simultaneous data flow: Data or signals are transmitted across all channels at the same time.

- Independent channels: Each channel operates separately and does not rely on others.

- Enhanced speed and reliability: Parallel transmission enables faster communication and the ability to maintain functionality even if some channels fail.

Advantages of parallel transmission:

- Speed: Data transmission can be faster since multiple devices transmit simultaneously.

- Reliability: Failure of one device or line does not affect the functioning of others.

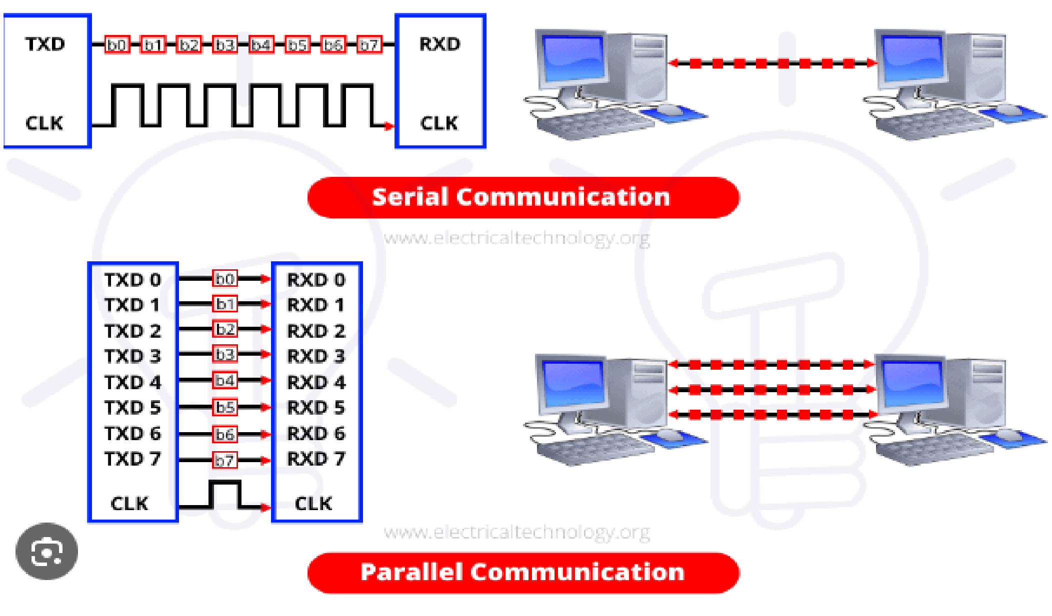
- Flexibility: Devices can be easily added or removed without interrupting the transmission.

Disadvantages of parallel transmission:

- Complexity: Implementing parallel transmission requires additional circuitry and cables, increasing the complexity and cost.

- Signal integrity: Due to the proximity of parallel lines, there can be issues with crosstalk or interference between the lines, affecting signal quality.

It's important to note that both series and parallel transmission have their own applications and trade-offs. The choice between them depends on factors such as the specific requirements of the system, data transmission speed, reliability, cost considerations, and the number of devices involved.



Source: https://www.google.com/url?saon-between-serial-communication

RS-232 (Recommended Standard 232) is a standard communication protocol widely used for serial communication between devices. An RS-232 cable, also known as a serial cable or DB9 cable, is used to establish a connection between devices that follow the RS-232 standard. Here are some features and applications of RS-232 cables:

Features of RS-232 cables:

1. Connector: RS-232 cables typically use a 9-pin D-sub connector called a DB9 connector. It consists of nine pins that transmit and receive data, control signals, and ground connections.

2. Serial Communication: RS-232 cables enable serial communication, where data is sent bit by bit in a sequential manner. It supports full-duplex communication, allowing data to be transmitted in both directions simultaneously.

3. Voltage Levels: RS-232 uses voltage levels to represent data. In standard RS-232, positive voltage represents logic 0, while negative voltage represents logic 1. The voltage levels can vary, but commonly used voltages are +12V to -12V.

4. Handshaking: RS-232 cables support various handshaking signals to control the flow of data between devices. These signals include Request to Send (RTS), Clear to Send (CTS), Data Terminal Ready (DTR), and Data Set Ready (DSR).

Applications of RS-232 cables:

1. Computer Peripherals: RS-232 cables were commonly used to connect computer peripherals such as modems, printers, scanners, and external storage devices to computers. Although newer interfaces like USB have largely replaced RS-232 for these applications, some legacy devices still utilize RS-232.

2. Industrial Control Systems: RS-232 cables are extensively used in industrial control systems for communication between computers and devices like programmable logic controllers (PLCs), data acquisition systems, and process control equipment. They provide a reliable and standardized means of communication in these applications.

3. Point-of-Sale Systems: RS-232 cables are employed in point-of-sale (POS) systems for connecting devices like cash registers, barcode scanners, and card readers to the central processing unit. RS-232 enables data exchange between these devices and the POS software.

4. Networking Equipment: RS-232 cables are used to configure and manage networking equipment, such as routers, switches, and firewalls. They allow administrators to establish a console connection to the networking devices for configuration and troubleshooting purposes.

5. Embedded Systems: RS-232 is commonly used in embedded systems for communication between microcontrollers, sensors, and other peripheral devices. It provides a simple and reliable communication interface for exchanging data in embedded applications.

Fig: RS232

IEEE 1284 is a standard that defines bi-directional parallel communications between computers and other devices.The IEEE 1284 standard allows for faster throughput and bidirectional data flow with a theoretical maximum throughput of 4 megabytes per second; actual throughput is around 2 megabytes/second depending on hardware. In the printer venue, this allows for faster printing and back-channel status and management. Since the new standard allowed the peripheral to send large amounts of data back to the host, devices that had previously used SCSI interfaces could be produced at a much lower cost. This included scanners, tape drives, hard disks, computer networks connected directly via parallel interface, network adapters and other devices. No longer was the consumer required to purchase an expensive SCSI card—they could simply use their built-in parallel interface.

The parallel interface has since been mostly displaced by local area network interfaces and USB.

Fig IEEE1248 B //Source: https://en.wikipedia.org/wiki/IEEE_1284

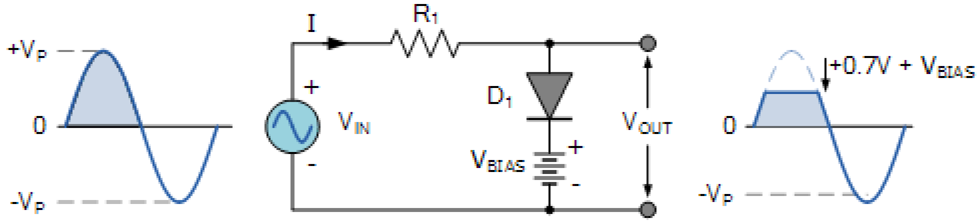
Effects of Noise in Instrumentation:

1. Measurement Errors: Noise causes random fluctuations in measured signals, leading to errors and deviations from the true value.
2. Reduced Signal-to-Noise Ratio (SNR): Noise increases the background signal level, making it harder to distinguish the desired signal from noise. This lowers measurement accuracy and increases uncertainty.
3. Drift and Instability: Noise introduces variations over time, making measurements inconsistent and less reliable.
4. Sensitivity Limitations: High noise levels can hide smaller signals of interest, limiting the sensitivity and dynamic range of measurements.
5. Interference and Crosstalk: Noise can interfere with desired signals, causing distortion and introducing additional noise from external sources or signal interactions.
6. Calibration and Accuracy: Noise affects instrument calibration, leading to systematic errors and inaccurate results if not properly accounted for.
7. Measurement Uncertainty: Noise contributes to overall measurement uncertainty, making it harder to determine the true value of a measurement with confidence.

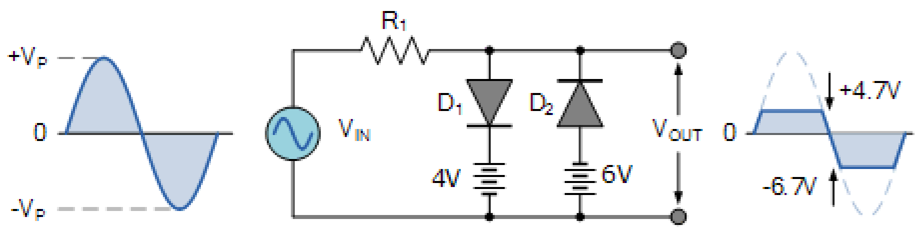
To mitigate noise effects, employ noise reduction techniques such as shielding, grounding, filtering, amplification, and differential measurements.

Wave shaping circuit: A simple waveshaping circuit is the diode clipper circuit, which uses diodes to modify the shape of a waveform by clipping off portions of the signal. Here is a basic schematic and explanation of a diode clipper circuit:

1. Series Diode Clipper Circuit:- A series diode clipper circuit consists of a diode connected in series with the signal source and a load resistor. When the input signal voltage exceeds the forward voltage drop of the diode (typically around 0.7V for a silicon diode), the diode becomes forward biased and conducts. The diode conducts and effectively "clips" or cuts off the excess voltage beyond its forward voltage drop, resulting in a clipped waveform. For example, if the input signal is a sinusoidal waveform with a peak voltage higher than the diode's forward voltage, the positive and negative peaks of the waveform will be clipped, resulting in a clipped waveform that retains the portion within the diode's forward voltage range. The output waveform depends on the diode's forward voltage drop, the amplitude of the input signal, and the polarity of the diode connection.



2. Shunt Diode Clipper Circuit: A shunt diode clipper circuit consists of a diode connected in parallel with the load resistor. When the input signal voltage exceeds the forward voltage drop of the diode, the diode becomes forward biased and conducts. The diode effectively provides a path of lower resistance compared to the load resistor, diverting current away from the load resistor. As a result, the diode "clips" the voltage across the load resistor, modifying the shape of the waveform. Depending on the polarity of the diode connection, either the positive or negative peaks of the waveform can be clipped. The output waveform depends on the diode's forward voltage drop, the amplitude of the input signal, and the polarity of the diode connection.



Diode clipper circuits are simple yet effective ways to shape waveforms by selectively removing portions of the signal. They can be used for various applications, including waveform distortion, amplitude limiting, or voltage protection. More complex waveshaping circuits involving multiple diodes, resistors, and capacitors can achieve more sophisticated wave shaping effects.

Digital Filter: A digital filter is a signal processing system that operates on discrete-time signals, which are represented as sequences of samples. Digital filters use mathematical algorithms to modify or extract specific frequency components from a signal. Digital filters can be implemented using software on a digital signal processor (DSP), microcontroller, or dedicated digital filter chips. Common types of digital filters include

Finite Impulse Response (FIR) filters and Infinite Impulse Response (IIR) filters. FIR filters have a linear phase response and can provide precise control over the frequency response. They are widely used for applications where a linear phase and sharp cutoff characteristics are required.

IIR filters are characterized by feedback, and they can provide more compact filter designs compared to FIR filters. They are often used when a more efficient implementation or specific frequency response shape is desired.

Digital filters can have adjustable parameters such as cutoff frequency, filter order, and filter type, allowing for flexibility and customization. **Advantages of digital filters** include the ability to process signals with high precision, ease of implementation on digital platforms, and the ability to handle complex processing tasks. Digital filters offer benefits such as repeatability, stability, and the ability to handle a wide dynamic range. However, digital filters also have **limitations**, including the requirement for sampling and quantization of the input signal, finite word-length effects, and the potential for additional processing delays.

Digital filters find **applications** in various fields such as audio processing, telecommunications, image processing, biomedical signal analysis, and control systems.

The design and implementation of digital filters involve considerations such as filter order, filter coefficients, frequency response specifications, and trade-offs between computational complexity and desired performance.

Analog filters are electronic circuits that process continuous-time signals by selectively attenuating or amplifying specific frequency components. They are implemented using analog components such as resistors, capacitors, inductors, and operational amplifiers (op-amps). Here are the main types of analog filters:

1. Low-pass Filter (LPF): A low-pass filter allows low-frequency signals to pass through while attenuating high-frequency signals. It is commonly used to remove high-frequency noise or unwanted signal components, allowing only the desired low-frequency content to remain.

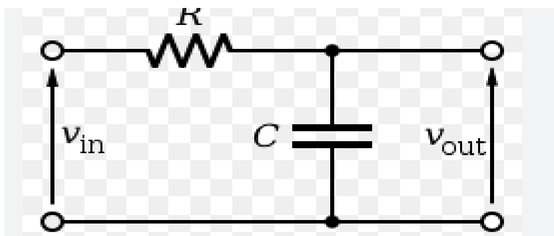
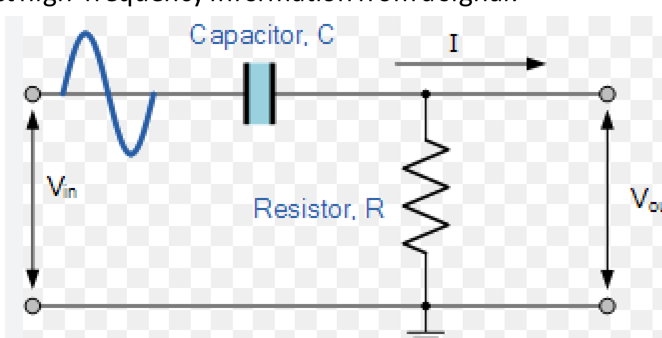
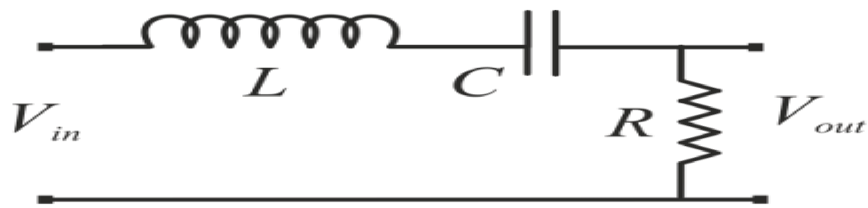


Fig: LP filter

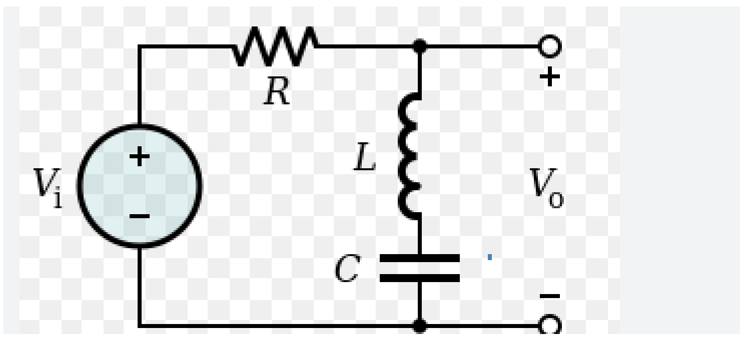
2. High-pass Filter (HPF): A high-pass filter allows high-frequency signals to pass through while attenuating low-frequency signals. It is used to block unwanted low-frequency components and emphasize or extract high-frequency information from a signal.

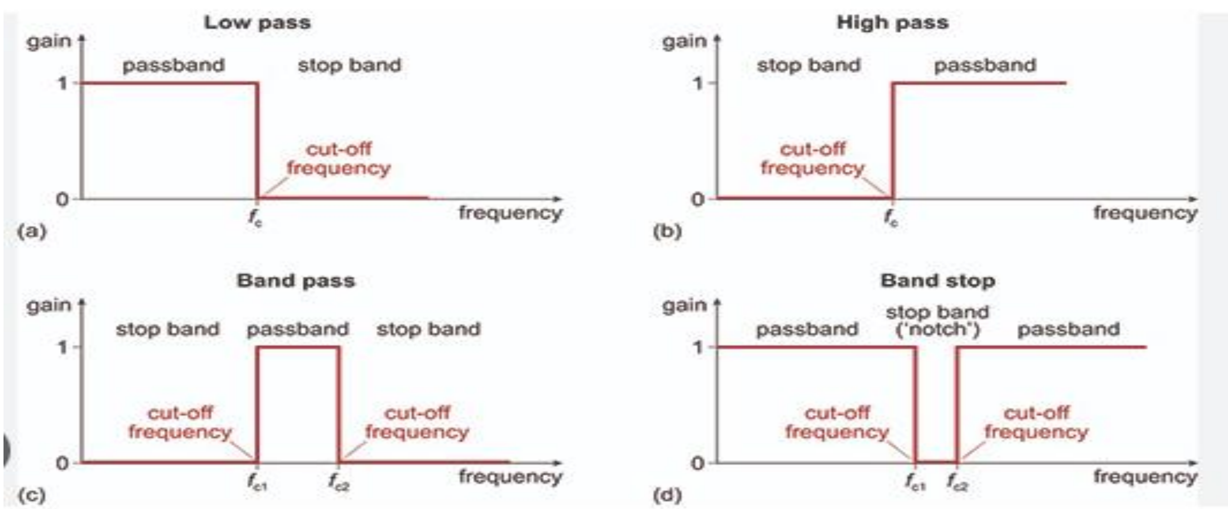


3. Band-pass Filter (BPF): A band-pass filter allows a specific range of frequencies, called the passband, to pass through while attenuating frequencies outside the passband. It is used to select and isolate a desired range of frequencies while rejecting frequencies above and below the passband.



4. Band-reject Filter or Notch Filter: A band-reject filter, also known as a notch filter, attenuates a specific range of frequencies while allowing frequencies outside that range to pass. It is used to reject or remove unwanted narrow frequency bands from a signal, such as specific interference or noise frequencies.





These are some of the commonly used analog filter types. Each filter type has its own characteristics, advantages, and limitations, making them suitable for different applications depending on the desired frequency response and performance requirements.

Chapter 4

4.3.5 Introduction to Delta-Sigma ADC

Among different types of ADC, Delta-sigma (ΔΣ) ADC is one and is most widely is used in today's world. Delta-sigma ADC is also known as oversampling ADC as it adopts oversampling while conversion. Sometimes Delta-Sigma ADC is also called as sigma-delta ADC. It employs a technique called oversampling, combined with noise shaping, to achieve high-resolution conversion with relatively low precision components.

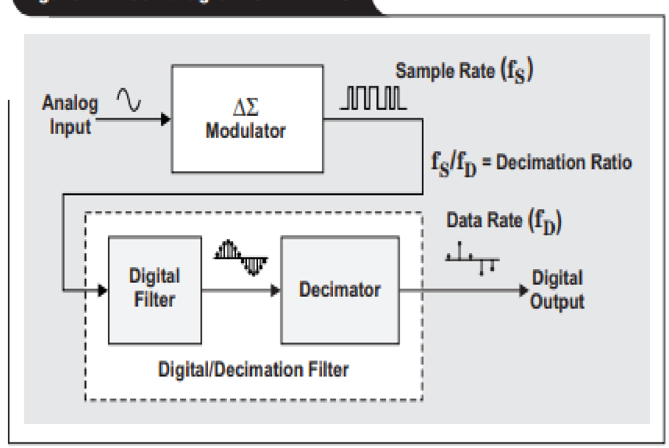
Working Principle:

The basic principle behind a delta-sigma ADC is to first oversample the input analog signal at a significantly higher sampling rate than the desired output sampling rate. This oversampling provides increased resolution and allows the ADC to capture high-frequency components accurately. Following blocks and steps are used for the conversion:

1. Oversampling: The input analog signal is sampled at a much higher rate than the desired output sampling rate. This oversampling provides increased resolution and allows for accurate capture of high-frequency components.

2. Delta-Sigma Modulator: The oversampled signal is passed through a delta-sigma modulator. The modulator consists of a comparator, a 1-bit digital-to-analog converter (DAC), and a feedback loop. The input analog signal is continuously compared with a feedback signal, which is a quantized representation of the ADC's digital output. The difference between the input and feedback signal, known as the error signal, is processed and quantized.

Figure 1. Block diagram of ΔΣ ADC



3. Quantization: The error signal is quantized into a 1-bit digital signal, representing either a high or low level. This 1-bit signal is commonly referred to as the "delta" or "sigma-delta" signal.

4. Digital Filter and Noise Shaping: The quantized delta signal is passed through a digital filter. This filter performs noise shaping, a technique that redistributes the quantization noise from the frequency band of interest to higher frequencies. The noise shaping process pushes the quantization noise energy to regions where it is less perceptible or can be filtered out more effectively. //source: google

5. Decimation: After the digital filter, the signal is downsampled to the desired sampling rate. The downsampling process reduces the sample rate to its original value, but with increased effective resolution and improved noise performance.

6. Digital Output: The decimated signal is now in digital form and represents a high-resolution digital representation of the original analog signal. This digital output can be further processed or used directly for various applications.

The key principle behind delta-sigma ADCs is the combination of oversampling, noise shaping, and digital filtering. By oversampling the input signal and utilizing a 1-bit quantization process, the quantization noise is shifted to higher frequencies, effectively reducing its impact in the desired frequency band. The digital filter after quantization and the downsampling process help reconstruct the original signal with improved resolution and reduced noise.

It should be noted that the specific implementation details of a delta-sigma ADC may vary based on the design, architecture, and application requirements.

A Pulse Width Modulation (PWM) type DAC

This type of DAC is also known as a PWM DAC, is a type of digital-to-analog converter that uses a pulse width modulation technique to convert digital signals into analog signals. It operates by varying the width of a pulse waveform to represent the amplitude of the analog signal.

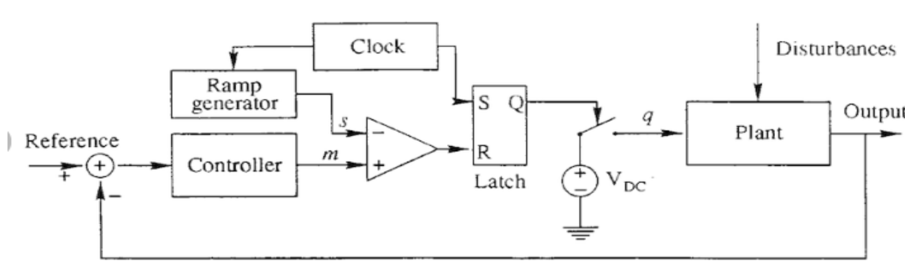
1. Digital Input: The digital input signal to the DAC represents the desired analog value to be generated.

2. Comparator: The digital input signal is compared with a ramp or sawtooth waveform generated by a clock. The comparator determines whether the pulse width should be high or low based on the comparison result.

3. Pulse Width Modulation: The output of the comparator controls the width of the output pulse. If the digital input value is higher than the ramp voltage, the output pulse width will be longer. If the digital input value is lower, the output pulse width will be shorter.

4. Low-Pass Filter: The output pulse waveform is then passed through a low-pass filter to smooth out the rapid changes and extract the average value. The low-pass filter removes the high-frequency components, leaving behind the desired analog signal.

5. Analog Output: The filtered waveform is the analog representation of the original digital input value. This analog signal can be used for various applications such as audio playback, motor control, or other systems that require analog voltage or current levels.



Advantage of DACs

- Simple,
- low cost,
- The ability to achieve high-resolution outputs with fast response times.

Disadvantage of DAC

- Potential for noise interference
- lower accuracy compared to other DAC types,
- sensitivity to variations in the clock frequency.

PWM type DACs are commonly used in applications where cost, speed, and resolution are important factors, such as audio amplifiers, motor control systems, LED brightness control, and power supply circuits.

Probes and connectors are essential components used in various fields, including electronics, electrical testing, telecommunications, and measurement equipment. They enable the connection of test instruments, sensors, and devices to circuits or systems for signal analysis, measurement, or data transfer.

Test leads are a type of probe used to establish electrical connections between test instruments and the circuit or device under test. They typically consist of a pair of insulated wires with probes or connectors at the ends. Test leads are essential tools for measuring voltage, current, resistance, and other electrical parameters. Different types of testing lead such as banana test leads, alligator clip test, needle test and probe test.

Twisted Pair Unshielded test leads

- Twisted pair unshielded test leads consist of two insulated wires twisted together.

- The twisting helps reduce electromagnetic interference (EMI) and noise pickup.

- These test leads do not have an additional shielding layer for EMI protection.

- They are commonly used in low-frequency signal measurements and general-purpose testing.

- Twisted pair unshielded test leads are more susceptible to EMI and noise compared to shielded leads.

- They are cost-effective and commonly included with multimeters and other test instruments.

- Keep the leads short and minimize exposure to EMI sources for better signal integrity.

- Shielded or coaxial test leads may be preferred in high EMI environments for stronger noise reduction.

Fig: Twisted Pair Unshielded test leads

Shielded Cables

- Shielded cables have an extra layer of shielding to protect against electromagnetic interference (EMI) and radio frequency interference (RFI).

- The shielding layer is typically made of metal, such as copper or aluminum.

- Shielding helps prevent external electromagnetic fields from interfering with the signals carried by the cable.

- Shielded cables are commonly used in environments with high EMI/RFI, like industrial settings and data centers.

- The shielding can be in the form of a foil or a braided mesh around the insulated conductors.

- Shielded cables provide improved noise immunity and signal integrity compared to unshielded cables.

- Proper grounding of the shielding is important to effectively divert unwanted electrical noise.

- Shielded cables are generally more expensive and less flexible than unshielded cables due to the additional shielding layer.

- **Connectors** are devices used to establish a connection between two or more objects, systems, or components.

- They facilitate the transmission of signals, data, power, or physical components between entities.

- Connectors come in various types and designs, each serving a specific purpose and providing a reliable and secure connection.

- Some common types of connectors include electrical connectors, data connectors, power connectors, audio connectors, video connectors, mechanical connectors, hydraulic and pneumatic connectors, and network connectors.

- Electrical connectors, such as USB and HDMI connectors, enable electrical connections between devices.

- Data connectors, like Ethernet and fiber optic connectors, transmit data between devices.

- Power connectors, such as AC power plugs and DC power jacks, supply electrical power to devices.

- Audio connectors, like 3.5mm audio jacks and XLR connectors, transmit audio signals between devices.

- Video connectors, such as VGA and HDMI connectors, transmit video signals between devices.

- Network connectors, like RJ-45 and fiber optic connectors, establish connections in computer networks.

- Connectors are essential in various industries and applications, enabling seamless connection and communication between different devices and systems.

- **Low capacitive probes** are specialized measurement devices used in electronic testing and troubleshooting.

- They are designed to minimize the impact of capacitance on the measurement circuit, ensuring accurate and reliable readings.

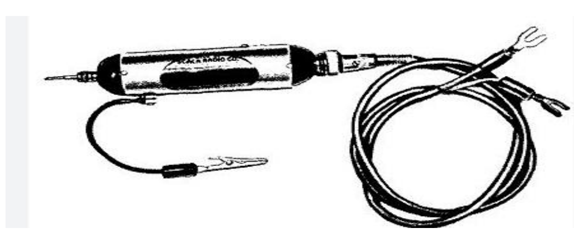
- These probes are particularly useful in high-frequency applications, where accurate measurements and signal integrity are crucial.

- They are commonly used with oscilloscopes and feature high input impedance to reduce capacitive loading and preserve signal integrity.

- Low capacitive probes often include features for ground compensation to mitigate the effects of stray capacitance.

- They are used in RF circuit testing, high-speed digital design verification, signal integrity analysis, and EMC testing.

- By minimizing capacitance, low capacitive probes help maintain accurate measurements and minimize the impact on the circuit under test.



- **High voltage probes** are specialized measurement devices designed for measuring high voltages safely and accurately.

- They are used in applications where the voltage levels exceed the capability of standard voltage measurement equipment.

- High voltage probes typically have higher voltage ratings and insulation to withstand the elevated voltages without compromising safety.

- These probes are commonly used in industries such as power distribution, electrical utilities, and high-voltage testing.

- They are often used with oscilloscopes, multimeters, or other measuring instruments to measure and monitor high voltage signals.

- High voltage probes typically feature a voltage divider circuit that attenuates the high voltage signal to a measurable level.

- They provide a safe and isolated measurement environment to protect the operator and the measuring instrument from high voltage hazards.

- High voltage probes may include additional safety features such as shielding, interlocking connectors, and reinforced insulation.

- Some high voltage probes are designed for specific applications, such as pulsed high voltage measurements or high-frequency measurements.

- When using high voltage probes, it is essential to follow proper safety procedures and guidelines to prevent electric shock and ensure accurate measurements.

- High voltage probes enable engineers, technicians, and researchers to safely and accurately measure and analyze high voltage signals in various industrial and testing applications.

- **Current probes**, also known as current clamps or current sensors, are used to measure electrical currents flowing through a conductor without the need for direct electrical contact.

- They operate based on the principle of electromagnetic induction, where a magnetic field generated by the current induces a voltage in the probe, which is converted into a current measurement.

- Current probes offer a non-invasive method of measuring current, as they can be clamped around the conductor without interrupting the circuit.

- There are different types of current probes, including passive and active probes. Passive probes generate a voltage proportional to the measured current, while active probes provide amplified and calibrated current measurements.

- Current probes can measure both AC and DC currents, and some are designed for specific frequency ranges.

- The output of current probes can be analog or digital, with analog probes providing a voltage or current output and digital probes offering digital data for direct interfacing with measurement instruments or computers.

- They are widely used in applications such as power quality analysis, motor testing, circuit troubleshooting, energy monitoring, and current waveform analysis.

- When using current probes, it is important to select a probe that can handle the expected current levels and to follow safety precautions to prevent electrical hazards.

- Current probes provide a convenient and accurate means of measuring electrical currents in various electrical and electronic systems.

Chapter 5

Wave Analyzer

A wave Analyzer is an instrument designed to measure the relative amplitudes of frequency components in a complex or distorted waveform. Usually, the instrument acts as a frequency selective voltmeter, which is tuned to the frequency of one signal while rejecting all other signal components. There are two types of wave analyzers, depending upon the frequency ranges used:

a) Frequency Selective wave analyzer
b) Heterodyne wave analyser

a) Frequency Selective Wave Analyzer

Principle: The frequency selective wave analyzer is one of the types of wave analyzer works on the principle of the frequency-selective voltmeter. It is operated to measure the frequency in the audio range of 20 Hz – 20 kHz. It uses a narrow-pass band filter and it is tuned to the desired frequency components to measure. The block diagram of the frequency selective wave analyzer is shown below.

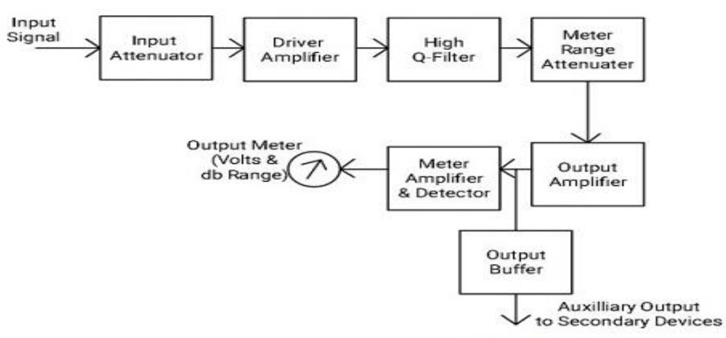


Fig: Block diagram of Frequency Selective wave Analyzer

Working:

The input signal that is to be analyzed is provided to an input attenuator. The signal contains maximum amplitude and it is attenuated by the input attenuator. It works as a range multiplier because a high range of amplitude of the signal is measured. The output of the input attenuator is amplified by the driver amplifier and its output is fed to the high-Q filter section. The high Q-filter section selected the particular frequency component and rejects the remaining unwanted frequencies of the signal. It contains two RC sections, two amplifier filters, connected in cascade. By varying the value of the capacitor, the frequency range can be changed. By varying the value of the resistor, the desired frequency can be changed within the desired range.

The output of the High Q-filter is fed to the meter range attenuator to select the AF input signal. The AF input signal is attenuated by a meter range attenuator. The output of the meter range attenuator is amplified by the output amplifier. The output buffer drives the AF signal to the output devices such as counters, recorders, etc. The meter circuits display the reading output of the AF signal in the range of volts and decibels.

b) Heterodyne Wave Analyzer

This type of analyzer is used to measure frequency megahertz range. Its working principle is heterodyne (mix) of high IF (intermediate frequency range) with the input signal, which is to be analyzed. The block diagram of this analyzer is shown in figure below: .

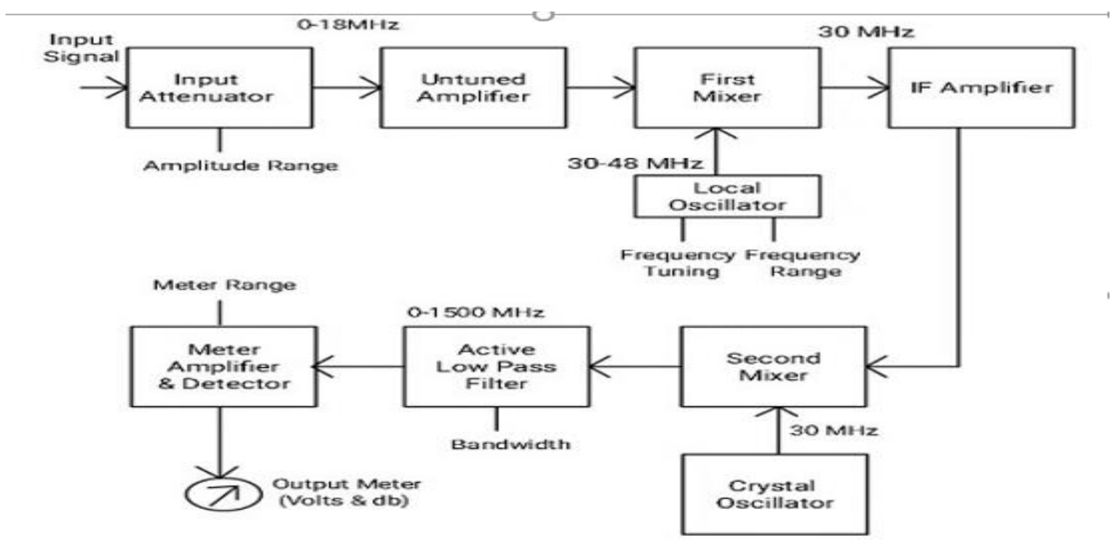


Fig: Heterodyne Wave Analyzer

- Input signal is fed through an attenuator and amplifier before being mixed with local oscillator
- Frequency of this oscillator is adjusted to give a fixed frequency output which is in the passband of the I.F amplifier
- This signal is the mixed with a second crystal controlled oscillator, whose frequency is such that the output from mixer is centred on zero frequency
- The subsequent active filter has controllable bandwidth, and passes the selected component of the frequency to the indicating meter
- In order to gain good frequency stability, frequency synthesizer can be used

Applications of Wave Analyzer

- Measures the harmonic distortion of the signal.

- Desired frequency components of the signal can be selected to analyze the signal
- Used in harmonics analyzation whose signal is to be analyzed.
- Measuring the amplitude of the selected frequency component in the signal.
- Used to reduce sound and vibration produced by the electrical machines in the industries.
- Used to measure the amplitude of the signal along with noise and interfering signals.
- Used as a harmonic distortion analyzer
- Used as an automatic frequency controller.
- Used in electrical measurements

5.2 Spectrum Analyzer

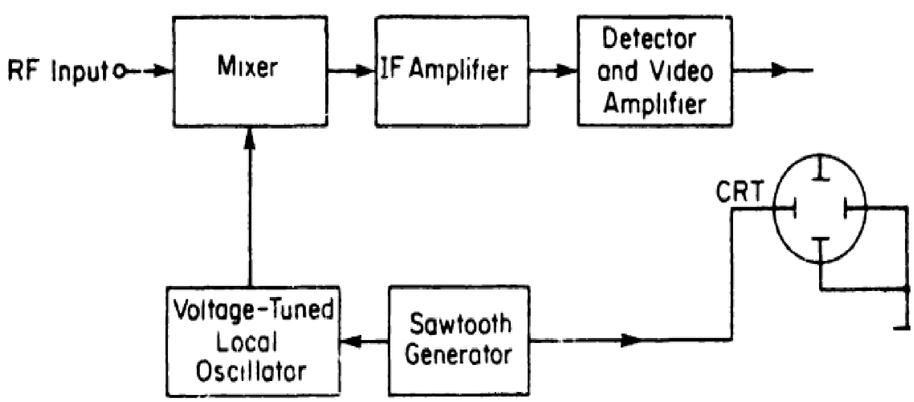
A spectrum analyzer is an electronic instrument used to measure and analyze the frequency spectrum of a signal. It provides a graphical representation of the amplitude or power level of the signal across different frequencies. Spectrum analyzers are widely used in various fields, including telecommunications, audio engineering, RF testing, and research and development.

Types of Spectrum Analyzer

A) Basic Spectrum Analyzer using Swept Receiver Design
B) IRF Spectrum Analyzer

A) Basic Spectrum Analyzer using Swept Receiver Design

Simplified block diagram of a swept frequency spectrum analyzer is shown below:



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

B) IFR Spectrum Analyzer

Make short notes in your own

Distortion Analyzer:

A sinusoidal waveform applied to an electronic device i.e. amplifier may not generate exact replication of input waveform due to different distortions. Distortion may be the result of the inherent non-linear characteristics of different instrument. This non-linear behavior of circuit elements introduces harmonic distortion.

There are different types of distortion:

a) Frequency Distortion: This occurs because the amplification factor of the amplifier is different for different frequencies

b) Phase Distortion: This occurs on account of energy storing element in system as they displace in phase with input signal

c) Amplitude Distortion: This occurs due the fact that the amplifier generates harmonics of the fundamental of the input signal

d) Intermodulation Distortion: This types of distortion occurs as a consequence of the interaction or heterodyning of two frequencies, giving an output which is sum or difference of the two original frequencies

e) Cross-Over Distortion: This type of distortion occurs in push-pull amplifiers on account of bias incorrect

Total Harmonic Distortion

A non-linear system produces harmonic of an input sine wave the harmonics of an input sine waves with frequencies which are multiples of the fundamental of the input signal. Total harmonic distortion (THD) is measured in terms of the harmonic content of the wave, as given

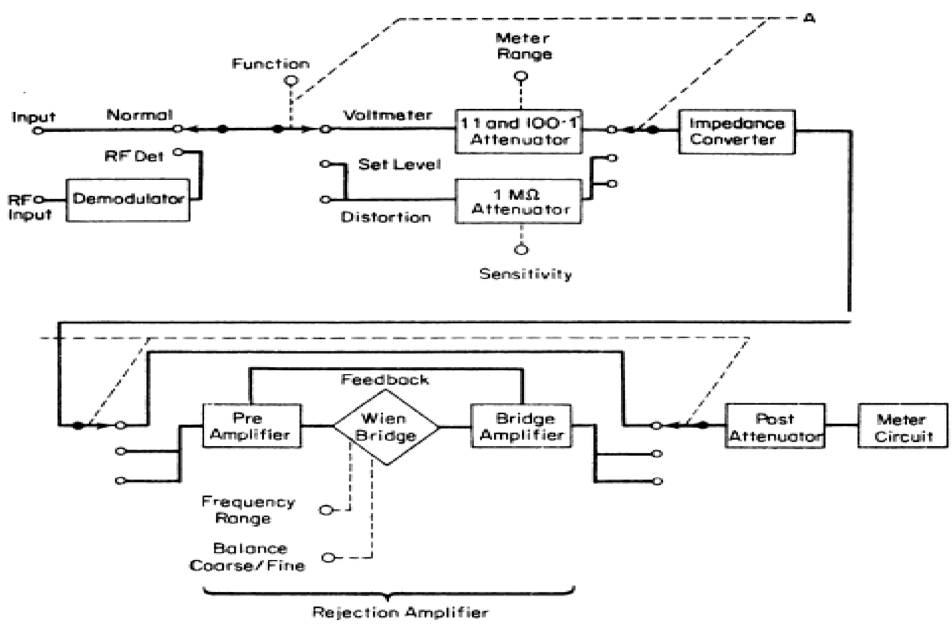
THD=$\frac{[\Sigma(Harmonics)^2]^1 1/2}{Fundamental}$

Fundamental Suppression Analyzer

The fundamental suppression method of measuring distortion is used when it is important to measure THD rather than distortion caused by individual component. In this method, the input waveform is applied to a network which suppress or reject the fundamental frequency component but passes all the harmonic-frequency components for subsequent measurement.

Block diagram of the fundamental suppression HD analyzer is shown below. The instruments consist of four major sections: 1) the impedance converter circuit 2) the rejection amplifier 3) the metering circuit 4) the power supply section. The impedance converter provides a low-noise, high impedance input circuit, independent of the signal source impedance placed at the input terminals to the instrument. The rejection amplifier rejects the fundamental frequency of the input signal and passes the remaining frequency components on to the metering circuit where the HD in terms of a percentage of total input voltage.

These instruments are simple and less expensive than instruments of the heterodyne type and can be used to advantage in combination with other types of analyzers. The fundamental suppression type of instrument has two advantages:



Harmonic Distortion Analyzer

- Used to measure THD
- Consist of a notch filter which remove the fundamental components from the signal

A distortion analyzer is an electronic instrument used to measure and analyze distortion in electrical signals. It is commonly used in audio engineering, telecommunications, and other fields where signal quality and fidelity are important.

13-5 Frequency Measurements

Frequency can be accurately measured by counting thc number of cycles of the unknown signal for a precisely controlled time interval. Figure 13-10 shows the logic block diagram for a counter in the *frequency* mode of operation.

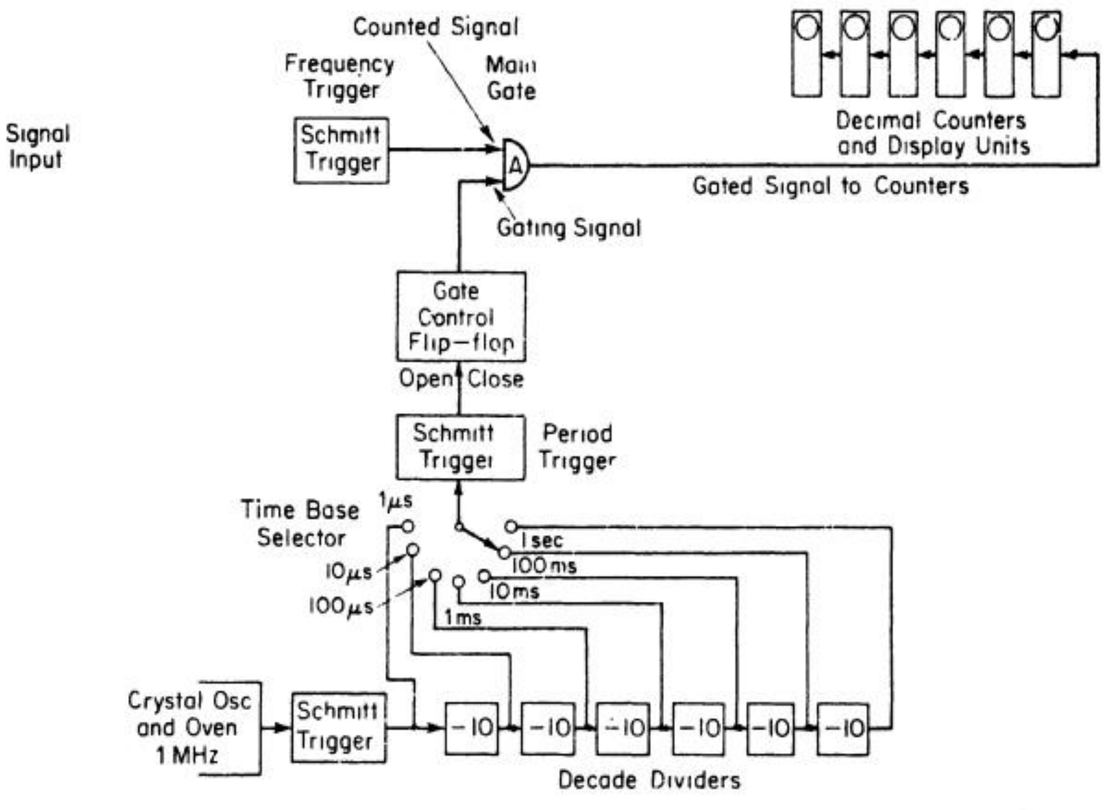


Figure 13-10
Block diagram of the electronic counter in the *frequency* mode of

There are two signals that need to be traced: the *input signal* (or measured frequency) and the *gating signal,* which determines the length of time during which the DCAs are allowed to accumulate pulses. The input signal is amplified and passed to a Schmitt trigger. Here it is converted into a square wave with very fast rise and fall times, then differentiated and clipped. As a result, the signal which arrives at the input to the main gate consists of a series of pulses separated by the period of the original input signal. In the block diagram of Fig. 13-10, the oscillator frequency is 1 MHz. The time-base output is shaped by a Schmitt trigger, so that positive spikes, 1 μs apart, are applied to a number of decade dividers. In the example shown, six DDAs are used whose outputs are connected to a time-base selector switch. This allows the time interval to be selected from 1 μs to 1 s. The first output pulse from the time-base selector switch passes through a Schmitt trigger to the gate control flip-flop. The gate flip-flop assumes a state such that an *enable* signal is applied to the main gate. Since this is an AND gate, the input signal pulses are allowed to enter the DCAs and they are totalized and displayed. This continues until the second pulse from the DDAs arrives at the control flip-flop. The gate control assumes the other state which removes the enable signal from the main gate. The main gate closes and no further pulses are admitted to the DCAs. The DCA display is now in a state which corresponds to the number of input pulses received during a precise time interval which was determined by the time base.

Since frequency is defined as the number of occurrences of a particular phenomenon in some length of time, the counter display corresponds to *frequency*. Usually the time-base selector switch moves the decimal point in the display area, allowing the frequency to be read directly in Hz, kHz, or MHz.

Time Measurement

Time-interval measurements can be made with the same basic blocks as ratio measurements. This measurement is very useful in determining the *pulse-width* of a certain waveform.

The block diagram for this measurement is given in Fig. 13-13. This configuration shows two parallel input signal channels, where one channel supplies the *enabling* pulse for the main gate and the other channel supplies the *disabling* pulse for the same gate. The main gate is *enabled* at a point on the *leading* edge of the input signal waveform and *closed* at a point on the *trailing* edge of the same waveform. The counter must then have a *slope-selection* feature, as indicated in the block diagram. The *trigger level* control permits selection of the point on the incoming signal waveform at which the measurement begins and ends.

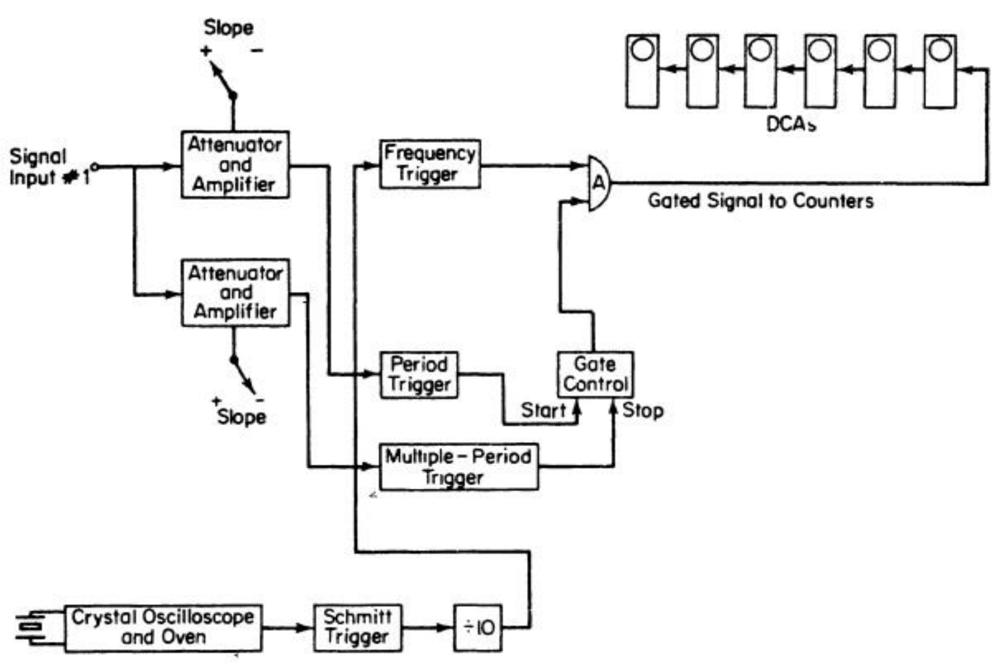


Figure 13-13
Block diagram of the *time interval* mode of operation.

13-6 Period Measurement

It is often desirable to measure the *period* of a signal rather than its frequency. The *same* building blocks used for the frequency measurement can be rearranged so that the counted signal and the gating signal are reversed. Figure 13-11 shows the block diagram of the period measurement using the same counter components as in the previous application. The gating signal is derived from the unknown input signal which now controls the opening and closing of the main gate. The precisely spaced pulses from the crystal oscillator are counted for one period of the unknown frequency. In the example shown in Fig. 13-11, the time base is set to 10 μs (100-kHz time-base frequency), and the number of pulses which occur during one period of the unknown signal are counted and displayed by the DCAs.

The accuracy of the period measurement may be increased greatly by using the multiple-period average mode of operation. This type of measurement is similar to the single-period measurement in that the gating signal is derived from the unknown input signal and the counted signal from the time-base oscillator. The basic difference is that the main gate is held open for more than one period of the unknown signal. This is accomplished by passing the unknown signal through one or more DDAs so that the period is extended by a factor of 10, 100, or more.

Figure 13-11 shows the multiple-period average mode of operation as a modification of the single-period measurement by the dashed portion of the block diagram. Notice that in Fig. 13-11 the 1-MHz crystal frequency is

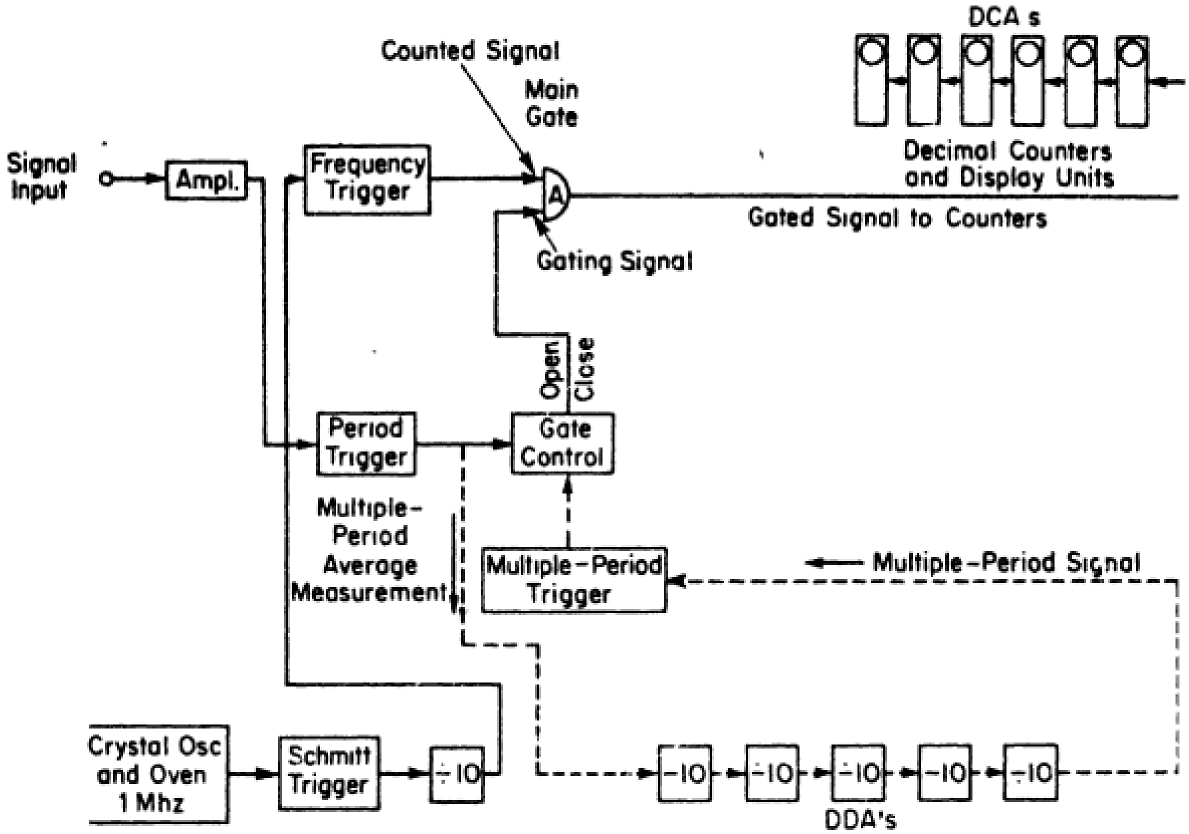


Figure 13-11
Block diagram of the *single period* and *multiple period average* measure-

divided by 1 DDA to a frequency of 100 kHz (10 μs period). These clock pulses are shaped by the frequency trigger and fed to the main gate to be counted. The input signal whose period is to be measured, is amplified, shaped by the period trigger, and fed to 5 DDAs in cascade counting the input frequency down by a factor of 10^5. This divided signal is now shaped by the multiple-period trigger (another Schmitt trigger circuit) and applied to the gate control flip-flop. The gate control provides the enable pulse and the stop pulse for the main gate. Obviously, the main gate will remain open for a greatly increased time interval, in fact increased by a factor of 10^5. The DCAs will, therefore, count the number of 10-μs intervals which occur during 100,000 periods of the input signal. The readout logic is so designed that the decimal point will be automatically positioned to display the proper units.

13-10 Measurement Errors

Frequency and time measurements made by an electronic counter are subject to several inaccuracies inherent in the instrument itself. Intelligent use of the counter for a given application requires an understanding of the *limitations* of the instrument.

One very common instrumental error resulting from counter measurement is the *gating error,* present whenever frequency and period measurements are made. Recall that, for a frequency measurement (Fig. 13-10), the main gate (also called the *signal* gate) is opened and closed by the oscillator output pulse. This allows the input signal to pass through the gate and be counted by the DCAs. The gating time is not synchronized with the input signal; they are, in fact, two totally unrelated signals.

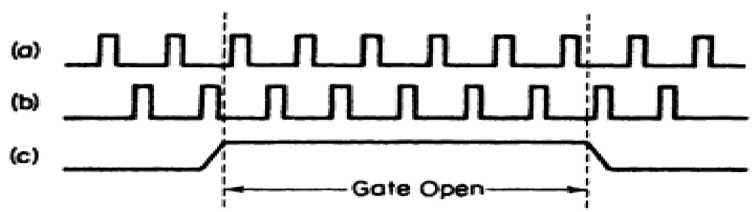


Figure 13-15 Illustrating the gating error.

In Fig. 13-15 the gating interval is indicated by waveform (c). Waveforms (a) and (b) represent the input signal in different phase relationships with respect to the gating signal. Clearly, in one case, six pulses will be counted; in the other case, only five pulses are allowed to pass through the gate. We have therefore a ± 1 count ambiguity in the measurement. When measuring *low frequencies,* the gating error may have an appreciable effect on the results. Take, for example, the case where a frequency of 10 Hz is to be measured and the gating time equals 1 s (a reasonable assumption). The decade counters would indicate a count of 10 ± 1 count, an inaccuracy of 10 per cent. *Period* measurements are therefore, to be preferred over frequency measurements at the *lower* frequencies.

frequencies.

The dividing line between frequency and period measurements may be determined as follows: Let

f_c = crystal (or clock) frequency of the instrument
f_x = frequency of the unknown input signal

In a *period* measurement, the number of pulses counted equals

$$N_p = \frac{f_c}{f_x} \tag{13-1}$$

In a *frequency* measurement with a 1-s gate time, the number of pulses counted is

$$N_f = f_x. \tag{13-2}$$

The *crossover frequency* (f_o) at which $N_p = N_f$ is

$$\frac{f_c}{f_o} = f_o \quad \text{or} \quad f_o = \sqrt{f_c} \tag{13-3}$$

Signals with a frequency *lower* than f_o should therefore be measured in the *period* mode, signals of frequencies *above* f_o should be measured in the *frequency* mode in order to minimize the effect of the ± 1 count gating error. The accuracy degradation at f_o caused by the ± 1 count gating error is $100/\sqrt{f_c}$ per cent.

Inaccuracies in the time base also cause errors in the measurement. In frequency measurements, the time base determines the opening and closing of the signal gate, and provides the pulses to be counted. *Time-base errors* consist of oscillator calibration errors, short-term crystal stability errors, and long-term crystal stability errors.

Several methods of *crystal calibration* are in common use. One of the simplest calibration techniques is to zero-beat the crystal oscillator against the standard frequency transmitted by a standards radio station, such as WWV (see Sec. 3-3). This method gives reliable results with a usual accuracy in the order of 1 part in 10^6, which corresponds to 1 cycle of a 1-MHz crystal oscillator. If the zero-beating is done with visual (rather than audible) means, for example, by using a CRO, the calibration accuracy can usually be improved to 1 part in 10^7.

Several very low-frequency (VLF) radio stations are presently covering the North American continent with precise signals in the 16–20-kHz range. Low-frequency receivers are available with automatic servo-controlled tuning which can be slaved to the signal of one of these stations. The error between the local crystal oscillator and the incoming signal can then be recorded on a strip-chart recorder. A simplified diagram of this procedure is given in Fig. 13-16. Improved calibration accuracy is obtainable by using VLF stations

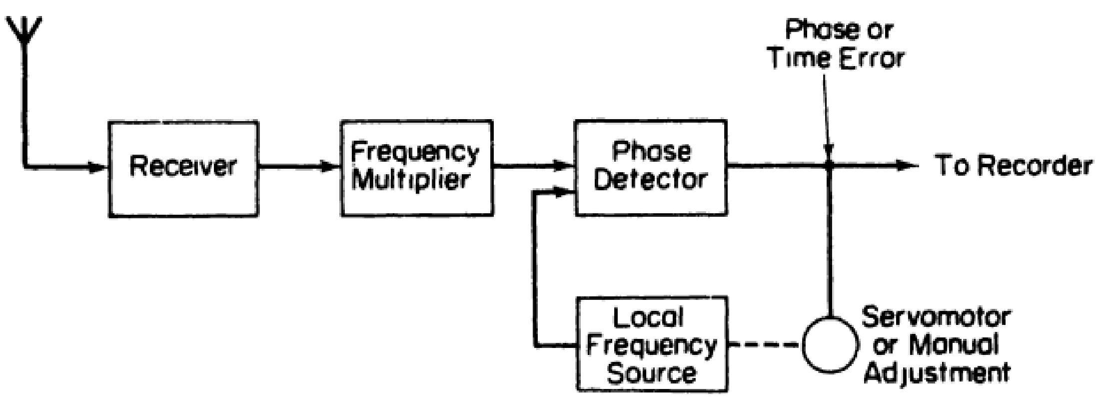


Figure 13-16
Calibration of a local frequency source.

rather than HF stations because the transmission paths for very low frequencies is shorter than for high-frequency transmissions.

Short-term crystal stability errors are caused by momentary frequency variations due to voltage transients, shock and vibration, cycling of the crystal oven, electrical interference, etc. These errors can be *minimized* by taking frequency measurements over *long* gate times (10 s to 100 s) and *multiple-period* average measurements. A reasonable figure for short-term stability of a standard crystal-oven combination is in the order of 1 or 2 parts in 10^7.

Long-term stability errors are the more subtle contributors to the inaccuracy of a frequency or time measurement. Long-term stability is a function of aging and deterioration of the crystal. As the crystal is temperature-cycled and kept in continuous oscillation, internal stresses induced during manufacture are relieved and minute particles adhering to the surface are shed reducing its thickness. Generally, these phenomena will cause an *increase* in the oscillator frequency.

A typical curve of frequency change versus time is shown in Fig. 13-17.

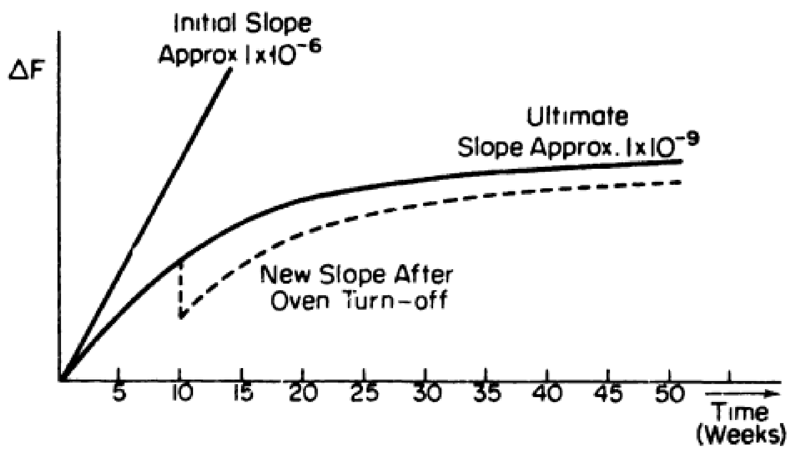


Figure 13-17

Frequency change versus time for an oven-controlled crystal.

Figure 13-17
Frequency change versus time for an oven-controlled crystal.

The *initial* rate of change of crystal frequency may be in the order of 1 part in 10^6 per day. This rate will decrease, provided that the crystal is maintained at its operating temperature, normally about 50° to 60°C, with ultimate stabilities of 1 part in 10^9. If, however, the instrument containing the crystal is unplugged from the power source for a period of time sufficient to allow the crystal to cool appreciably, a new slope of aging will ensue when the instrument is put back into operation. It is possible that the actual frequency of oscillation after cool-off will vary by several cycles and that the original frequency will not again be reached unless calibration is done.

To show the effect of long-term stability on the absolute accuracy of the measurement, assume that the oscillator was calibrated to within 1 part in 10^9 and that a long-term stability of 1 part in 10^8 per day was reached. Assume further that calibration was done sixty days ago. The guaranteed accuracy at this time is then $1 \times 10^{-9} + 60 \times 10^{-8} = 6.01 \times 10^{-7}$, or 6 parts in 10^7. It can be seen therefore that maximum absolute accuracy can be achieved only if an exact calibration is performed a relatively short time *before* the measurement is taken.

In time-interval and period measurements the signal gate is opened and closed by the input signal. The accuracy with which the gate is opened and closed is a function of the *trigger-level error*. In the usual application the input signal is amplified and shaped and then applied to a Schmitt trigger circuit which supplies the gate with its control pulses. Usually the input signal contains a certain amount of unwanted components or noise, which is amplified along with the signal. The time at which triggering of the Schmitt circuit occurs, is a function of the input signal amplification and of its signal-to-noise ratio. In general, we can say that trigger-time errors are reduced with large signal amplitudes and fast rise times.

Maximum accuracy can be obtained from digital frequency and time measurements if the following suggestions are followed:

(1) The effect of the one-count gating error can be minimized by making frequency measurements above $\sqrt{f_c}$ and period measurements below $\sqrt{f_c}$, where f_c is the clock frequency of the counter.

(2) Since long-term stability has a cumulative effect, the accuracy of measurement is mostly a function of the time since the last calibration against a primary or secondary standard.

(3) The accuracy of time measurements is greatly affected by the *slope* of the incoming signal, controlling the signal gate. *Large* signal amplitude and *fast* rise time assure maximum accuracy.

10-7 Digital Voltmeters

The digital voltmeter (DVM) displays measurements of dc or ac voltages as discrete numerals in the decimal number system, rather than as the pointer deflection on a continuous scale commonly used in analog devices. Numerical readout is advantageous in many applications since it reduces human reading and interpolation errors, eliminates parallax error, increases reading speed, and often provides outputs in digital form suitable for further processing or recording.

The DVM is a versatile and accurate instrument used in many laboratory measurement applications. Since the development and perfection of integrated circuit (IC) modules, the size, power requirements, and cost of the DVM suitable transducers.

Most digital voltmeters on the market can be classified according to one of the following categories:

(1) Ramp-type DVM.
(2) Integrating DVM.
(3) Potentiometric DVM.
(4) Successive-approximation type DVM.
(5) Continuous-balance DVM.

Ramp-Type DVM. The operating principle of the ramp-type DVM is measurement of the time it takes for a linear ramp voltage to change from 0 V to the level of the input voltage (or vice versa). This time interval is then measured with an electronic time-interval counter and the count is displayed as a number of digits on electronic indicating tubes.

Conversion from a voltage to a time interval is illustrated by the waveform diagram of Fig. 10-14. At the start of a measurement cycle, a ramp voltage is initiated; this voltage can be positive- or negative-going. The negative-going ramp, shown in the example of Fig. 10-14, is compared continuously with the

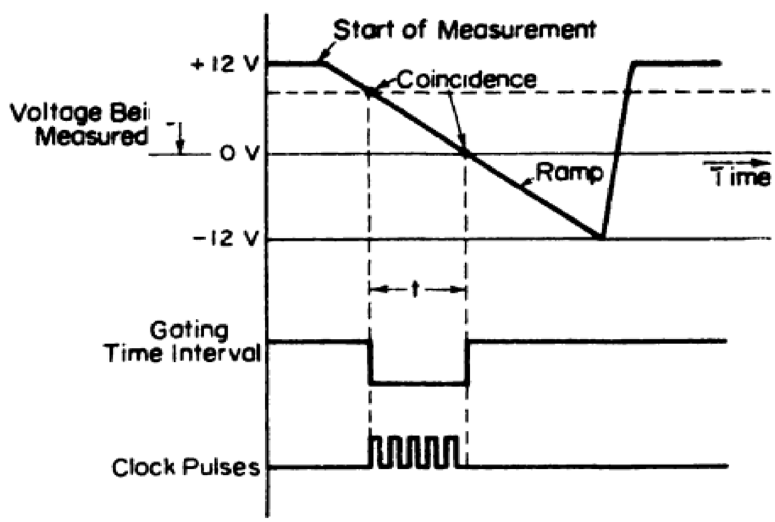


Figure 10-14
Illustrating a voltage-to-time conversion by using gated clock pulses.

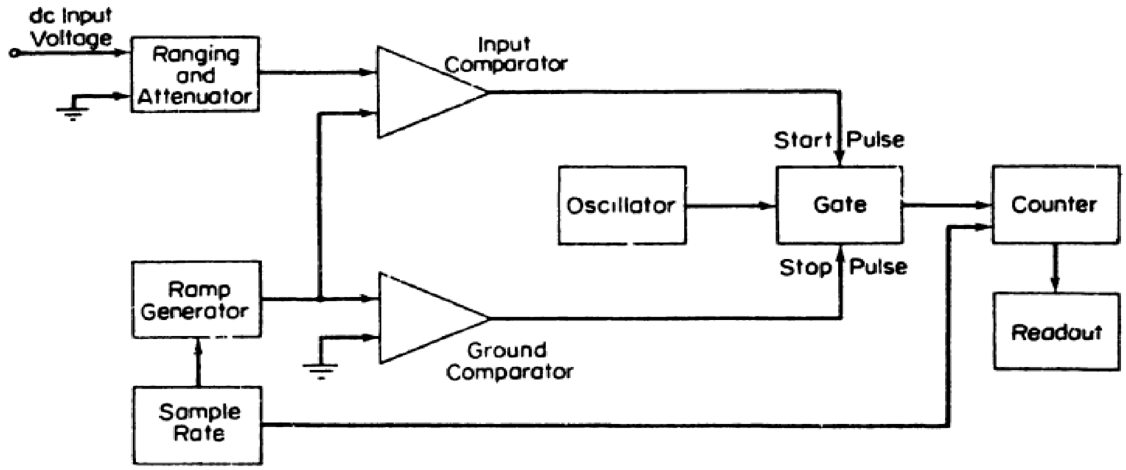


Figure 10-15
Block diagram of a ramp-type digital voltmeter.

unknown input voltage. At the instant that the ramp voltage equals the unknown voltage, a coincidence circuit or *comparator* generates a pulse which opens a gate (see Fig. 10-15). The ramp voltage continues to decrease with time. When it finally reaches 0 V (or ground potential), a second comparator generates an output pulse which closes the gate.

An oscillator generates *clock pulses* which are allowed to pass through the gate to a number of decade counting units (DCUs) which totalize the number of pulses passed through the gate. The decimal number, displayed by the indicator tubes associated with the DCUs, is a measure of the magnitude of the input voltage.

The *sample-rate* multivibrator determines the rate at which the measurement cycles are initiated. The oscillation of this multivibrator can be adjusted by a front panel control, marked *rate*. In some instruments the rate is fixed, a typical value being five measuring cycles per second. 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 returns all the DCUs to their 0 state, removing the display momentarily from the indicator tubes.

The Integrating-Type Digital Voltmeters. This voltmeter measures the ***true average*** of the input voltage over a fixed measuring period, in contrast to the ramp-type DVM which *samples* the voltage at the end of a measuring cycle. A widely used technique to accomplish integration employs a voltage-to-frequency (V/F) converter. The V/F converter functions as a feedback control system which governs the rate of pulse generation in proportion to the magnitude of the input voltage.

The simplified block diagram of an integrating DVM is given in Fig. 10-17. The dc voltage under test is applied to the input stage which isolates the meter circuitry from the test circuit and provides the necessary input attenuation. The attenuated input signal is applied to the V/F converter. This circuit consists of an integrating amplifier, a level detector (*comparator circuit*), and a pulse generator. The integrating amplifier produces an output voltage proportional to the input voltage and related to the input and feedback elements by the equation

$$\begin{aligned} V_{\text{out}} &= -\frac{1}{C}\int i\,dt \\ &= -\frac{1}{RC}\int V_{\text{in}}\,dt \end{aligned} \tag{10-5}$$

If the input voltage is constant, the output is a linear ramp following the equation

$$V_{\text{out}} = -V_{\text{in}}\frac{t}{RC} \tag{10-6}$$

When the ramp reaches a certain negative voltage level, the level detector triggers the pulse generator, which applies a negative voltage step to the summing junction of the integrating amplifier. The sum of the input voltage and the pulse voltage is negative, causing the ramp to reverse its direction. This "retrace" is very rapid since the pulse is large in amplitude compared to the input voltage. When the now positive-going ramp reaches 0 V, the level detector generates a reset trigger to the pulse generator. The negative pulse is removed from the summing junction of the integrating amplifier and only the original input voltage is left. The amplifier then produces a negative-going ramp again and the procedure repeats itself.

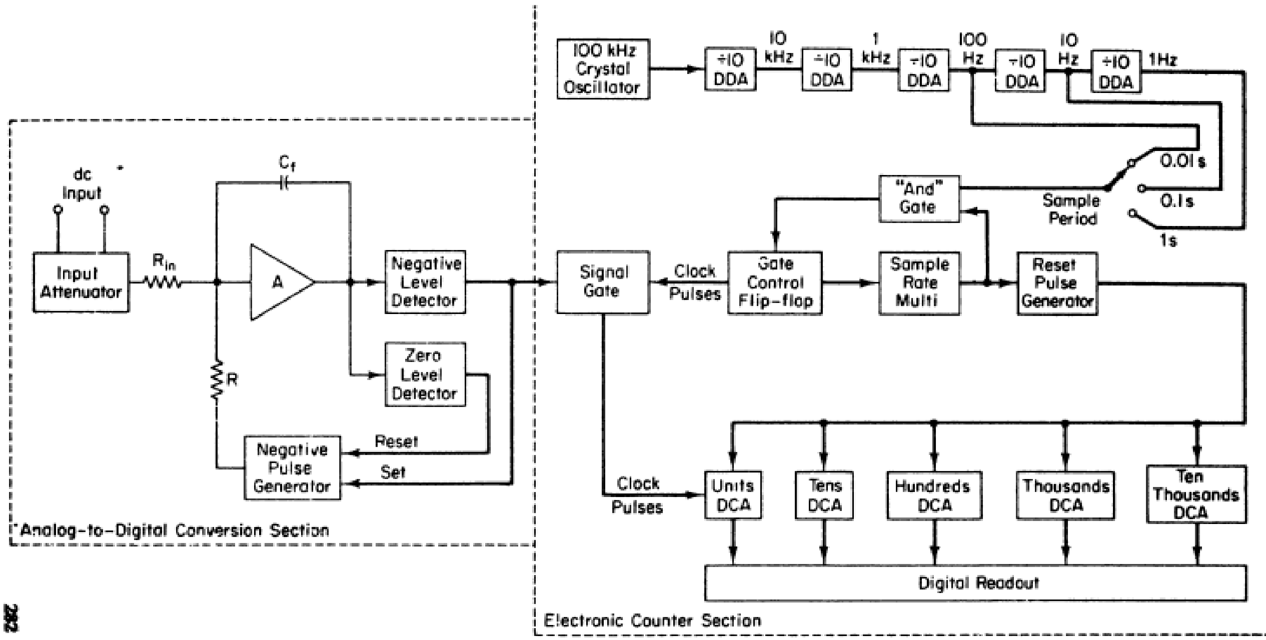


Figure 10-17. Block diagram of the intergrating digital voltmeter.

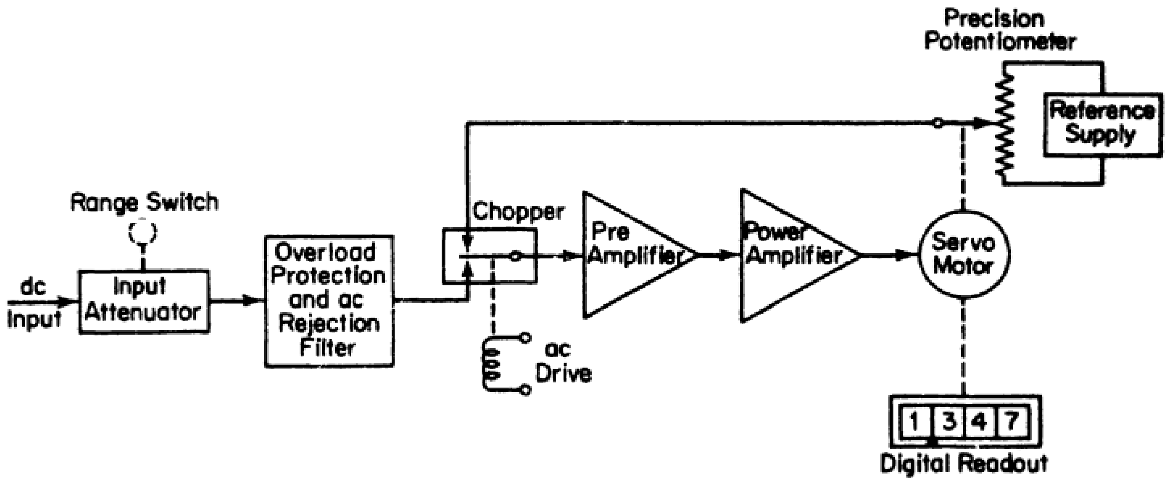
The rate of pulse generation is governed by the magnitude of the dc input voltage. A larger input voltage causes a steeper ramp and therefore a higher pulse repetition rate (PRR).

The major advantage of this system of A/D conversion is its ability to measure accurately in the presence of large amounts of superimposed noise, since the input is integrated.

The level-detector output pulse controls the signal gate allowing the decimal counters to accumulate a count provided by the crystal oscillator circuitry. The remainder of the circuit is essentially identical to any conventional counter and needs no further elaboration.

The Servo-Balancing Potentiometer-Type DVM. This is a low-cost instrument providing excellent performance. The accuracy of this meter is usually in the order of 0.1 per cent of its input range. It has an input impedance of about 10 MΩ, and acceptable resolution.

The block diagram of this DVM is given in Fig. 10-18. The dc input volt-



age is applied to an ***input attenuator*** providing suitable range switching. This is a front panel control, which also causes a decimal point indicator to move on the display area in accordance with the input range selected. After passing through an overvoltage protection circuit and ac rejection filter, the input voltage is applied to one side of a mechanical ***chopper comparator***. The opposite side of the comparator is connected to the wiper arm of the motor-driven precision potentiometer. The potentiometer is connected across a precision reference supply. The output of the chopper comparator, which is driven by the line voltage and vibrates at the line frequency rate, is a square-wave signal. The amplitude of the square wave is a function of the difference in magnitude and polarity of the dc voltages connected to the opposite sides of the chopper. The square-wave signal is amplified by a high-impedance, low-noise preamplifier and fed to a power amplifier. This amplifier has special damping to minimize overshoot and hunting at the null position. The servo motor, upon receiving the amplified square-wave difference signal, drives the arm of the precision potentiometer in the direction required to *cancel* the difference voltage across the chopper comparator. The servo motor also drives a drum-type mechanical indicator which has the digits from 0 to 9 imprinted about the periphery of its drum segments. The position of the servo motor shaft corresponds to the amount of feedback voltage required to null the chopper input, and this position is indicated by the drum-type indicator. The position of the shaft therefore is an indication of the magnitude of the input voltage.

It is clear that this instrument does not "sample" the unknown dc voltage at regular intervals, as is the case with more sophisticated instruments, but it continuously seeks to *balance* the input voltage against the internally generated reference. Due to the different mechanical movements involved in the mechanism, such as the positioning of the potentiometer arm and the rotation of the indicator mechanism, the average reading time is approximately 2 s. Simplicity of design and low cost, however, make this instrument a very attractive choice when extreme accuracy is not required.

10-9 The Vector Voltmeter

A *vector voltmeter* measures the amplitude of a signal at two points in a circuit and simultaneously measures the phase difference between the voltage waveforms at these two points. This instrument can be used in a wide variety of applications, especially in situations where other methods are very difficult or time consuming. The vector voltmeter is extremely useful in very *high-frequency measurement situations* and is capable of accurate phase determinations at frequencies up to several GHz. The vector voltmeter may be used successfully in the following measurements:

amplifier gain and phase shift
complex insertion loss
filter transfer functions
two-port network parameters

The vector voltmeter converts two RF signals of the same fundamental frequency in the range from 1 MHz to 1 GHz to two IF signals with 20-kHz fundamental frequencies. The IF signals have the same amplitudes, waveforms, and phase relationships as the RF signals. Consequently, the fundamental components of the IF signals have the same amplitude and phase relationships as the fundamental components of the RF signals. These fundamental components are filtered from the IF signals and measured by a voltmeter and a phase meter.

The instrument consists of five major sections, incicated in the block diagram of Fig. 10-21 by the dashed outlines. They are identical channel A and channel B RF-to-IF converters, an automatic phase control section, a phase meter, and a voltmetor. The RF-to-IF converters and the phase control section produce two 20-kHz sine waves which have the same amplitudes and phase relationship as the fundamental components of the RF signals applied to channels A and B. The phase meter section continuously monitors these two 20-kHz sine waves and provides a meter display of the phase angle between them. The voltmeter section is manually switched to channel A or channel B (20-kHz sine wave) and provides a meter display of the amplitude.

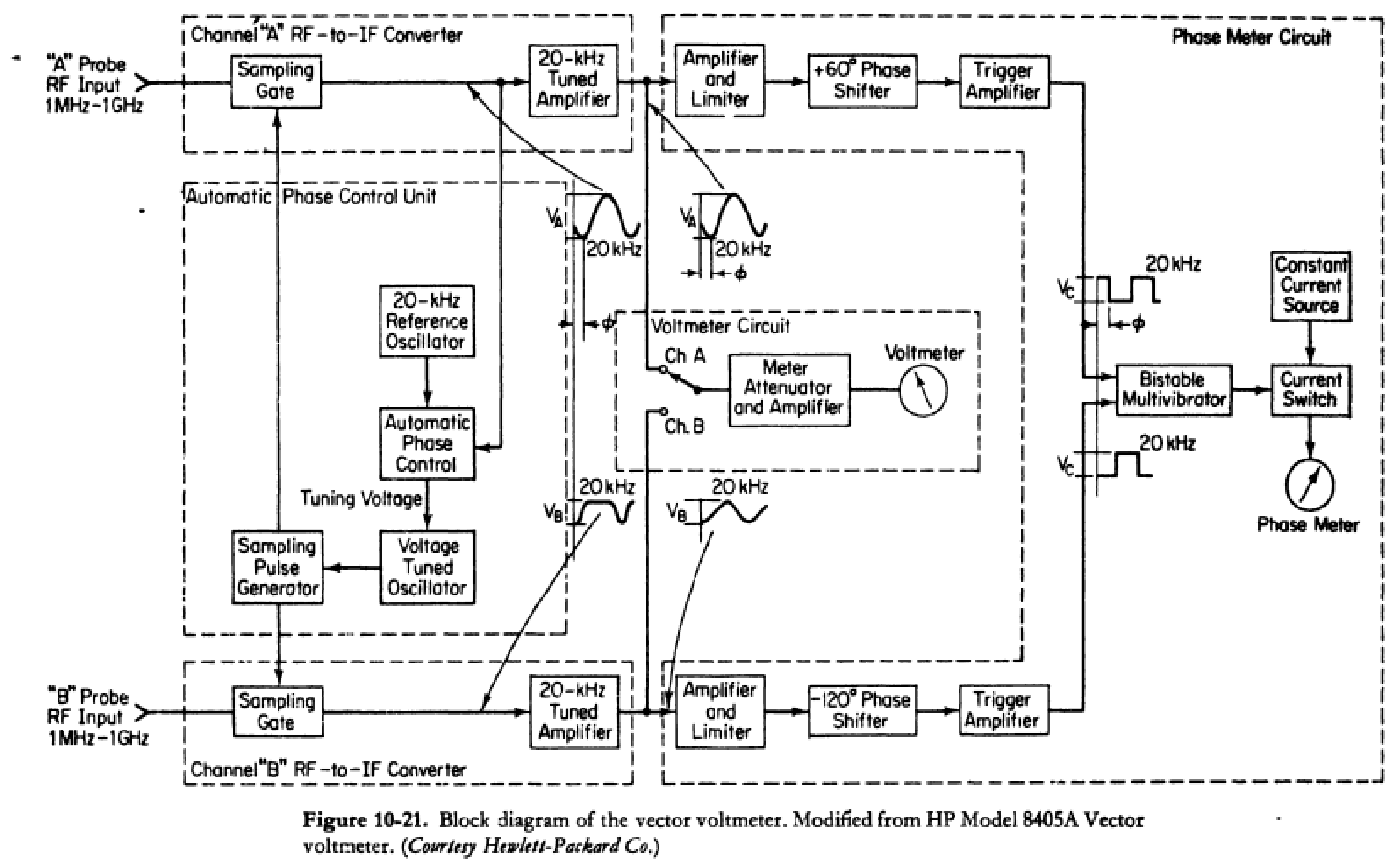


Figure 10-21. Block diagram of the vector voltmeter. Modified from HP Model 8405A Vector voltmeter. (*Courtesy Hewlett-Packard Co.*)

Digital Multimeter

Computer Based Digital Instruments: IEEE488 GPIB Instrument: