RAJIV GANDHI PROUDYOGIKI VISHWAVIDYALAYA, BHOPAL
New Scheme Based On AICTE Flexible Curricula
Electronics & Communication Engineering III-Semester
EC-301 ELECTRONIC MEASUREMENTS AND INSTRUMENTATION

Unit-1 Theory of Measurement: Introduction, Characteristics of Instruments and measurement
systems (Static &Dynamic) Error analysis: Sources, types and statistical analysis. Instrument

Calibration: Comparison Method. DC and AC Ammeter, DC Voltmeter- Chopper type and solid-state, AC voltmeter using Rectifier. Average, RMS, Peak responding voltmeters, Multi-meter, Power meter, Bolometer and Calorimeter.

Unit-2 CRO: Different parts of CRO, Block diagram, Electrostatic focusing, Electrostatic deflection, Post deflection acceleration. Screen for CRTs, Graticules, Vertical and Horizontal deflection system, Time base circuit, Oscilloscope Probes, Applications of CRO, Special purpose CROs- Multi input, Dual trace, Dual beam, Sampling, Storage (Analog and Digital) Oscilloscope

Bridges : Maxwell's bridge (Inductance and Inductance-Capacitance), Hay's bridge, Schering bridge (High voltage and Relative permittivity), Wein bridge. Impedance measurement by Q-meter

Unit-3 (Transducer): Classification of Transducers, Strain gauge, Displacement Transducer Linear Variable Differential Transformer (LVDT) and Rotary Variable Differential Transformer (RVDT), Temperature Transducer- Resistance Temperature Detector (RTD), Thermistor, Thermocouple, Piezo-electric transducer, Optical Transducer- Photo emissive, Photo conductive, Photo voltaic, Photo-diode, Photo Transistor

Unit-4 Signal and Function Generators, Sweep Frequency Generator, Pulse and Square Wave Generator, Beat Frequency Oscillator, Digital display system and indicators, Classification of Displays, Display devices: Light Emitting diodes (LED) and Liquid Crystal Display(LCD).

Unit-5 Advantages of Digital Instrument over Analog Instrument, Digital-to-analog conversion (DAC) - Variable resistive type, R-2R ladder Type, Binary ladder, Weighted converter using Op-amp and transistor, Practical DAC. Analog-todigital Conversion (ADC) - Ramp Technique, Dual Slope Integrating Type, Integrating Type (voltage to frequency), Successive Approximations. Digital voltmeters and multi-meters, Resolution and sensitivity of digital multi-meter.

Text/Reference Books:
1. Albert D. Helfrick, William David Cooper, "Modern electronic instrumentation and measurement techniques", TMH 2008.
2. Oliver Cage, "Electronic Measurements and Instrumentation", TMH, 2009.
3. Alan S. Morris, "Measurement and Instrumentation Principles", Elsevier (Buterworth Heinmann), 2008.
4. David A. Bell, "Electronic Instrumentation and Measurements", 2nd Ed., PHI, New Delhi 2008.
5. H.S. Kalsi, "Electronics Instrumentation", TMH Ed. 2004
6. A.K.Sawhney, "A Course in Electrical and Electronic Measurements and Instrumentation", Dhanpat Rai.
7. MMS Anand, "Electronic Instruments & Instrumentation Technology", PHI Pvt. Ltd., New Delhi Ed. 2005

UNIT I

Accuracy and Precision, Sensitivity, Linearity, Resolution, Hysteresis, Loading Effect, Measurements of Current, Voltage, Power and Impedance: DC and AC Ammeter, DC Voltmeter- Chopper type and solid-state, AC voltmeter using Rectifier. Average, RMS, Peak responding voltmeters, Multi-meter, Power meter, Bolometer and Calorimeter

Measurement is a comparison of a given unknown quantity with one of its predetermined standard values adopted as a unit. The result of any measurement is a concrete number consisting of a unit of measurement having its particular name & the number which shows how many times this particular unit is contained in the quantity being measured.

The primary purpose of measurement in process industries & industrial manufacturing is to help in the economics of industrial operations by improving the quality of the product & efficiency of production and also in the maintenance of proper operation.

Functional Elements of an in Instrument: All instruments contain various parts that perform prescribed functions in converting a variable quantity or condition into a corresponding indication. Thus, the operation of an instrument can be described in terms of the functional elements of instrument systems.

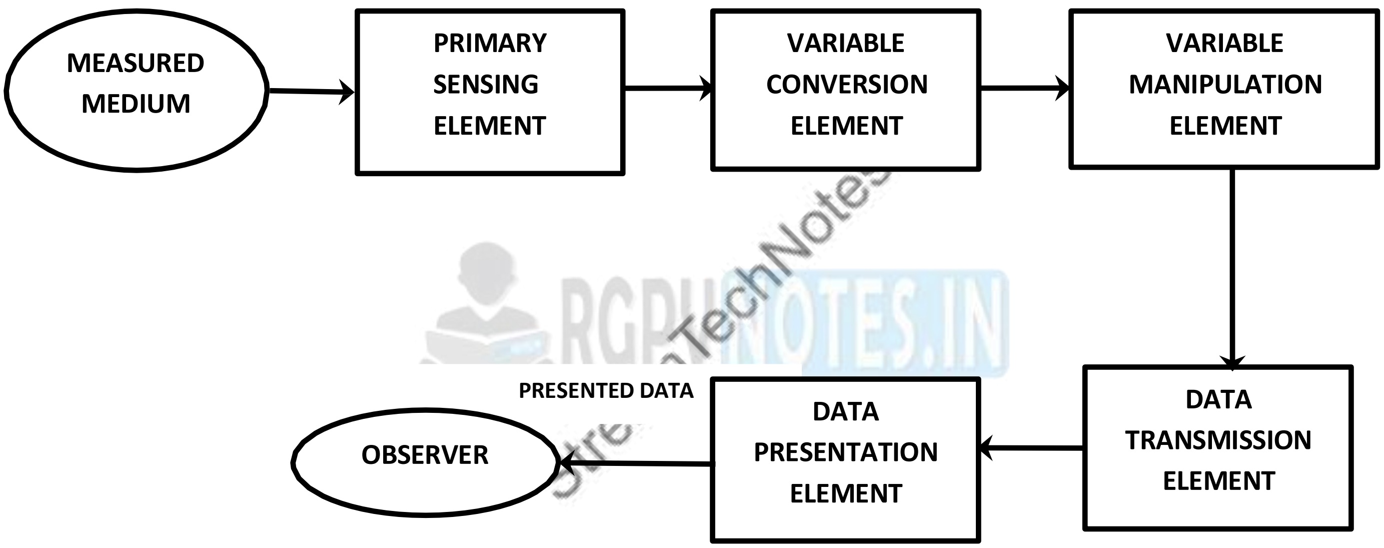


Fig. 1.1: Functional elements of an instrument system

Primary Sensing Element: It receives energy from the measured medium & produces an output depending in some way on the value of measured quantity.

Variable Conversion Element: It converts the output signal of the primary sensing element (which is some physical variable such as voltage or a displacement) into a more suitable variable or condition useful to the function of the instrument. (It may be noted that every instrument need not include a variable conversion element which some requires).

Variable Manipulation Element: It manipulates the signal represented by some physical variable to perform the intended task of an instrument. In the manipulation process; the physical nature of the variable is preserved. A variable manipulation element does not necessarily follow a variable-conversion element; it may precede it, appear elsewhere in the chain, or not appear at all.

Data Transmission Element: It transmits the data from one element to the other. It may be as simple as shaft and bearing assembly or as complicated as a telemetry system for transmitting signals from one place to another.

Data Presentation Element: It performs the translation function, such as the simple indication of a pointer moving over a scale or recording of a pen moving over a chart.

Measurement System Performance

There are two categories for instrument and measurement system which are follows:

(i) Static characteristics and *(ii}* Dynamic characteristics

(i) Static characteristics

When the physical quantities which are either constant or vary very slowly with time in that case the measurement is in the form of **statics characteristics** of the instrument and provide quality measurement.

(ii) Dynamic characteristics

When the physical quantities which rapidly varying with time in that case the dynamic relation exists between the output and input for measurement and is called as **Dynamic Characteristics.**

. Differential equations are used for such cases.

Static Calibration

Static calibration means comparing not varying quantity with time using some known standard. Calibration process is performed with either a primary standard or a secondary standard with higher accuracy than the instrument to be calibrated, or an instrument of known accuracy.

Static Characteristics

The main static characteristics are as follows:

(i) Accuracy	(ii) Sensitivity	*(iii)* Reproducibility
(iv) Drift	*(v)* Static error	(vi) Dead· Zone

The qualities (i), (ii) and (iii) are desirable; while qualities (iv), (v) and *(vi)* are undesirable.

Accuracy and Precision

(i) **Accuracy:** It is the degree of closeness through which· an instrument reading approaches the true value of the quantity being measured. Thus accuracy of a measurement means conformation to the truth.

The accuracy can be classified in following ways:

a) **Point accuracy:** Point accuracy is specified at only one particular point of measuring scale and does not provide accuracy on other points of the scale

b) **Accuracy as percentage of scale span:** When an instrument has uniform scale then its accuracy is defined in terms of scale span.

c) **Accuracy as percentage of true value:** when the accuracy is defined in terms of percentage with respect to uniform scale then it is called Accuracy as percentage of true value.

(ii) **Sensitivity:** The sensitivity of an instrument is the ratio of the magnitude of the output signal to the magnitude of input signal.

Figure 1.2 shows the calibration curve in linear form and no linear form. Here the sensitivity of the instrument is defined by slope of calibration curve. If the plot is linear then sensitivity of the instrument remains same for the entire range and if nonlinear then it varies from point to point. Sensitivity is expressed by:

$$Sensitivity = \frac{infinitesimal\ change\ in\ output}{infinitesimal\ change\ in\ Input} = \frac{\Delta q_o}{\Delta q_i}$$

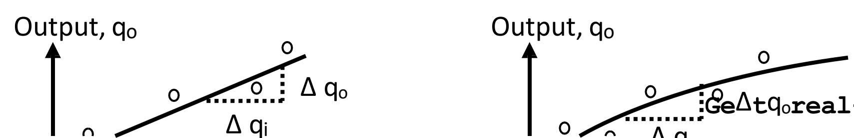


Figure 1.2(i) Sensitivity for Straight line, (ii) Sensitivity for non Straight line

The Deflection factor is inversely proportional to sensitivity and expressed as:

$$Inverse\ Sensitivity\ or\ deflection\ factor = \frac{1}{Sensitivity} = \frac{\Delta q_i}{\Delta q_o}$$

(iii) Reproducibility: It is the degree of closeness through which a given value is repeatedly measured. Perfect reproducibility means that the instrument has no drift. No drift means that with a given input the measured values do not vary with respect to time.

(iv) Drift:

Drift may be classified into three categories:

a) **Zero drift:** If the whole calibration gradually shifts due to slippage then zero drift occurs.

b) **Span drift**: If the output varies proportionally with respect to nominal curve and increase for upward scale with the nominal curve than it is called span drift.

c) **Zero and span drift:** When the combination of both zero and span drift occurs, then the instrument shows both drift at the same time.

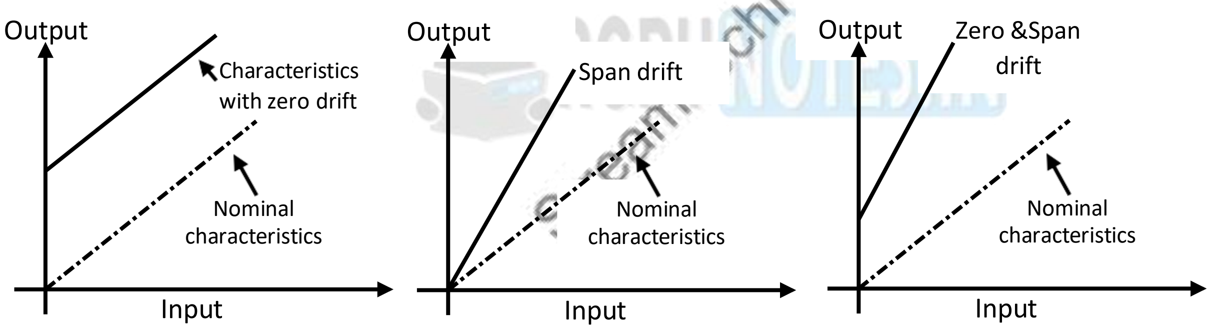


Figure1.3 (i) Zero drift,(ii) Span drift,(iii)Zero and span drift

(v) Static Error

When the instrument reading do not reach to the true value then error occurs which is termed as static error. The accuracy of an instrument is measured in terms of its error.

It is never possible to measure the true or exact value of a quantity; it is nearly always possible to give a best measured value. Static error is defined as the difference between the measured value and the true value of the quantity. Then:

δA =Am - At........(1)

Where δA = error,

Am =measure value of quantity,

(vi) Dead Zone

If large change in the input quantity for which no output is indicated by instrument is called as **dead zone**. This is mainly due to backlash or hysteresis in the instrument.

Precision: It defines the reproducibility of the measurements for the same applied input signal. The term precise means clearly or sharply defined. High precision is achieved by clearly defined, finely divided, distinct scale and a knife edge pointer with mirror arrangement to remove parallax.

Indication of Precision

Precision is composed of two characteristics:

(i) Conformity *(ii) Number* of significant figures

Precision is used in measurements to describe the reproducibility of results.

High precision means accurate reading for repeated results while low precision indicates error in results.

Linearity:

When the output signal is directly proportional to the input signal defines the linearity of measurement. Figure 1.4 shows the curve between actual curve and it maximum deviation with respect to the straight line.

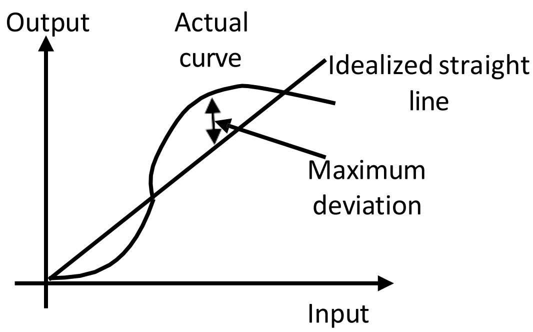


Figure 1.4 Curve between Actual and Maximum deviation

$$Non\ linearity = \frac{Maximum\ deviation\ of\ output\ from\ the\ idealized\ straight\ line}{Full\ scale\ deflection} \times 100$$

Repeatability:

Repeatability is the degree of closeness through which a given input quantity is measured again and again.

Resolution: When the input is gradually varied from some non-zero value and there is no change in output until a small increment. This increment is called resolution of the instrument. **Threshold:** When the input is gradually varied from zero value and it is found that for the minimum value no output is detected is called the threshold value.

Range or Span: The minimum & maximum value of a quantity for which an instrument is designed for measurement is called its range or span.

- **Hysteresis**

When measured variable is increasing at that point if output curve is decreasing then there maximum output hysteresis is present. If the same happen in Negative side also then it is called as Maximum input hysteresis as shown in Figure 4. The hysteresis is normally defined in percentage of the full-scale of input or output reading.

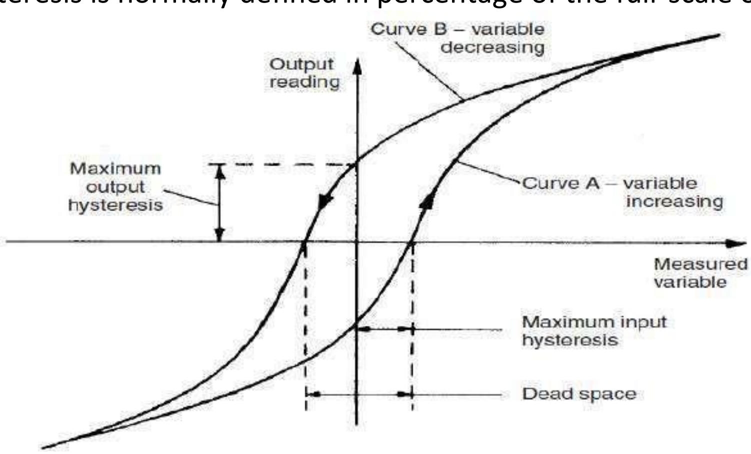


Figure 1.5 Instrument characteristic with hysteresis

Hysteresis occurs in instruments that contain electrical windings formed by rounding wire on an iron core, due to the magnetic field. This occurs in devices like the variable inductance displacement transducer or in LVDT.

- **Loading Effect:**

When the signal is applied for measurement purpose in that case the measuring of quantity is done by various elements which require some energy for their operation. This energy is extracted from the applied input signal and due to this the signal gets distorted and the same value is not measured. This is called the loading effect.

Loading Effect of a Voltmeter:

The necessary requirements for any measuring instruments are:

(i) With the introduction of the instrument in the circuit, the circuit conditions should not be altered. Thus, the quantity to be measured should not get affected due to the instrument used.

(ii) The power consumed by the instruments for their operation should be as small as possible.

Ideally, the voltage measuring device must have infinite input impedance. But practically the input impedance of voltage measuring devices is very high but finite. Due to this, the devices keeps on drawing some current from the test circuit by measuring device is called ***Loading Effect***. Higher the value of current drawn by the device, higher is the loading effect & higher is the error in the measurement.

Consider an example where a voltmeter is used to measure the voltage across a resistor in the circuit fig.1.6

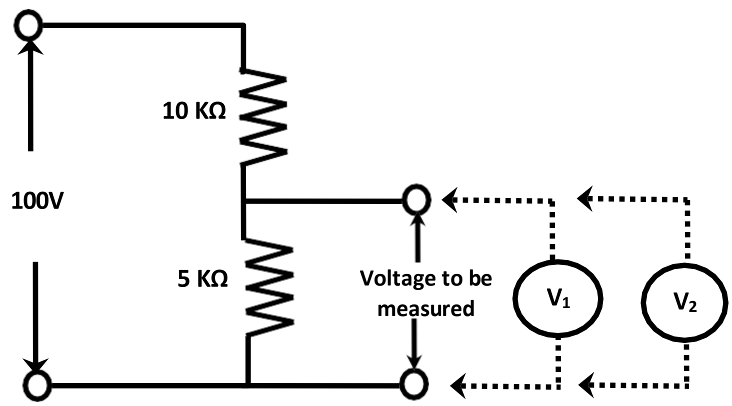
From the circuit, true value of voltage across the terminals A-B is

$$V_{true} = \frac{5X10^3}{[(5+10)X10^3]}X100 = 33.33V$$

With voltmeter V_1, Z_{in} = 10KΩ appears in parallel with 5KΩ & effectively becomes,

R' = 5KΩ|| 10KΩ = 3.33KΩ

$$V_1 = \frac{3.33X10^3}{(10+3.33)X10^3}X100 = 25V$$



For voltmeter V_1, Z_{in} = 10KΩ; V_1, Z_{in} = 100KΩ

Fig. 1.6: Loading Effect of a voltmeter

With voltmeter V_2, Z_{in} = 100KΩ appears in parallel with 5KΩ & effectively becomes,
R' = 5KΩ|| 100KΩ = 4.762KΩ

$$V_2 = \frac{4.762X10^3}{(10+4.762)X10^3}X100 = 32.253V$$

Thus, voltmeter V_2 draws more closer to true value as its Z_{in} is high & it draws less current comparatively. Hence, higher the input impedance of the voltage measuring device, lesser is the loading effect & loading error.

Problem: The expected value of the voltage across a resistor is 120V. However, the measurement gives a value of 118V. Calculate absolute error, % error, relative accuracy & % of accuracy.

Solution:

Given: The expected voltage drop **(Y_n)** across a resistor = 120V
On measurement, measured value **(X_n)** across the resistor = 118V

(i) Absolute error, e = $Y_n - X_n$ = 120V – 118V = 2V

(ii) % Error = ($Y_n - X_n$/ Y_n)X100 = [(120 – 118)/120]X100 = 1.67%

(iii) Relative accuracy, A = 1 - | ($Y_n - X_n$)/Y_n) | = 1 - | (120 – 118)/120) | = 0.9833

(iv) % of accuracy, a = 100 X A = 100 X 0.9833 = 98.33%

Or

a = 100% -% of error = 100% -1.67% = 98.33%

Dynamic Characteristics: Instruments rarely respond instantaneously to changes in the measure variables. Instead they exhibit slowness or sluggishness due to mass, thermal capacitance, electric capacitance.

The dynamic behavior of an instrument is determined by subjecting its primary element (sensing element) to some unknown & predetermined variations in the measured quantity.

Dynamic characteristics of an instrument are:

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

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

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

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

Problem 2: Design an Aryton shunt to provide an ammeter with the current ranges of 1A, 5A & 10A. A basic meter resistance is 50Ω & full scale deflection current is 1 mA

Solution:

Given: I_{fsd} = 1mA; R_m = 50Ω;

For 0-1A range:

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

I_{sh} = 1000mA – 1mA = 999mA

$999 \times 1\times10^{-3} \times (R_1 + R_2 + R_3) = 1mA \times 50$

$999 \times 1\times10^{-3} \times (R_1 + R_2 + R_3) = 1\times10^{-3} \times 50$

$R_1 + R_2 + R_3 = (1\times10^{-3} \times 50)/999 \times 1\times10^{-3}$

= 0.05 Ω............. (1)

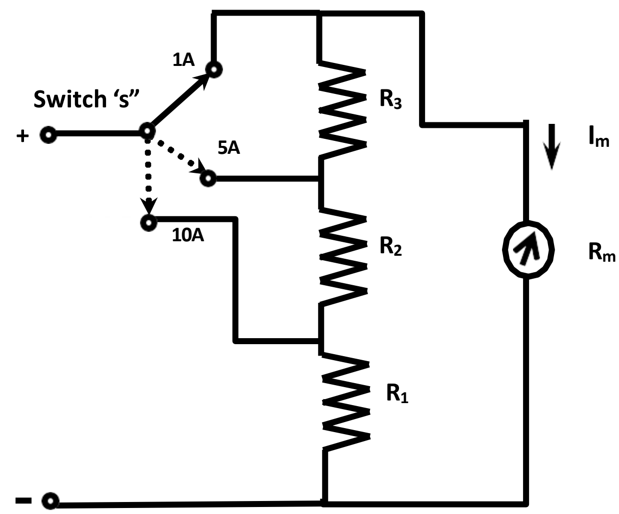


Fig. 1.7: Aryton Shunt

For 0-5A range:

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

I_{sh} = 5000mA – 1mA = 4,999mA

$4{,}999 \times 1\times10^{-3} \times (R_1 + R_2) = 1mA \times (R_3 + 50)$

$4{,}999 \times 1\times10^{-3} \times (R_1 + R_2) = 1\times10^{-3} \times (R_3 + 50)$ .... (2)

For 0-10A range:

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

I_{sh} = 10,000mA – 1mA = 9,999mA

$9{,}999 \times 1\times10^{-3} \times R_1 = 1mA \times (R_2 + R_3 + 50)$

$9{,}999 \times 1\times10^{-3} \times R_1 = 1\times10^{-3} \times (R_2 + R_3 + 50)$........................(3)

But $R_1 + R_2 = 0.05 - R_3$ substituting in equation no. 2, we have

$4{,}999 \times 1\times10^{-3} \times (0.05 - R_3) = 1\times10^{-3} \times (R_3 + 50)$

$249.95 - 4{,}999 \times R_3 = R_3 + 50$

$199.95 = R_3 (1 + 4{,}999)$

R_3 = 0.03999Ω

From equation no. 1, we have

$R_2 = 0.01 - R_1$..................................(4)

Substituting value of R_2 in equation no. 3, we have

$9{,}999 \times 1\times10^{-3} \times R_1 = 1\times10^{-3} \times (0.01 - R_1 + 0.03999 + 50)$

$9{,}999 \times 1\times10^{-3} \times R_1 = 1\times10^{-3} \times (50.04999 - R_1)$

On solving,

$\mathbf{R_1 = 0.005\Omega}$

$R_2 = 0.01 - R1 = 0.01 - 0.005$

$\mathbf{R_2 = 0.005\Omega}$

Hence, multiplier resistor R_1, R_2, R_3 has values as **0.005Ω, 0.005Ω, 0.03999Ω respectively.**

Error is the deviation from the true value of the measured variable. No measurement can be made with perfect accuracy but it is important to find out what the accuracy is & how different errors have entered into the measurement. Study of errors is a first step to reduce them & to determine the accuracy of the final test result.

$$\%\ \text{Error} = \frac{actual - apparent\ value}{actual\ value} X100$$

Errors may come from different sources & it may be classified as:

1) **Gross Errors:** Largely human errors, among them misreading of instruments, incorrect adjustment & improper application of instruments & computational mistake. Some gross errors are easily detected; others may be elusive. One common gross error committed frequently by beginners in measurements, involves the improper use of an instrument. In general, indicating instruments change conditions to some extent when connected into a complete circuit so that the measured quantity is altered by the method employed.

2) **Systematic Errors:** Short comings of the instruments such as defective or worn parts & effects of the environment on the equipment or the user. Two types of systematic errors:

a) Instrumental errors, defined as short comings of the instrument

b) Environmental errors, due to external conditions affecting the measurement.

a) **Instrumental Error:** These are the errors inherent in measuring instruments because of their mechanical structure. For example, in the d'arsonval movement friction in bearings of various moving components may cause incorrect readings

It can be avoided by:

i) Selecting a suitable instrument for the particular measurement application.
ii) Applying correction factors after determining the amount of instrumental errors
iii) Calibrating the instrument against a standard.

b) **Environmental Errors:** These are due to conditions external to the measuring device, including conditions in the areas surrounding the instrument, such as the effects of changes in temperature, humidity, barometric pressure or of magnetic or electrostatic fields. To reduce these types of errors one can include air conditioning, hermetically sealing certain components in the instrument, use of magnetic shields.

Systematic errors can also be sub divided into static & dynamic errors. Static errors are caused by limitations of the measuring device or the physical laws governing its behavior. A static error is introduced in a micrometer when excessive pressure is applied in torquing the shaft. Dynamic errors are caused by the instrument's not responding fast enough to follow the changes in a measured variable.

3) **Random Errors:** Those due to causes that cannot be directly established because of random variations in the parameter or the system of measurement.

Problem 3: A PMMC instrument with full scale deflection current = 50μA & R_m = 1700Ω is to be employed as a voltmeter with ranges of 10V, 50V & 100V. Calculate the required values of multiplier resistors for the circuits.

Solution:

Given: I_{fsd} = 50μA; R_m = 1700Ω;

Voltage ranges: 0-10V; 0-50V; 0-100V

Required multiplier resistance will be,

For 0-10V range at V_3 position:

Total circuit resistance is

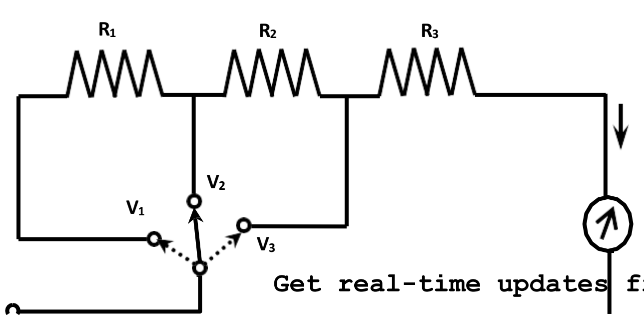


Fig. 1.8: voltmeter with ranges of 10V, 50V & 100V

For 0-50V range at V_2 position:
Total circuit resistance is
$R_t = V/I_{fsd} = 50/50\mu A = 1M\Omega$
Therefore, $R_2 = R_t - R_m = 1M\Omega - 1700\Omega$
$R_2 = 0.9983M\Omega$

For 0-100V range at V_3 position:
Total circuit resistance is
$R_t = V/I_{fsd} = 100/50\mu A = 2M\Omega$
Therefore, $R_3 = R_t - R_m = 1M\Omega - 1700\Omega$
$R_3 = 1.9983M\Omega$

True RMS Reading Voltmeter

The measurement of complex waveform is done with the help of True RMS Voltmeter. For such type of voltmeter input is applied to the heater. The heater is heated up and transforms heat energy to the thermocouple. Coupling thermocouple converts the heat into electrical voltage which is applied to the DC amplifier. DC amplifier amplifies the DC signal and applied to PMMC instrument for indicating the voltage output. To provide accurate measurement the output is feedback to the input side where the heater is heated up and balancing thermocouple converts the DC signal to voltage. The function of feedback loop is to provide balanced condition for measuring thermocouple which is present in form of non linearity. Figure 1.9 shows the construction of true RMS voltmeter.

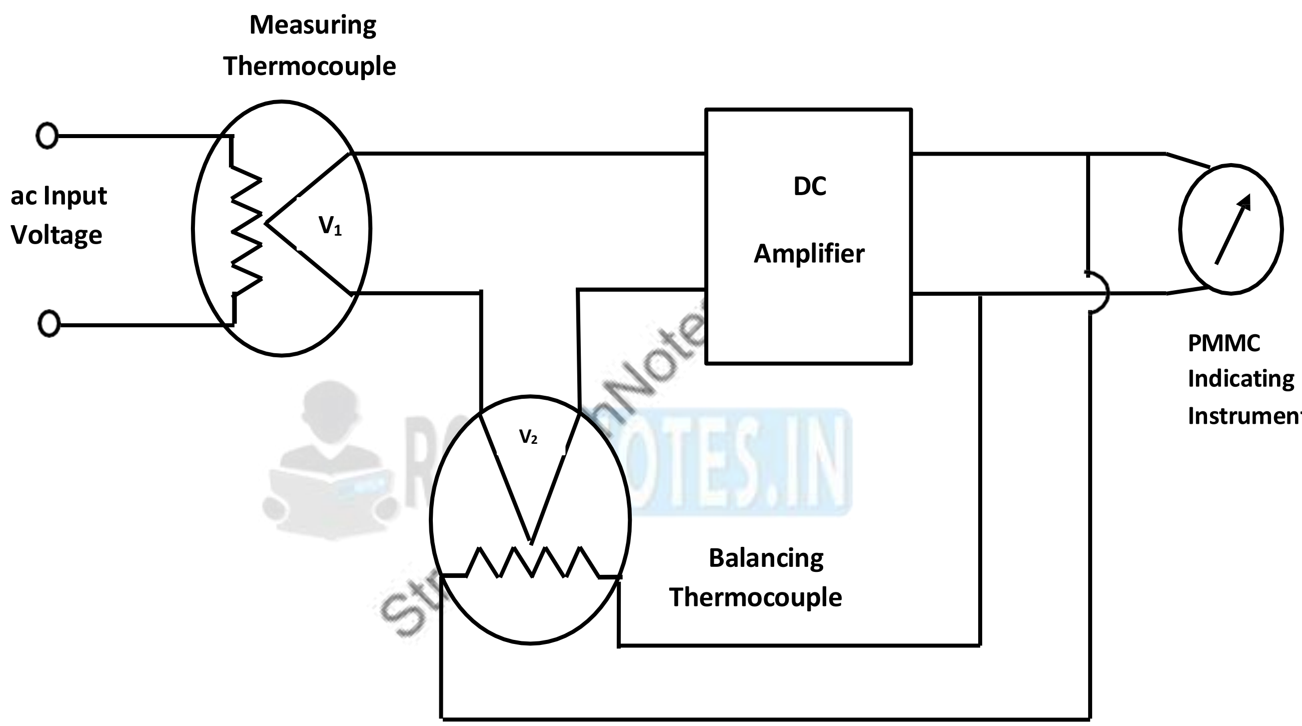


Figure 1.9: Diagram of True RMS reading voltmeter

Average Reading AC Voltmeters

Average reading voltmeters are used for measuring AC signals in terms of calibrated RMS value on the meter scale. This measurement can be achieved by using Vacuum tube diode and a resistance which is connected in parallel with the applied AC voltage as shown in figure 1.10.

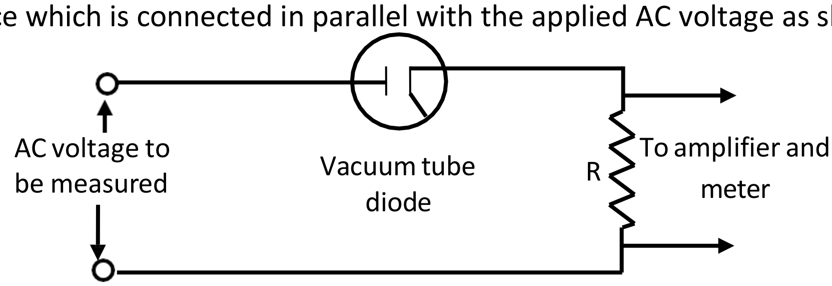


Figure 1.10: ac Voltmeter using Vacuum Tube Diode

Vacuum tube diode should have linear volt –current characteristics. This is essential to make current directly proportional to the applied input signal. The PMMC instrument is used for measurement of input signal.

The average current through the meter will be given by the expression

$$I_{av} = \frac{V_{av}}{2R} = 0.45 * [\frac{V_{rms}}{R}]I_{av}$$

V_{rms} is the rms value of applied voltage. I_{av} *is the average current measured.*

Peak Reading AC Voltmeter:

Peak Reading AC Voltmeter uses semiconductor diode for making measurement in term of DC signal. The half wave rectifier is used with capacitor connected in parallel form with the applied input signal. The output of rectifier is pulsating DC which is applied to the capacitor. The function of capacitor is to pass the AC signal present in rectified output and blocks the DC signal .This action provides static output which is applied to the load resistance to measure DC output with the help of PMMC instrument. The circuit arrangement is as shown in figure 1.11.

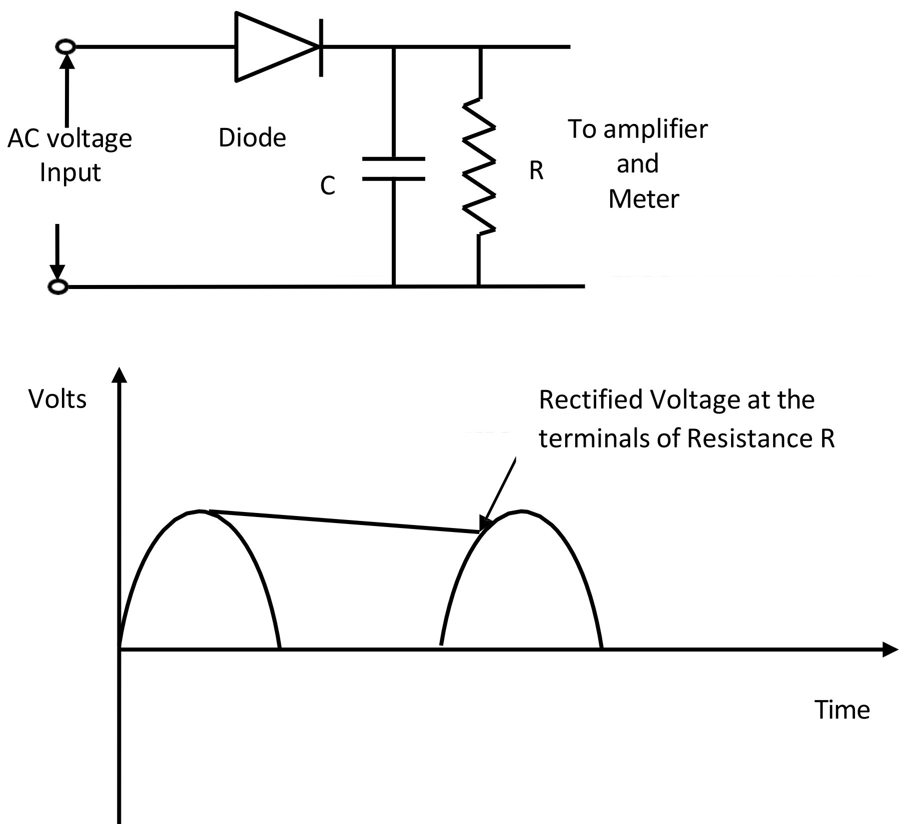


Figure 1.11: Diode Rectifier with related waveform

When the positive half cycle is applied across the diode it becomes forward biased and acts as a closed switch. The current flows through the device and positive going cycle is present at the output side. In negative half cycle the diode is reversed biased and it acts as open switch.

1. **Rectifier type Voltmeter**

Bridge rectifier consists of four diodes which are connected in the form of the bridge. The AC input voltage is applied to step down transformer which is provided to the bridge rectifier to convert AC signal to average DC signal. The resistance R is connected across the bridge. The DC signal measured across the resistance is directly proportional to the applied input signal. The bridge rectifier circuit is shown in figure 1.12

Operation:

For the first positive half cycle of the input AC voltage diodes D_1 and D_2 becomes forward biased and current flows from positive terminal to D_1 to R to D_2 and reaches to negative terminal, whereas diodes D_3 and D_4 remains in reverse biased condition and no current flows through it.

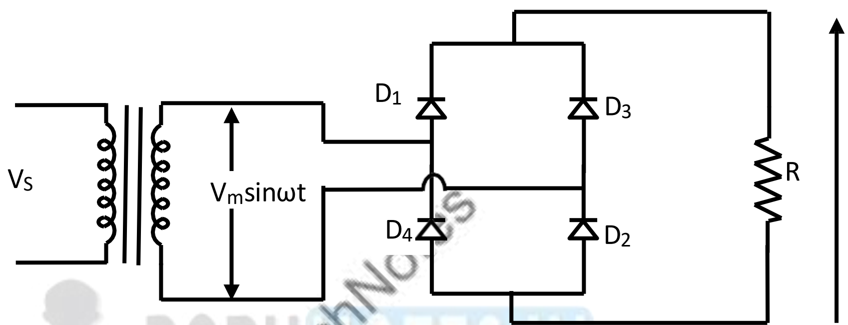


Figure 1.12: Bridge rectifier circuit diagram

For the negative half cycle the diodes D_3 and D_4 are forward biased and current flows in same direction from D_3 to R to D_4 to negative terminal, whereas diodes D_1 and D_2 remains in reverse biased condition and no current flows through it.

Hence with the help of bridge rectifier the positive and negative going cycles i.e. AC signal is converted into positive going cycles i.e. DC signal.

- **Electronic Multi meters**

Electronic multi meter is the measuring instrument which is used for measurement of AC, DC voltages and current. With the help of multi meter resistance can also be measured. The multi meter uses the application of differential amplifier. The differential amplifier is implemented by using FET as semiconductor device. Multi meter consists of following elements:

- Balanced-bridge with DC amplifier and indicating meter
- RANGE switch is used to limit the value of the applied input voltage to the desired value for measurement
- Rectifier to convert an AC input voltage to a proportional DC value
- to measure the resistance, internal battery and additional circuitry is provided
- FUNCTION switch is used to select the various measurement functions of the instrument

working of individual Components

Balanced Bridge DC amplifier

Figure 1.13 shows the balanced bridge DC amplifier which uses FET for various measurements.

Two FETs are used to make the circuit stable with the help of resistances which are connected in the form of bridge. Resistors R_1 and R_3 together with ZERO adjust resistor R_2, form the lower arms of the bridge. The meter is connected between the source terminals of the FETs, representing two opposite corners of the bridge. Without an input signal, the gate terminals of the FETs are at ground potential as well the bridge is in balanced condition and the indicator shows the null deflection.

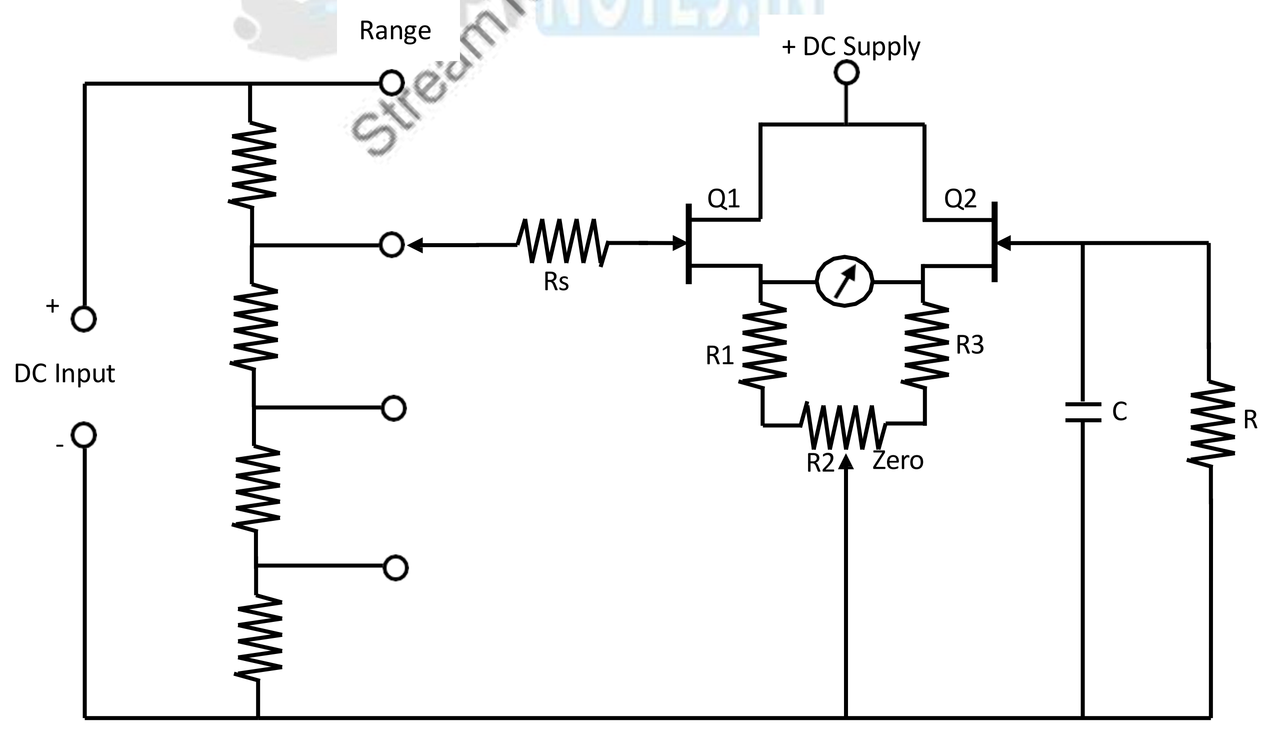


Figure 1.13: Balanced Bridge dc amplifiers with input attenuator and indicating meter

With no any input is applied to instrument and it shows deflection on indicator then with the help of ZERO adjustment using R_2 potentiometer the null deflection is set.

Output Indication

When a positive voltage is applied to the gate of FET Q1 its drain current increases which causes the voltage at across bridge to rise. Due to rise in voltage as compared with Q2, the bridge becomes unbalance and meter indicates the reading which is directly proportional to applied input signal.

Measurement of Low Power

Bolometer:

Bolometer is an instrument which is used for measurement of low microwave power in the range of 0.01mW to 10 mW. The microwave power in terms of heat energy is sensed by RTD which has positive temperature coefficient of resistance and converts the heat energy into electrical resistance. The resistance is converted into electrical voltage with the help of Wheatstone bridge. The RTD is inserted into one arm of the bridge where other three arms are fixed resistance. When the bridge all the resistances of each arm are equal, then the output voltage is null. When microwave power is applied on RTD its resistance changes, results in unbalancing the bridge, hence potential difference is created across the bridge. The resultant output voltage is directly proportional to applied input power.

For making the bridge in balanced condition auxiliary RTD is used in parallel with the battery, which maintains the bridge into null condition when power is not applied. Figure 1.14 shows the circuit diagram of Bolometer.

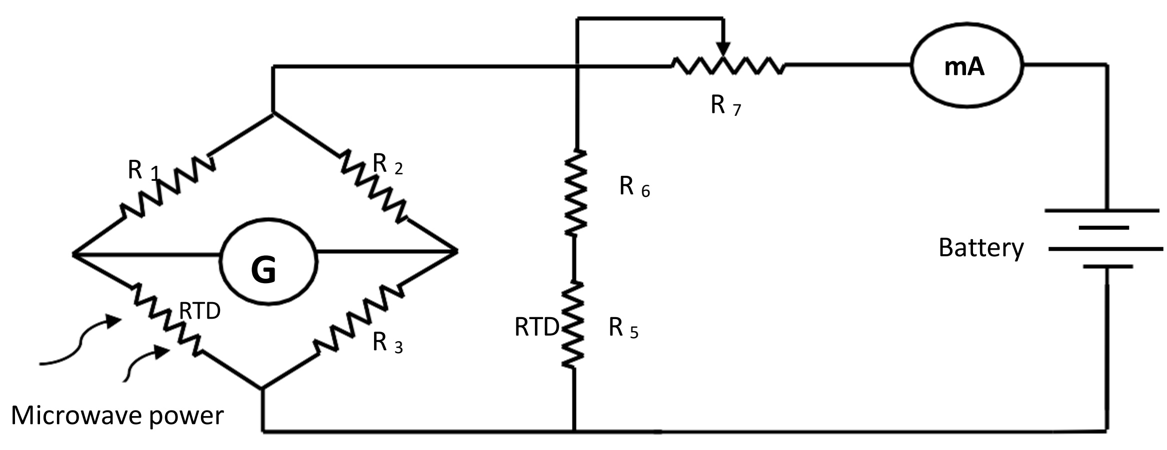


Figure 1.14: Bolometer for low power measurement

Calorimeter:

Calorimeter is an instrument used for measurement of medium microwave power between the ranges of 10mW to 1W. Water is used for measurement of microwave power, where microwave power is transferred to the water and the difference of outlet temperature to inlet temperature is directly proportional to applied microwave power.

It consists of one waveguide; glass tube inserted into waveguide, water pump, flow meter and thermometer fro measurement of temperature. Water is pumped with water pump and provided to glass tube which is placed into the waveguide which senses the temperature and provided to outlet. The flow of water is measured with the help of flow meter.

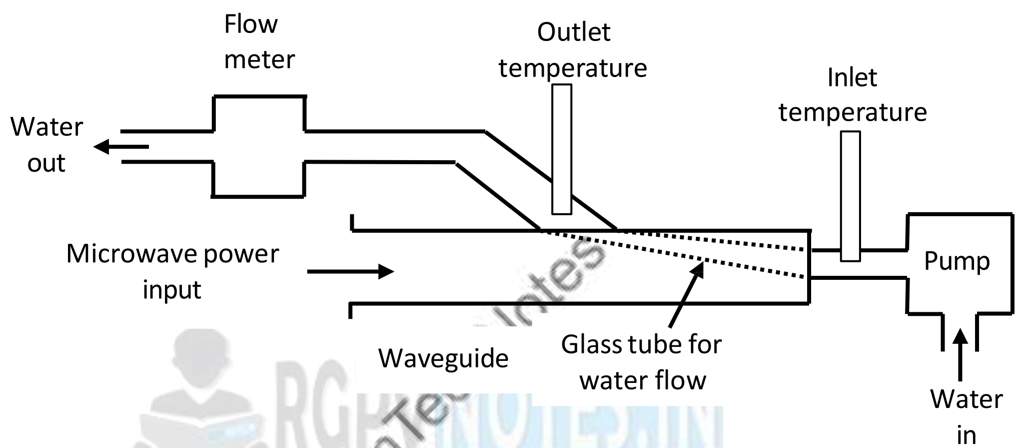


Figure 1.15: Calorimeter for medium power measurement

P=4.187 V d Cp T watts

P is power; V is rate of flow of calorimeter; D is specific gravity; Cp is specific heat

Chopper Type Micro Voltmeter the dc input voltage is converted into an ac voltage amplifies by an ac amplifier & then converted back into a dc voltage proportional to the original input signal. To measure small voltages, a chopper type dc amplifier is used.

PRINCIPLE: Referring fig 1.16, an ac amplifier which has a very small drift compared to a dc amplifier is used. The chopper may be mechanical or electronic. Photo diodes are used as non-mechanical chopper for modulation (conversion of dc to ac) & demodulation (conversion of ac to dc)

Photo conductors have a low resistance, ranging from a few hundreds to a few thousand ohms, when they are illuminated by a neon or incandescent lamp. Photo conductors resistance increases sharply (several MΩ) when not illuminated.

A chopper amplifier is normally used for the first stage of amplification in very sensitive instrument of a few µV ranges. In such an amplifier, the dc voltage is chopped to low frequency of 100-300Hz. It is passed through a blocking capacitor, amplified & then passed through another blocking capacitor to remove the dc drift of the amplified signal.

Basic Principle: Referring fig. 1.17 & 1.18 a flashing light source, whose intensity varies from maximum to minimum almost instantaneously, causes the photo diode resistance to change from R_{min} to R_{max} quickly. Therefore, the output voltage is an ac, because the photo diode has a high output when its resistance is high & a low output when its resistance is low.

Working: Referring the fig.1.19, an oscillator drives two neon lamps into illumination on alternating half cycles of oscillation. The oscillator frequency is limited to a few 100 cycles, because the transition time required for the photo diode to change from high resistance to a low resistance limits the chopping range. Each neon lamp illuminates one photo diode in the input circuit of the amplifier & one in the output circuit. The two photo diodes form a series shunt half wave modulator or chopper. When one photo diode or the input has maximum resistance, the other has minimum resistance. The same condition exists at the output circuit.
Together they acts as a switch across the input to the amplifier, alternatively opening & closing at a rate determined by the frequency of the neon oscillator. The input signal to the amplifier is a square wave whose amplitude is proportional to the input voltage with a frequency equal to the oscillator frequency. The ac amplifier delivers an amplified square wave at its output terminals.

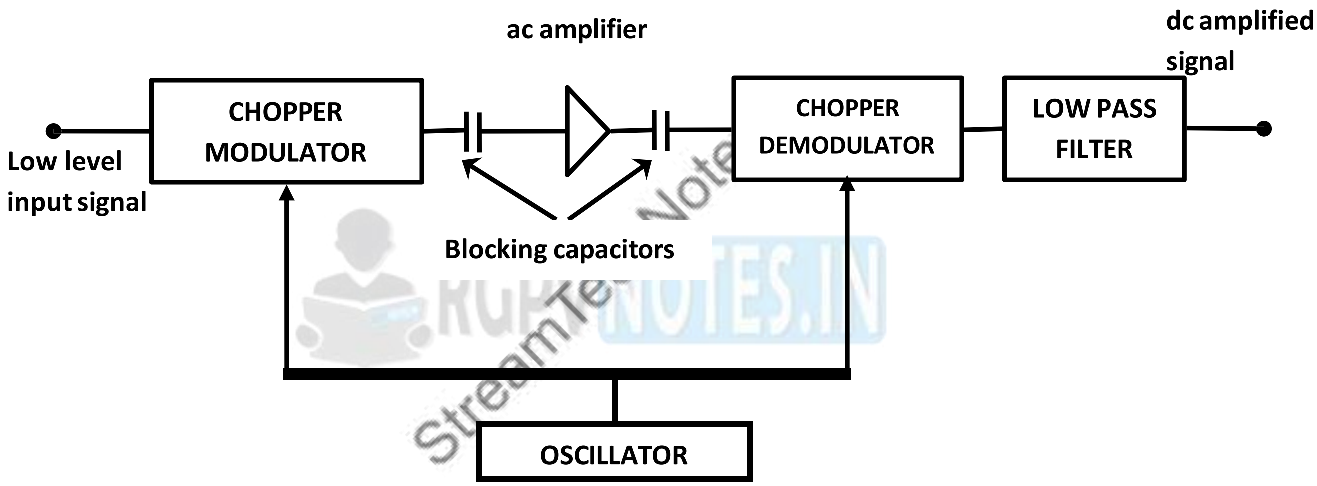
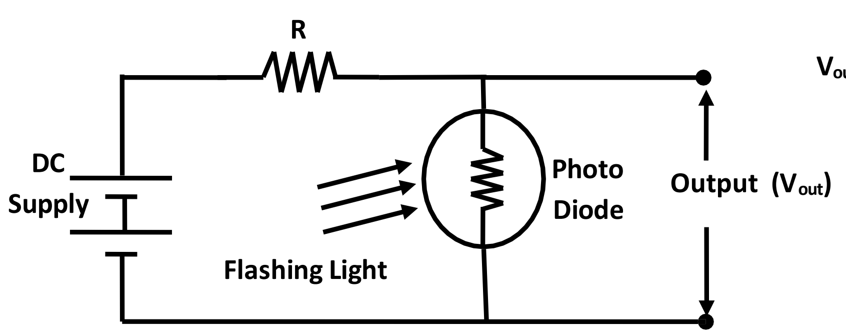


Fig.1.16: Principle of operation (chopper type voltmeter)



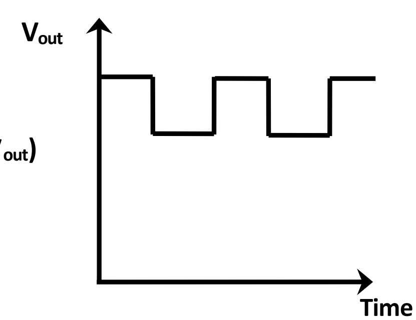


Fig. 1.17: Electronic Modulator **Fig.1.18 Output from the circuit**

The photo diodes (demodulator) in the output circuit operate in antisynchronously with the input chopper, recovering the dc signal by demodulating action. The dc output signal is then passed to a low pass filter to remove any residual ac component. This amplified drift free dc output is then applied to a PMMC movement for measurement. The chopper eliminates the needs of high gain dc amplifier with its inherent drift & stability problems.

A commercially available instrument using a photo chopper amplifier has an impedance of 100MΩ a resolution of 0.1µV & input ranges from 3µV full scale to 1KV full scale with an accuracy of ±2% of full scale deflection.

Advantages: The input impedance of a chopper amplifier of the order of 10MΩ or higher.

With the use of ac amplifier, drift can be cut down by a factor of 100, thus allowing an input signal range of about 0.01mV = 10µV full scale to be handled.

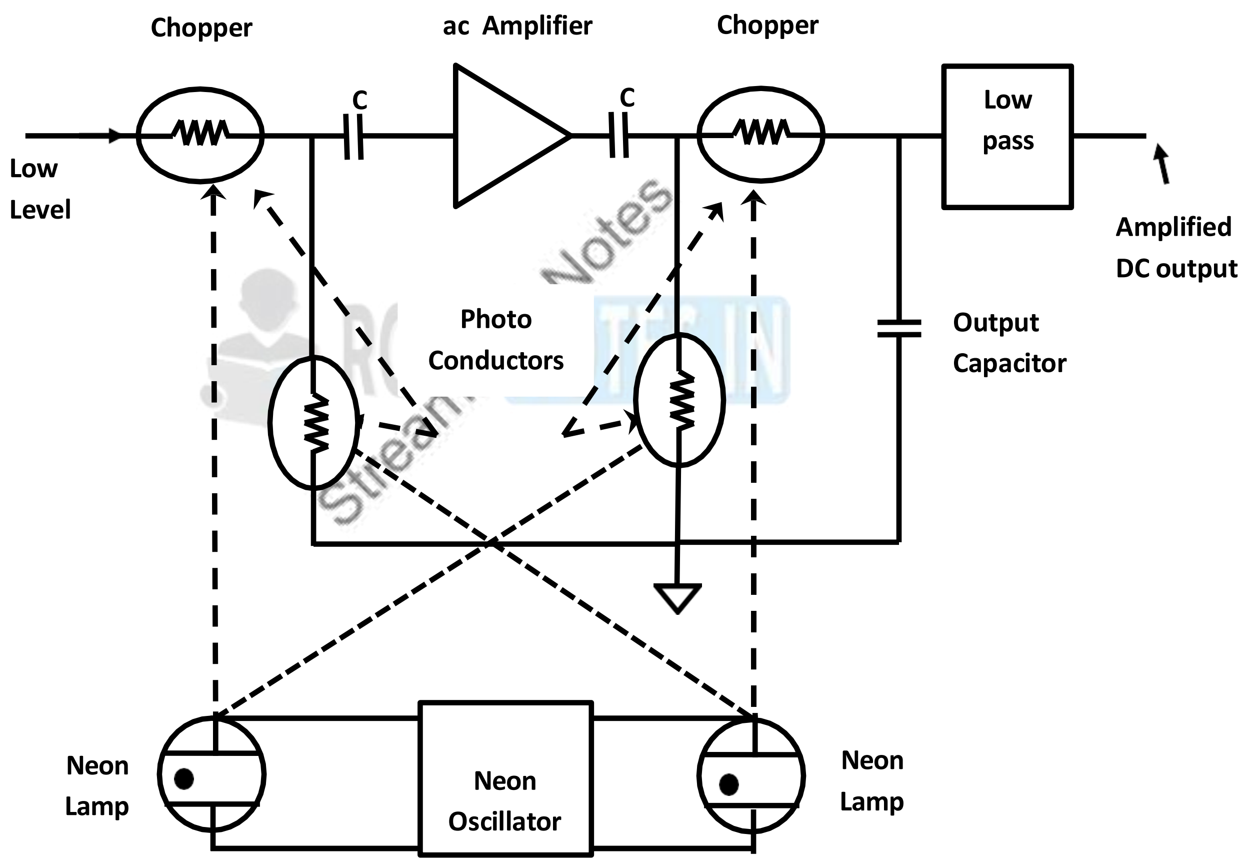


Figure 1.19: Circuit Diagram of a Chopper Type Micro Voltmeter

UNIT II

Different parts of CRO, Block diagram, Electrostatic focusing, Electrostatic deflection, Post deflection acceleration, Screen for CRTs, Graticules, Vertical and Horizontal deflection system, Time base circuit, Oscilloscope Probes, Applications of CRO, Special purpose CROs- Multi input, Dual trace, Dual beam, Sampling, Storage (Analog and Digital) Oscilloscope.
Maxwell's bridge (Inductance and Inductance-Capacitance), Hay's bridge, Schering Bridge, Wein bridge Impedance measurement by Q-meter

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The ***cathode ray oscilloscope*** is probably the most useful and versatile laboratory instrument for the development of electronic circuits and systems. It is used for studying wave shapes of alternating currents and voltages as well as for measurement of voltage, current, power and frequency, in fact, almost any quantity that involves amplitude and waveform. It allows the amplitude of electrical signals as a function of time on the screen. It is widely used for trouble shooting radio and TV receivers as well as laboratory work involving research and design. It can also be employed for studying the wave shape of a signal with respect to amplitude distortion and deviation from the normal. In true sense the cathode ray oscilloscope has been one of the most important tools in the design and development of modern electronic circuits.
The oscilloscope is basically an electron beam voltmeter. The main part of oscilloscope is the Cathode Ray Tube (CRT) which makes the applied signal visible by the deflection of a thin beam of electrons. Since electron have practically no weight, and hence no inertia, therefore the beam of electrons can be moved to follow waveforms varying at a rate of times/second. Thus, the electron beam faithfully follows rapid variations in signal voltage and traces a visible path on the CRT screen. In this way, rapid variations, pulsations or transients are reproduced and the operator can observe the waveform as well as measurer amplitude at nay instant of time.

The major block circuit shown in below Fig. 2.1 of a general purpose CRO is as follows:

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

1. CRT

This is the cathode ray tube which emits electrons that strikes the phosphor screen internally to provide a visual display of signal. Cathode Ray Tube is the heart of the oscilloscope. When the electrons emitted by the electron gun strikes the phosphor screen of the CRT, a visual signal is displayed on the CRT.

2. Vertical Amplifier

This is a wide band amplifier used to amplify signals in the vertical section. In Vertical Amplifier, the input signals are amplified by the vertical amplifier. Usually, the vertical amplifier is a wide band amplifier which passes the entire band of frequencies.

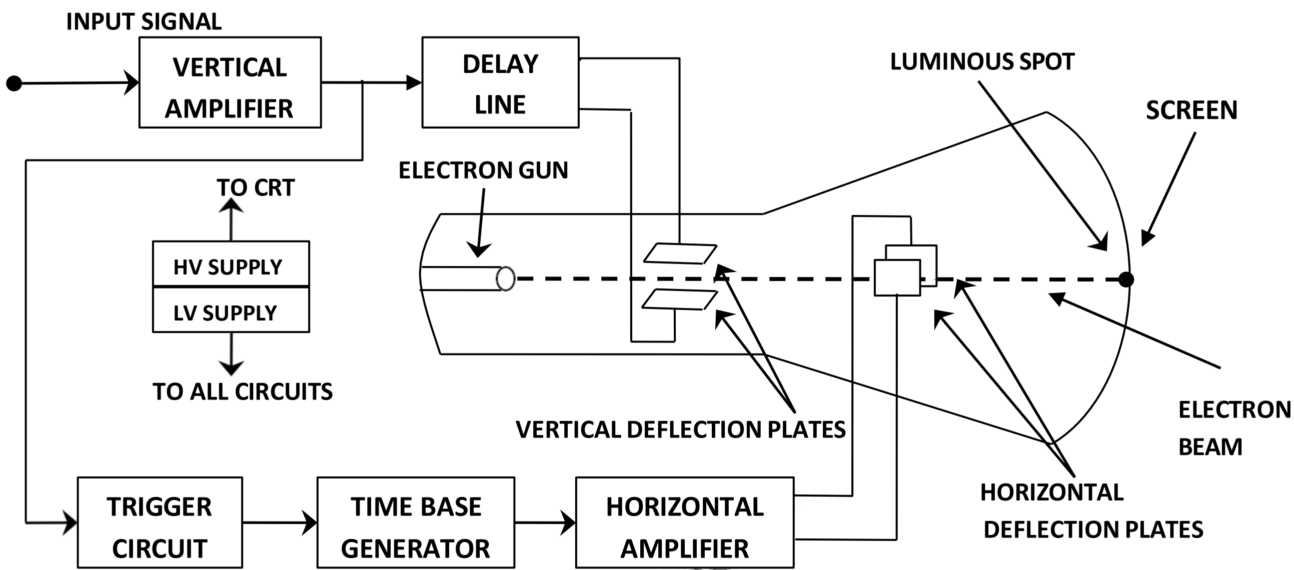


Fig. 2.1: Block Diagram of a general CRO

3. Delay Line

It is used to display the signal for some time in the vertical section. Delay Line as the name suggests that, this circuit is used to; delay the signal for a period of time in the vertical section of CRT. The input signal is not applied directly to the vertical plates because the part of the signal gets lost, when the delay Time not used. Therefore, the input signal is delayed by a period of time.

4. Time Base

It is used to generate the sawtooth voltage required to deflect the beam in the horizontal section. Time base circuit uses a unijunction transistor, which is used to produce the sweep. The saw tooth voltage produced by the time base circuit is required to deflect the beam in the horizontal section. The spot is deflected by the saw tooth voltage at a constant time dependent rate.

5. Horizontal Amplifier

This is used to amplify the sawtooth voltage before it is applied to horizontal deflection plates. In Horizontal Amplifier, the saw tooth voltage produce by the time base circuit is amplified by the horizontal amplifier before it is applied to horizontal deflection plates.

6. Trigger Circuit

This is used to convert the incoming signal into trigger pulses so that the input signal and the sweep frequency can be synchronized. In the trigger circuit the signals which are used to activate the trigger circuit are converted to trigger pulses for the precision sweep operation whose amplitude is uniform. Hence input signal and the sweep frequency can be synchronized.

7. Power Supply

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

Internal Structure of a CRT:

The cathode ray oscilloscope (CRO) is used for display, measurement and analysis of waveforms. CROs are in fact very fast *X*- Y plotters, displaying an input signal versus another signal or versus time. **Cathode Ray Tube (CRT)** is the heart of CRO. This is the cathode ray tube which emits electrons that strikes the phosphor screen internally to provide a visual display of signal. Cathode Ray Tube is the heart of the oscilloscope. When the electrons emitted by the electron gun strikes the phosphor screen of the CRT, a visual signal is displayed on the CRT.

The main parts of a CRT are:

(i) Electron gun assembly, (ii) Deflection plate assembly, (iii) Fluorescent screen,
*(iv)*Glass envelope, (v) Base.

(i) Electron gun assembly:

It produces a sharply focused beam of electrons which are accelerated to high velocity. After leaving the electron gun, the electron beam passes through two pairs of "Electrostatic deflection plates". Voltages applied to these plates deflect the beam. Voltages applied to one pair of plates move the beam vertically up and down and the voltage applies to the other pair of plates move the beam horizontally from one side to another. The figure 2.2 shows the internal structure of Cathode Ray Tube.

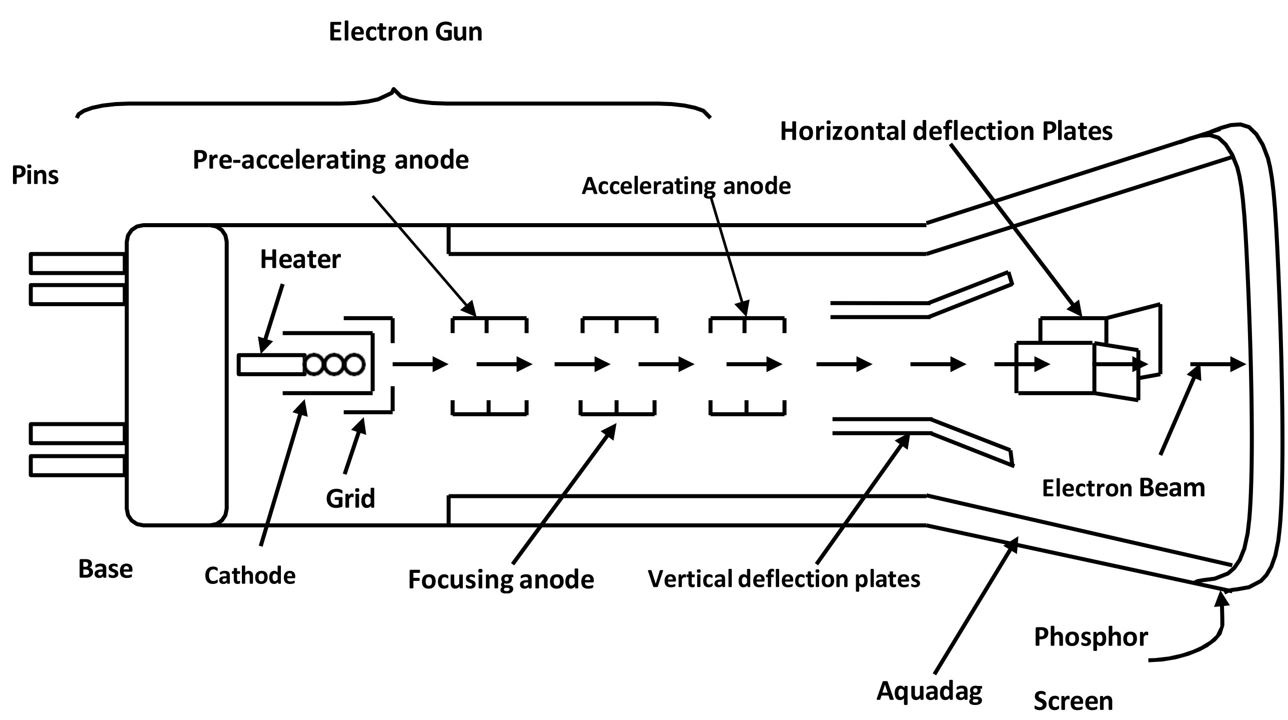


Figure 2.2: Internal structure of Cathode Ray Tube

Electron Gun: The role of this section is to produce electrons at a high, fixed, velocity. This is done through a process known as thermionic emission. A filament in the cathode is heated to the point where its electrons become loose. An anode with a high voltage applied to it accelerates the electrons towards the screen due to electrostatic attraction. On the way, the electrons pass through a series of control grids which control the brightness of the image produced. The more negative the grid, the darker the image and vice versa.

The electron gun consists of a heater a cathode, a grid, a pre-accelerating anode, a focusing anode and an accelerating anode.
In smaller CRTs, connections to the various electrodes are brought out through pins in the base of the tube as shown in Figure 2.2.Larger types and medium sized high performance tubes operate at very high voltages, and these leads are usually brought out through the sides of the glass envelope. Electrons are emitted from the indirectly heated cathode. These electrons pass through a small hole is the "control grid".
This control grid is usually a nickel cylinder, with a centrally located hole,-co-axial with the CRT axis. The grid with is negative bias controls the number of electrons emitted from the cathode and hence the intensity is controlled by the grid.
The electrons, emitted from the cathode and passing through the hole in the control grid are accelerated by the high positive potential which is applied to the "pre-accelerating" and "accelerating anodes".
There are two methods of focusing an electron beam:

(i) Electrostatic focusing and

(ii) Electromagnetic focusing

The CRO uses electrostatic method of focusing as compared to a TV picture tube which employees electromagnetic focusing.

Electrostatic Focusing

The expression for force on an electron is given by – qE, where q is the charge of electron ($q = 1.6 \times 10^{-19}$ C), E is the electric field intensity and negative sign indicates that the direction of force is in opposite direction to that of electric field intensity. This force is applied to deflect the beam of electrons coming out of electron gun with the help of two cases which are illustrated below.

Case One

In this case we are having two plates. One plate A is at potential + E while the other plate is at potential – E. The equi-potential surfaces are also shown in the figure 2.3 which is perpendicular to the direction of electric field.

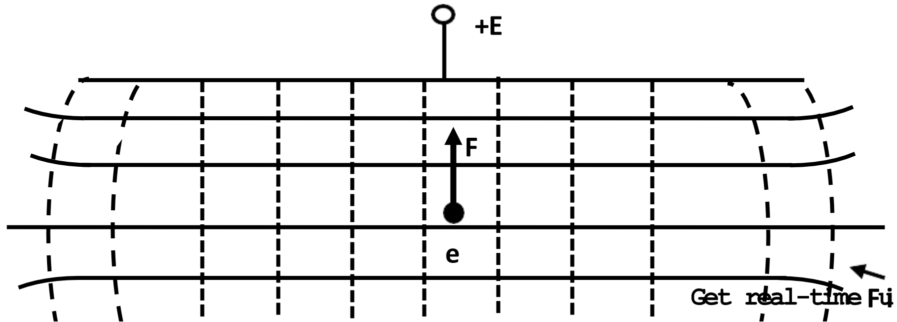


Figure 2.3: Electric field between parallel plates

Case Second

Two cylinders with a potential difference are applied between them as shown in the figure 2.4 The resultant direction of electric field and the equi potential surfaces are also shown in the figure. The equi potential surfaces are marked by the dotted lines which are curved in shape. Now here we are interested in calculating the deflection angle of electron beam when it passes through this curved equi potential surface.

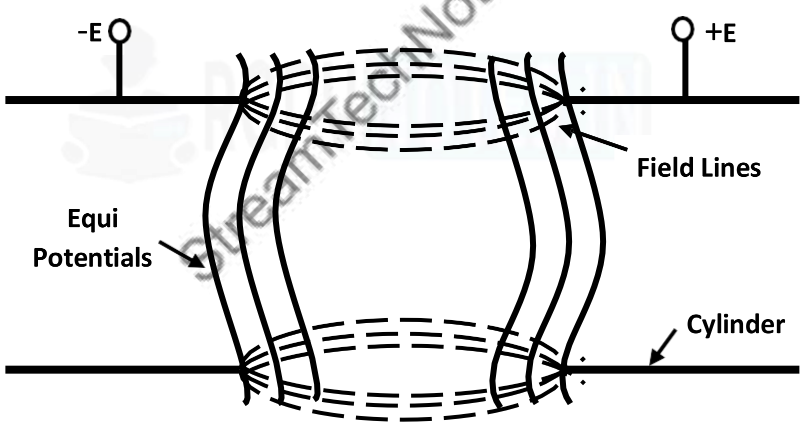


Figure 2.4: Field between two co axial cylinders

Electrostatic Deflection

The electron beams entering the field will be deflected towards the normal and the beam is thus focused towards the centre of the tube. By changing the voltage of the focusing anode, the refractive index is changed and therefore the focal point of the beam can be changed. The change in voltage of focusing anode is done by changing the potentiometer. The figure 2.5 shows Electro static focusing arrangement.

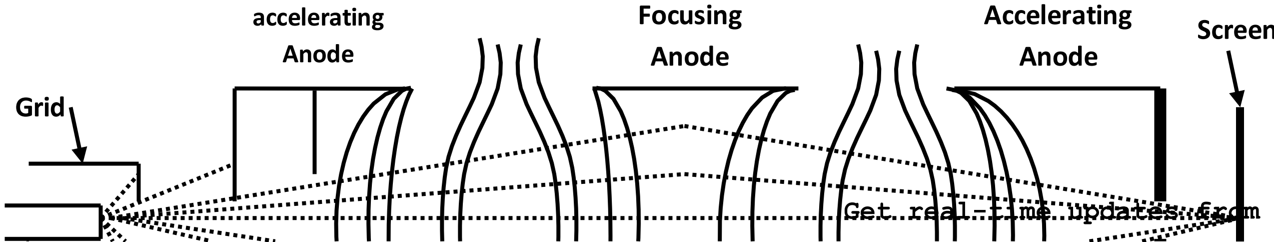


Figure 2.5: Electro static focusing arrangement

(iii) Fluorescent screen

The role of this part is to display where the electrons are hitting the CRT. It is a screen coated with a material that emits light when struck by electrons. Zinc sulfide or Phosphorus is two commonly used materials.

A CRT TV works by having the electron beam "scan" the screen at a rate faster than our eyes can perceive. This means that it shoots across the screen like a machine gun, and the images we see are actually made from many fluorescent dots. The fluorescence caused by the beam striking the screen lasts a bit longer so that the next scan can be made without the previous image disappearing. It scans twice each time, first filling in the odd "holes" then the even ones. Each scan is about 1/50 of a second.

iv) Glass Envelope: A cathode ray tube comprises of many parts that work altogether in coordination and also some of them require vacuum for their functioning that is why it becomes necessary to enclose them in a cage this purpose it served this glass envelope. That assembles all the parts of the tube in vacuum.

Also electrons generated by electron gun are to be directed towards deflection plates and then finally towards the fluorescent screen so for well propagation of electron without getting deflected any other object in its way it must be placed inside a sealed container.

v) Base: It is one of the essential parts of a CRO as through connecting pins electrical connections are made to other parts.

Graticule: The viewing screen of a CRO is the glass face plate, the inside wall of which is coated with phosphor. The viewing screen is a rectangular screen having graticules marked on it. The standard size used nowadays is 8 cm x l0 cm (8 cm on the vertical and 10 cm on horizontal).

Each centimeter on the graticule corresponds to one division (div). The standard phosphor color used nowadays is blue

Graticule: The graticule is a grid of lines that serves as a scale when making the time and amplitude measurements. There are three types of graticule

1. External graticule
2. Internal graticule
3. Projected graticule

External graticule: The graticule can be easily changed to make different types of measurements and its position can be adjusted to align it when the trace on the CRT. But it suffers from parallax errors.

Internal graticule: This is deposited on the internal surface of the CRT face plate and is therefore on the same surface is phosphor. It requires some method of electrical alignment. This is also difficult to illuminate for photography unless special illumination is provided.

Projected graticule:

It is available with some camera and provides flexibility .The face plate is sometimes tinted neutral grey to reduce ambient light interference or external filters.

Sampling Oscilloscope:

When the frequency of the vertical deflection signal increases, writing speed of electron beam increases causing reduction in the image intensity on the CRT screen. In order to obtain sufficient image brilliance the electron beam must be accelerated with higher velocity. So we need sampling oscilloscope. The sampling oscilloscope basically pickup samples from the sampling pulses in accordance with the input applied signal. The reconstruction formed through many samples taken during recurrent cycles of the input wave form. The horizontal displacement of the beam is synchronized with trigger pulses which also determine the moment of sampling. The resolution of final image on the CRT screen is determined by the size of steps of stair case generator.

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

Fig 2.6: shows a block diagram of a sampling oscilloscope. The input is applied to the sampling gate. The input waveform is sampled whenever a sampling pulse opens the sampling gate. The sampling must be synchronized with the input signal frequency. The signal is delayed in the vertical amplifier, allowing the horizontal sweep to be initiated by the input signal. The waveforms are shown in fig.2.7

At the beginning of each sampling cycle, the trigger pulse activates an oscillator and a linear ramp voltage is generated. This ramp voltage is applied to a voltage comparator which compares the ramp voltage to a staircase generate-When the two voltages are equal in amplitude, the staircase advances one step and a sampling pulse is generated, which opens the sampling gate for a sample of input voltage. The resolution of the final image depends upon the size of the steps of the staircase generator. The smaller the size of the steps the larger is the number of samples and higher the resolution of the image.

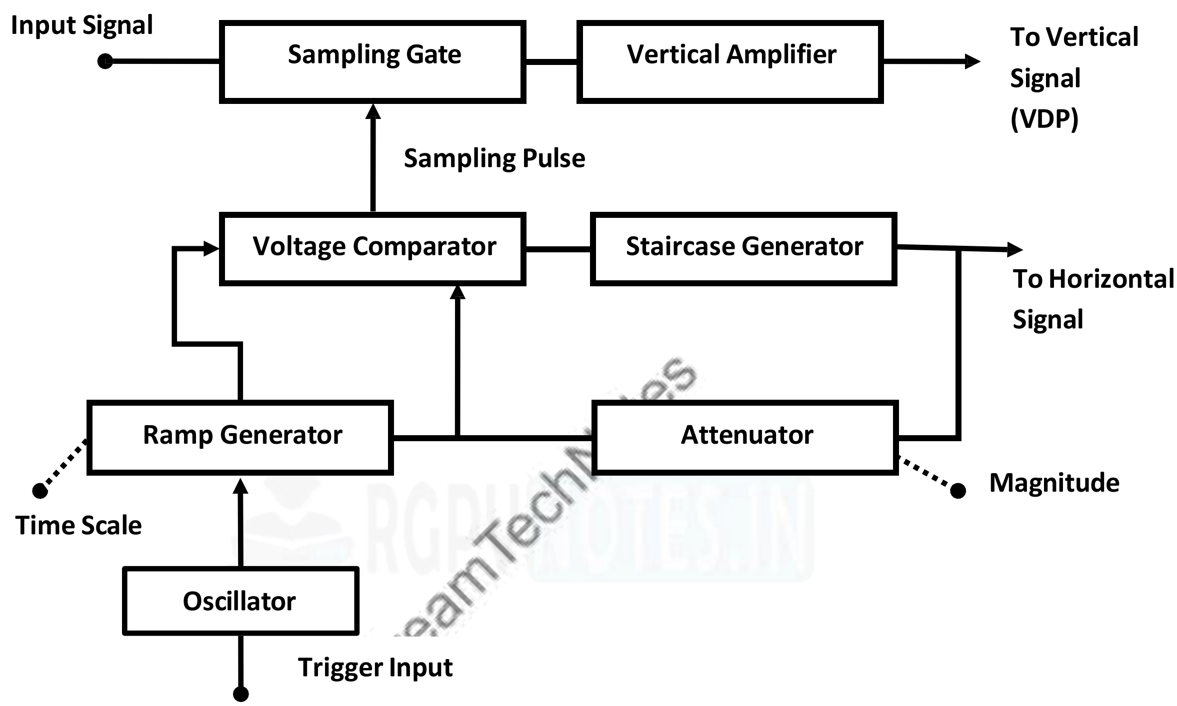
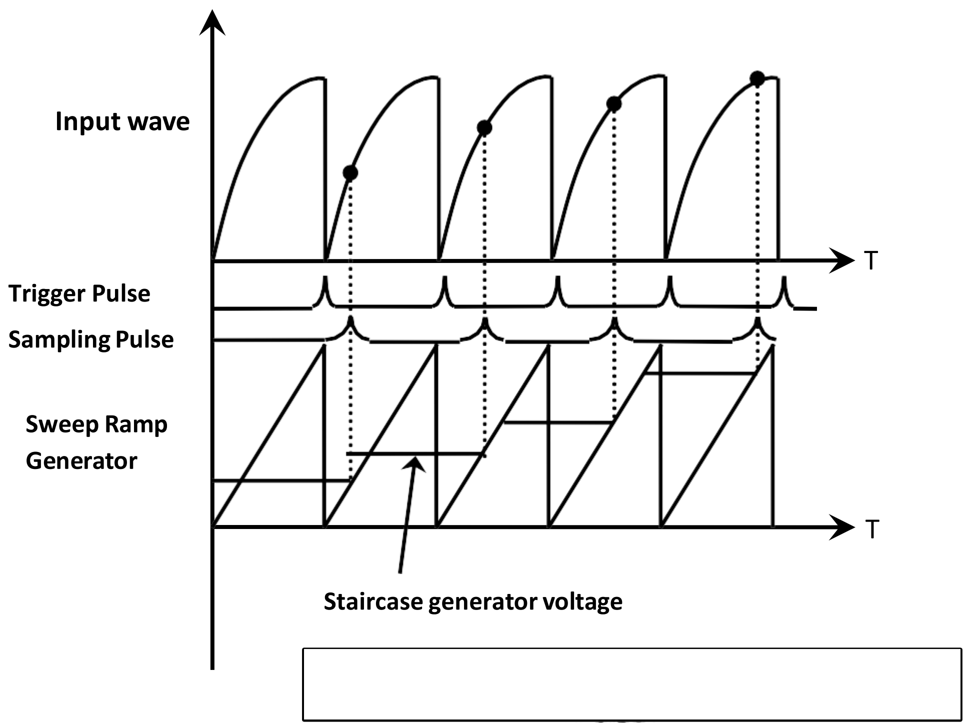


Fig. 2.6: Block Diagram of a Sampling Oscilloscope



Comparison between Dual Trace CRo & Dual Beam CRO

Sl. No.	Dual Trace CRO	Dual Beam CRO
1.	One electron beam is used to generate two traces	Two electron beams are used.
2.	One vertical amplifier is used.	Two vertical amplifiers are used.
3.	Two signals are not displayed simultaneously in real time but appear to be displayed simultaneously.	Two signals are displayed simultaneously.

4.	Same beam is shared between the two signals hence difficult to switch quickly between the traces.	Two separate beams are used hence easy to switch between the traces.
5.	As two signals are displayed separately, the signals may have different frequencies.	The two signals must have same frequency or their frequencies must be integer multiples of each other.
6.	The size & weight is less	The size & weight is more
7.	Cannot be operated at fast speeds hence two separate fast transient signals cannot be grabbed.	Can be operated at very high speed hence two separate fast transients signals can be easily grabbed.
8.	The cost is less due to single beam	The cost is more due to two separate beams
9.	The two different modes of operation are alternate and chop	The two different types are using double gun tube or split beam using single electron gun

Sections of a CRO: Vertical amplifier

The sensitivity (gain) and frequency bandwidth (B.W) response characteristics of the oscilloscope are mainly determine by the vertical amplifier. Since the gain-B W. product is constant, to obtain a greater sensitivity the B.W. is narrowed, or vice-versa. The figure 2.8 shows the Block diagram of Vertical amplifier.

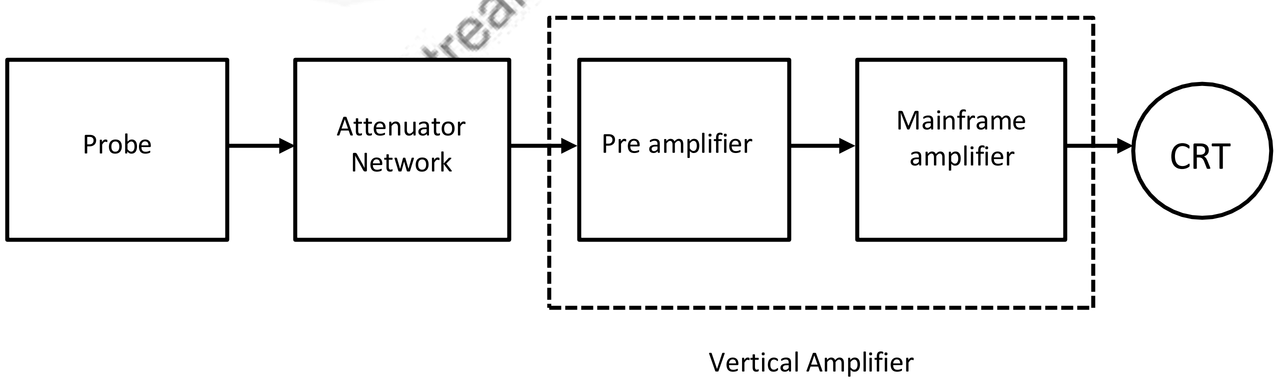


Figure 2.8: Block diagram of Vertical amplifier

Horizontal amplifier

Horizontal amplifier is used for two purposes that can be listed as follows:

1. When the oscilloscope is used in ordinary mode of operation then horizontal amplifier amplifies sweep generator output.
2. If X-Y mode is used the signal to horizontal amplifier is amplified.

A push pull amplifier is applied in case of vertical amplifier; horizontal amplifier also contains a push-pull amplifier. The block diagram of Horizontal amplifier is shown in figure 2.9:

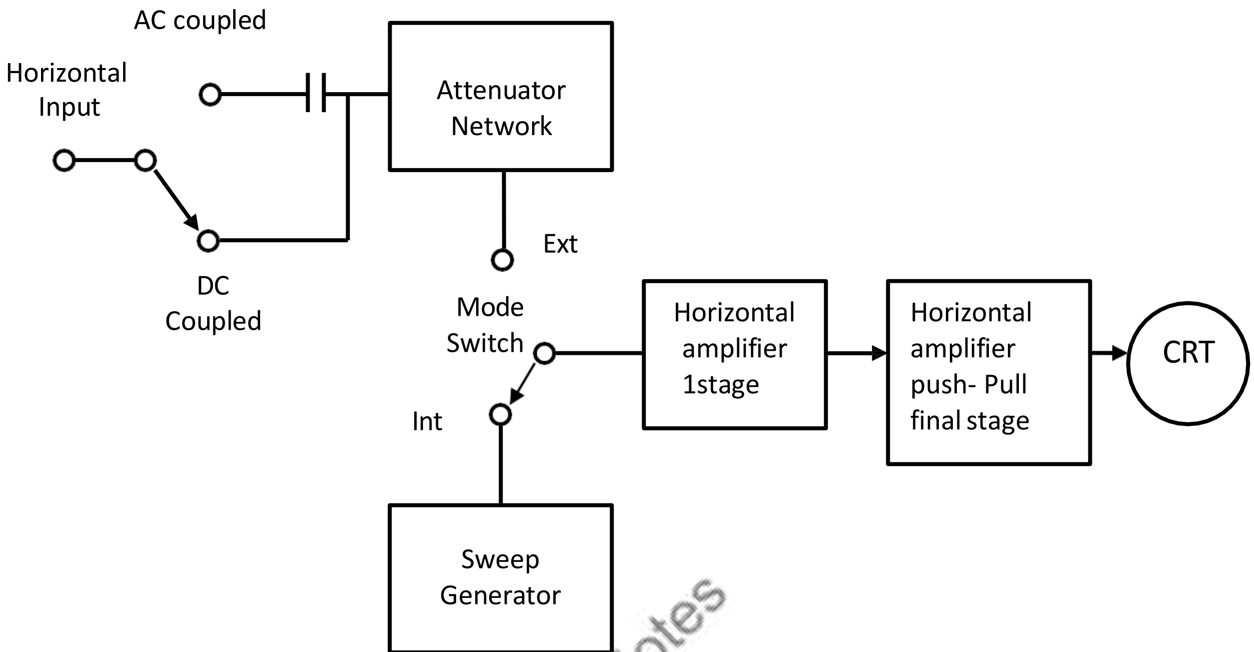


Figure 2.9: Block Diagram of Horizontal amplifier

Dual Beam Cathode Ray Oscilloscope

The dual-beam oscilloscope uses two electron beams that are displayed simultaneously on a single screen.

Construction of Double Beam Oscilloscope

There are two individual vertical input channels for two electron beams coming from different sources. Each channel has its own attenuator and pre-amplifier. The two channels may have common time base circuits. Each beam is applied on different channels for separate vertical deflection before it crosses a single set of horizontal plate. The horizontal amplifier consists of sweep generator to drive the horizontal deflection plate. Figure 2.10 shows the Block Diagram of Dual beam oscilloscope.

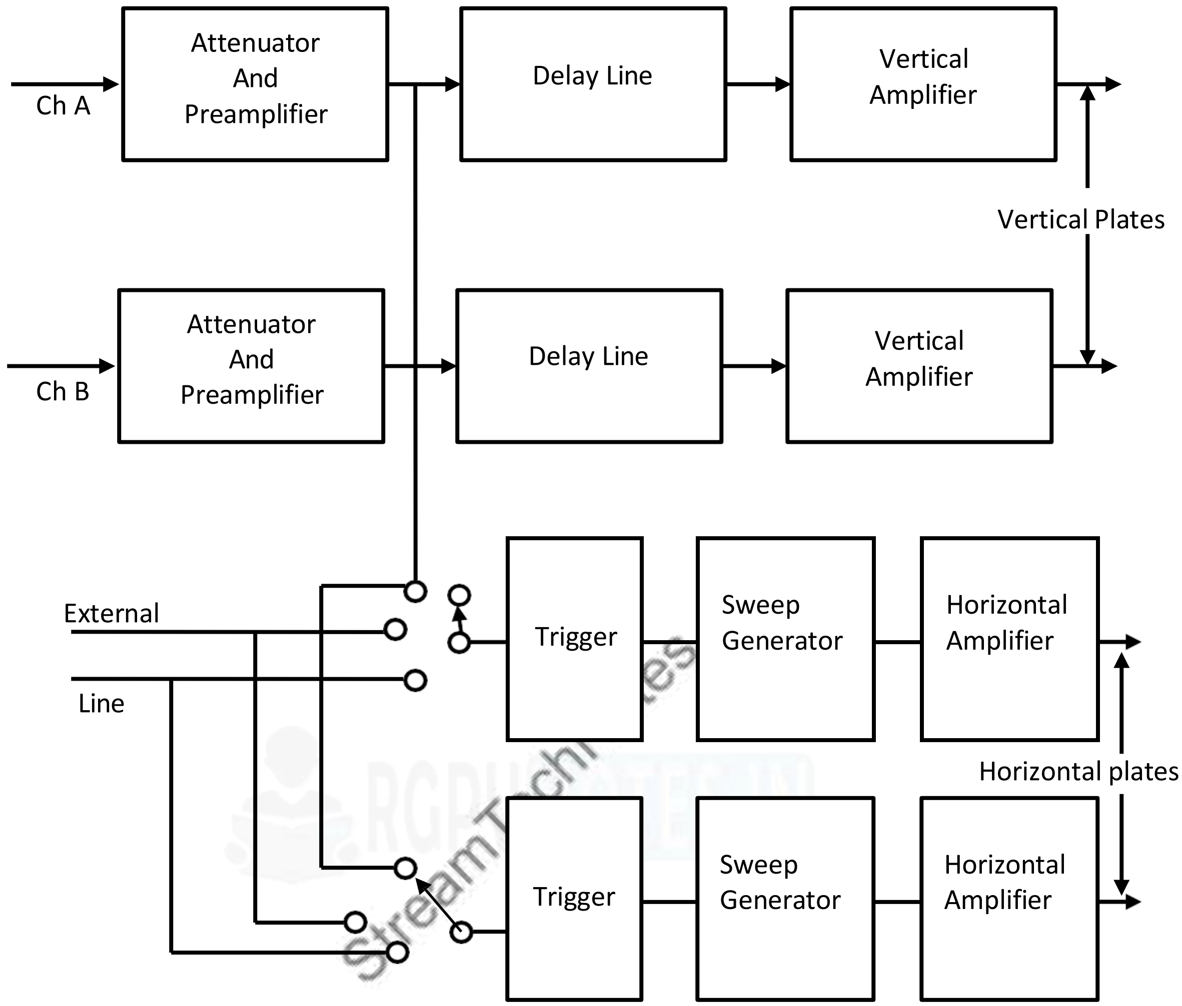


Figure2.9: Block Diagram of Dual beam oscilloscope

Dual beam oscilloscope generates two electron beams using double electron gun tube.

Digital storage oscilloscope

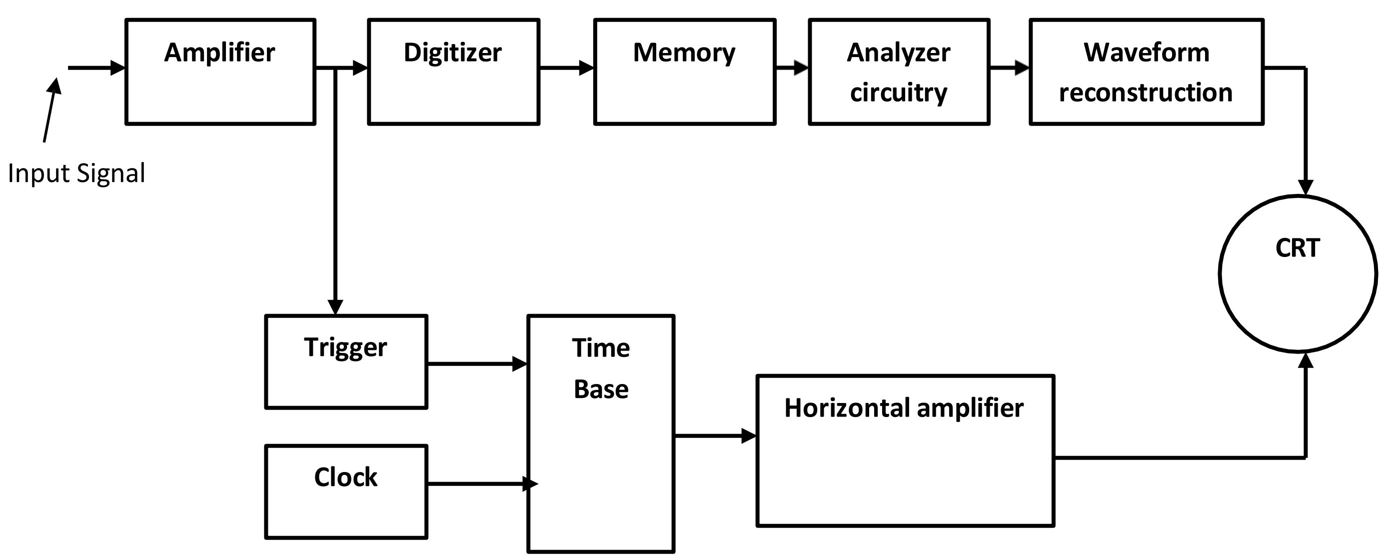


Figure 2.10: Block diagram of Digital storage oscilloscope

Digital oscilloscope is used for storing the waveform for further use. This is done by converting the analog signals to digital signals with the help of analog to digital converter and storing this digital data in the memory devices. Whenever the signal is required it is again converted into analog signal with the help of digital to analog converter. The figure 2.10 shows the block diagram of digital storage oscilloscope.

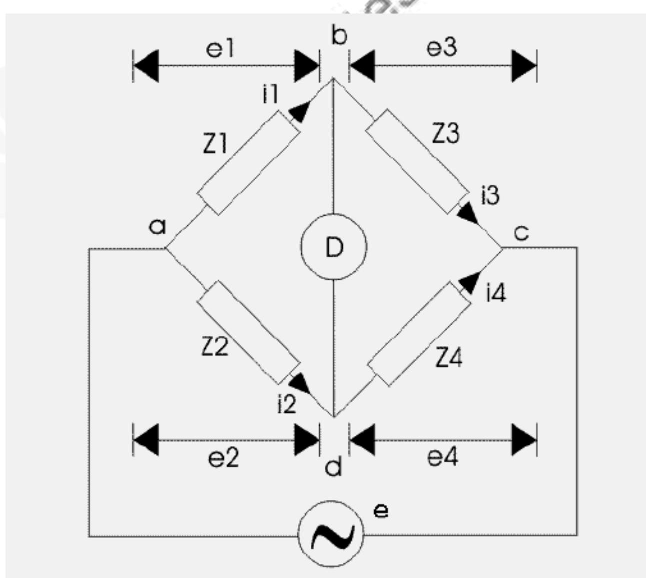
Bridges:

The four impedances of an a.c. bridge as shown in fig.2.11.

Z_1= 400Ω $\angle 50°$, Z_2= 200Ω $\angle 40°$, Z_3= 800Ω $\angle -50°$ and Z_4= 400Ω $\angle 20°$

Find out whether the bridge is balanced under these conditions or not. Justify your answer.

Solution: Z_1= 400Ω $\angle 50°$, Z_2= 200Ω $\angle 40°$, Z_3= 800Ω $\angle -50°$ and Z_4= 400Ω $\angle 20°$



Fg.2.11: an a.c. bridge

The bridge is said to be balanced when the products of the magnitudes of the opposite arms must be equal while sum of the phase angles of the opposite arms must be equal.

$$Z_1 \cdot Z_4 = Z_2 \cdot Z_3 \text{..........} \textbf{magnitude condition}$$

$$\theta_1 + \theta_4 = \theta_2 + \theta_3 \text{..........} \textbf{phase condition}$$

Thus, the bridge is said to be balanced when both the conditions magnitude as well as phase are equal.

Equating magnitudes, we have

$|Z_1 Z_4| = 400 \text{ X } 400 = 1600$; $|Z_2 Z_3| = 400 \text{ X } 400 = 1600$

Thus, magnitude condition is satisfied.

Now, $\theta_1 = 50°$, $\theta 2 = 40°$, $\theta_3 = -50°$ & $\theta_4 = 20°$

$\theta_1 + \theta_4 = 50° + 20° = 70°$; $\theta_2 + \theta_3 = 40° + (-50°) = -10°$

Thus, phase angle condition is not satisfied. Hence, the bridge is not under balanced condition.

Maxwell Inductance Bridge is used for measurement of unknown inductance by comparing with a variable standard inductance. Figure 2.12 shows the setup of Maxwell Inductance Bridge.

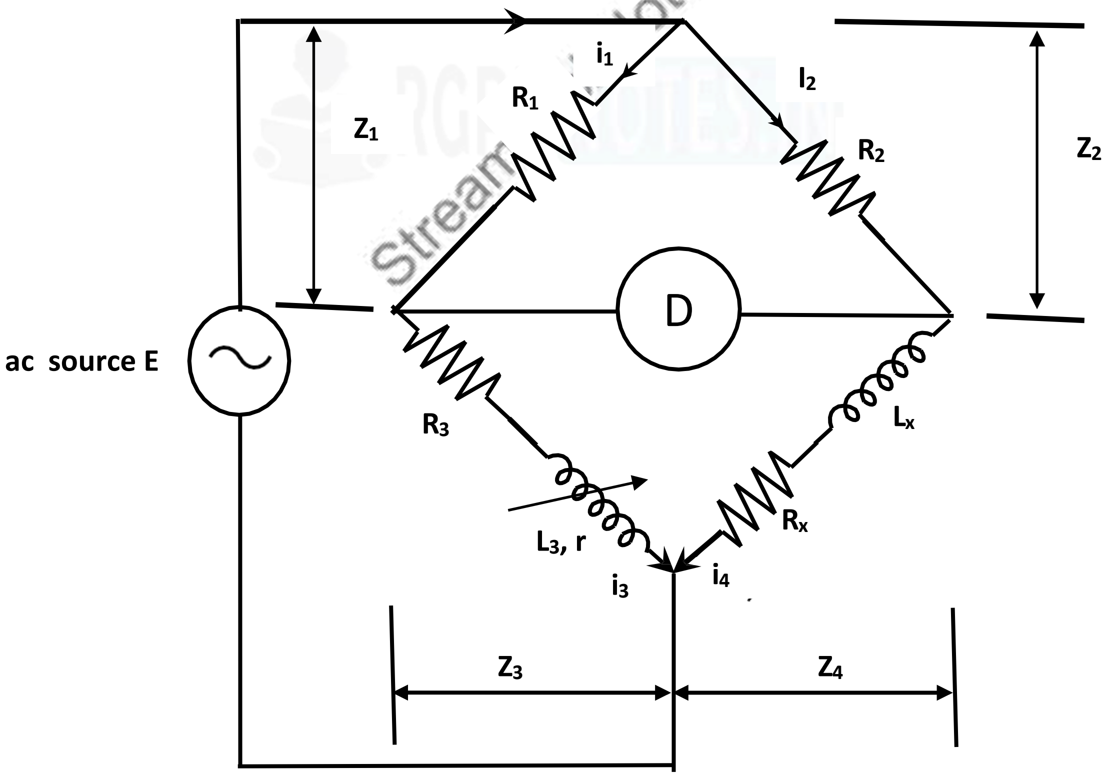


Figure 2.12: Maxwell Inductance Bridge

Bridge contains:

1) Two non-inductive resistances R_1 & R_2.

2) One of the arms consist variable inductance with series resistance r.
3) The remaining arm contains unknown inductance L_x.

At balance condition, $\mathbf{Z_1 \cdot Z_4 = Z_2 \cdot Z_3}$

$$\frac{R_1}{[(R_3 + r) + jwL_3]} = \frac{R_2}{R_x + jwL_x)}$$

$$R_1.(R_x + jwL_x) = R_2.[(R_3 + r) + jwL_3]$$

$$R_1.R_x + jwR_1.L_x = R_2.(R_3 + r) + jwR_2.L_3$$

Equating imaginary terms, we have

$$R_1L_x = R_2L_3 \implies L_x = R_2 \cdot (L_3/R_1)$$

$$\mathbf{L_x = R_2 \cdot \frac{L_3}{R_1}}$$

Equating real terms, we have

$$\mathbf{R_1R_x = R_2\,(R_3+r)}$$

$$\boldsymbol{R_x = \frac{R_2}{R1} \cdot (R_3 + r)}$$

Maxwell Inductance Capacitance Bridge

Maxwell Inductance Capacitance Bridge is used for measurement of unknown inductance with the help of variable resistor and capacitor. Figure 2.13 shows the setup of Maxwell Inductance Capacitance Bridge

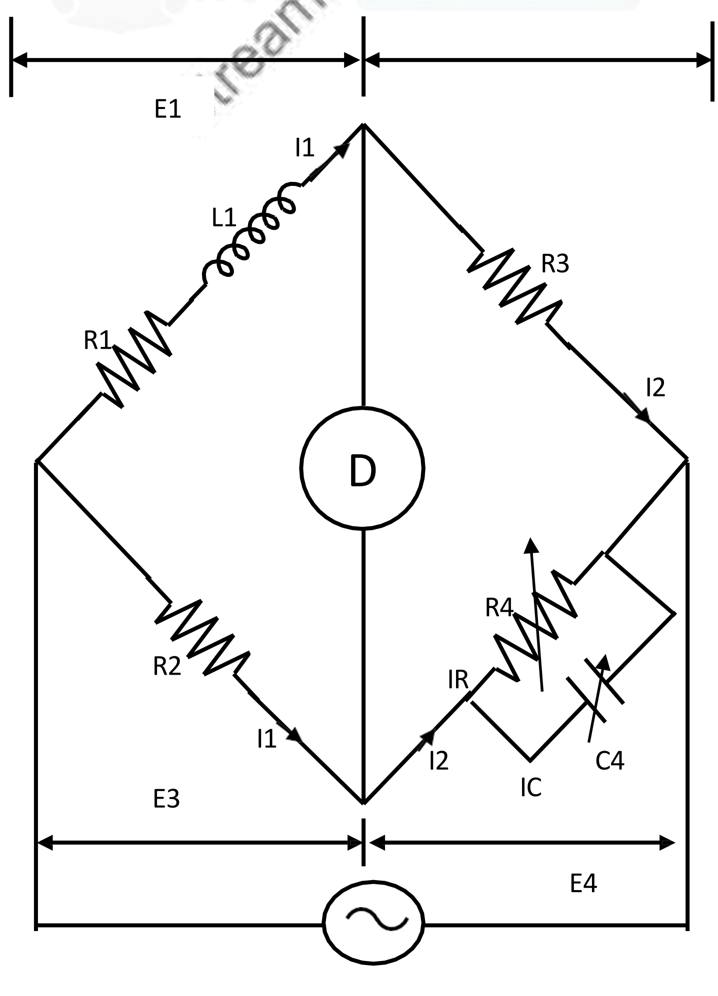


Figure 2.13: Maxwell Inductance Capacitance Bridge

Here, L1 is unknown inductance,
R1 is effective resistance of inductor L1
C4 is variable standard capacitor.
R2, R3, R4 are known non inductive resistance
Balance conditions Z1.Z4 = Z2.Z3

$$(R_1 + jwL_1)\left(\frac{R_4}{1 + jwC_4R_4}\right) = R_2R_3$$

$$R_1R_4 + jwL_1R_4 = R_2R_3 + jwC_4R_2R_3R_4$$

Separating real and imaginary parts

$$R_1R_4 = R_2R_3$$

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

$$jwL_1R_4 = jwC_4R_2R_3R_4$$

$$L_1R_4 = C_4R_2R_3R_4$$

$$L_1 = \frac{C_4R_2R_3R_4}{R_4}$$

$$L_1 = C_4R_2R_3$$

Quality factor $Q = \frac{wL_1}{R_1}$

Substituting the R1 and L1 in the above equation

$$Q = \frac{wC_4R_2R_3}{\frac{R_2R_3}{R_4}} = wC_4R_4$$

Advantages of Maxwell's Bridge

Advantages of Maxwell's bridge are

1. The frequency does not appear in any equation
2. Useful for measurement of inductor at audio frequencies.

Disadvantages of Maxwell's Bridge

1. Variable standard capacitor is very expensive.
2. The bridge is limited to measurement of low quality coils (1 < Q < 10).

Hay's Bridge

Referring fig. 2.14, Hay’s bridge is the modification of Maxwell Inductance Capacitance Bridge.
Here, L_1 is unknown inductance,
R_1 is effective resistance of inductor L_1
C_4 is standard capacitor.

R_2, R_3, R_4 are known non inductive resistance
Balance conditions $Z_1.Z_4 = Z_2.Z_3$

$$(R_1 + jwL_1)\,(R_4 - \frac{j}{wC_4}) = R_2R_3$$

$$R_1R_4 + jwL_1R_4 - \frac{jR_1}{wC_4} - \frac{j^2wL_1}{wC_4} = R_2R_3$$

$$R_1R_4 + jwL_1R_4 - \frac{jR_1}{wC_4} + \frac{L_1}{C_4} = R_2R_3$$

Separating real and imaginary parts

$$R_1R_4 + \frac{L_1}{C_4} = R_2R_3$$

And

$$jwL_1R_4 - \frac{jR_1}{wC_4} = 0$$

$$jwL_1R_4 = \frac{jR_1}{wC_4}$$

Or

$$wL_1R_4 = \frac{R_1}{wC_4}$$

Or

$$L_1 = \frac{R_1}{w^2C_4R_4}$$

Substituting L_1 in real term

$$R_1R_4 + \frac{\frac{R_1}{w^2C_4R_4}}{C_4} = R_2R_3$$

$$R_1R_4 + \frac{R_1}{w^2C_4^2R_4} = R_2R_3$$

$$w^2C_4^2R_1R_4^2 + R_1 = R_2R_3w^2C_4^2R_4$$

$R_1(1 + w^2C_4^2R_4^2)$=$w^2C_4^2R_2R_3R_4$

$$R_1 = \frac{w^2C_4^2R_2R_3R_4}{1 + w^2C_4^2R_4^2}$$

Substituting R_1 in imaginary term

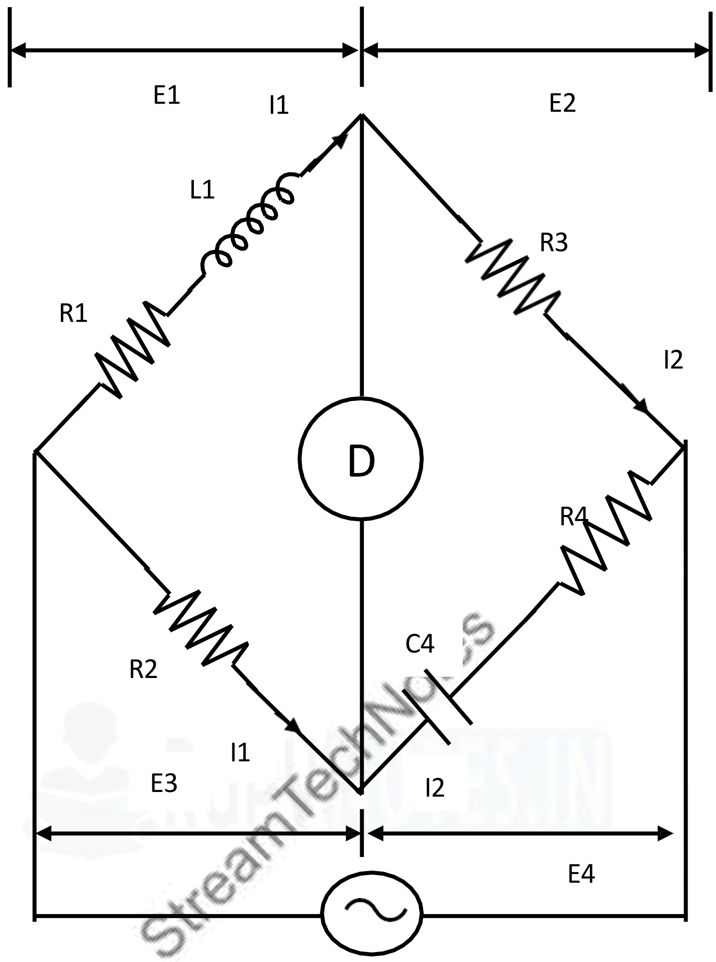
$$L_1 = \frac{\frac{w^2C_4^2R_2R_3R_4}{1 + w^2C_4^2R_4^2}}{w^2C_4R_4}$$

$$L_1 = \frac{R_2R_3R_4}{1 + w^2C_4^2R_4^2}$$

Quality factor of the coil $Q = \frac{wL_1}{R_1}$

Substituting the value of L_1 and R_1

$$Q = \frac{1}{wC_4 R_4}$$



AC source E

Figure 2.14: Hay's Bridge

Advantages:

1. This bridge gives a very simple expression for unknown inductance for high Q coils and is suitable for coils having q>10.
2. From the expression of Q it is clear that R_4appears in the denominator and hence the high coils its value is small. The bridge requires only a low value of resistor forR_4, where the Maxwell's bridge requires a parallel resistor of a very high value.

Disadvantages:

1. This bridge is suited for measurement of high Q inductors those inductor having Q greater than 10.
2. This bridge is not suited for measurement of low Q coils.

Schering Bridge: Used for measurement of unknown capacitance.
C_1 is unknown capacitance and r1 is series resistance indicating losses in capacitor
C_2 is standard capacitor

R_3 a non inductive resistance
R_4 variable non inductive resistance in parallel with capacitor C_4
At balance, $Z1.Z4 = Z_2.Z_3$

$$(r_1 + \frac{1}{jwC_1})(\frac{R_4}{1 + jwC_4R_4}) = \frac{1}{jwC_2}R_3$$

$$(r_1 + \frac{1}{jwC_1})\, xR_4 = \frac{R_3}{jwC_2}(1 + jwC_4R_4)$$
$$(r_1 - \frac{j}{wC_1})\, xR_4 = -\frac{jR_3}{wC_2}(1 + jwC_4R_4)$$
$$(r_1 - \frac{j}{wC_1})\, xR_4 = -\frac{jR_3}{wC_2}(1 + jwC_4R_4)$$
$$r_1xR_4 - \frac{jR_4}{wC_1} = -\frac{jR_3}{wC_2} - \frac{j^2wC_4R_3R_4}{wC_2}$$

$$r_1xR_4 - \frac{jR_4}{wC_1} = -\frac{jR_3}{wC_2} + \frac{wC_4R_3R_4}{wC_2}$$

Separating real and imaginary terms:

Real Term

$$r_1xR_4 = \frac{C_4R_3R_4}{C_2}$$

$$r_1 = \frac{C_4R_3}{C_2}$$

Imaginary term

$$\frac{R_4}{C_1} = \frac{R_3}{C_2}$$
$$C_1 = \frac{C_2R_4}{R_3}$$

Dissipation factor $D = wC_1r_1$
Substituting the value of C_1 and r_1

$$D = \frac{C_2R_4}{R_3}x\frac{C_4R_3}{C_2}$$

$$D = wC_4R_4$$

Advantages:

1. C_1 can be measured with the help of R_3
2. $D = wC_4R_4$ .The frequency is fixed C_4 can be measured directly.

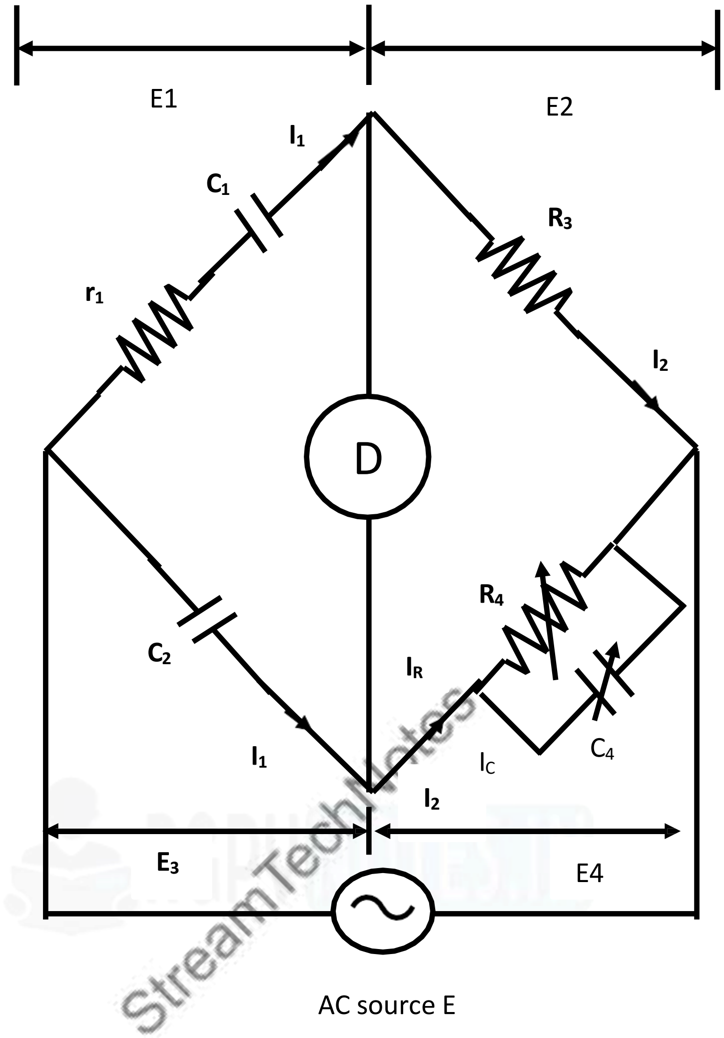


Figure 2.15: Schering Bridge

Wien's Bridge:

Measurement of unknown frequency is done with the help of Wien's Bridge.

$$Z1.Z4 = Z_2.Z_3$$

$$\left(\frac{R_1}{1 + jwC_1R_1}\right) R_4 = \left(R_2 - \frac{j}{wC_2}\right) R_3$$

$$\frac{R_1R_4}{1 + jwC_1R_1} = R_2R_3 - \frac{jR_3}{wC_2}$$

$$R_1R_4 = (1 + jwC_1R_1)\left(R_2R_3 - \frac{jR_3}{wC_2}\right)$$

$$R_1R_4 = R_2R_3 + jwC_1R_1R_2R_3 - \frac{jR_3}{wC_2} + \frac{C_1R_1R_3}{C_2}$$

$$R_1R_4 = R_3\left(R_2 + jwC_1R_1R_2 - \frac{j}{wC_2} + \frac{C_1R_1}{C_2}\right)$$

$$\frac{R_4}{R_3} = \frac{R_2}{R_1} + jwC_1R_2 - \frac{j}{wC_2R_1} + \frac{C_1}{C_2}$$

Separating real and imaginary terms:

Real terms:

$$\frac{R_4}{R_3} = \frac{R_2}{R_1} + \frac{C_1}{C_2}$$

Imaginary terms:

$$wC_1R_2 - \frac{1}{wC_2R_1} = 0$$

$$w^2C_1C_2R_1R_2 - 1 = 0$$
$$w^2C_1C_2R_1R_2 = 1$$

$$w^2 = \frac{1}{C_1C_2R_1R_2}$$

Or

$$\mathrm{w} = \frac{1}{\sqrt{C_1C_2R_1R_2}}$$

If w=2πf and C1=C2 and R1=R2

Then

$$\mathrm{f} = \frac{1}{2\pi \mathrm{CR}}$$

This bridge is difficult to balance unless the waveform of the applied voltage is sinusoidal.

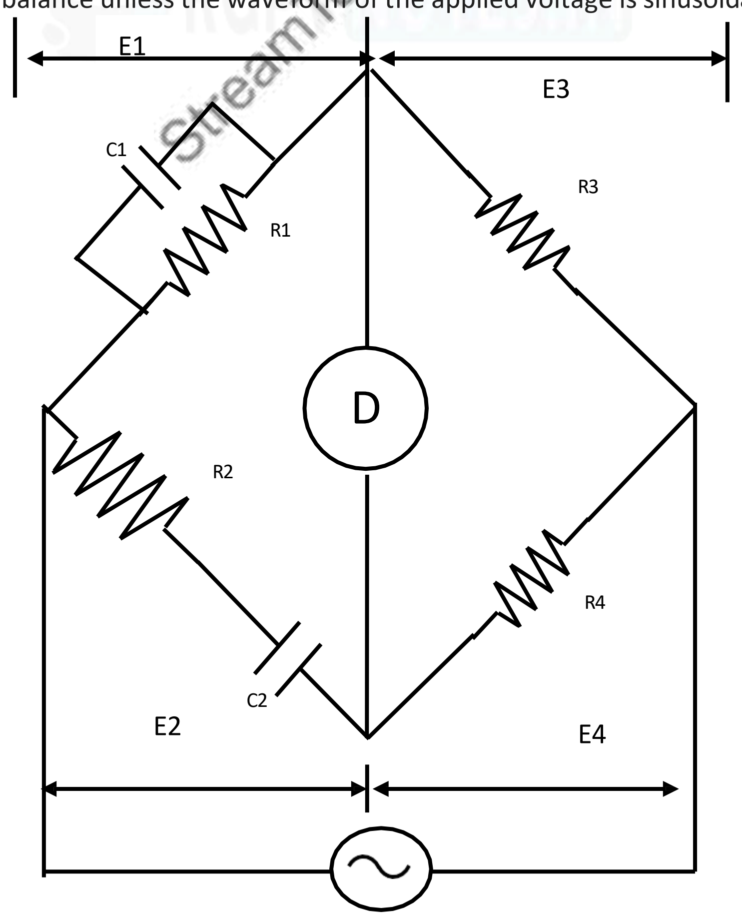
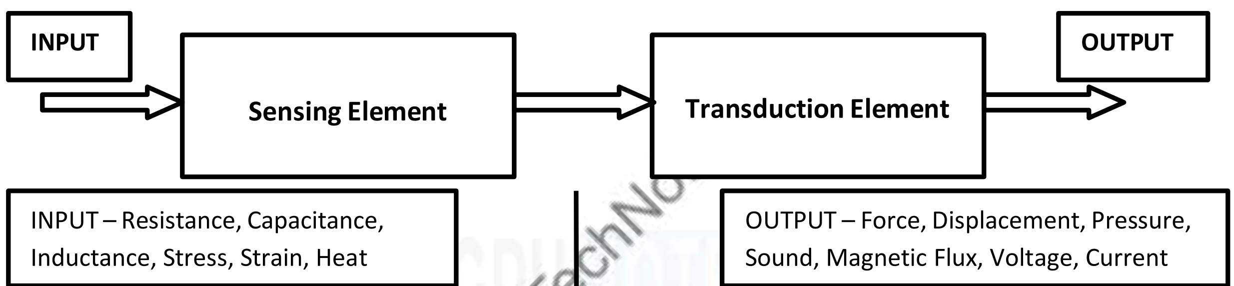


Figure 2.16: Measurement of frequency using Wien's bridge

Unit III

Non-Electrical Quantities (Transducer): Classification of Transducers, Strain gauge, Displacement Transducer Linear Variable Differential Transformer (LVDT) and Rotary Variable Differential Transformer (RVDT), Temperature Transducer- Resistance Temperature Detector (RTD), Thermistor, Thermocouple, Piezo-electric transducer, Optical Transducer- Photo emissive, Photo conductive, Photo voltaic, Photo-diode, Photo Transistor.

Transducer:
A transducer is a device that is used to convert a physical quantity into its corresponding electrical signal. In most of the electrical systems, the input signal will not be an electrical signal, but a non-electrical signal. This will have to be converted into its corresponding electrical signal if its value is to be measured using electrical methods.



Transducer Block Diagram

A transducer will have basically two main components. They are

1. Sensing Element

The physical quantity or its rate of change is sensed and responded to by this part of the transistor.

2. Transduction Element

The output of the sensing element is passed on to the transduction element. This element is responsible for converting the non-electrical signal into its proportional electrical signal.

There may be cases when the transduction element performs the action of both transduction and sensing. The best example of such a transducer is a thermocouple. A thermocouple is used to generate a voltage corresponding to the heat that is generated at the junction of two dissimilar metals.

Selection of Transducer

Selection of a transducer is one of the most important factors which help in obtaining accurate results. Some of the main parameters are given below.

- Selection depends on the physical quantity to be measured.
- Depends on the best transducer principle for the given physical input.
- Depends on the order of accuracy to be obtained.

The transducers are classified as follows:

(i) On the basis of transduction form used
(ii) Primary and secondary transducer
(iii) Passive and active transducer
(iv) Analog and digital transducer
(v) Transducer and inverse transducer

On the basis of transduction form used:

The transducer works on the basic principle of converting energy from one form to other. The energy transformation principle is resistive, inductive and capacitive. They can be classified as piezoelectric, photoelectric, thermoelectric etc.

Primary and secondary transducer:

Primary transducer is used to sense the physical quantity and convert the physical quantity into displacement. Like applying force on mass it provides the displacement from original position. This displacement is sensed by secondary which converts displacement into electrical quantity like LVDT (Linear variable differential transformer).

Passive and active transducer:

Passive transducer is the transducer which requires external electrical power supply to convert physical quantity to electrical signals like LVDT. LVDT requires external electrical power supply for measurement of displacement in terms of electrical signals.

Active transducer is the transducer which does not require any external electrical power supply to convert physical quantity to electrical signals like piezoelectric material. When force is applied material senses the force and converts this force into electrical quantity.

Analog and digital transducer:

Analog transducer converts input physical quantity into an analog output which is a continuous function of time signal .Like LVDT, RTD, Thermocouple etc are the Analog transducer.

Digital transducer converts input physical quantity into a digital signal in terms of pulses

Transducer and inverse transducer:

Transducer converts physical quantity like displacement, temperature, Liquid level etc into electrical signal as LVDT, Thermocouple is the example of Transducer.

Inverse Transducer converts electrical signals into physical quantity like piezoelectric material converts electrical quantity into sound signal is known as inverse transducer.

Strain gauge:

When any metal is stressed or compressed in those cases its dimension changes in form of length and diameter also there is change in the resistivity and this property is known as Piezo resistive effect. The strain gauge is used for measurement of strain and weight.

The relation between Resistance and dimensional change is given by:

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

Where R resistance of the metal

ρ Resistivity of the metal

L is the length of the metal
A is the area of the metal
D is the diameter of the metal

When the strain is applied on the metal its dimensions are change in terms of Length where the change in length is directly proportional to the Resistance and inversely proportional to change in diameter. When strain is applied the length increases and diameter decreases. The figure 3.11 shows the concept used in strain gauge.

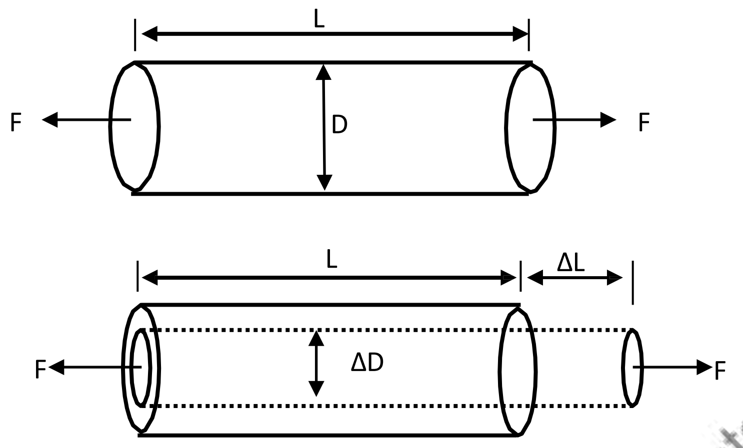


Figure 3.1: Change in the dimensions of a strain gauge element when subjected to tensile force

RTD (Resistance Temperature Detector):

RTD is used for measurement of temperature. The concept used is when temperature is applied on the conductor its resistance changes.RTD converts the temperature applied into electrical resistance.

The relationship between Resistance and temperature is expressed by:

$$R = R_o(1 + \alpha_1 T + \alpha_2 T^2 + \cdots)$$

R_o is resistance at temperature at T=0 and α_1, α_2 are constants.

The RTD is found in terms of resistive wire wounded on mandrel having two output terminals. The metal used is Platinum which provides the better relationship between changes in temperature to change in resistance. The value of resistance on 0°C is 100Ω and per degree centigrade change it provides the resistance temperature coefficient of 0.00385/ °C.RTD is positive temperature coefficient of resistance it means that when the temperature is increased its resistance also increases.

Thermistor:

Thermistor is used for measurement of temperature. Thermistor is made up of semiconductor material .Thermistor is negative temperature coefficient of resistance it means that when the temperature is increased its resistance decreases. The range of temperature for measurement is -60°C to 150°C. Thermistor is high sensitive devices in terms of linearity. Thermistor is made up of metallic oxide such as Mg, Ni, Cu and Fe. They are in the form of bead, Probe, rod and Disc. The figure 3.2 shows the bead type of Thermistor.

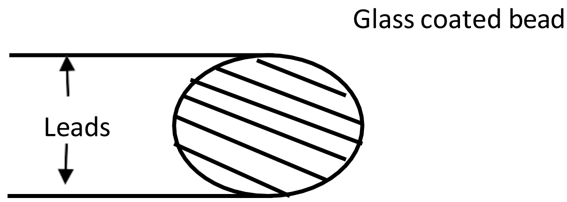


Figure 3.2: Bead type Thermistor

Resistance temperature relationship is expressed by:

$$R_{T1} = R_{T2} exp\, [\beta\, (\frac{1}{T_1} - \frac{1}{T_2})]$$

R_{T1} Resistance of the thermistor at absolute temperature T1
R_{T2} Resistance of the thermistor at absolute temperature T2
β Constant

Thermocouple:

Thermocouple is a device used for high temperatures. It is an active transducer which converts temperature in to electrical voltage without using external source of power supply. The concept used to form thermocouple is when the two dissimilar metals are joint together and one junction is kept at higher temperature with respect to other than the current flows from hot junction towards the cold junction a potential difference is created. Here one metal is used as iron and as a constantan which are joined together and the other end is connected to the junction box and the output of junction box is connected to the indicating instrument which the potential difference of two lead which are connected through the copper leads. The figure 3.3 set up for temperature measurement using thermocouple

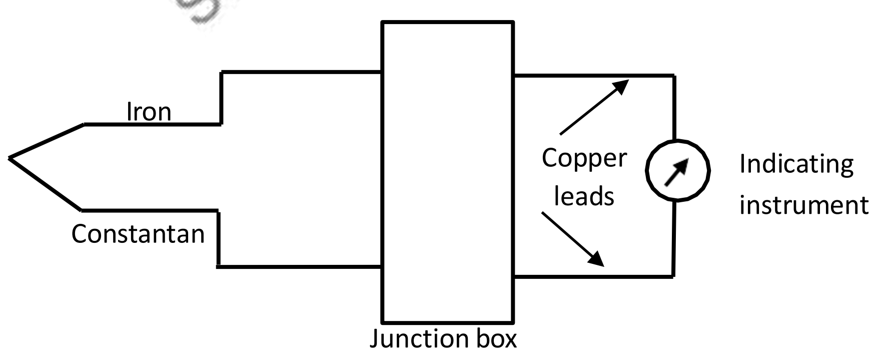


Figure 3.3: Set up for temperature measurement using thermocouple

The expression for emf produced is expressed by:

$$E = a(\Delta\theta) + b(\Delta\theta)^2$$

$\Delta\theta$ Difference in temperature between the hot junction and the reference junction

LVDT: Linear variable differential transformer

The linear variable differential transformer (LVDT) (also called just a differential transformer, linear variable displacement transformer, or linear variable displacement transducer) is a type of electrical transformer used for measuring linear displacement (position). A counterpart to this device that is used for measuring rotary displacement is called a rotary variable differential transformer (RVDT).

The LVDT converts a position or linear displacement from a mechanical reference (zero, or null position) into a proportional electrical signal containing phase (for direction) and amplitude (for distance) information. The LVDT operation does not require an electrical contact between the moving part (probe or core assembly) and the coil assembly, but instead relies on electromagnetic coupling.

LVDT is made up of primary and secondary winding of the transformer and an iron core is placed between the primary and secondary. The two secondary winding of the transformer are connected in series opposition to get the differential output. The two secondary windings have equal number of turns and the sum of two is equal to the number of turn of primary winding.

Working:

(i) **Null condition:** When the core is placed in middle with primary and two secondary winding and the AC source of supply is applied on the primary winding of the transformer then the flux linkage from primary to two secondary winding in the same manner through the concept of transformer action, so the emf induced in two secondary winding are equal and hence Es1=Es2 in that case the difference of two winding induced voltage is same and the output show null. The figure 3.4 shows the LVDT in null position.

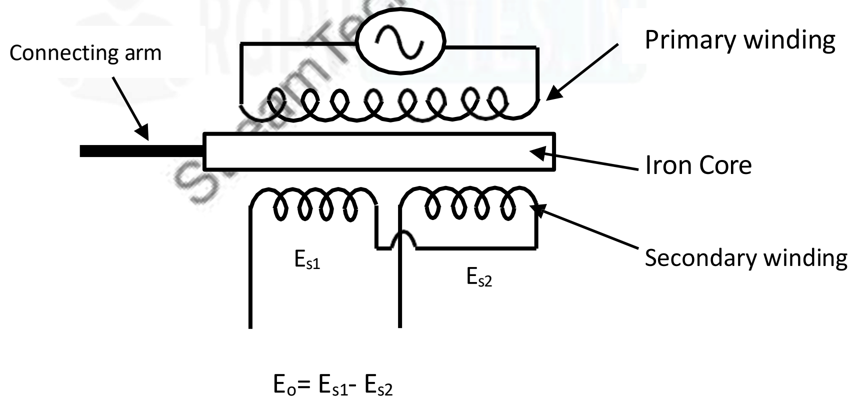


Figure 3.4: LVDT in null position

(ii) **Core at right side:** When the displacement is applied towards the right side then the maximum flux linkage shall takes place through the S2 winding and emf induced will be maximum as Es2.It means Es1 is smaller than Es2 and the output voltage is out of phase w. r. t applied input voltage. Hence the output is negative. The figure 3.5 shows the LVDT in right direction displacement.

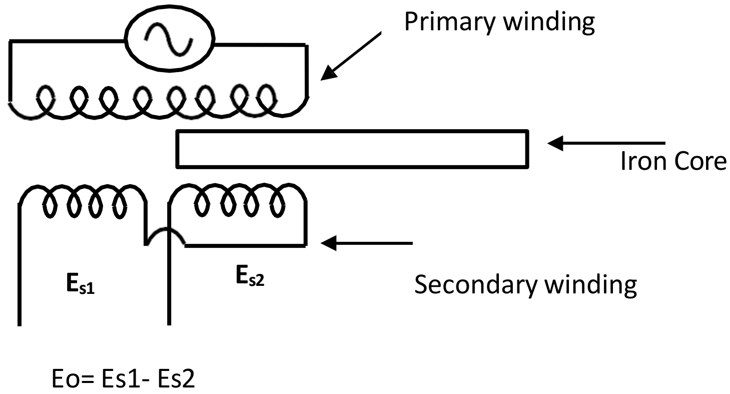


Figure 3.5: LVDT in right direction displacement

(iii) **Core at left side:** When the displacement is applied towards the left side then the maximum flux linkage shall takes place through the S1 winding and emf induced will be maximum as Es1.It means Es2 is smaller than Es1 and the output voltage is in phase w. r. t applied input voltage. Hence the output is positive. The figure 3.6 shows the LVDT in left direction displacement.

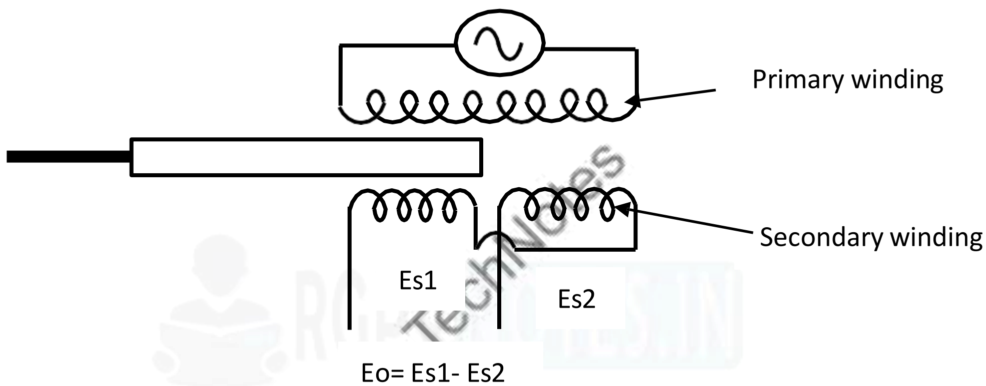


Figure 3.6: LVDT in left direction displacement

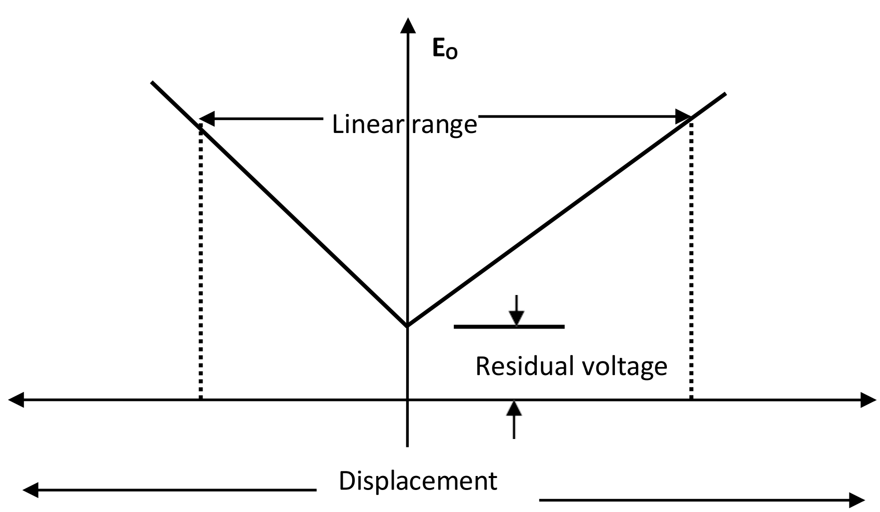


Figure 3.7 show the displacement versus Output voltage graph for movement in left and right direction

Rotary Variable Differential Transformer (RVDT):

RVDT is used for rotary displacement or angular displacement. At null of position of the core the output of secondary winding is equal to each other. When both the secondary winding is equal output is equal to zero. When the core rotate in clock wise direction the output is increasing and remains in phase and when in anti clock wise direction the output is increasing but out of phase. The figure 3 8 shows the diagram of rotary transducer.

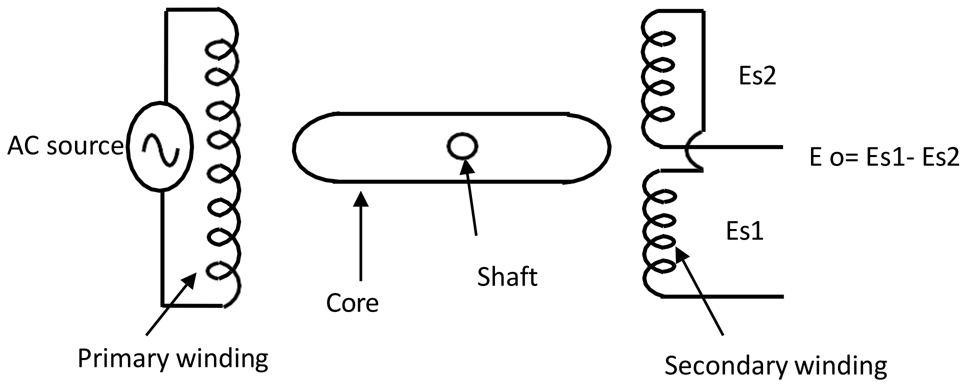


Figure 3.8 Diagram of rotary transducer

Piezo-electric transducer:

Piezoelectric transducer is used for measurement of force applied to it. It is an active transducer which does not require any type of external power supply for the measurement of physical quantity. When the force is applied on transducer it deforms and charge separation takes place which generate potential difference across the electrodes. This effect is called as piezoelectric effect. There are different types of piezoelectric materials which can be classified in two forms one is natural and other is synthetic. The example of natural materials is Quartz and Rochelle salt and synthetic material is lithium sulphate. When the force is applied its thickness decreases hence separation of charges takes place which are collected on electrodes. The figure 3.9 shows the piezoelectric effect when force is applied.

,

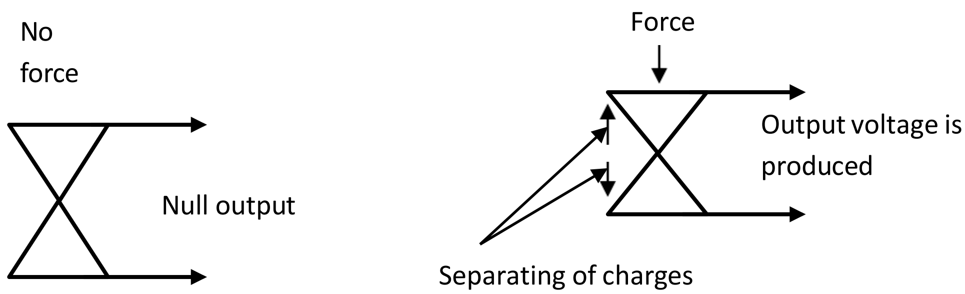


Figure 3.9 Piezoelectric effect

Photo conductive cell:

Photoconductive cell is used for detecting the light intensity. It is a passive transducer which requires external source of supply for its operation. It is also known as LDR means light

Dependent resistor. The material used for making the cell is Cadmium sulphide which is sensitive towards light when the light fall on the cell its resistance decreases and when light is not applied then it resistance increases. The figure 3.10 shows the setup of photoconductive cell for detection of light.

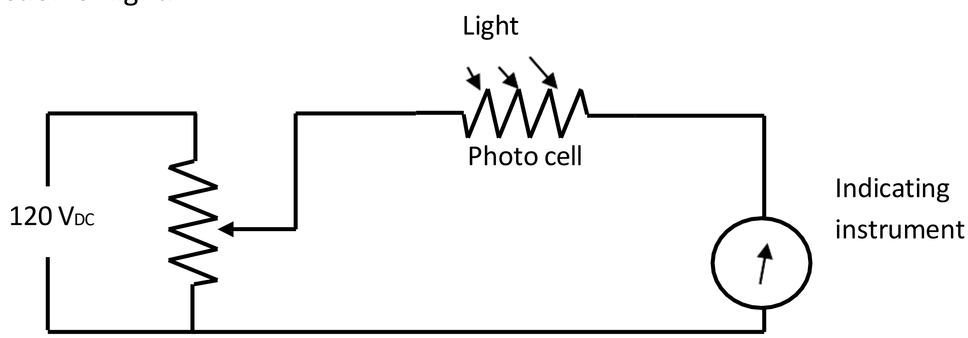


Figure 3.10 Setup of photoconductive cell for detection of light

When no light is applied on the photo cell its resistance is very high in that case indicating instrument shows a very small deflection in terms of current. When light is applied on the photo cell its resistance is very low in that case indicating instrument shows a large deflection in terms of current.

Photo voltaic cell:

Photo voltaic cell is used for converting light signal into electrical signal by using Gold doped germanium cells which are sensible towards the applied light. When the light signals are applied on the cells the electrons absorb and travels towards the p region with higher velocity and absorb y the load connected with the cells and electric current flows through the device. The gold is very sensitive towards light signal which is absorbed and provide this energy to germanium semiconductor to conduct current.

Photo-diode:

The photo diode works in reverse biased condition and only a small leakage current flows through the device if the junction is not exposed to light. When the photodiode junction is exposed to light then light in term of heat energy is applied on junction who is already reversed biased then due to avalanche break down the depletion reduces and rise of current is obtained. The current depends upon the applied intensity of light. As the intensity of light increases then the reverse leakage current also increases. Figure 3.11 shows the application of photodiode.

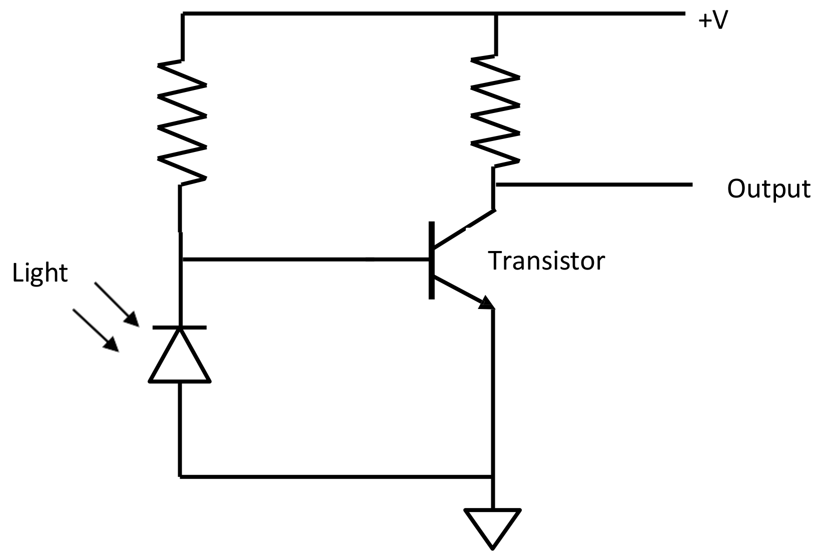


Figure 3.11 Application of photodiode

When no light is applied on the photodiode then it acts as open circuited it means the current applied flows through the base of the transistor it conduct and acts as a closed switch at that time output is zero. When the light applied on the junction the current flows through the photodiode and the current does not flow through the base of the transistor and it does not conduct and output is obtained.

Photo Transistor:

The sensitivity of photo diode can be increased by a factor of 100 by addition of a junction which makes it a NPN photo transistor. Illumination of the central region causes the release of electron hole pairs. This lowers the barrier potential across both junctions, causing an increase in the flow of electrons .For the small area when the light incident it provides much larger output current than that is available from a photo diode and therefore photo transistor is much more sensitive than a photo diode. The figure 3.12 shows the symbolic representation of photo transistor.

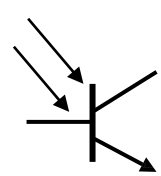


Figure 3.12 Symbolic representation of photo transistor

Unit IV

Signal and Function Generators, Sweep Frequency Generator, Pulse and Square Wave Generator, Beat Frequency Oscillator, Digital display system and indicators, Classification of Displays, Display devices: Light Emitting diodes (LED) and Liquid Crystal Display(LCD).

Signal Generator

Signal generator are used for trouble shooting and repair of faulty equipment like alignment of radio and TV circuits. Modulation facility is provided internally in signal generator. Frequency, Amplitude and Pulse modulation are most common used modulation shown in figure 4.1.

The block diagram for signal generator is shown in figure 1.Voltage controlled oscillator (VCO) is the heart of signal generator. The frequency of VCO is determined by voltage at control input. The audio signal drives the control input of oscillator to produce frequency modulated carrier.

The frequency accuracy and stability are very important for signal generators used to test receivers.

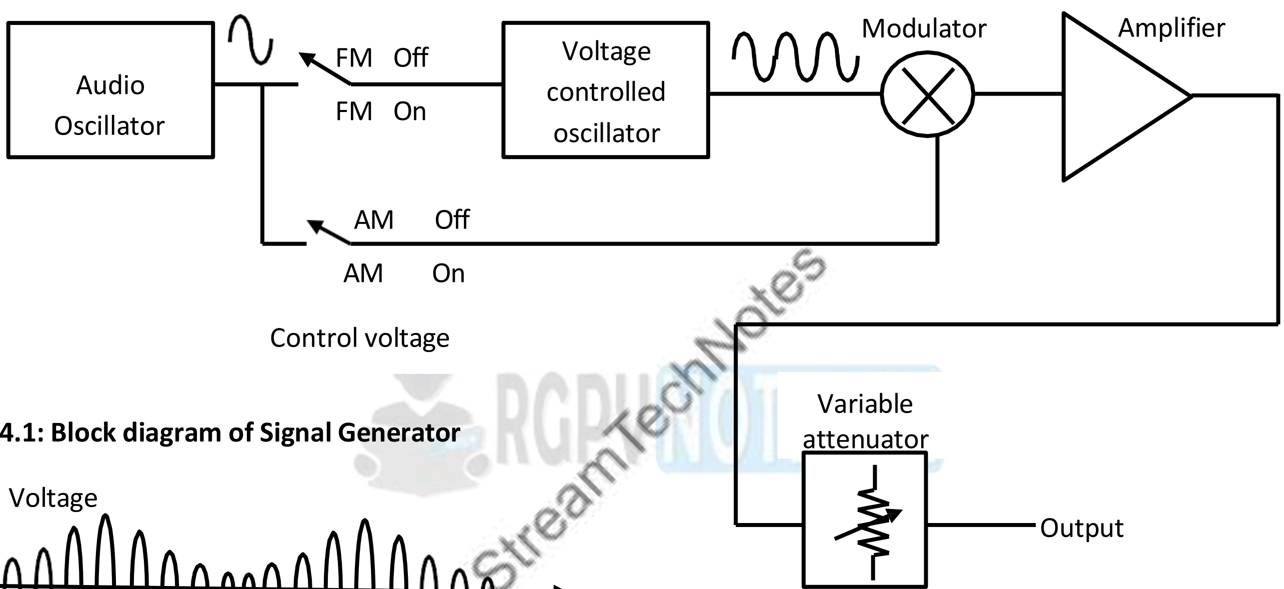


Figure 4.1: Block diagram of Signal Generator

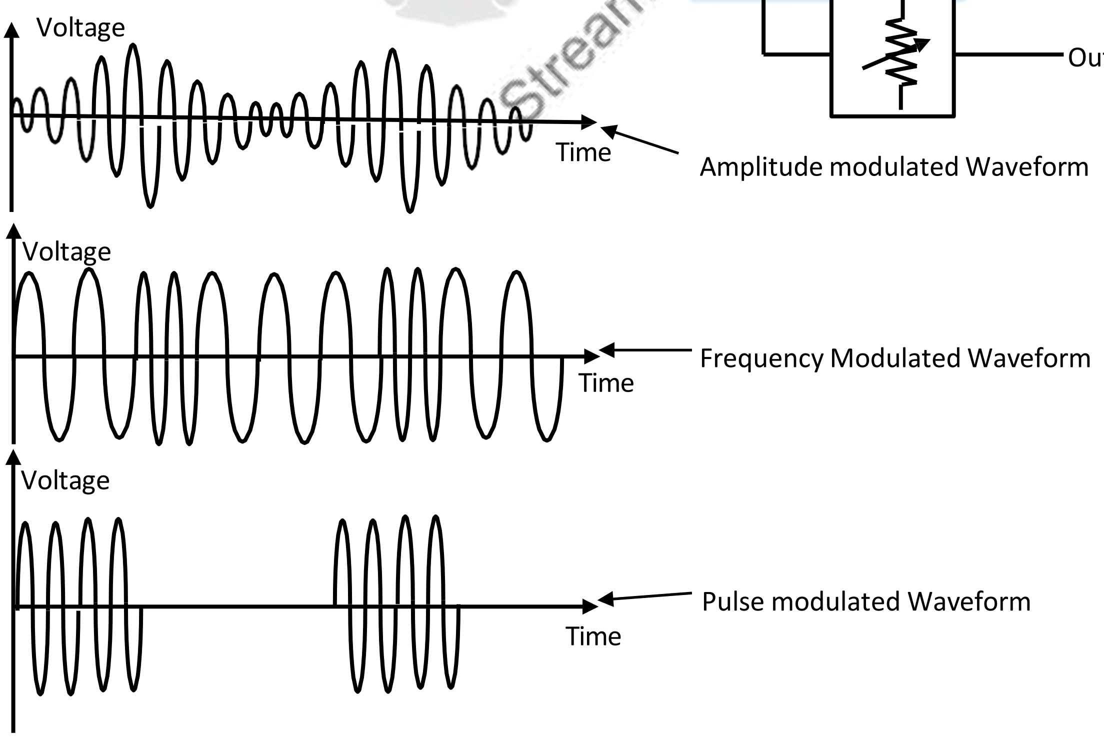


Figure 4.2 Waveform produced by Signal Generator

Function Generators

A function generator is an instrument which is used for generation of different type of waveforms whose frequency and amplitude can be varied. The most common waveform output are sine wave, triangular wave and square waveform having the frequency range of 0.01 Hz to 100 KHz. The frequency control voltage regulates two current sources. The upper current source supplies a constant current to the integrator whose output voltage increases linearly w. r. t time. The slope of waveform is increased or decreased by supplying current through upper constant current source. The voltage comparator multi vibrator changes its state at a level on the positive slope and switches the state at a level of negative slope. The lower constant current source applies a negative current which decreases the output of integrator in linear manner. The block diagram of function generator is shown in figure 4.3.

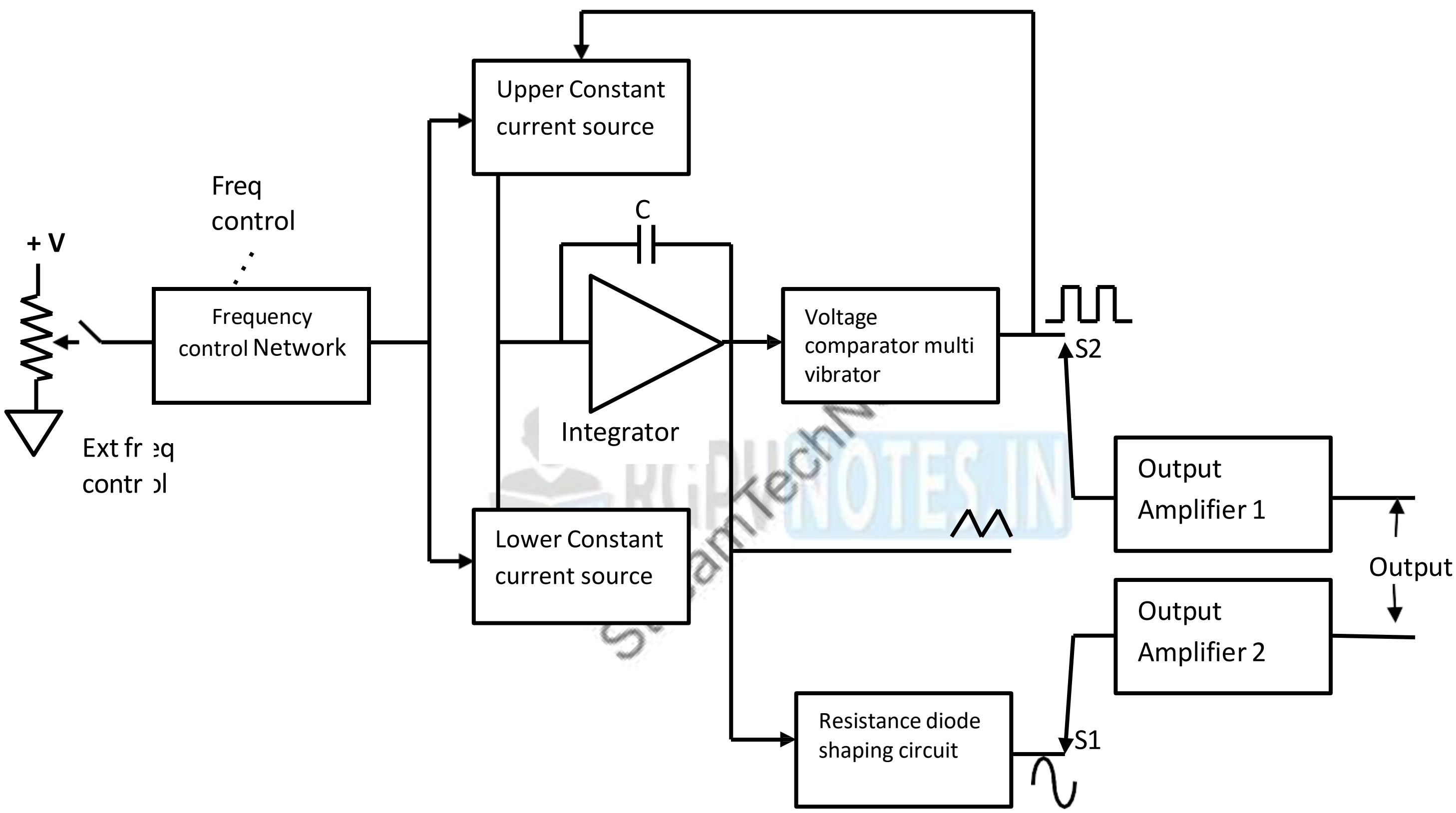


Figure 4.3 Basic elements of functional Generator

When the integrator output is applied to the resistance diode shaping circuit, it converts the triangular wave into sinusoidal waveform by shaping the triangular waveform. It is used for testing the instruments where sine, triangular or square waveform is used.

Sweep Frequency Generator

Sweep frequency generator is used for generating sine waves which can be swept over a wide frequency range in a short duration of time. It sweeps the frequency in linear manner. The signal produced is used for driving CRO for frequency response testing. Figure 4.4 shows the block diagram of sweep frequency generator.

The VCO is driven by Ramp generator to produce frequency sweep which is amplified and passes through the attenuator.

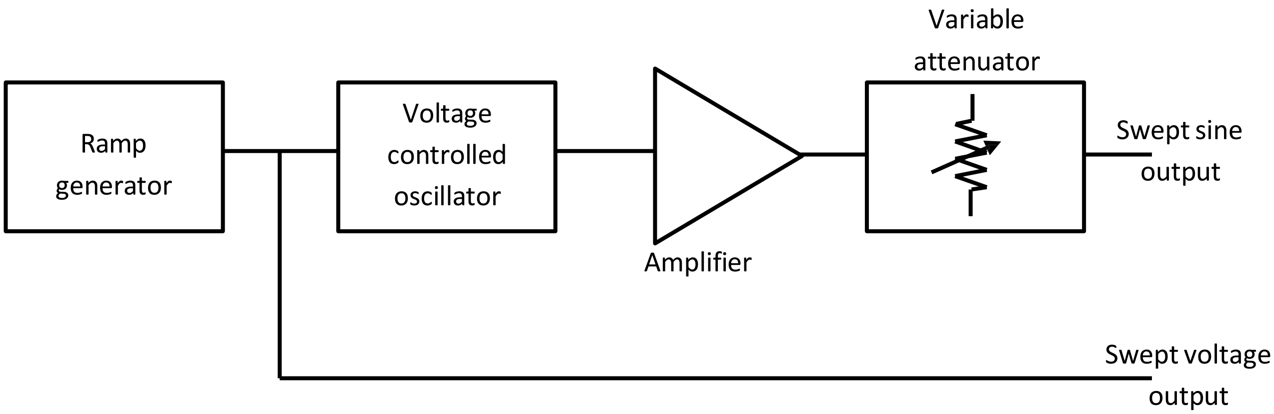


Figure 4.4 Block Diagram of a sweep generator

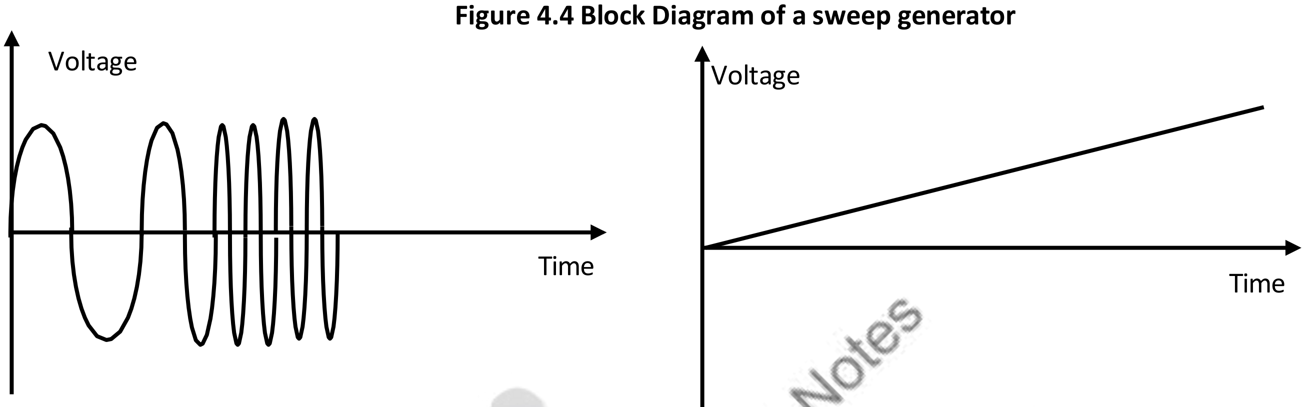


Figure 4.5 (i) Swept sine wave, (ii) Swept Voltage

Figure 4.5 shows the type of sweep generated by sweep frequency generator.

Pulse and Square Wave Generator

Pulse and Square Wave Generator is used with oscilloscope. Duty cycle is basic term which is used to differentiate between pulse and square wave. The duty cycle is defined as the ratio of pulse width to time period. Square wave has the duty cycle of 50% means that it has equal on time and off time. Pulse wave has the duty cycle between 50% to 95%.Very low short duration pulses have low duty cycle. The figure 4.6 shows the block diagram of Pulse and Square wave generator.

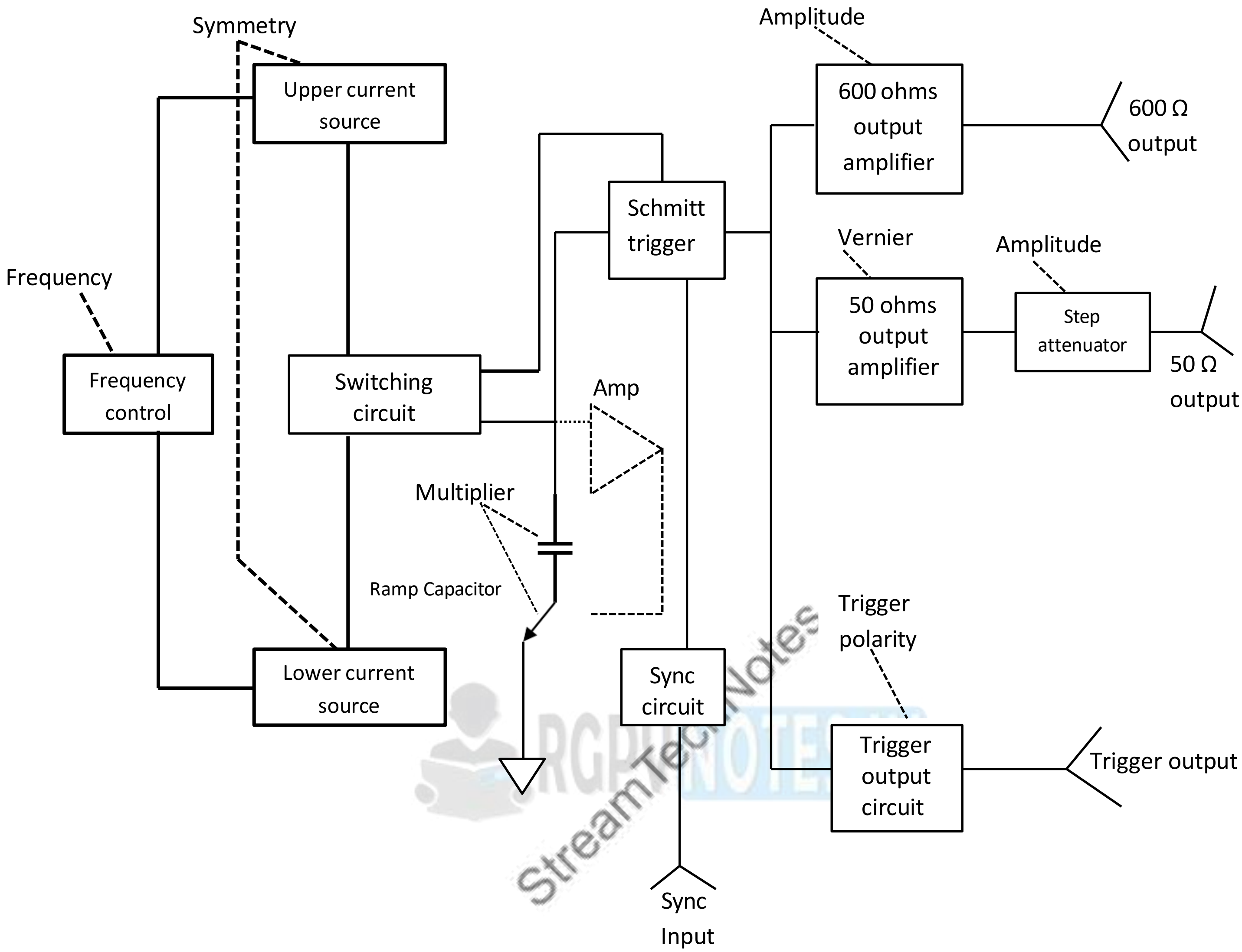


Figure 4.6 block diagram of pulse and square generator

Square waveforms are used for investigating the systems having low frequency characteristics. Pulses are used for measurement of transistor gain.

Pulse Characteristics and Terminology

1) Pulse Rise Time :The pulse rise time is the time needed for the pulse to go from 10% to 90% of its amplitude.
2) Pulse Fall Time:The pulse fall time is the time needed for the trailing edge to go from 90% to 10% of its amplitude.
3) Linearity: The linearity of a pulse is deviation from an edge from the straight line drawn through 10% to 90% points, expressed as percent of the pulse amplitude.
4) Pulse Preshoot: The pulse preshoot is deviation prior to reaching the base line at the start of the pulse. The overshoot is the maximum height immediately following the leading edge.

5) Ringing: It is the positive and negative peak distortion, excluding overshoot

6) Settling Time: It is the period needed for pulse ringing to be within a specified percentage of the pulse amplitude, measured from 90% point to the leading edge.

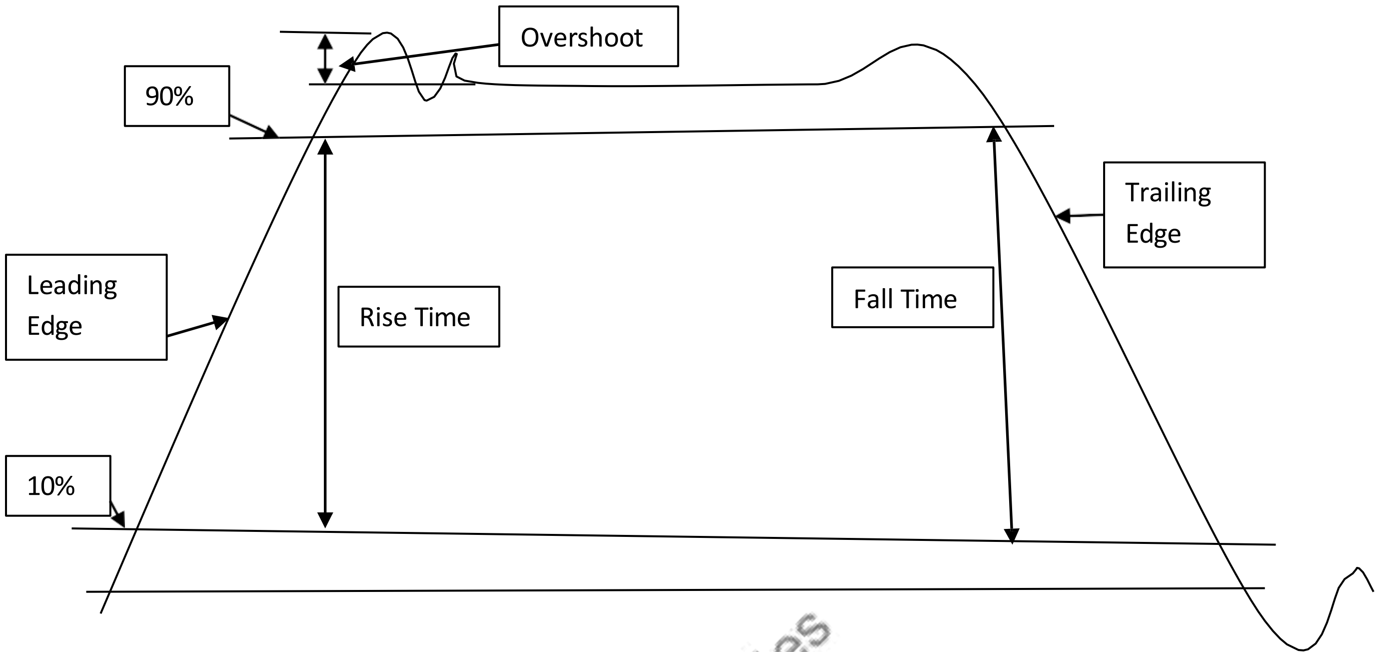


Figure Illustration of critical Pulse parameters

Beat Frequency Oscillator (BFO)

BFO is generally used to obtain variable frequency output in the range of audio frequency. Frequency dial is used for obtaining a wide range of frequencies. Figure 4.7 shows the block diagram of beat frequency oscillator. Variable frequency oscillator generates the audio frequencies in the range of 0 to 20 kHz in terms of the variable frequency which is applied to the mixer where the output of fixed frequency oscillator having the frequency of 100 kHz is mixed and obtains the output of mixer as difference of two frequencies has a range of 100 kHz to 120 kHz. Mixer output is amplified using AF amplifier.

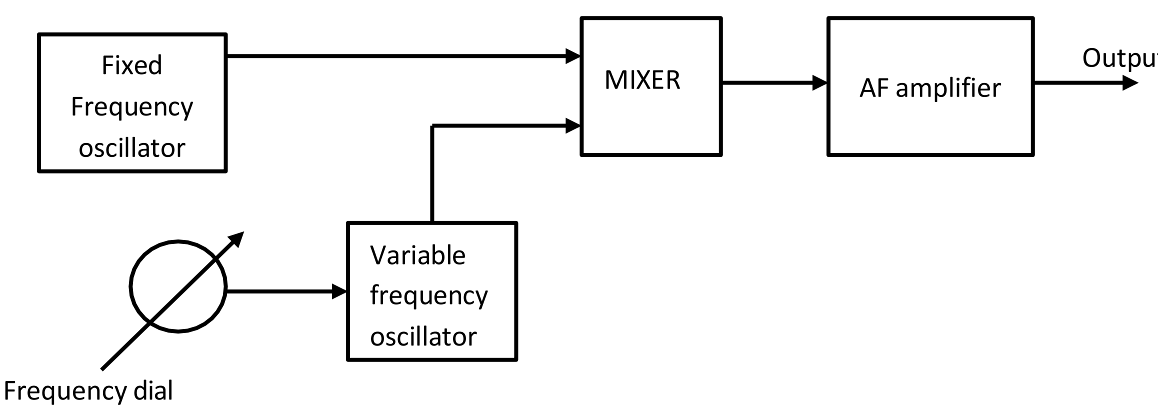


Figure 4.7 Beat Frequency Oscillator

BFO is not used now days because it is more complicated than that of Wien bridge oscillator.

Digital display system

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

Classification of Displays

Displays are classified as follows:

1. CRT
2. LED (Light emitting diode)
3. LCD (Liquid crystal display)

1. **CRT** is briefly defined in Unit II

2. **LED**

The LED is a semiconductor PN junction diode capable of emitting heat radiation in visible frequency spectrum depending on type of material used under forward biased condition.

Construction

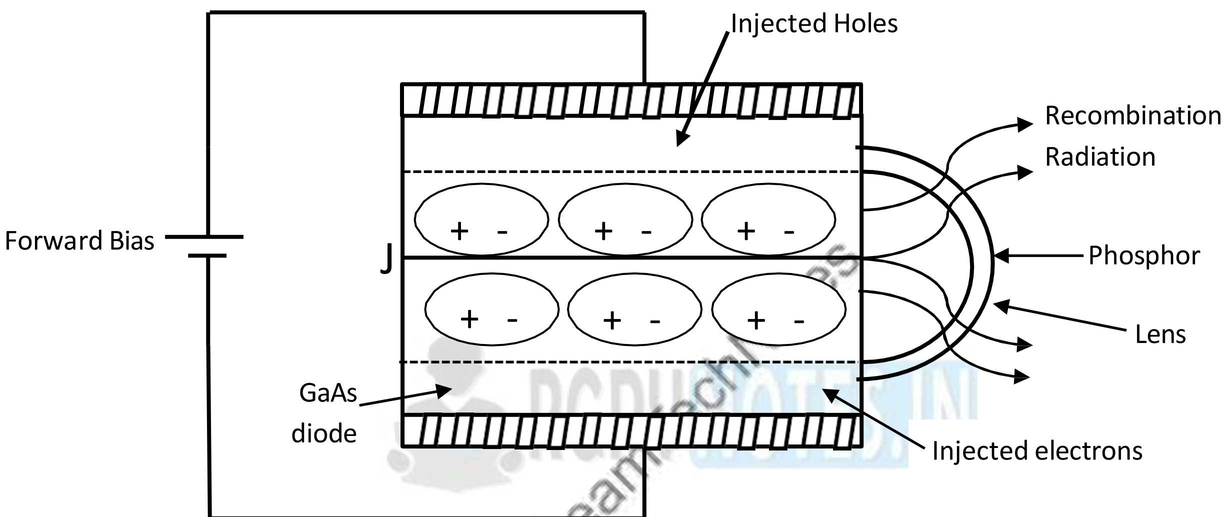


Figure 4. 8 Construction of LED

The construction of LED is shown in figure 4.8, when the LED is constructed in same manner as normal PN junction diode. In Ge and Si semiconductor most of the energy is released in the form of invisible heat radiation. When the Gallium Phosphide and Gallium arsenide Phosphide material is injected in LED then when the forward biased is applied on the diode maximum recombination of electrons and holes takes place near by the junction which emits the heat radiation in the form of light which strikes to Phosphor material to provide visible light. The color of light emitted depends on the semiconductor material and doping level.

Advantages of LED:

1. LEDs are very small device and can be considered as point source of light.
2. Operating voltages are very less as well power consumption is very less.
3. LED emits different color of light like red, green and yellow.
4. LEDs are very fast devices having a turn ON-OFF time of less than 1nsec.
5. Less in weight and long life.

Materials and colors:

Gallium Arsenide (GaAs) red color of light

Gallium Arsenide Phosphide (GaAsP) Red or yellow color of light

Gallium Phosphide (GaP) Green color of light.

3. **Liquid Crystal Display (LCD)**

LCD is a passive display device characterized by very low power requirement and good contrast ratio. The common characteristics are as:

1. They are light scattering.
2. It works in a reflective or transmissive configuration
3. It does not generate light and depend on back light for its operation.

The operation of LCD is based on the utilization of a class of organic materials which remains in a regular crystal like structure. The figure 4.9 shows the basic of LCD.

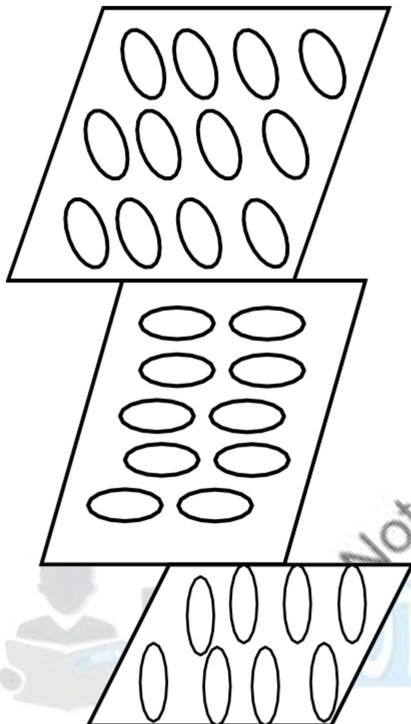


Figure 4.9 basic of LCD

The liquid is normally transparent but if it is subjected to strong electric field, ions moves through it and disrupts the well ordered crystal structure to reform and the material regains its transparency. Basically the LCD comprises of a thin layer of fluid about 10µm thick sandwiched between two glass plates having electrodes at least one of which is transparent.LCD is characterized by:

Low power dissipation, Low cost, large area and low operating speed.

LCDs are usually of the seven segment type for numeric use and have one common back electrode and seven transparent front electrode characters. The figure 4.10 shows the seven segment arrangement of transparent fronts.

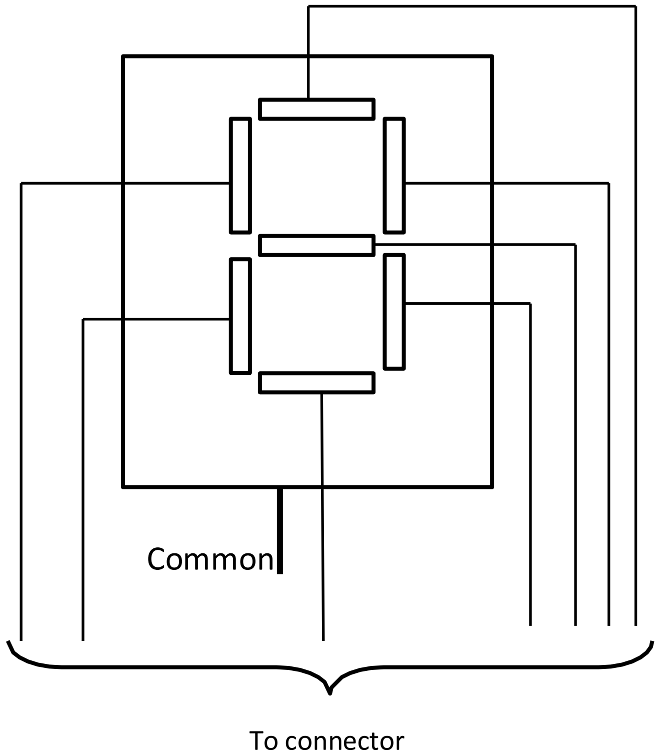


Figure 4.10 seven segment arrangement of transparent fronts with electrodes

Segment displays using LEDs

In segment displays it is usual to employ a single Led for each segment. For conventional seven segment LEDs display the wiring pattern is simplified by making one terminal common to all LEDs and other terminals corresponding to different segments. The terminals can be either of the common anode form or common cathode form. The figure 4.11 shows the LEDs seven segment Format.

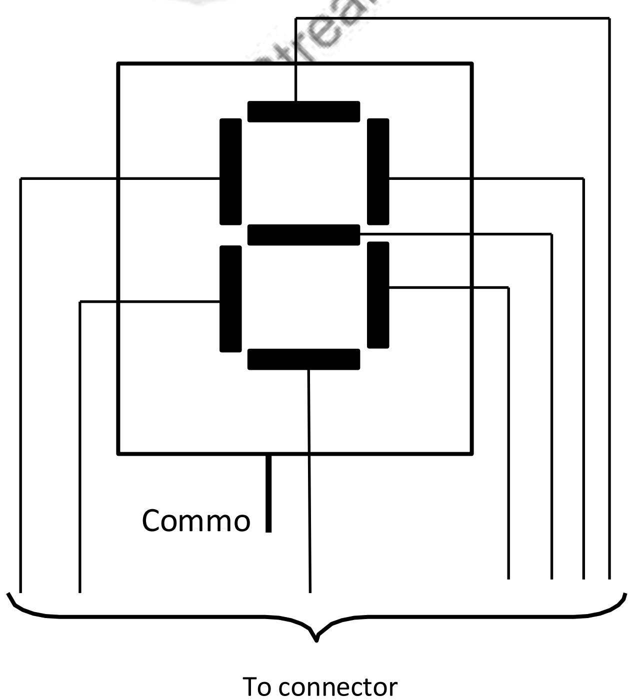


Figure 4.11 LEDs seven segment Format

Advantages of Digital Instrument over Analog Instrument, Digital-to-analog conversion (DAC) - Variable resistive type, R-2R ladder Type, Binary ladder, weighted converter using Op-amp and transistor, Practical DAC, Analog-to digital Conversion (ADC) -Ramp Technique, Dual Slope Integrating Type, Integrating Type (voltage to frequency), Successive Approximations. Digital voltmeters and multi-meters, Resolution and sensitivity of digital multi-meter

Advantages of Digital Instrument over Analog Instrument

(i) Parallax and approximation are eliminated by indicating the readings directly in decimal numbers

(ii) Any number of significant figures can be carried out positioning the decimal point.

(iii) As the output of digital instrument is in digital form so it can be stored in memory devices like tape recorders, floppy discs, hard discs and digital computers.

(iv) Digital instrument requires low power for their operation.

(v) Digital instruments are cheap and simple.

Digital versus Analog instrument

For choosing the analog or digital instrument depends on many factors which are as follows:

(i) **Accuracy:** Analog instruments have the accuracy with in ± 0.1 % of full scale range whereas Digital instruments can be made with greater accuracy.

(ii) **Reaction to the environment:** Analog instruments are relatively simple and operate under wide range of environment. Digital instruments are relatively complex and made up of various components hence affected by temperature.

(iii) **Resolution:** Analog instruments have resolution limit of one part in several hundred, whereas digital instruments have resolution limit of one part in several thousands.

(iv) **Power Requirements:** Power requirements for digital meters are negligible as compared to analog instruments. Input impedance of digital instruments is much higher as compared to analog instruments.

(v) **Cost and portability:** Analog instruments are portable and do not require any power supply for measurements and can be moved from one place to other easily, whereas digital instruments requires external power supply hence it may be not possible to move from one place to other.

(vi) **Range and Polarity:** Operator training, measurement error and possible damage of instrument through overloads are over come with the help of digital instrument.

(vii) **Freedom from observational errors:** Digital instruments are free from observational errors like parallax and approximation errors. They directly indicate the quantity being measured in decimal form with the help of digital displays.

Digital-to-analog conversion (DAC)

Digital to analog conversion involves translation of digital information into equivalent analog information.

Variable resistive type

This type of digital to analog converter works by designing a resistive network which changes each of the digital levels into an equivalent binary weighted voltage. For understanding the binary weight consider the truth table having 3 bit binary signal in table no.5.1

Table no.5.1 for a 3 bit Binary

Binary weighted voltage			Analog signal
MSB		LSB	
$2^2=4$	$2^1=2$	$2^0=1$	
0	0	0	0
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	4
1	0	1	5
1	1	0	6
1	1	1	7

From the truth table it is clear that smallest number represented by 000 is 0 volts and 111 is 7 Volts. The smallest number present is 2^0 .The resistive network is designed such that a 1 in the 2^0 position causes 7x1/7=1 V at the output. 2^1 bit causes an output change of 7x2/7= 2 V and so on up to the last bit conversion. The binary equivalent weight assigned to the LSB is $\frac{1}{2^n-1}$ where n is the number of bits. Figure 1 shows the block diagram of resistive type DAC.

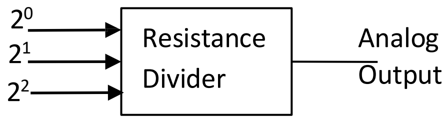


Figure 5.1 Resistive type DAC

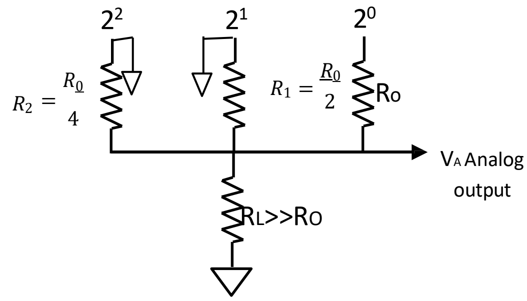


Figure 5.2 Resistive ladder

R_0, R_1 and R_2 forms the resistive network, RL is the load to which divider is connected. If 001 is the input applied then 2^2 and 2^1 must be connected to ground as shown in figure 5.2.

Millman's theorem is used to determine analog output V_A which states that the voltage obtained on any node in a resistive network is equals to the summation of the current entering the node divided by the summation of the conductance connected to the node.

The expression of Millman's theorem is expressed by:

$$V = \frac{\frac{E_1}{R_1} + \frac{E_2}{R_2}}{\frac{1}{R_1} + \frac{1}{R_2}}$$

Drawbacks:

1. Each resistance in the network has different value.
2. The resistance used in MSB is required to handle large current.

R-2R ladder Type

The R-2R ladder type DAC is constructed by only two resistors having the value of R and 2R which eliminate the drawback of binary weighted resistor. The figure 5.3 shows the R-2R ladder type DAC.

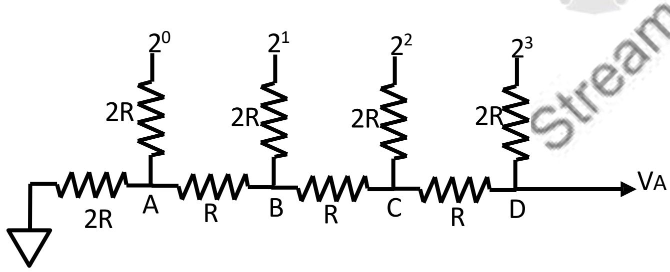


Figure 5.3 R-2R ladder type DAC

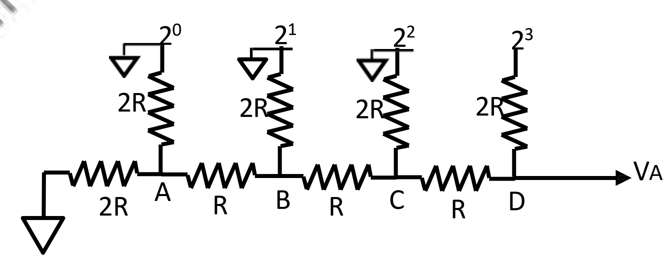


Figure 5.4 1000 bit arrangements

The figure 5.4 shows the resistors arrangement for R-2R ladder in which four bits are defined by four terminals as shown where three terminals are grounded and one terminal is connected to +V to show 1000 which provides the output of 8V at VA.

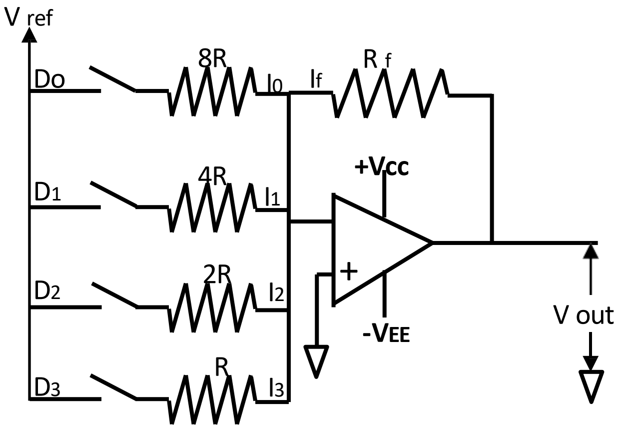
Binary weighted resistance converter using operational amplifier:

The resistor used for conversion of digital information into analog form is binary weighted like R, 2R, 4R, 8R etc.

It consists of following:

(i) On-Off Switches
(ii) Binary weighted resistors
(iii) Reference source
(iv) Current to voltage converter using operational amplifier

The figure 5.5 shows the circuit arrangement .Operational amplifier is used in inverting mode for conversion of digital signal to analog form. When the input is applied to the input of operational amplifier it provides the output in out of phase form with respect to applied input signal. The resistive network consists of four resistors weighted in terms of binary numbers, so it converts the four bit binary number into analog number. All the resistors are connected in parallel form, so that individual binary bit can be applied on four resistors. The input is applied to the resistors by using switches which can switch the input between 1 and 0 or high and low input.



$$I_{in} = I_0 + I_1 + I_2 + I_3$$

Where $I_3 = \frac{V_{ref}}{R}, I_2 = \frac{V_{ref}}{2R}, I_1 = \frac{V_{ref}}{4R}, I_0 = \frac{V_{ref}}{8R}$

$$I_{in} = \frac{V_{ref}}{8R} + \frac{V_{ref}}{4R} + \frac{V_{ref}}{2R} + \frac{V_{ref}}{R}$$

$$I_{in} = \frac{V_{ref}}{R}\left(\frac{1}{8} + \frac{1}{4} + \frac{1}{2} + 1\right)$$

$$I_{in} = \frac{V_{ref}}{R}(D_3 + 2^{-1} D_2 + 2^{-2} D_1 + 2^{-3} D_1)$$

Figure 5.5 Digital to Analog converter using operational amplifier

Weighted converter using transistor

Figure 5.6 shows a circuit diagram of weighted converter using transistor.

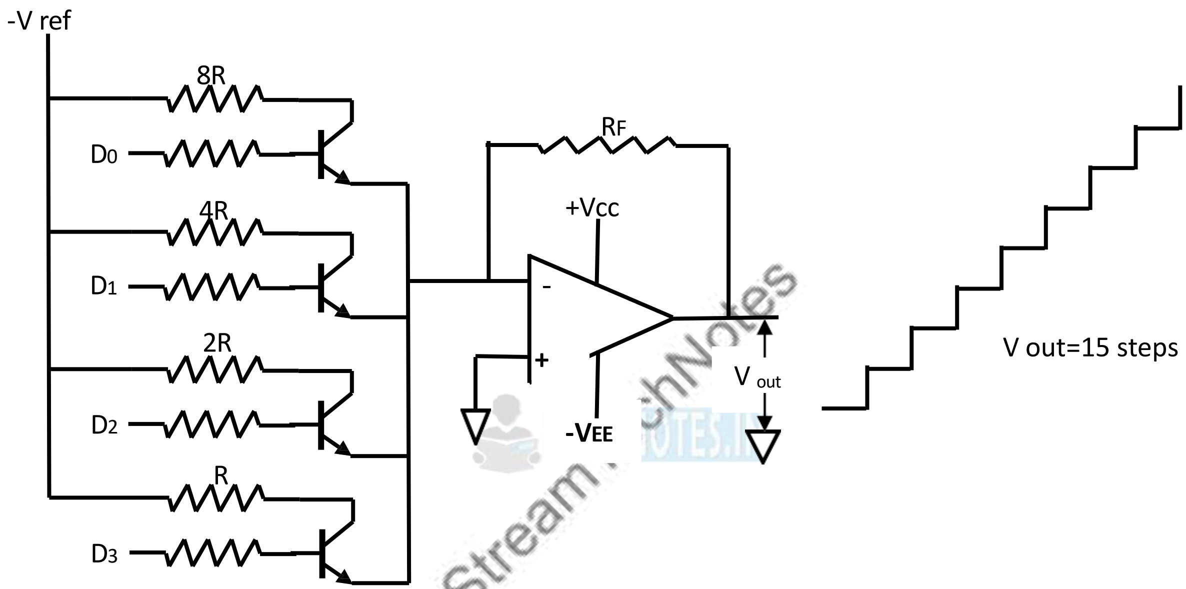


Figure 5.6 weighted converter using transistor with its output waveform

When any one of the input is high the base current flow through that transistor and it saturates. When D bit is low of any one the transistor it remains in off state. For the applied digital binary signal a relative voltage is generated which provides the equivalent output in analog form and the output is seems to the staircase for the input 0000 to 1111.

Practical DAC

It consists of a resistor which is RS flip flop to store digital information. It has level amplifier between the register and resistive network .There is a form of gating the input to the register. Block diagram is shown in figure 5.7.

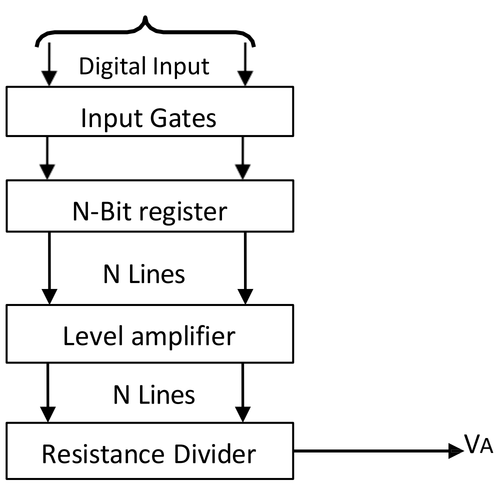


Figure 5.7 Block diagram of Practical DAC

The resistive network used is ladder type. The level amplifier have two input .one input is +`10 V from precision voltage source and the other is from FF. The amplifier works is to show the high input as 10 V and low input as 0V.Four flip flops are used to store digital information. Each flip flop is simple RS flip flop. When the line goes high, one of the two gates connected to the flip flop sets or reset. Hence data are entered into register each time the pulse occurs.

Analog to Digital converter

The function of Analog to Digital converter is to convert analog signal to digital equivalent.

Ramp Technique

When the analog signal is applied to the comparator and when it becomes equal to the input analog voltage the conversion would be complete. The figure 5.8 shows the block diagram of ramp type.

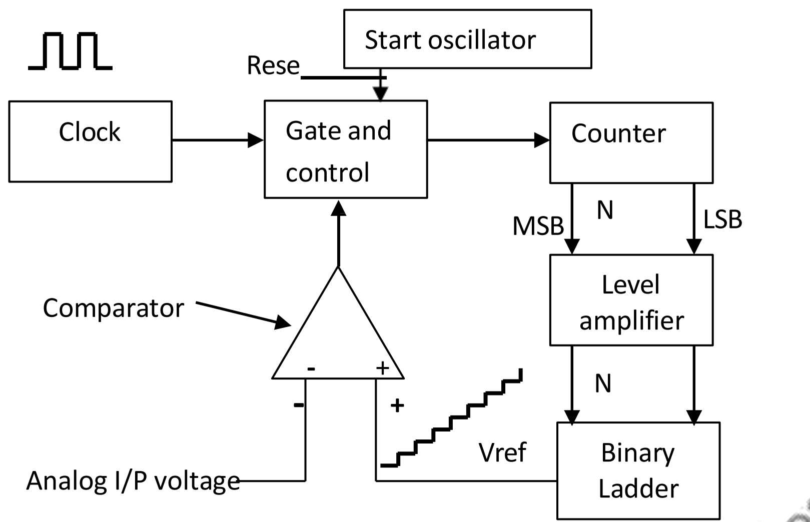


Figure 5.8 Ramp type ADC

Before starting the conversion the counter is reset to zero. When conversion signal appears on the start line the gate opens and clock pulses are allowed to pass through the input of the counter. The counter increment through its normal binary count sequence and the stair case waveform is generated at the output of the binary ladder. This staircase waveform input is applied to one side of the comparator and the analog Input voltage is applied to the other side. When the reference voltage is equals to the applied input voltage, the output of comparator goes low or zero and gate is closed the counter stops and the conversion is completed. The digits stored in the counter are now the digital equivalent of the analog Input voltage. This type of ADC converter can be readily considered as a closed loop control system. An error signal is generated at the output of the comparator by taking the difference between the analog I/P and input reference voltage. This error is detected by the gate and control circuit and the clock is allowed to advance the counter. The counter advances in such a way as to reduce the error signal by increasing the feedback voltage.

Advantage

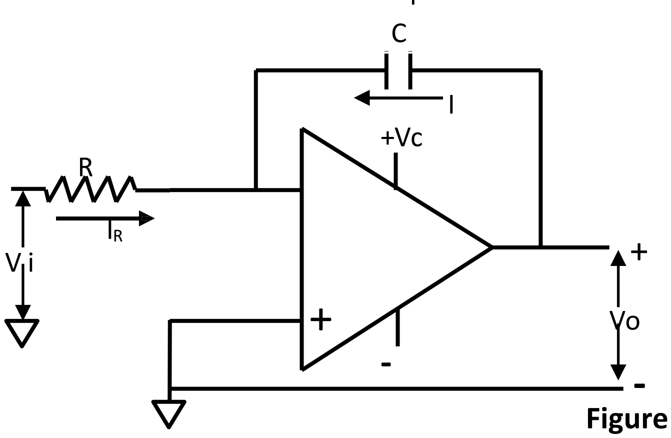
Very good method for digitizing analog signal to a high resolution

Disadvantage

Conversion time required is longer

Integrating Type (Voltage to Frequency method)

The heart of this converter is Ramp Generator. The circuit diagram of ramp generator is shown in figure 5.9.



$$V_o = -\frac{1}{C}\int i dt$$

$$V_o = -\frac{V_i}{RC} \times t$$

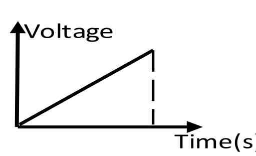


Figure 5.9 Ramp generator

The output voltage begins at zero and increases linearly up to a maximum voltage V m. The block diagram of Integration type is shown in figure 5.10.

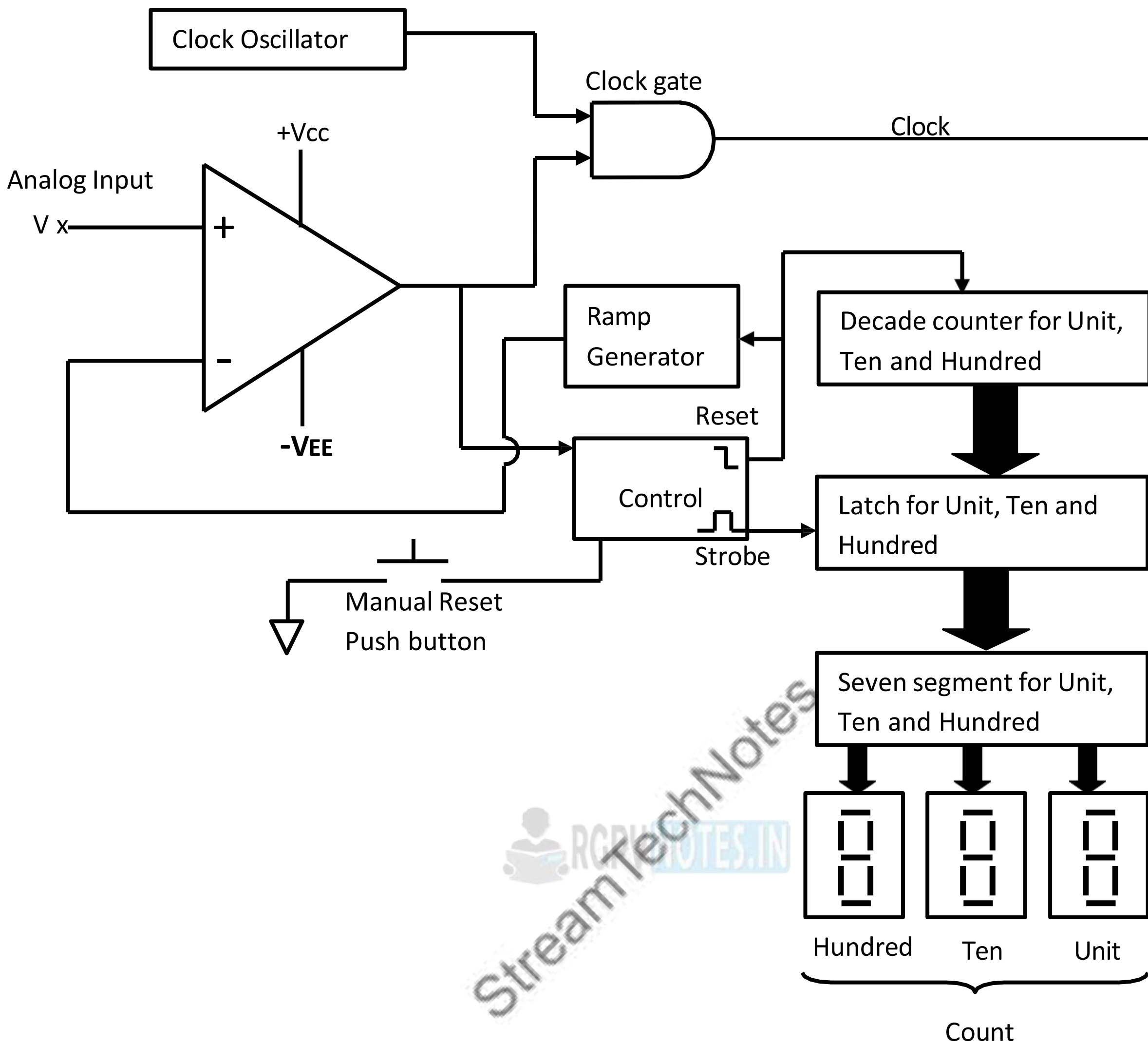


Figure 5.10 Block diagram of Integration type

For beginning a conversion cycle the manual reset button is used. Manual reset generates a reset pulse that clears all the decade counters to 0s and reset the ramp voltage to zero. Since the analog input V x is positive so ramp begins from zero. The output of comparator V c must be high or 1.This voltage enables the clock to be applied to the decade counter. The counter begins counting upward and the ramp continuous upward until the ramp voltage is equal to unknown voltage input V x. At this point the output of the comparator V c goes low thus disabling the clock gate. The negative transition on V c generates a strobe signal in the control box that shifts the contents of the three decade counters in to the latch condition. Shortly thereafter, a reset pulse is generated by the control box that resets the ramp and clears the decade box that resets the ramp and clear the decade counters to zero and another conversion cycle begins. In the mean time the contents of the previous conversion are contained in the latches and are displayed on the seven segments LEDs.

Drawback:

Ramp generator is completely dependent on R and C which are temperature dependent. This problem can be overcome by Dual slope A to D converter.

Dual Slope Integrating Type

In the beginning we assume that the clock is running and Input is positive. A conversion cycle begins with the decade counters cleared to all 0s, the ramp reset to 0V.And the Input switched to the known input Voltage. Since V x is positive the integrator output V c will be negative ramp. The comparator output V g is thus positive and the clock is allowed to pass through the clock gate to the counter. It allows the ramp to proceed for a fixed time period t1, determined by the counter for time t1.The actual voltage V c at the end of the fixed time period t1 will depends on the unknown input V_X, since it is known that $V_c = -\frac{V_x}{RC} \times t1$ for an integrator. The figure 5.11 shows the block diagram of dual slope integrating type.

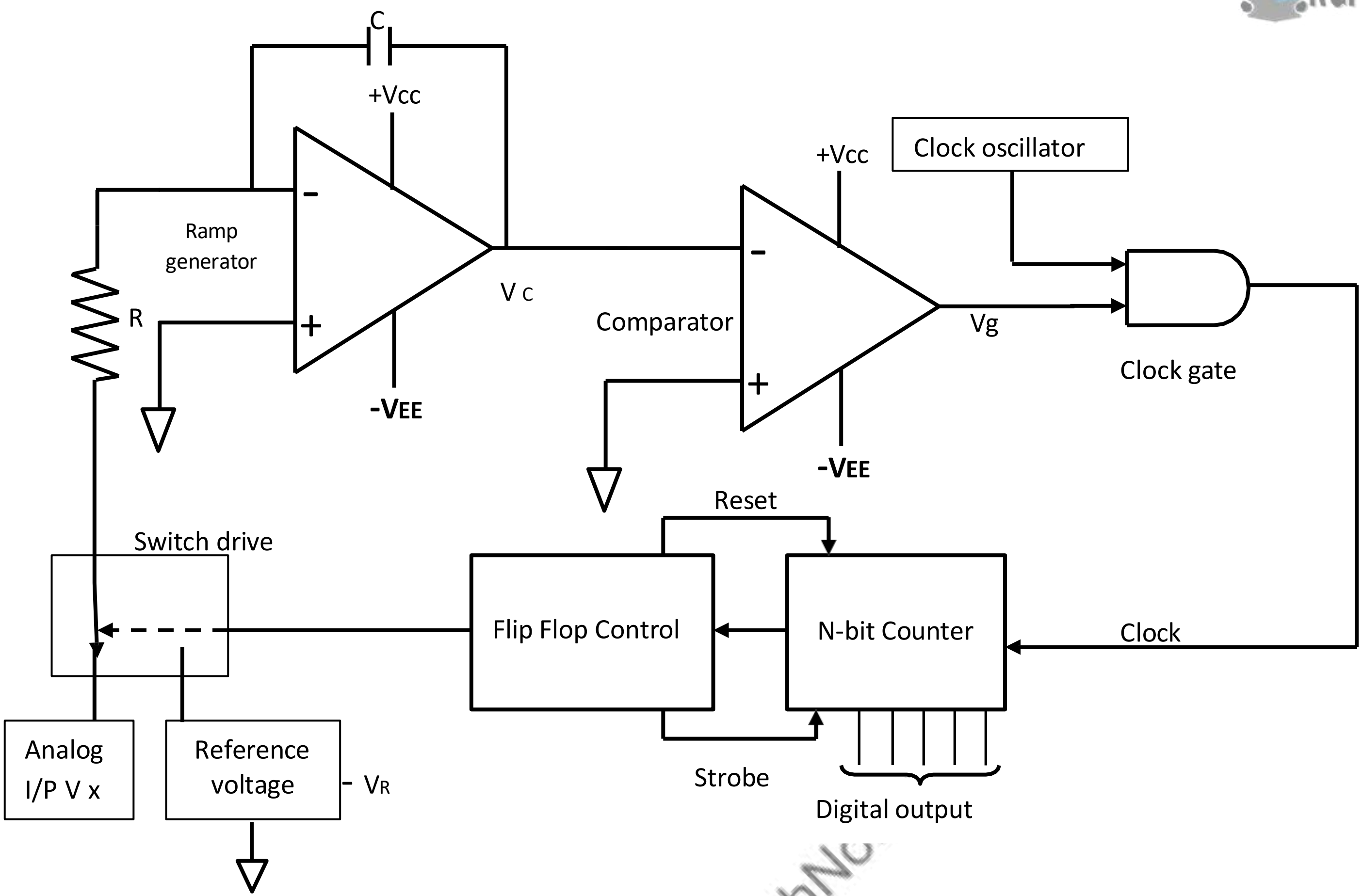


Figure 5.11 Block Diagram of Dual slope integrating type

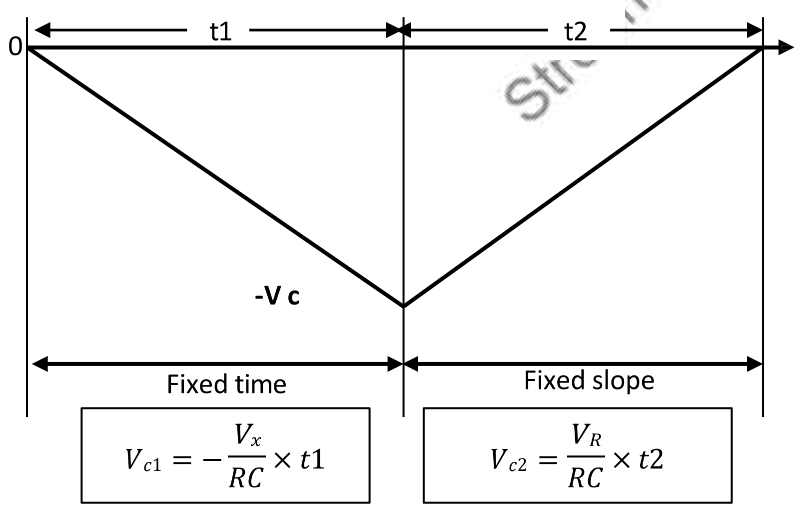


Figure 5.12 Dual slope integrating type curves

When the counter reaches the fixed count at time t1, the control unit generates a pulse to clear the decade counters to all zeros and switch the integrator Input to the negative reference voltage V_R. The integrator will now begins to generate a ramp beginning at –V c and increasing steady upward until it reaches to zero volts. All this time the counter is counting and the conversion cycle ends when V c= 0.Since the clock is now disabled. The equation for this positive ramp is

$$V_{c2} = \frac{V_R}{RC} \times t2$$

When $V_{c1} = V_{c2}$

Then

$$\frac{V_x}{RC} \times t1 = \frac{V_R}{RC} \times t2$$

So

$$V_x = V_R \times \frac{t2}{t1}$$

From the above equation it is clear that V_R is known and t1 is predetermined time. SoV_x is directional proportional to $t2$.

Successive Approximation method

The successive approximation method is the process of approximating the analog voltage by trying 1 bit at a time beginning with MSB. The converter operates by successfully dividing the voltage range in half. The counter resets to all zeros, then MSB is set to 1 i.e. 10000000. One conversion cycle normally require one cycle of the clock. For example 8 bit converter operating with 1MHz clock has a conversion time of 8 bits x 10^{-6}sec/bit=8µsec. The figure 5.13 shows the block diagram of successive approximation method.

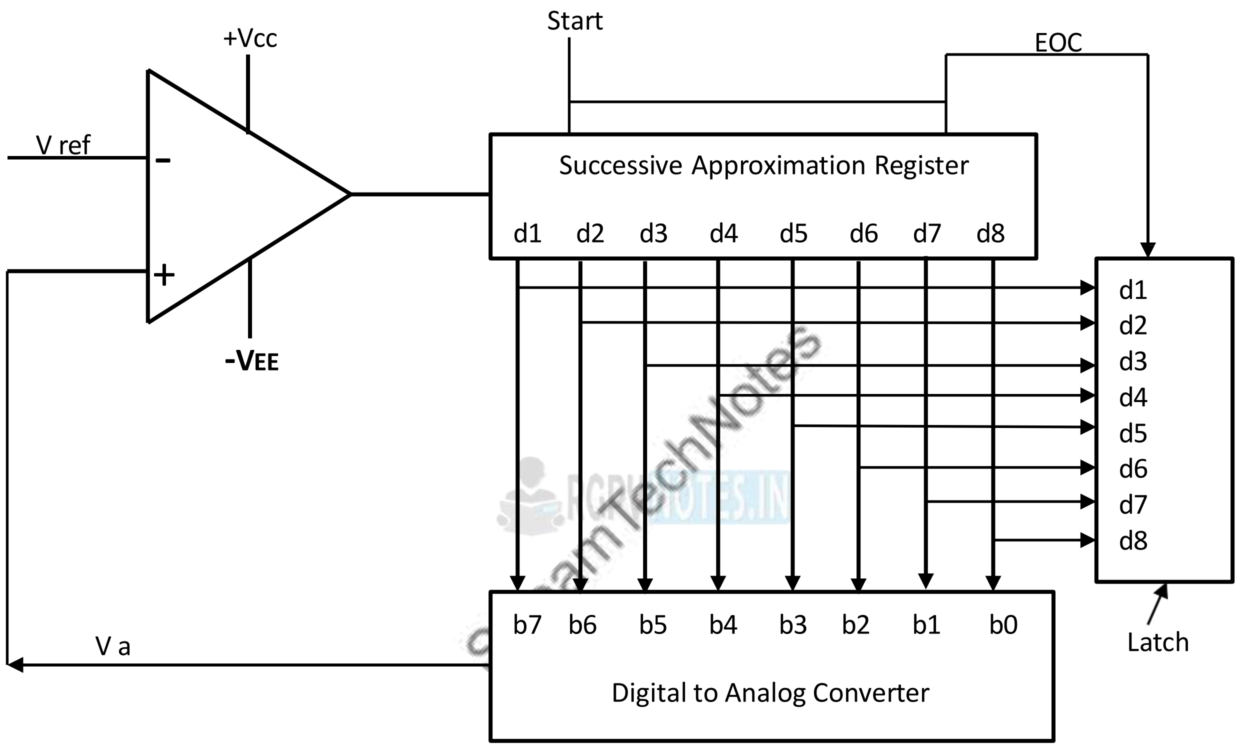


Figure 5.13 Block diagram of Successive Approximation Method

When the start command is provided to the SAR sets the MSB d1= 1 with all other bits to zero so that the trial code is 10000000. The output Va of the DAC is now compared to the reference Input V R. If V R> V a then 10000000 is less than the correct digital representation. The MSB d1 is left at 1 and the next LSB is made 1 and further tested. However V R<Va than 11000000 is greater than the correct digital representation. So the MSB is reset to 0 and go on to the next lower LSB. This procedure is repeated for all subsequent bits one at a time until all bit position has been tested. Whenever the DAC output crosses V R, the comparator changes the state and this is taken as the end of conversion EOC command. The EOC command is high to indicate that the parallel output lines contain valid data. The cc signal turns enable the latch and digital data appears at the output of the latch.

Advantage:

High Speed and Excellent resolution

Digital voltmeters

Successive Approximation DVM

The successive approximation method is the process of approximating the analog voltage by trying 1 bit at a time beginning with MSB. The converter operates by successfully dividing the voltage range in half. The counter resets to all zeros, then MSB is set to 1 i.e. 10000000. One conversion cycle normally require one cycle of the clock. For example 8 bit converter operating with 1MHz clock has a conversion time of 8 bits x 10^{-6}sec/bit=8µsec. The figure 5.14 shows the block diagram of successive approximation method.

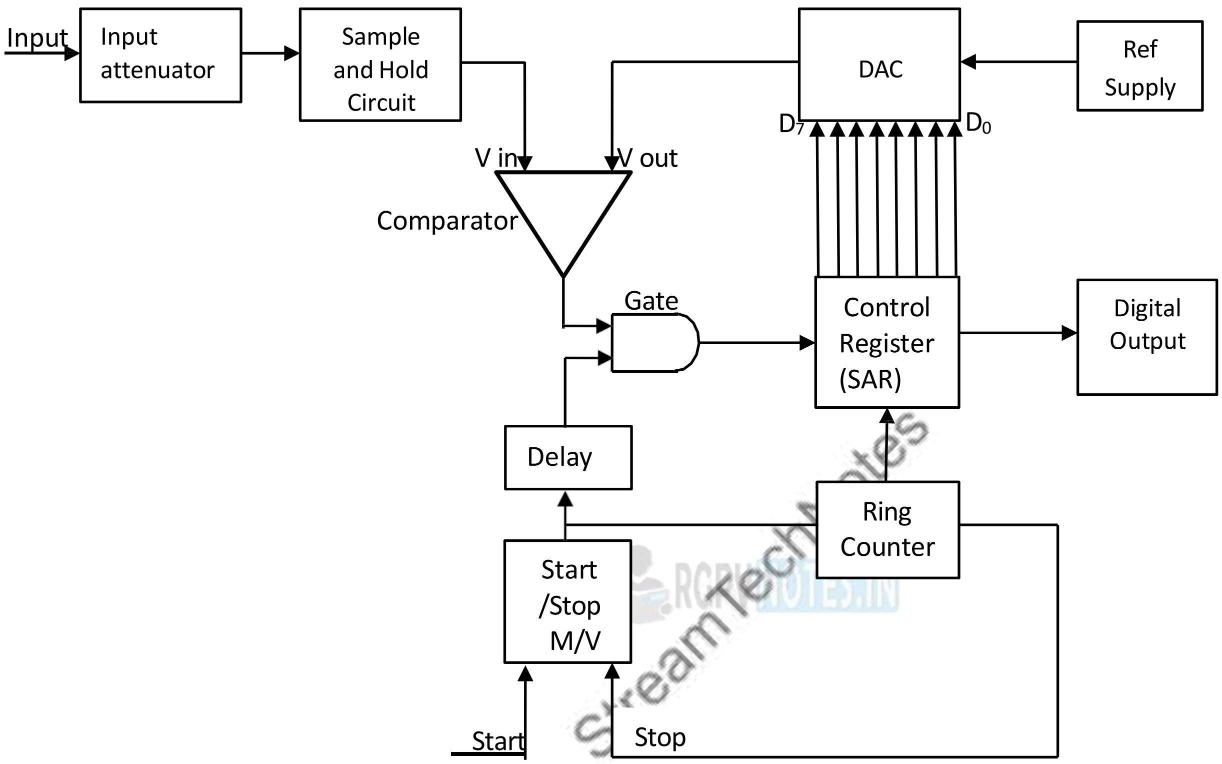


Figure 5.14 Successive approximation DVM

When the start command is provided to the start-stop multi vibrator, it sets the MSB to 1 of the control register with all other bits to zero so that the trial code is 10000000. The output V out of the DAC is now compared to the reference Input V_R. If $V_{in} > V_R$ then 10000000 is less than the correct digital representation. The MSB is left at 1 and the next MSB is made 1 with the help of ring counter and now the outcome of control register is 11000000 and further compared with unknown input. However $V_{in} < V_R$ than 11000000 is greater than the correct digital representation. So the second lower MSB is reset to 0 and go on to the next lower MSB by using ring counter and set to 1. This procedure is repeated for all subsequent bits one at a time until all bit position has been tested. Whenever the DAC output crosses V in, the comparator changes the state and this is taken as the end of conversion. Therefore, Vin nearly equals to Vout.

Advantage:

Speed is very fast.

Capable of taking 1000 readings per second

Sample and hold Circuit

For avoiding digitization and decisions made during conversion are not consistent. To avoid this error, a sample and hold circuit is used and placed in the input directly following the input attenuator and amplifier. In its simplest form the sample and hold circuit can be represented by a switch and a capacitor as shown in figure 5.15.

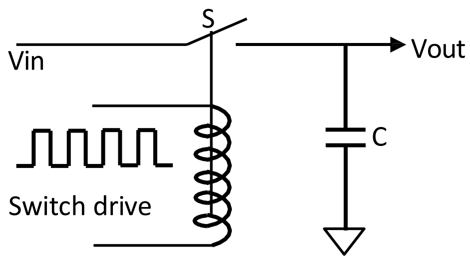


Figure 5.15 Simple sample and hold circuit

In the sample mode, the switch is closed and the capacitor charges to the instantaneous value of the input voltage. In the hold mode, the switch is opened and the capacitor holds the voltage that it had at the instant the switch was opened. If the switch drive is synchronized with the ring counter pulse, the actual measurement and conversion takes place when the S/H circuit is in the Hold mode. The output waveform is shown in figure 16.

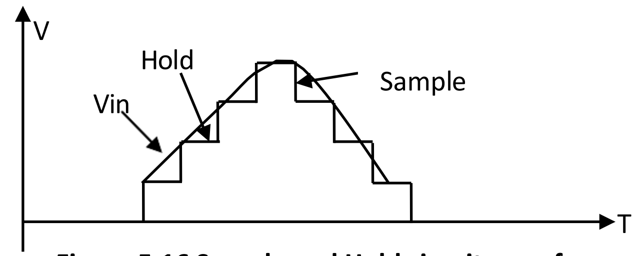


Figure 5.16 Sample and Hold circuit waveform

Ramp type digital voltmeter:

The block diagram of Ramp Type of digital voltmeter is shown in figure 5.17

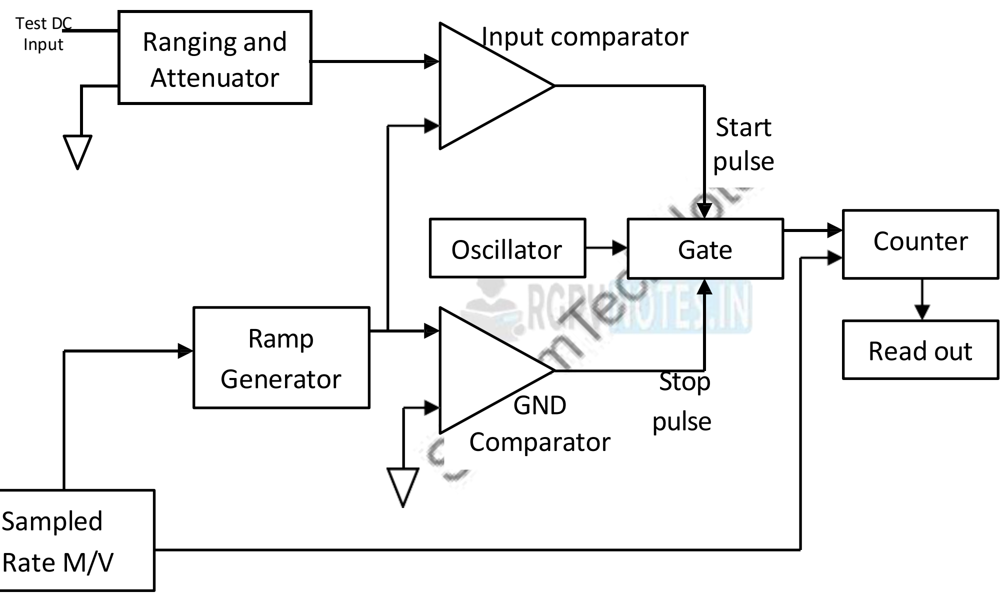


Figure 5.17 Block diagram of Ramp Type of digital voltmeter

For beginning of measurement a ramp voltage is initiated. The ramp voltage is continuously compared with the voltage that is being measured. At the instant these two voltages become equal hence the input comparator generates a start pulse. The ramp continuous until the second comparator circuit senses that the ramp has reached zero value. The ground (GND) comparator compares the ramp with ground. When the ramp voltage is equal to zero the ground comparator generates a stop pulse. The output pulse from this comparator closes the gate. The time duration of the gate opening is proportional to the input voltage value. The stored value in the counter is latched and output is providing to digital readout.

Advantages:

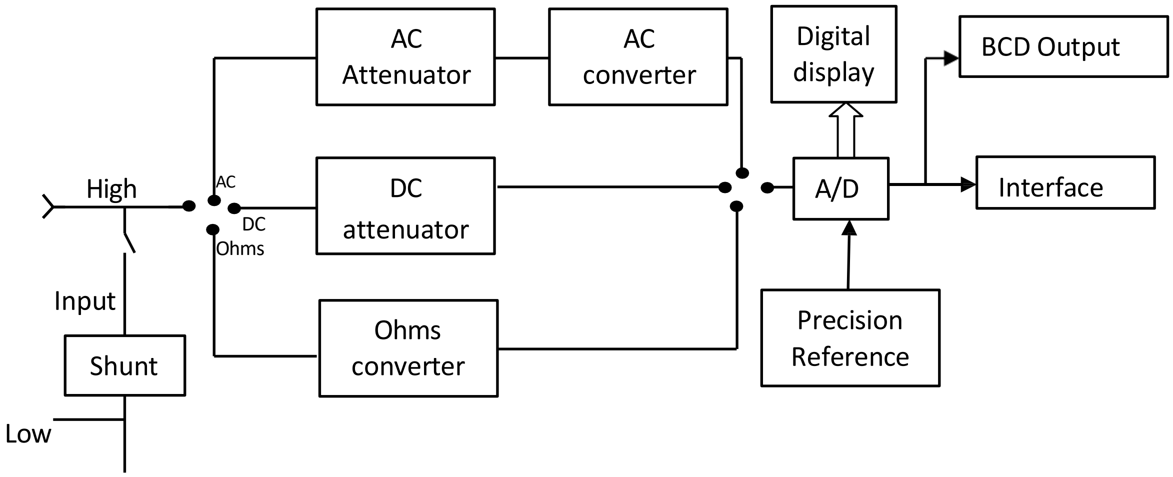
1. Easy to design and its cost is low.
2. Output can be transmitted over long feeder lines

Disadvantages:

1. Large errors are possible due to R and C of ramp generator which is temperature dependent.

Digital Multi meter

Digital meters offers high accuracy, high input impedance and are smaller in size. The block diagram of digital multi meter is shown in figure 5.18.



In this current is converted to voltage by passing it through a precision low shunt resistance while alternating current is converted into DC by employing rectifiers and filters For resistance measurement the meter includes a precision low current source that is applied across the unknown resistance; again this gives a DC voltage that is digitized and read out as ohms.

Resolution and sensitivity of digital meters

Resolution

If n= number of full digits, then resolution (R) is $1/10^n$.

The resolution of DVM is determined by the number of full or active digits used,

If n=3 then $R = \frac{1}{10^n} = \frac{1}{10^3} = 0.001 \; or \; 0.1\%$

Sensitivity of digital meters:

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

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

Where fs) $_{min}$=Lowest full scale of the meter

R= resolution expressed as decimal