# ELECTRONIC INSTRUMENTS FOR MEASUREMENT OF VOLTAGE, CURRENT, RESISTANCE AND OTHER CIRCUIT PARAMETERS

## 3.1. Introduction

Electronic measuring instruments are either of the indicating or recording type, just like electrical measuring instruments. Electrical instruments are instruments that use the mechanical movement of electromagnetic meter to measure voltage, power, current, resistance etc. The major difference between the electrical and electronic instruments is that electrical measuring instruments convert the electrical signals into a mechanical deflection over a scale while electronic measuring instruments manipulate the signals (eg amplify) before they are displayed. Electronic instruments can be used to measure current, resistance, voltage as well as other circuit parameters.

## 3.2 Current Measurement with Electronic Instruments

Electronic instruments for current measurement can either be of DC type, AC type, analog type or digital type. Instruments that measure current are called ammeter. An electronic DC analog ammeter can be constructed in two ways;

i. Shunt type technique.
ii. Op-amp technique.

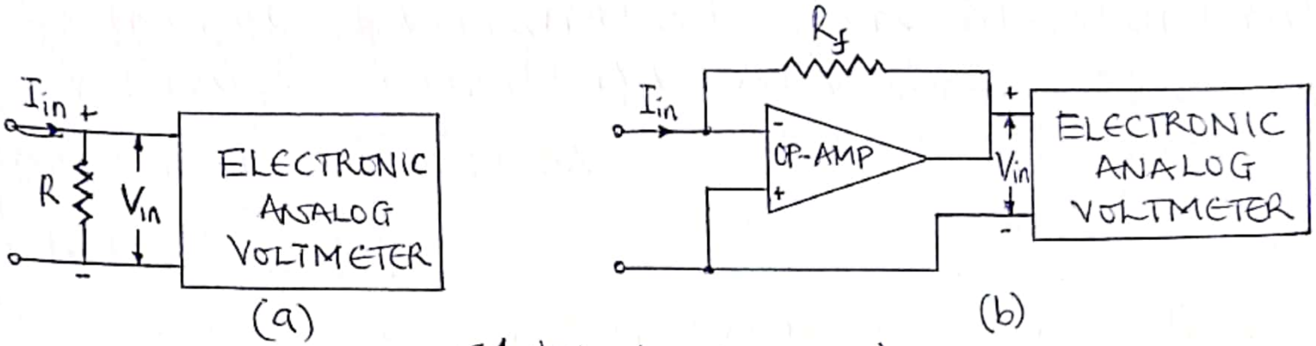



Fig.3.1 Electronic analog DC Ammeter

The shunt type is presented in fig3.1(a) while the op-amp type is shown in fig3.1(b). In the shunt type technique the input current, $I_{in}$, is converted into a voltage by passing it through a precision resistor, R. This voltage, $V_{in}$, which is proportional to input current $I_{in}$ is then measured by the electronic analog ammeter. The value of precision resistor, R is kept as small as possible so as to offer minimum input resistance to the current. This ammeter is capable of measuring currents in the order of microamperes and milliamperes.

The second method shown in fig. 1(b) use an op-amp as its current to voltage converter. This is particularly useful for measurement of very small currents in the order of picoampere. In this case the input current $I_{in}$ flows through the resistance $R_f$ resulting in the input voltage, $V_{in}$.

$$V_{in} = -I_{in} R_f$$

This voltage is then measured by the electronic analog voltmeter, caliberated in current units. The op-amp used should have low bias current and noise so as to be able to measure very small currents.

For the case of AC measurement the electronic analog AC meter makes use of shunt type technique similar to that used for DC measurement. Input current $I_{in}$ is passed through a precision resistor and the voltage developed thereby is measured by the electronic analog AC voltmeter, caliberated in current units. The major difference between AC and DC measurement is the AC electronic voltmeter makes use of a rectifier which converts the $I_{in}$ from AC to DC.

## 3.3. Resistance Measurement with Electronic Instrument

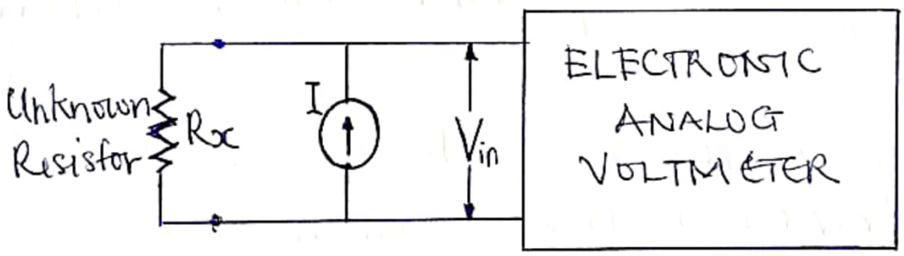



Fig 3.2 Electronic Ohmmeter

An ohmmeter is the measuring instrument for resistance. Ohmmeters could either be analog having pointers that deflect over a caliberated scale or digital having digital displays. As shown in fig 3.2 the electronic analog ohmmeter consist of a known constant current source and an electronic voltmeter. In its

Operation a constant current of known magnitude is made to flow through the resistor under test and the resulting voltage drop is measured by the voltmeter, Caliberated in resistance units. For multirange measurement of resistance the value of current is changed.

Depending of resisistance to be measured several types of ohmmeter exists;

i. Two-wire sensing ohmmeter.
ii. Four-wire sensing ohmmeter.
iii. Series ohmmeter
iv. Shunt ohmmeter.
v. Liniear ohmmeter

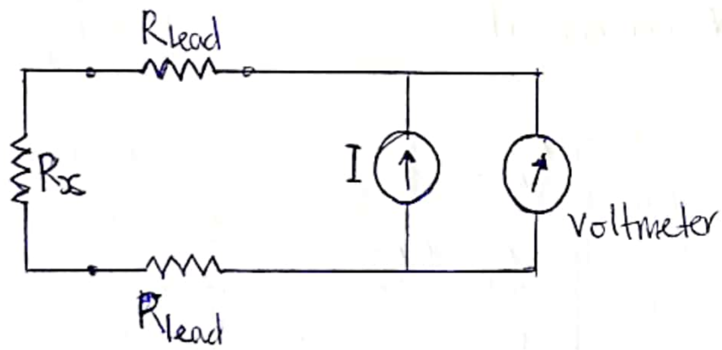



Fig3.3 Two-wire Sensing

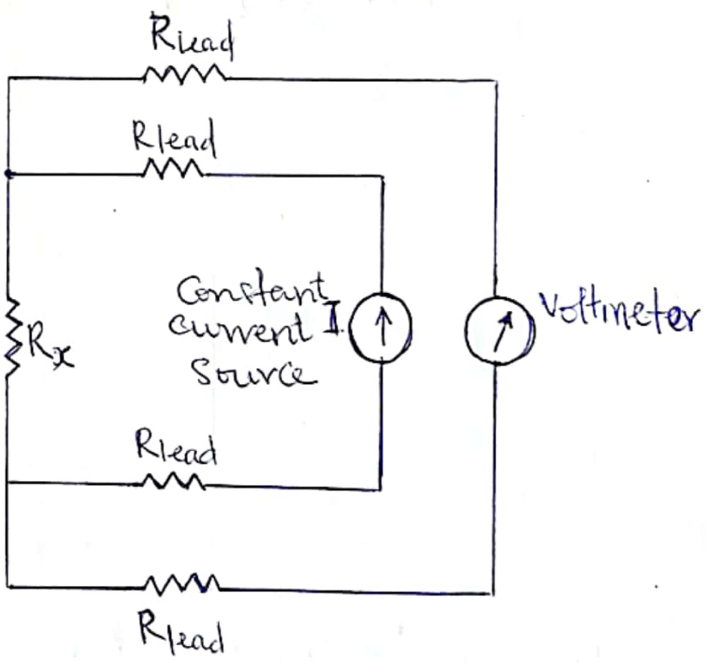



Fig.3.4. Four-wire Sensing.

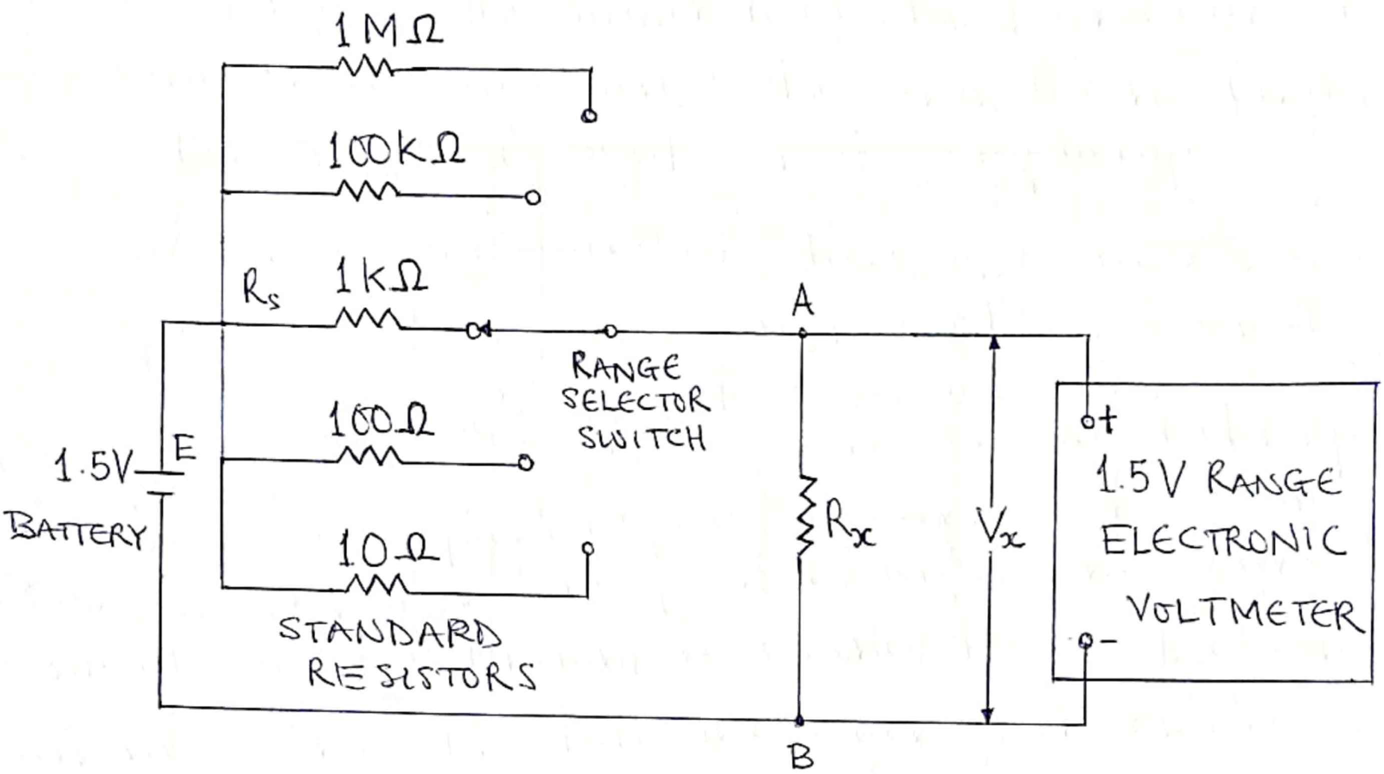
Simplified schematies of two-wire sensing and four-wire sensing are presented in fig3.3 and fig3.4. In the two wire sensing the same meter terminals are used for measuring the voltage drop across the unknown resistor

$R_x$ and also to supply the current. In this arrangement the resistance of the meter leads $R_{lead}$ contributes to the resistance being measured, thus introducing large error. It is therefore mostly used for its simplicity.

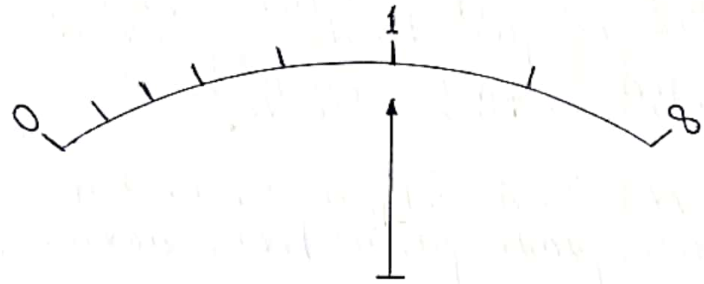
The errors introduced by lead resistances are eliminated by the four-wire sensing technique, which provides a most accurate method for measuring small resistances. Also called the Kelvin sensing technique it involves two separate pairs of connection to the unknown resistor, $R_x$. One pair known as the source leads connects the unknown resistance $R_x$ to the constant current source, I, while the other pair known as the sensing leads connects the unknown resistor to the voltmeter (having a high input resistance). The current supplied by the current source develops a voltage across the unknown resistor, $R_x$ and $R_{lead}$. Since the voltmeter is connected only across $R_x$ it measures only the voltage across $R_x$ which is equal to $IR_x$ because no current flows through $R_{lead}$ of the sensing lead.

The voltmeter indication is also independent of $R_{lead}$ of source lead, thus eliminating errors due to voltage drop from source leads and sensing leads completely. This arrangement is widely used in applications where lead resistances become large and variable.

# Series Ohmmeter




(a)




(b)

Fig3.5.(a) Series ohmmeter circuit (b) Scale

Consider fig35(a) showing the internal circuit of a series ohmmeter and scale. The ohmmeter contains a 1.5V range electronic voltmeter, a range selector switch and several standard resistor switches. The electronic voltmeter measures the voltage drop across the unknown resistor $R_x$ connected between terminals A and B.

Assume the range selector is set to $R_s = 1k\Omega$. With the unknown resistor, $R_x$, disconnected the voltmeter deflects full-scale to the right ($\infty$) as shown in fig 3.5(b). With terminals A and B short circuited the voltmeter deflects full-scale to the left, $0\Omega$. Now let the unknown resistance $R_x$ of a value between $0\Omega$ and $\infty$ be connected between A and B. The battery voltage E is devided between $R_s$ and $R_x$. If $V_x$ is the voltage across $R_x$ then

$$V_x = E \frac{R_x}{R_s + R_x}$$

$\therefore$ For $R_s = R_x = 1k\Omega$

$$V_x = \frac{1k}{1k + 1k} \times 1.5 = 0.75V$$

0.75V corresponds to half full-scale deflection (1.5V) of the voltmeter. Thus the pointer on the ohmmeter scale would indicate a reading of $1k\Omega$

The point to note therefore is that the series ohmmeter requires two adjustments before use. First is the zero point corresponding to short circuit between A and B and the second is the $\infty$ point corresponding to open circuit between A and B.

# Shunt Ohmmeter

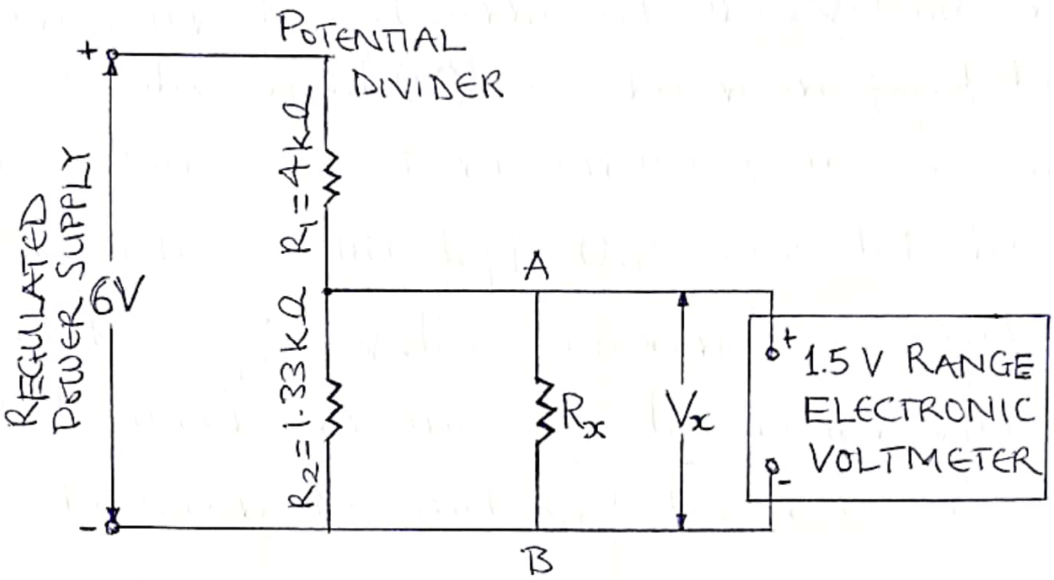



Fig.3.6.Shunt ohmmeter circuit.

Fig.3.6 shows a shunt ohmmeter consisting of a 1.5V range electronic voltmeter, 6V regulated power supply and standard value resistors connected as potential divider. The standard value resistors act as precision resistors connected across the regulated power supply.

For the setup of fig3.6. and with terminals A and B open-circuited;

$$V_x = E\frac{R_2}{R_1+R_2} = \frac{1.33\,E}{4k\Omega + 1.33\,k\Omega}$$

$$= 0.25 \times 6$$

$$= 1.5V$$

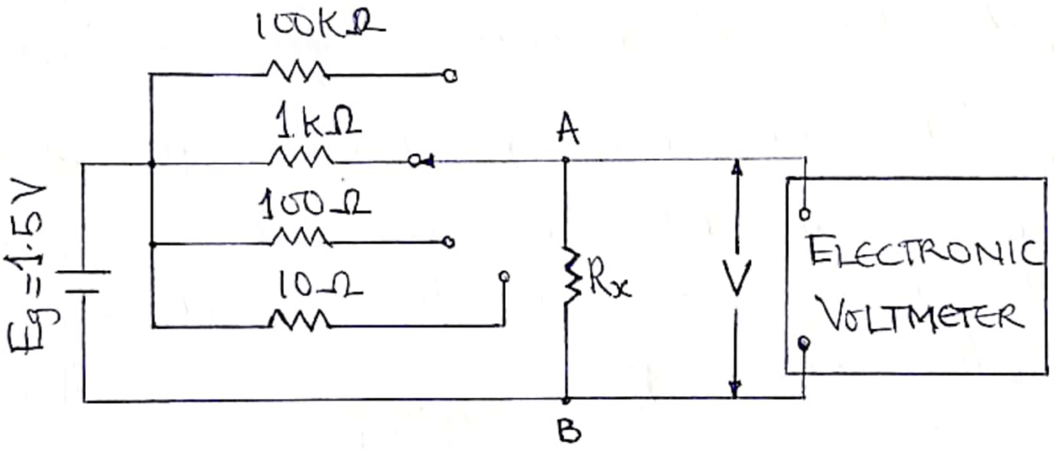
This implies that the voltmeter gives full-scale deflection of 1.5V corresponding to infinite($\infty$) resistance.

However with terminals A and B short-circuited ($R_x=0$) $V_x = 0$, and the pointer deflects to the extreme LHS. For any other value of $R_x$ to be measured

$$V_x = E \frac{R_2 \| R_x}{R_1 + R_2 \| R_x}$$

Example

Calculate the resistance reading $R_x$ of a series ohmmeter if the electronic voltmeter indicates (a) 25% (b) 75% of full-scale deflection.




Solution

(a) 25% of full-scale $= 0.25 \times E_g$

$= 0.25 \times 1.5$

$V_x = 0.375V$     i

but $V_x = E_g \dfrac{R_x}{1k + R_x} = \dfrac{1.5 R_x}{1k + R_x}$     ii

equating i & ii

$$0.375 = \frac{1.5 R_x}{1k + R_x}$$

$$375 + 0.375 R_x = 1.5 R_x$$

$$375 = 1.125 R_x$$

$$\therefore R_x = 333.3\ \Omega$$

(b) 75% of full-scale $= 0.75 \times E_g$

$$\therefore V_x = 0.75 \times 1.5$$

$$= 1.125\ V$$

but $V_x = E_g \times \dfrac{R_x}{1k + R_x} = \dfrac{1.5 R_x}{1k + R_x}$ V

$$\therefore 1.125 = \frac{1.5 R_x}{1k + R_x}$$

$$1125 + 1.125 R_x = 1.5 R_x$$

$$R_x = \frac{1125}{0.375}$$

$$= 3k\Omega$$

## 3.4. Electronic Voltmeter for Measuring Voltage.

Electronic voltmeters are either digital (having digital display) or analog (making use of a pointer deflecting over a graduated scale). Electronic analog voltmeter circuit operate on the principle of a permanent magnet moving coil (PMMC) instrument or D'Arsonval movement. In such instruments a pointer deflection is obtained proportional to the voltage to be measured and obtained by amplification in one or more stages with a high input impedance. In most cases they make use of the rectifying properties of diodes. Electronic voltmeters are either DC type or AC type.

## Direct Current (DC) Voltmeters

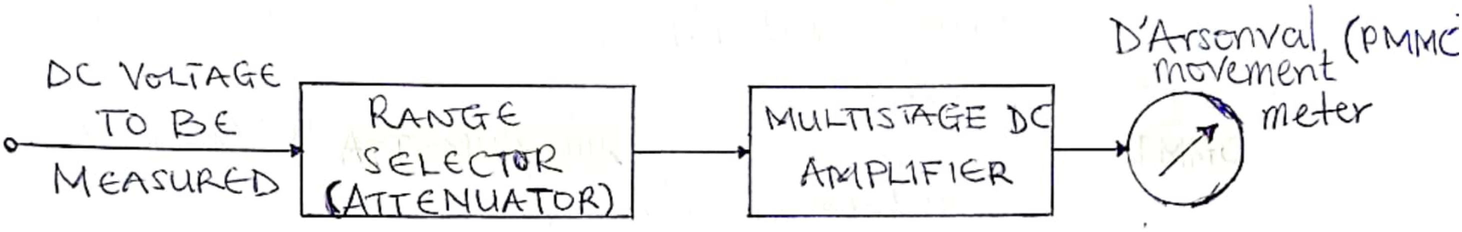



Fig.3.7. Block diagram of Electronic Analog DC Voltmeter

The diagram of the electronic analog DC voltmeter is shown in fig3.7. consisting of a range selector, amplifier and D'Arsonval movement. In its operation the amplifier receives the signal to be measured, amplifies it and feeds it to the D'Arsonval movement. The D'Arsonval movement converts the signal into an indication by causing a pointer to deflect along a calibrated scale. DC voltmeters are further divided into three types;

1) Direct coupled amplifier DC voltmeter
2) Chopper type DC voltmeter
3) Emitter follower DC voltmeter

# Direct Coupled Amplifier DC Voltmeter

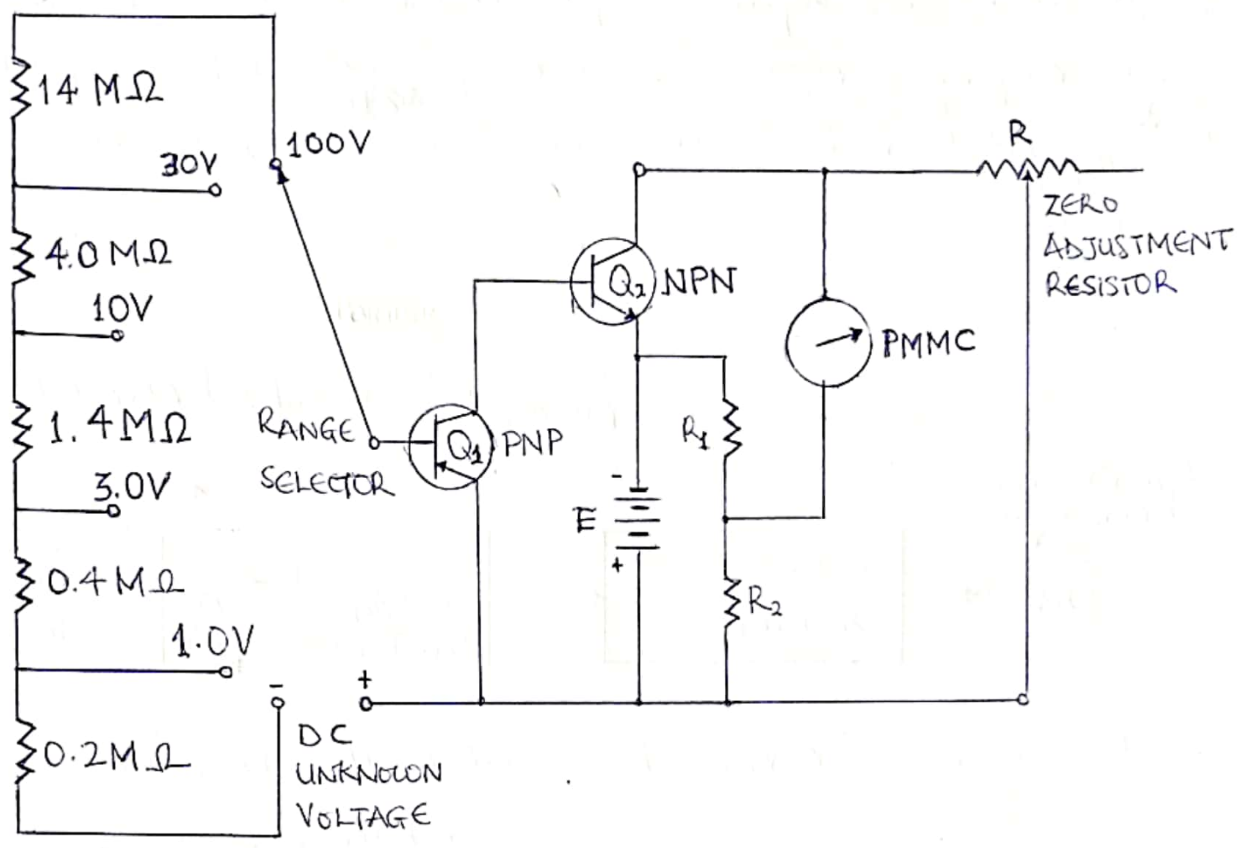



Fig.3.8. Direct Coupled amplifier DC voltmeter

The circuit diagram of a direct coupled amplifier DC voltmeter is given in fig3.8. It is very common because of its low cost. However it only measures voltage of the order of millivolts because of its limited amplifying power.

Range selection is achieved by connecting a resistance in series with transistor $Q_1$. The two transistors are cascaded to increase the instrument sensitivity. So $Q_1$ and $Q_2$ are connected to form a direct coupled amplifier. The variable resistor R is for zero adjustment of PMMC. The drawback of this instrument is that it has to operate under specified temperature to get the required accuracy.

# Emitter Follower DC Voltmeter

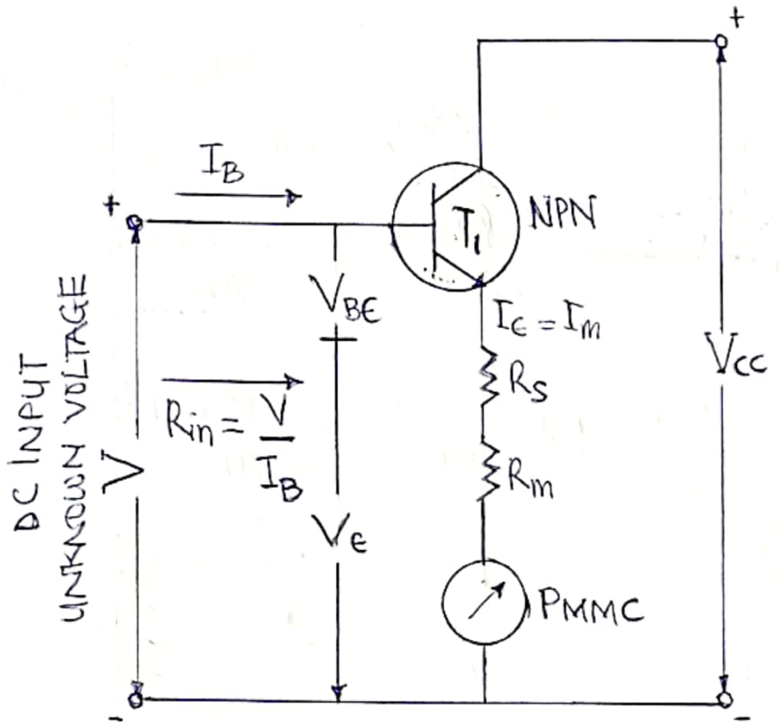



Fig. 3.9. Basic emitter follower DC voltmeter circuit

The circuit diagram for the basic emitter follower DC voltmeter is shown in fig 3.9. As seen it consists of a transistor, $T_1$, in series with resistance $R_s$ and a PMMC. The voltage to be measured is connected between the transistor base and the transistor -ve supply.

The DC supply to the transistor is connected between the collector and PMMC meter. The transistor base current is given as;

$$I_B = \frac{I_E}{h_{ff}} = \frac{I_m}{h_{ff}}$$

where $h_{ff}$ is the transistor current gain

the input resistance is given as;

$$R_{in} = \frac{V}{I_B} = \frac{V \times h_{ff}}{I_m}$$

Thus presenting a high input resistance. The drawback of this instrument is that the transistor base-emitter voltage $V_{BE}$ introduces an error.

# Alternating Current (AC) Voltmeters

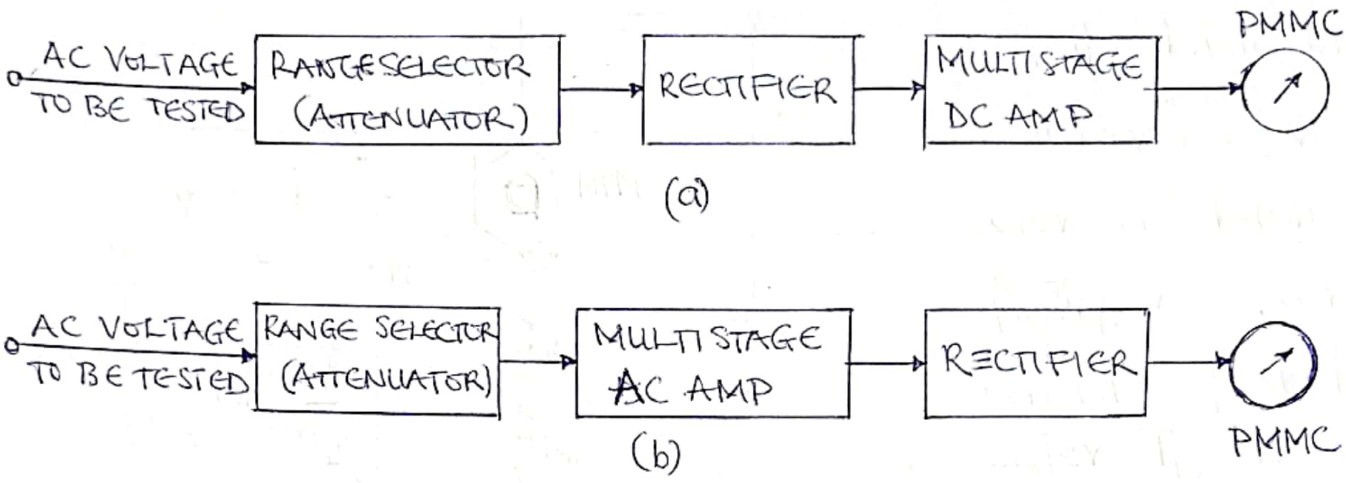



Fig 3.10 Block diagram of alternating current (AC) analog voltmeter

As seen in fig 3.10. the analog AC electronic voltmeter offers two configurations, depending on whether the rectifier unit comes before or after the amplification stage. The first arrangement which makes use of a DC amplifier comes at a lower cost since DC amplifies are cheaper than AC amplifiers. Broadly, AC voltmeters are divided into three categories;

i. Average reading AC voltmeters.
ii. Peak reading AC voltmeters.
iii. True RMS reading voltmeters.

## Average Reading AC Voltmeters

Since AC voltage is sinusoidal in nature these AC voltmeters measures the average value of the voltage signal while the meter caliberated in terms of rms value. The circuit diagram of an average reading AC voltmeter is given in Fig 3.11.

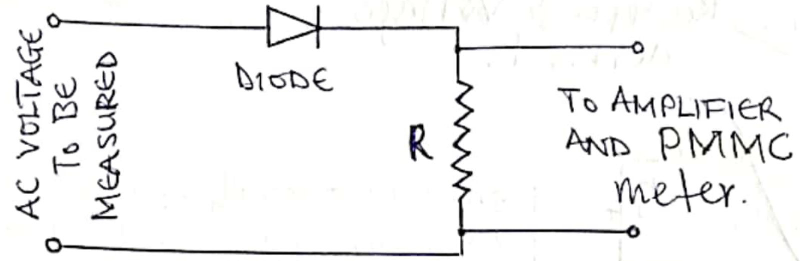



Fig.3.11 Average reading AC Voltmeter

The arrangement consist of a diode, a high input resistance and a PMMC instrument all connected in series. The main advantages of these instruments are low cost, simple construction, high input impedance, low power consumption and a uniform scale. The disadvantage is that due to non-linear volt-ampere characteristics lower voltage readings are not correct. Also radio frequency interference introduces errors.

## Peak Reading AC Voltmeters

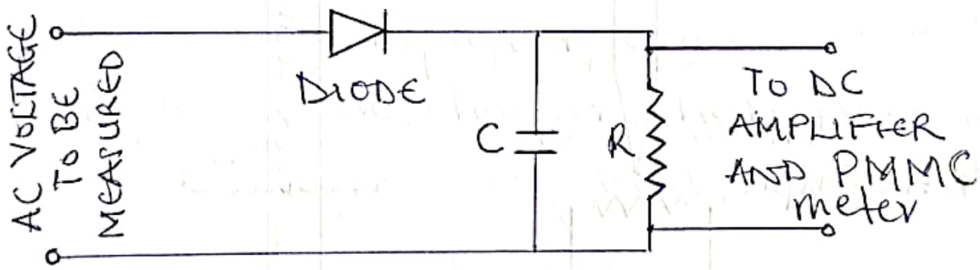



Fig.3.12 Peak reading AC voltmeter

Fig.3.12 presents the circuit diagram for peak reading voltmeter. This type of voltmeter responds to peak value of the voltage under test. This is made possible by the capacitor C connected in parallel with the input resistance. The capacitor is charged to the peak value of supply voltage and this is maintained almost constant and equal to the voltage under test (fig3.13). The PMMC senses and measures the voltage across C and R.

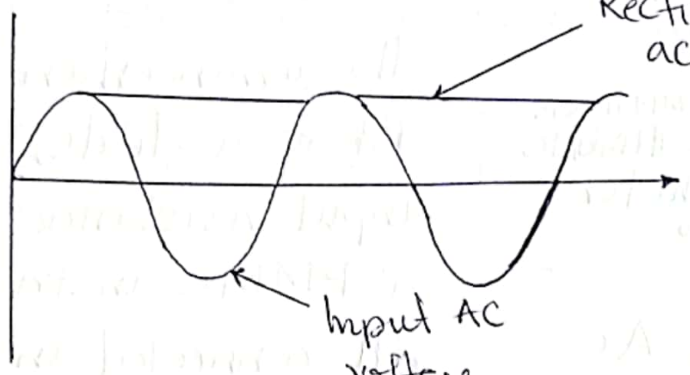



Fig.3.13. Voltage across resistor (R) and capacitor (C)

## True RMS Reading Voltmeters

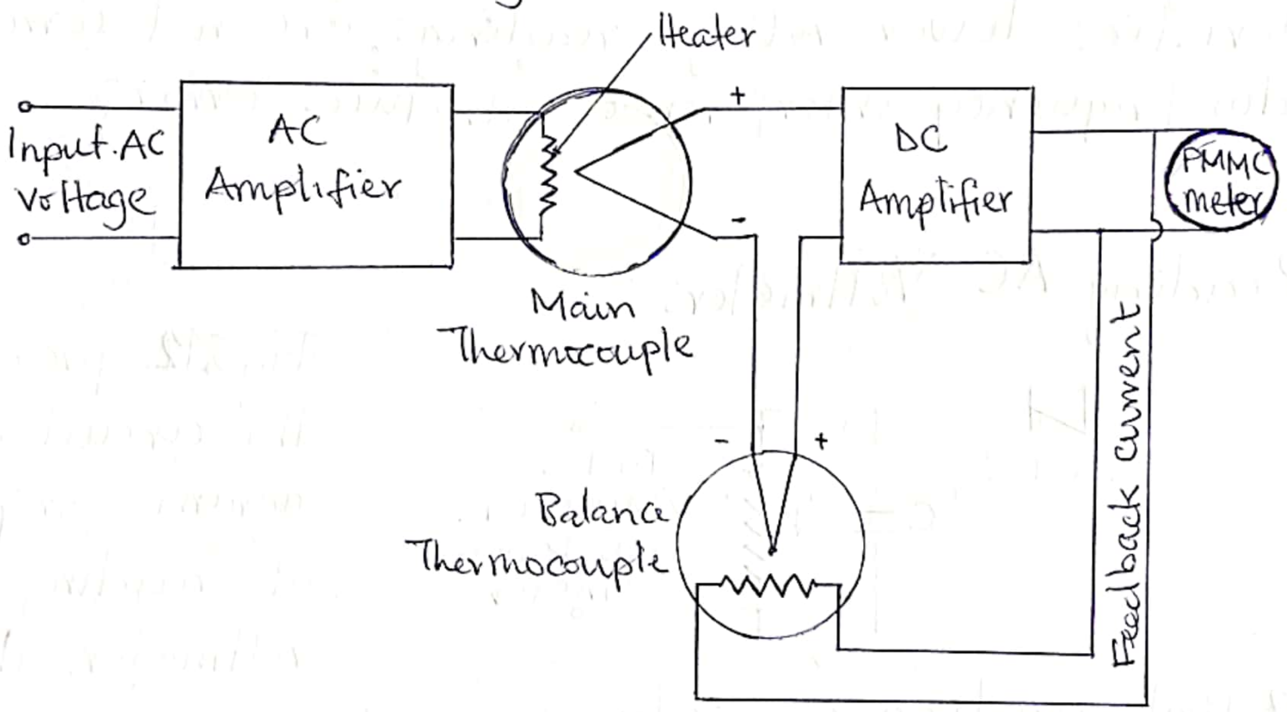



Fig 3.14. True RMS reading voltmeter

The true RMS reading voltmeter is illustrated in fig 3.14. This instrument measures the true RMS value of voltage under test. The meter indication is gotten by sensing the heating effect of the voltage to be measured. The voltage to be measured is amplified and supplied to the heater. The main thermocouple senses the heating effect and converts same back to an electrical signal which is amplified and sent to the PMMC meter for indication. The balance thermocouple helps to cancel and balance the non-linearity of the main thermocouple.

## Electronic Multimeter (VOM)

This instrument is capable of measuring DC and AC voltages and currents as well as resistance which makes it one of the most versatile general purpose instruments. The electronic multimeter consist of the following elements;

1. A balanced bridge DC amplifier and a PMMC meter.
2. An attenuator at the input stage which also serves as a range selector.
3. A rectifier which converts AC input to proportional DC values.
4. An internal battery and circuitary for resistance measurement capabilities.
5. A switch for selecting different measurement functions eg voltage, current and resistance.

In addition the instrument may also be provided built in power supply for operation on AC supply.

The circuit diagram of the electronic voltmeter is presented in fig 3.15.

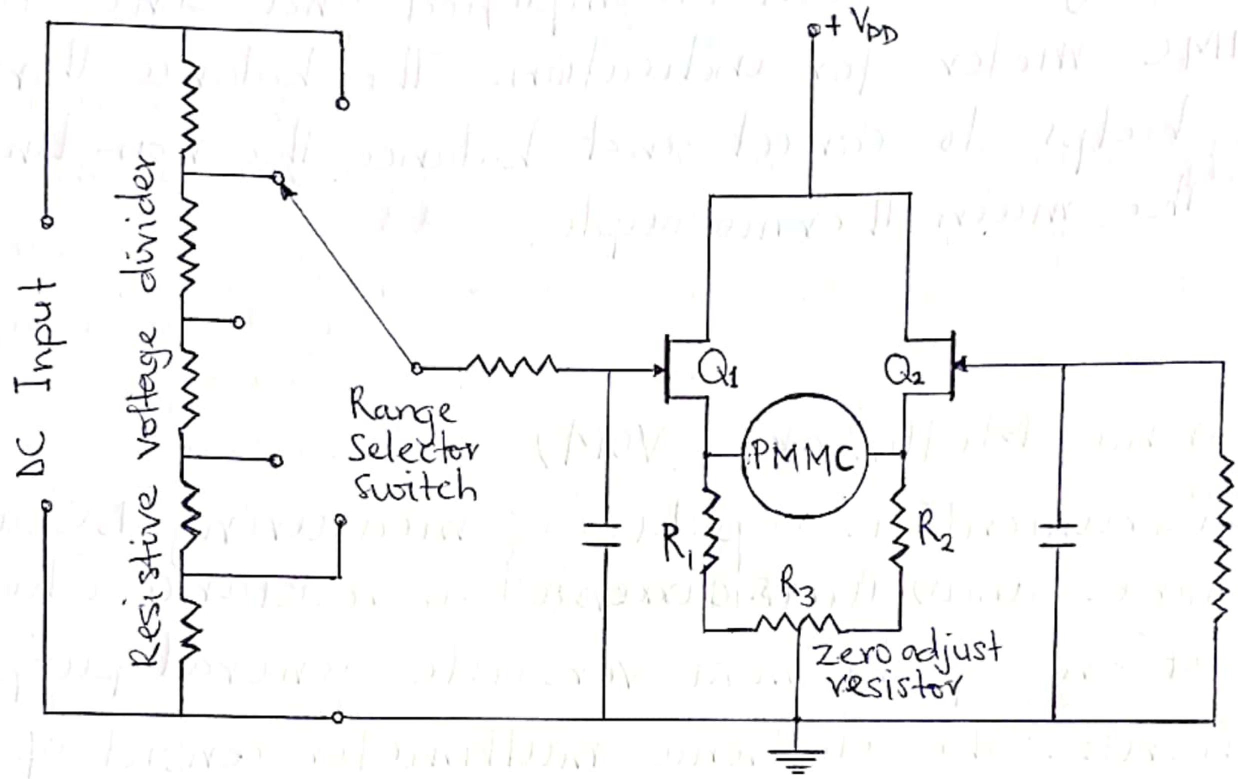



Fig. 3.15. Electronic multimeter

The two field effect transistors (FETs) and the resistors $R_1$, $R_2$, $R_3$ constitute a bridge circuit. The PMMC meter is connected between the source terminals of the FETs. In the absence of input signals idealy no current flows through the PMMC meter but on account of mismatch between the two FETs and the values of the resistors a current might flow causing the indicator to deflect from zero. This current is reduced to zero by the zero adjustment resistor, $R_3$.

When a positive input signal is applied to the gate of FET $Q_1$ a resulting unbalance between the two FETs $Q_1$ and $Q_2$ source voltages is indicated as a meter movement.

For the purpose of resistance measurement the multimeter's function is switched to the OHM position. The unknown resistor is connected in series with the internal battery of the multimeter. Current flows through the unknown resistance producing a voltage drop across it. and the PMMC meter measures the voltage drop across it, since the voltage drop is proportional to the resistance.

A noteworthy difference between the multimeter and conventional ohmeter is that while a conventional ohmeter indicates increasing resistance from right to left the multimeter indicates from left to right. This is because the multimeter sees a large resistance as a higher voltage while the conventional meter sees a high resistance as a small current

## 3.5. LCR Meter

The LCR meter is an instrument which gives a direct reading of inductance, capacitance and resistance. The resistance is measured using wheatstone bridge while inductance and capacitance are measured by comparing with a standard capacitor in RC bridge circuits. The block diagram of LCR meter is shown in fig. 16.

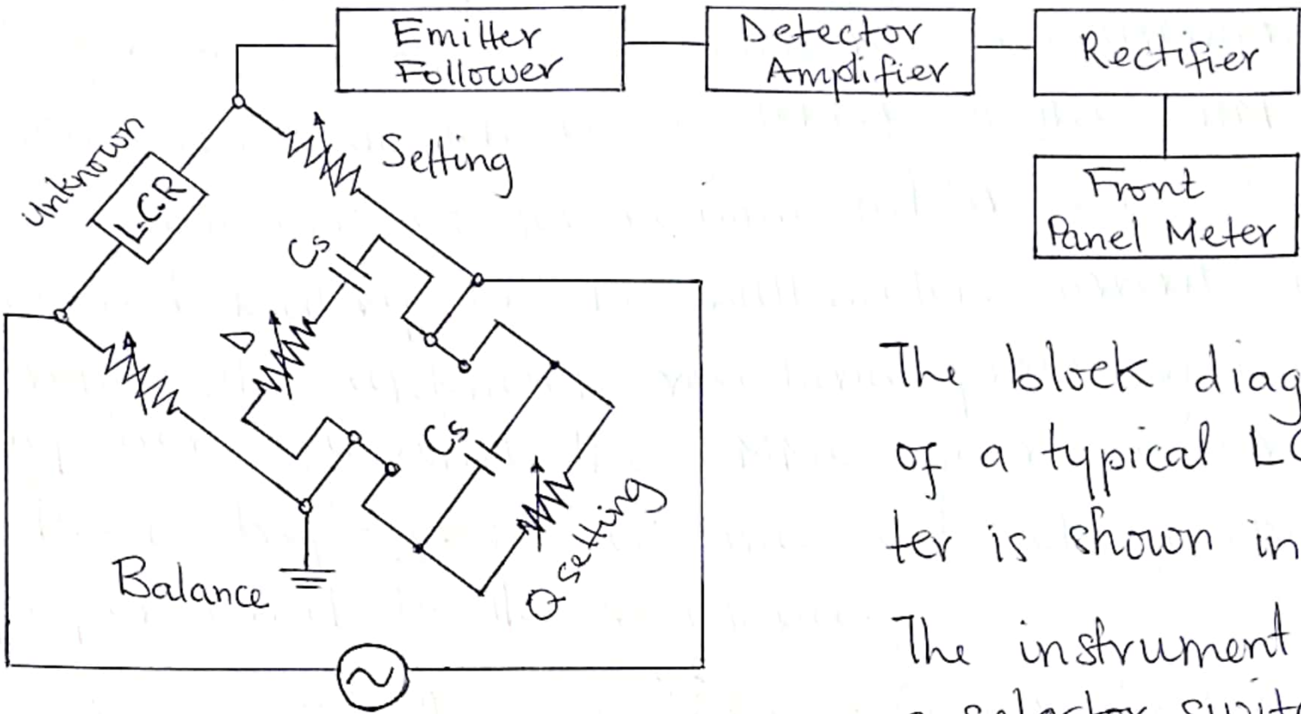



Fig3.16. Block diagram of LCR meter

The block diagram of a typical LCR meter is shown in fig3.16. The instrument has a selector switch to go from AC to DC measurement and vice versa.

An internal oscillator which generates AC signal is provided for bridge excitation for AC measurement. For DC resistance measurements a separate provision is made to excite the bridge with DC voltage. Provision is also made for exciting the bridge with an external oscillator.

The output from the bridge is fed through an emitter follower to the detector amplifier. The output from the amplifier is rectified and fed to the front meter consisting of a PMMC instrument. The scale is caliberated in terms of R, L and C. The important controls on the face panel of the LCR meter are shown in fig3.17.

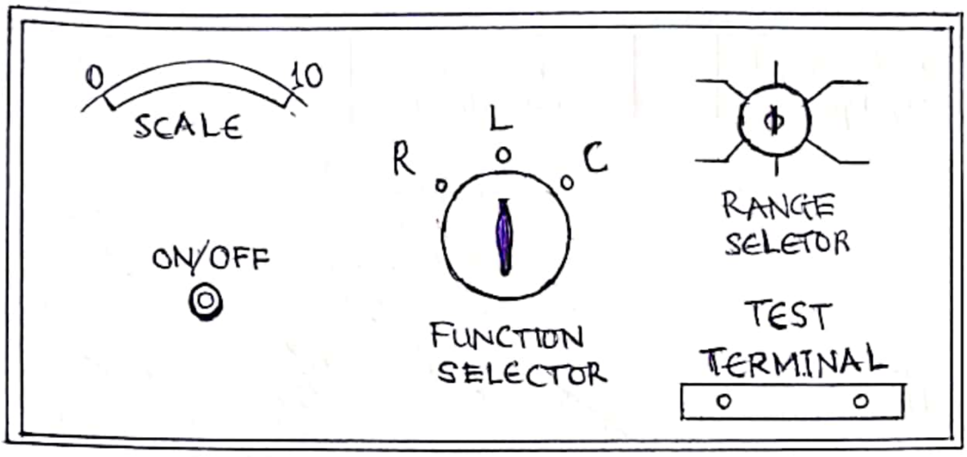



Fig.3.17. Face panel of LCR meter

The important-ant features are;

1. ON/OFF switch for turning the instrument on or off.
2. Scale for indicating the Value of the component under test.
3. Function selector to switch between induct Capacitance and resistance measurement.
4. Range selector to select the appropriate range for the element under test.
5. Test terminals. for connecting with element under test.

## 3.6. Digital Voltmeters (DVM)

The digital voltmeter (DVM) like other digital instruments displays measured AC or DC Voltages as descrete numbers instead of a pointer deflection on a continuous scale Scale as in analog instru-ments. DVMs can now compete with analog inst-uments both in cost and portability because of advancement in IC technology. The block diagram of a typical (simple) DVM is shown in fig3.18.

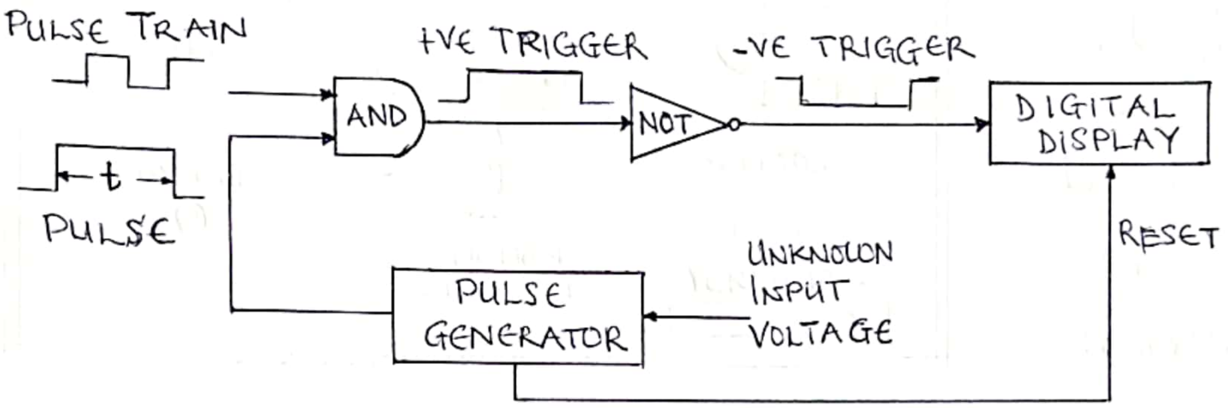



Fig.3.18. Block diagram of simple digital voltmeter.

In its operation the unknown voltage signal (to be measured) is fed into the pulse generator which generates a pulse whose width is proportional to the input unknown voltage. The output of the pulse generator is supplied to one leg of the AND gate. A pulse train is fed to the other leg of the AND gate. The output of the AND gate which is a +ve trigger train is fed to the NOT gate. The NOT gate inverts the +ve trigger train into a -ve trigger train and feeds it into the display. The display is made of a counter which counts the number of triggers appearing in a time, t, which is proportional to the voltage to be measured. The counter (display) can thus be caliberated in voltage units.

From the foregoing it can be deduced that the DVM is an analog to digital converter (ADC) since it converts an analog voltage signal into a digital trigger train proportional to the voltage input.

The block diagram of the DVM is shown in fig. 18

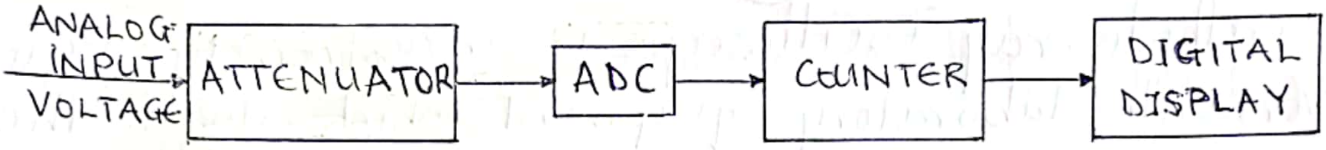



Fig.3.19 Block diagram of DVM

On the basis of type of ADC used DVMs are classified as follows;

1. Ramp type DVM.
2. Dual slope integrating type DVM
3. Integrating type DVM (voltage to frequency conversion)
4. Successive approximation DVM.
5. Potentiometric type DVM.
6. Recirculating remainder type DVM.