Anjani

UNIT - 6

DIGITAL METERS

Introduction:-

The measurement of a given quantity is the result of comparison between the quantity to be measured and a definite stardard. The instruments which are used for such measurements are called measuring instruments.

→ The three basic quantities in the electronic measurement are current, voltage and power

→ The measurement of these quantities is important as it is used for obtaining measurement of some other quantity or used to test the performance of some electronic circuits or componentsetc.

→ The various types of instruments which are used to measure current, voltage and power are classified as analog instruments, electronic instruments and digital instruments. The digital instruments are increasing in number now a days.

The necessary requirements for any measuring instruments are

i, with the introduction of the instrument in the circuit, the circuit should not get affected due to the instrument used.

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

Comparision of Analog and Digital instruments :-

S.NO	Parameters	Analog	Digital
1	Accuracy	less upto ±0.1 % of full scale	Very high accuracy upto ±0.005% of reading.
2.	Resolution	limited upto 1 part in several hundreds.	High upto 1 part in several thousands.
3.	Power	Power required is high hence can cause loading.	Negligible power is required. Hence no loading effects.
4.	cost	low in cost	High in cost compared to analog.
5.	frictional errors	Errors due to ~~imp~~ moving parts are present	No moving parts hence no errors
6.	Range and polarity	No facility of autoranging and autopolarity.	Has the facility of autoranging and autopolarity.
7.	input impedence	low input impedence	very high input impedence
8.	Speed	Reading speed is low	Reading speed is high.
9.	Programming facility	Not available	can be programmed & well suited for the computerised control.
10	compatibility	Not compatiable. with modern digital instruments.	The digital output can be directly fed into memory of modern digital instruments.

Digital Voltmeters:-

The digital voltmeters generally referred as DVM, convert the analog signals to digital and display the voltages to be measured as discrete numericals. instead of pointer deflection, on the digital displays. such voltmeters can be used to measure a.c and d.c voltages and also to measure the quantities like pressure, temperature, stress etc. using proper transducer and signal conditioning circuit. The output voltage is displayed on the digital display on the front panel.

→ The output voltage is displayed on the digital display on the front panel.

→ Such a digital output reduces the human reading & interpolation errors and parallax errors.

The DVM's have various features and the advantages over the conventional analog voltmeters having pointer deflection on the continuous scale.

Advantages of Digital Voltmeters:-

The DVM's have no.of advantages over conventional analog voltmeters, which are,

1. Due to the digital display, the human reading errors, interpolation errors and parallax errors are reduced.
2. They have input range from ±1V to 1000 V with the automatic range selection and the overload indication.
3. The accuracy is high upto ±0.005% of the reading.

4. The resolution is better as $1\mu V$ reading can be measured on 1 v range.

5. The input impedence is an high as $10 M\Omega$

6. The reading speed is very high due to digital display.

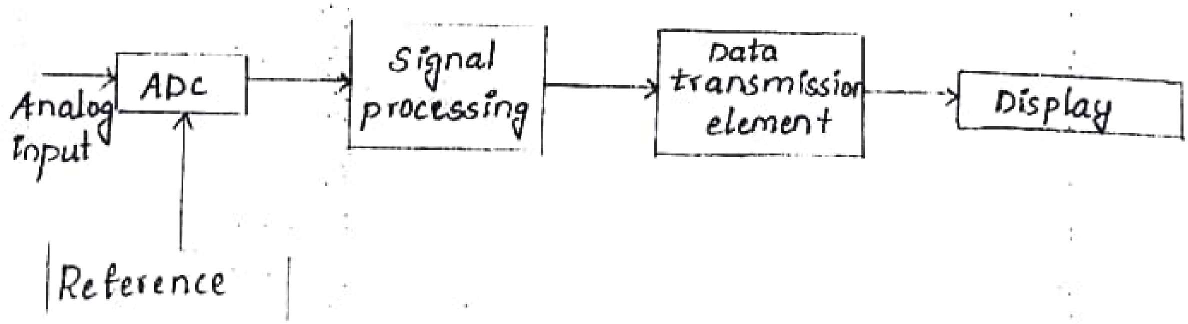
7. they can be programmed and well suited for computerised control.

8. Due to small size, are portable

9. The BCD output can be printed or used for digital processing.

Basic Block Diagram of DVM:-

Any digital instrument requires to digital converter at its input. Hence first block in a general DVM is ADC as shown in the fig



→ Every ADC requires a reference.

→ The reference is generated internally and reference generator circuitry depends on the type of ADC techniques used.

→ The output of ADC is decoded and signal is processed in the decoding state.

→ Such a decoding is necessary to drive the seven segment display.

→ the data from decoder is then transmitted to the deplay.

Classification of Digital Voltmeters:-

The digital voltmeters are classified mainly based on the technique used for the analog to digital conversion. Depending on this, the digital voltmetess are mainly classified as.

a) Successive approximation type

b) Ramp type
 * Linear type
 * staircase type

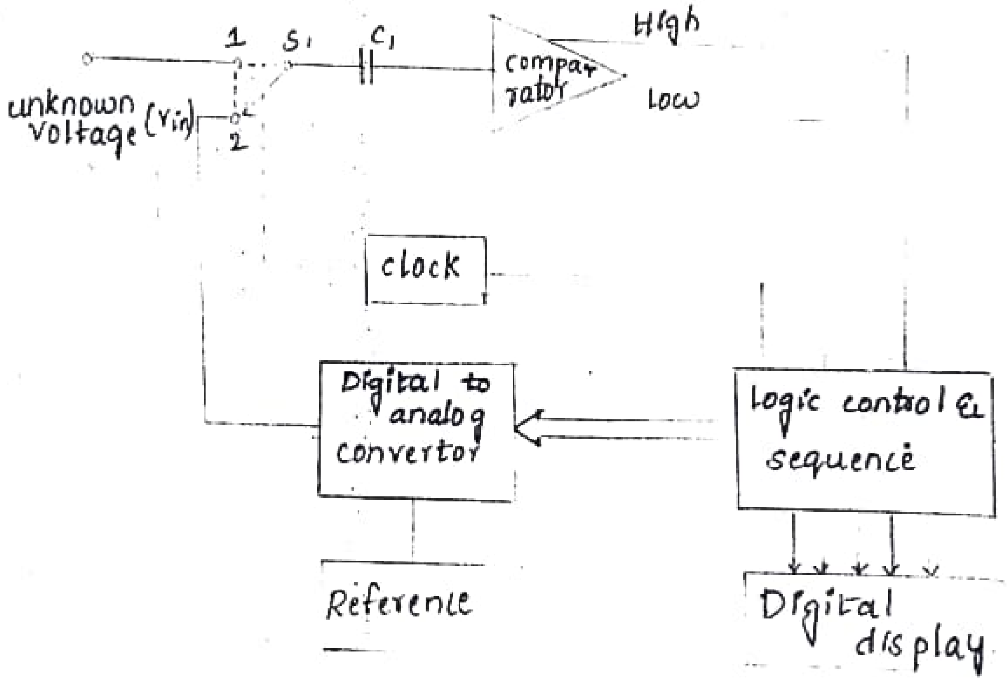
c) Dual slope integrating type.

Successive Approximation type:-

The potentiometer used in the servo balancing type DVM is a linear divider but in succesive approximation type a digital divider is used. The digital divider is nothing but a digital to anolg (D/A) converter. The servomotor is replacing by an electronic

Logic.

The basic principle of measurement by this method is similar to the simple example of determination of weight of the object. The object is placed on one side of the balance and the approximate weight is placed on the other side. If weight placed is more, the weight is removed and smaller weight is placed. If this weight is smaller than the object another small weight is added to the weight present. thus by such successive procedure of adding & removing, the weight of the object is (succe) determined. The successive approximation type DVM works (exactly on the same (converter) principle.



The capacitor is connected at the input of the comparator. The output of the digital to analog convertor is compared with the unknown voltage, by the comparator. The output of the comparator is given to the logic control and sequencer. This unit generates the sequence of code which is applied to digital to analog converter. The logic control also drives the clock which is used to alternate the switch S_1 between the positions 1 and 2, as per the requirement.

Consider the voltage to be measured is 3.7924 V. The set pattern of digital to analog converter is say 8-4-2-1. At the start, the convertor generates 8V & switch is at the position 2. The capacitor C_1 charges to 8V. The clock is used to change the switch position. So during next time interval, switch position is 1 and unknown input is applied to the capacitor. As the capacitor is charged to 8V which is more than the input voltage 3.7924V, the comparator send HIGH signal to the logic control & sequencer circuit.

→ The high signal resets the digital to analog converter which generates its next step of 4V. The again generates high signal. This again resets the converts to generate the next step of 2V.

Now 2V is less than the input voltage. The comparator generates Low signal and sends it to logic control and sequencer circuit. Thus the process of successive approximation continues till the converter generates 3.7924 This voltage is then displayed on the digital display.

At each low signal, there is an incremental change in the output of the digital to analog converter. this output voltage approaches the value of the unknown voltage. The speed depends upon the type of switches used. The accuracy depends on the internal supply associated with the digital to analog convertor and the accuracy of the converter itself.

Advantages:-

1. The accuracy is high
2. The method of ADC is inexpensive.
3. Very high speed of the order of 100 readings per second possible.
4. The resolution upto 5 significant digits is possible.

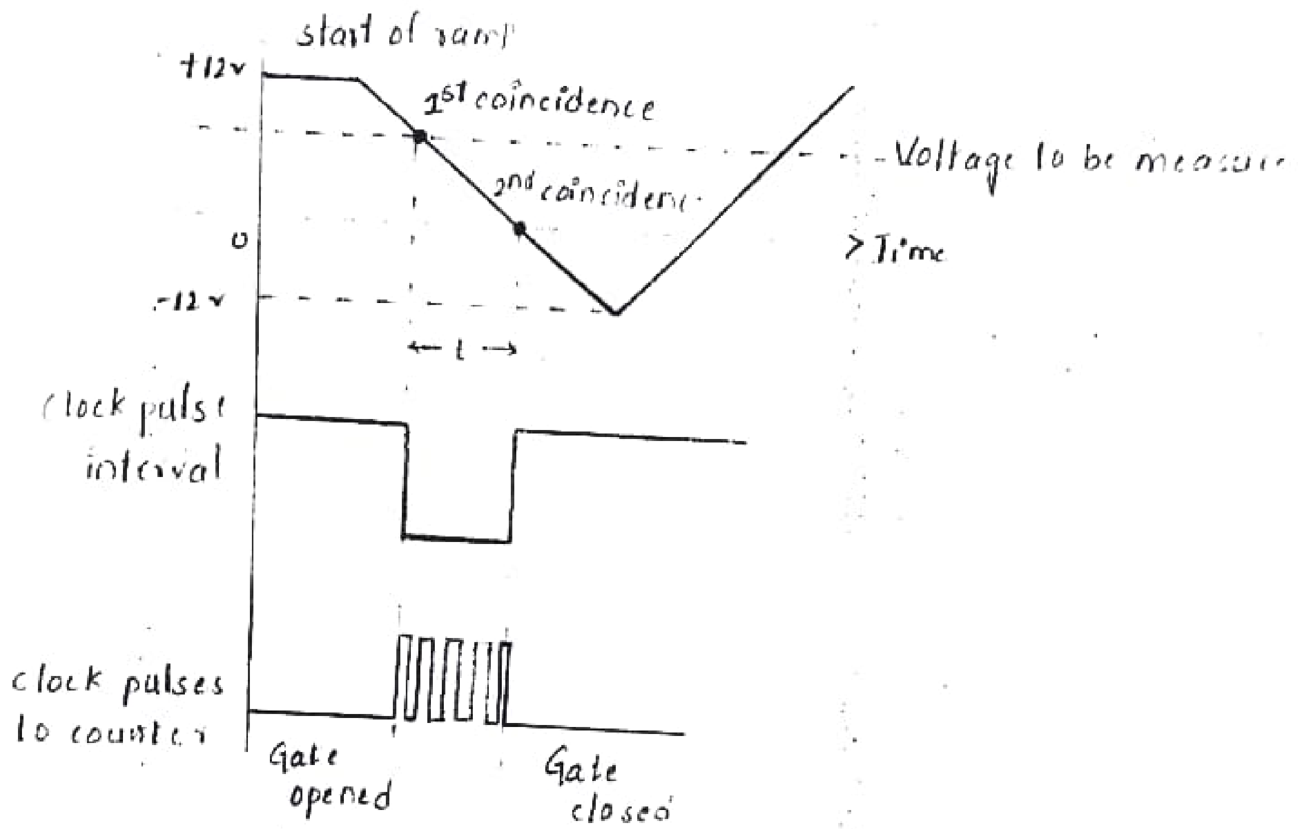
Disadvantages:-

1. The circuit is complex
2. The DAC is also required
3. The input impedance is variable
4. The noise can cause error due to incorrect decisions made by comparator.

Ramp type DVM :-

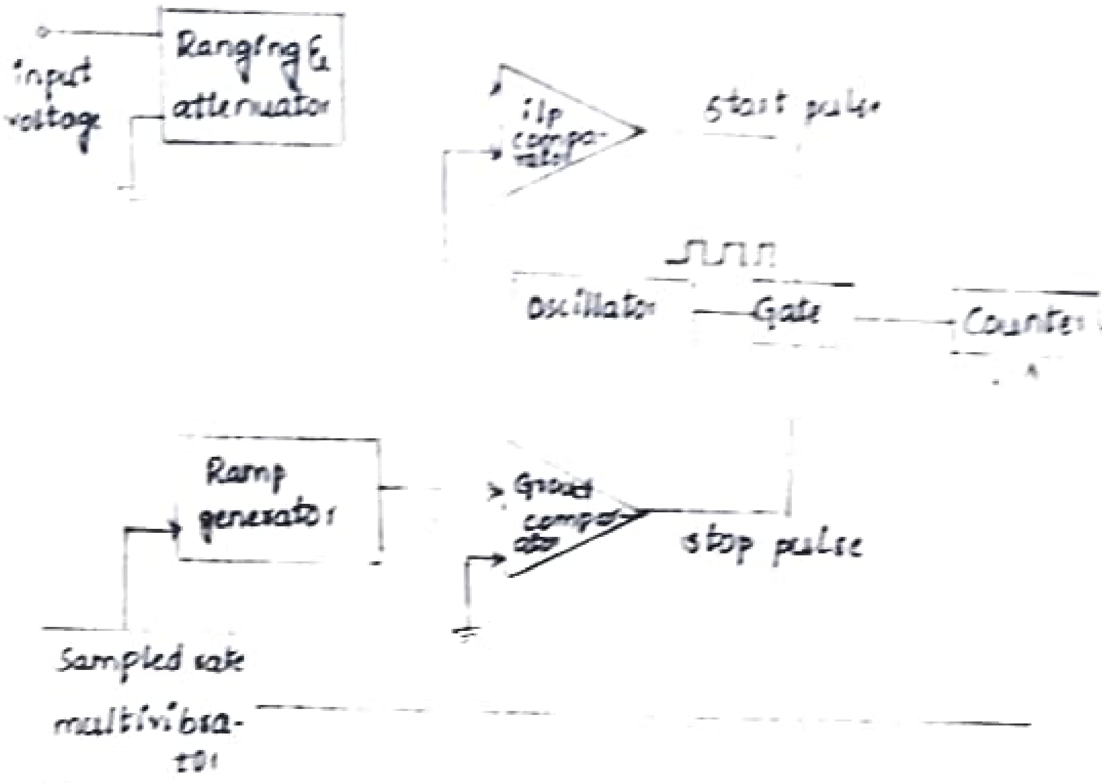
It uses a linear ramp technique or staircase ramp technique. The staircase ramp technique is simpler than the linear ramp technique. Let us discuss both the techniques.

Linear Ramp Technique :-



The basic principle of such measurement is based on the measurement of the time taken by a linear ramp to rise from 0V to the level of the input voltage or to decrease from the level of the input voltage to zero. This time is measured with the help of the electronic interval counter and the count is displayed in the numeric from with the help of a digital display.

Basically it consists of a linear ramp which is positive going or negative going. The range of the ramp is ± 12 V while the base range is ± 10V. The conversion from a voltage to a time interval shown in the above fig.



At the start of measurement, a ramp voltage is initiated which is continuously compared with the i/p voltage. When these two voltages are same, the comparator generates a pulse which opens a gate i.e the input comparator generates a start pulse. This is sensed by the second comparator or ground comparator.
The number of clock pulses are measured by the counter. Thus the time duration for which the gate is opened, is proportional to the input voltage.
The magnitude of the count indicates the magnitude of the input voltage, which is displayed by the display.

Properly attenuated input signal is applied as one input to the input comparator. The ramp generator generates the proper linear ramp signal which is applied to both the comparators. Initially the logic circuit sends a reset signal to the counter and the readout.

When the input and ramp are applied to the input comparator and at the point when negative going ramp becomes equal to input voltages the comparator sends start pulse, due to which gate opens.

The oscillator drives the counter. The counter counter starts counting the pulses received from the oscillator.

Now the same ramp is applied to the ground comparator and it is decreasing.

When ramp becomes zero, both the inputs of ground comparator becomes zero equal and it sends a stop pulse to the gate due to which gate gets closed. Thus the counter stops receiving the pulses from the local oscillator.

The oscillator of this multivibrator is usually adjusted by a front panel control named rate, from few cycles per second to as high as 1000 or more cycles per second. The typical value is 5 measuring cycles/second with an accuracy of ±0.005% of the reading. A The sample rate provides an initiating pulse to the ramp generator to start its next ramp voltage. At the same time, a reset pulse is also generated which resets the counter to the zero state.

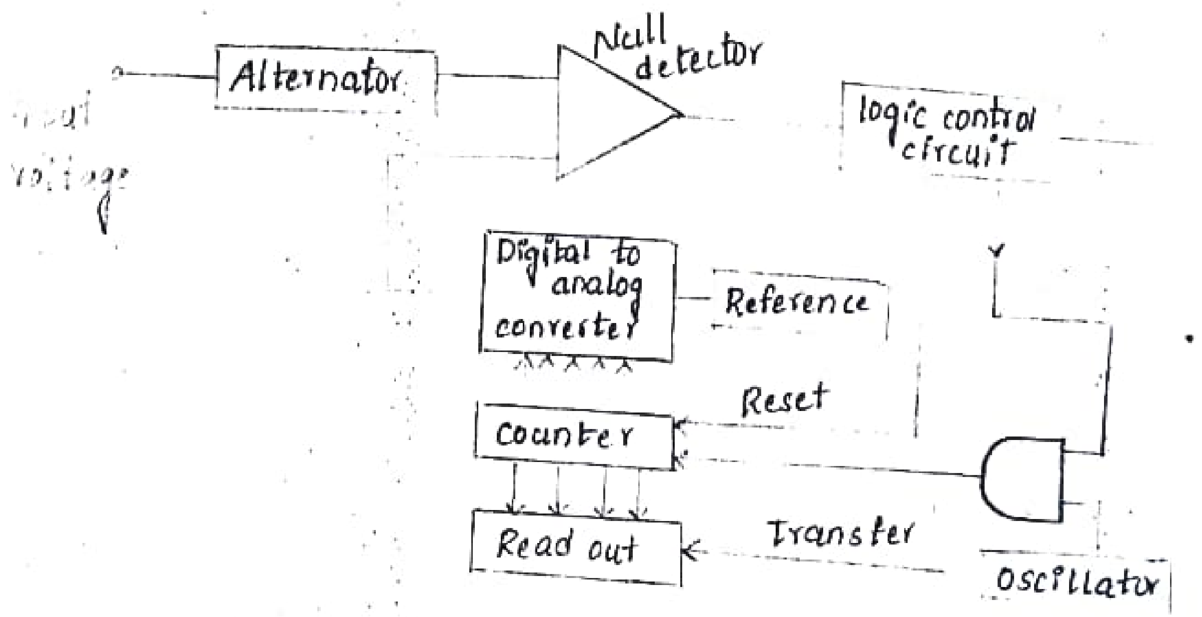
Advantages:-

1. The circuit is easy to design
2. The cost is low
3. The input signal is converted to time, which is easy to digitize
4. By adding external logic, the polarity of the input also can be displayed.

Disadvantages:-

1. The ramp requires excellent characteristics regarding its linearity.
2. The accuracy depends on slope of the ramp & stability of the local oscillator.
3. large errors are possible if noise is superimposed on the input signal.
4. The speed of measurements is low.

Staircase Ramp Technique:-



The technique of using staircase ramp is also called null balance technique. The input voltage is properly attenuated and is applied to a null detector. The ramp to null detector is the staircase ramp generated by digital to analog converter. The ramp is continously compared with the i/p signal.

Initially the logical control circuit sends a reset signal. This signal resets the counter. The digital to analog converter is also resetted by same signal.

At the start of measurement, logic control circuit sends a starting pulse which opens the gate. The counter starts counting the pulses generated by the local oscillator.

The output of counter is given to the digital to analog converter which generates the ramp signal. At every count there is an incremental change in the ramp generated. Thus the staircase ramp is generated at the output of the digital to analog convertor. This is given as the second input of the null detector. The increase in ramp continues till it achieves the voltage equal to input voltage.

When the two voltages are equal, the null detector generates a signal which in turn initiates the logic control circuit. Thus logic control circuit sends a stop pulse, which closes the gate and the counter stops counting.

At the same time, the logic control circuit generates a transfer signal due to which the counter information is transferred to the readout. The readout shows the digit result of the count.

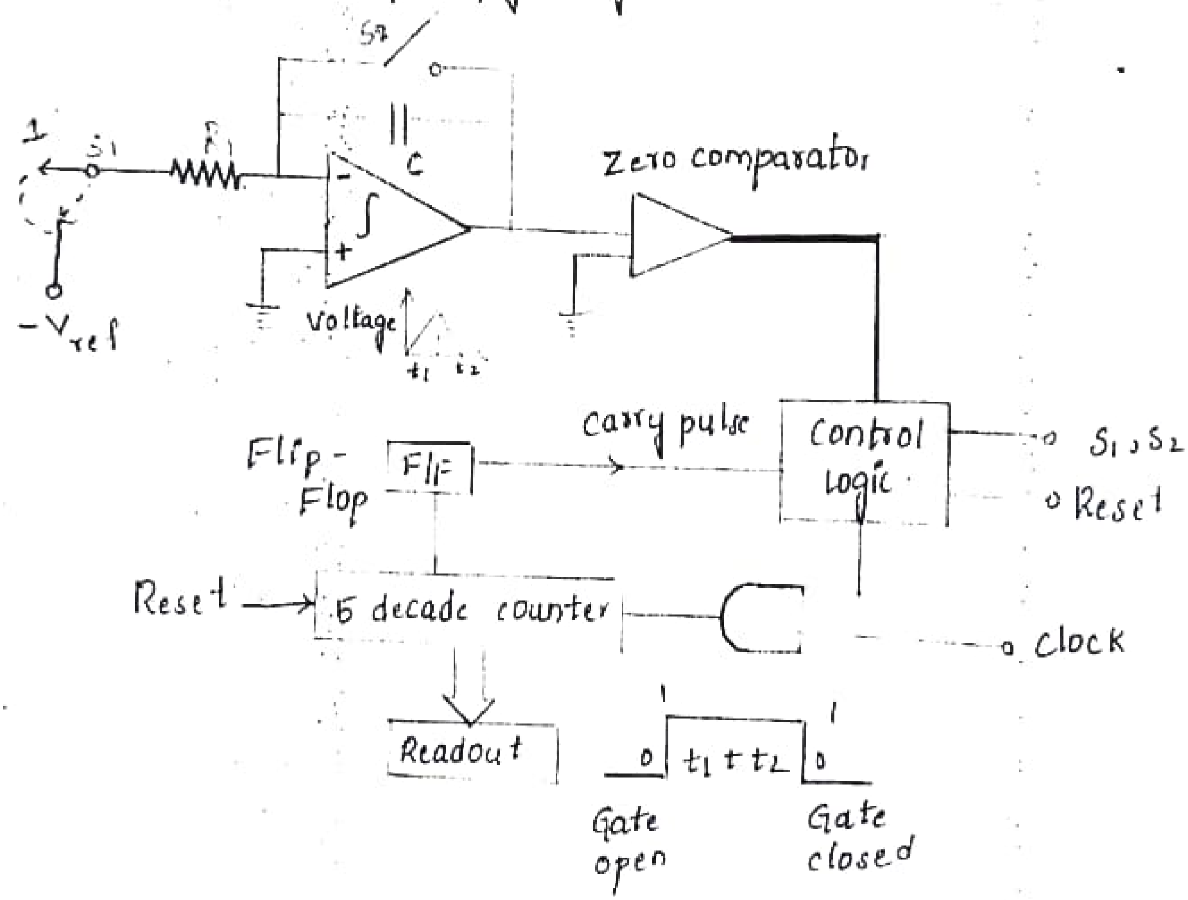
Advantages:-

1. The greater accuracy is obtained than the linear ramp technique.
2. The overall design is more simple hence economical.
3. The input impedence of the digital to analog converter is high when the compensation is reached.

Disadvantages:-

1. Through accuracy is higher than linear ramp, it is dependent on the accuracy of digital to analog converter and its internal reference.
2. The speed is limited upto 10 readings per seccond.

Dual Slope Integrating Type DVM:-



This is the most popular method of analog to digital conversion. In this ramp techniques, the noise can cause large errors but in dual slope method the noise is averaged out by the positive and negative ramps using the process of integration. The (avera-ged out by the positive) basic principle of this method is that the input signal is integrated for a fixed interval of time. And then the same integrator is used to integrate the reference voltage with reverse slope. Hence the name given to the technique is dual slope integration technique.

It consist of five blocks, an op-amp used as an integrator, a zero comparator, clock pulse generator, a set of decimal counters and a block of control logic.

When the switch S_1 is in position 1, the capacitor c starts charging from zero level. The rate of charging is proportional to the input voltage level. The output of the op-amp is given by

$$V_{out} = -\frac{1}{R_1 C}\int_0^{t_1} V_{in}\,dt$$

$$\boxed{V_{out} = -\frac{V_{in} t_1}{R_1 C}} \longrightarrow (1)$$

where

t_1 = time for which capacitor is charged

V_{in} = i/p voltage, R_1 = series resistance

C = Capacitor in feedback path.

After the interval t_1, the input voltage is disconnected and a negative voltage V_{ref} is connected by throwing the switch S_1 in position 2. In this position, the output of the op-amp is given by

$$V_{out} = \frac{1}{R_1 C}\int_0^{t_2} -V_{ref}\,dt$$

$$\boxed{V_{out} = -\frac{V_{ref}\,t_2}{R_1 C}} \longrightarrow (2)$$

Subtracting eq (1) from (2)

$$V_{out} - V_{out} = 0 = \frac{-V_{ref}\,t_2}{R_1 C} - \left[-\frac{V_{in}\,t_1}{R_1 C}\right]$$

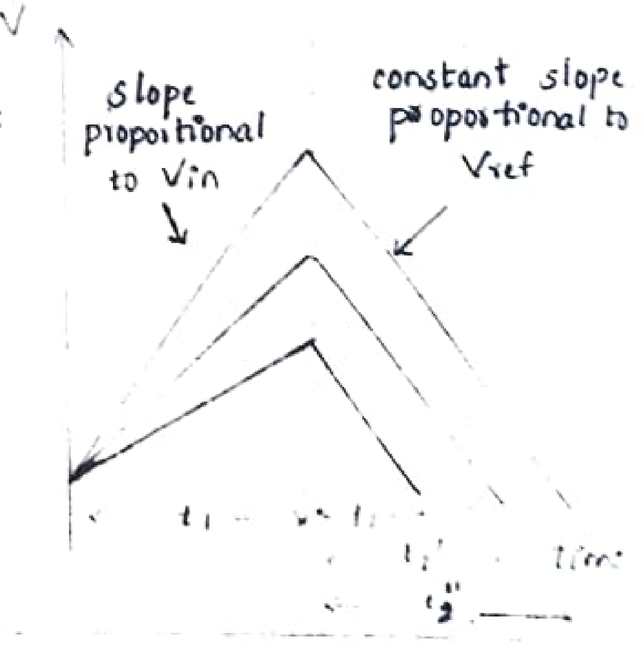
$$\frac{V_{ref}\,t_2}{R_1 C} = \frac{V_{in}\,t_1}{R_1 C}$$

$$V_{ref}\,t_2 = V_{in}\,t_1$$

$$\boxed{V_{in} = V_{ref}\frac{t_2}{t_1}} \longrightarrow (3)$$

Thus the input voltage is dependent on the time periods t_1 and t_2 and not on the values of R_1 and C.

This basic principle of this method is shown in the fig.



At the start of the measurement, the counter is resetted to zero. The output of the flip flop is also zero. This is given to the control logic. This control sends a signal so as to close an electronic switch to position 1 & integration of the input voltage starts. It continues till the time period t_1. As the output of the integrator changes from its zero value, the zero comparator output changes its state. This provides a signal to control which inturn opens the gate and the counting of the clock pulses starts.

The counter counts the pulses and when it reaches to 9999, it generates a carry pulse and all digits go to zero. The flip-flop output gets activated to the logic level 1. This activates the control logic. This sends a signal which changes the switch S_1 position from 1 to 2. Thus $-V_{ref}$ gets connected to op-amp. As V_{ref} polarity is opposite, the capacitor starts discharging. The integrator output will have constant negative slope as shown in above fig. The output decreases linearly and after the interval t_2, attains zero value, when the capacitor C gets fully discharged.

At this instant, the output of zero comparator changes its state. This inturn sends a signal to the control logic and the gate gets closed. Thus gate remains open for the period $t_1 + t_2$. The counting operation stops at this instant. The pulses counted are then transferred to the readout.

From eq(3) we can write

$$V_{in} = V_{ref} \frac{t_2}{t_1}.$$

Let time period of clock oscillator be T and digital counter has counted the counts n_1 and n_2 during the period t_1 and t_2 respectively.

$$\boxed{V_{in} = V_{ref} \frac{n_2 T}{n_1 T} = V_{ref} \frac{n_2}{n_1}}$$

Thus the unknown voltage measurement is not dependent on the clock frequency, but depedent on the counts measured by the counter.

Advantages.

1. Excellent noise rejection as noise & Superimposed a.c are averaged out during the process of integration.
2. The RC time constant does not affect the input voltage measurement
3. The capacitor is connected via an electronic switch the capacitor is an auto zero capacitor and avoids the effects of offset voltage.
4. the integrator responds to the average of the input hence sample & hold circuit is not necessary.
5. the accuracy is high & can be readily varied according to the specific requirements.

the only disadvantages of this type of DVM is its slow speed.

3-½ and 4-½ digit

The resolution of digital meters depends on the no. of digits used in the display. the three digit display for 0-1V range can indicate the values from 0 to 999 mv with the smallest increment of 1mv.

practically one more digit which can display with only 0 or 1 is added. this digit is called half digit & display is called 3-½ digit display. this is shown in the fig 9.15.1

In such a display the meter can read the values above 999 upto 1999, to give the overlap b/w the ranges for convenience. this process is called over-ranging.

In case of 4-½ digit display, there are 4 full digits & 1 half digit. the number obtained is from 0 to 19999. For this operation the time period required for counting obtained operation should be reduced. This can be achieved by changing the frequency of the clock signal. The wave shaping & amplifier circuitry should be more accurate for 4-½ digit display. It is necessary to add one more BCD counter, latch, BCD to 7 segment decoder & 7 segment display unit. The resolution of 4-1/2 digit display is better than 3-1/2 digit display while the accuracy is 10times better.

Problem

A 3-1/2 digit DVM has an accuracy specification of ± 0.5% of the reading ± 1 digit.

i) What is error in volts, when the reading is 5.00V on its 10V range?

ii) What is the % error of reading, when the reading is 0.10V on its 10V range?

Solution As no.of digits $n = 3$

$R = 1/10^3 = 0.001$

For 10V range,

$R = 0.01 \times 10 = 0.01V$

1 digit $= 0.01V$ on 10V range.

∴

i) The reading is 5.00V

∴ Error due to reading $= \pm 0.05\%$ of $5.00 = \frac{0.5}{100} \times 5$

$= 0.025V$

and 1 digit error $= 0.01V$

total error $= 0.025 + 0.01 = 0.035V$

ii) When reading is 0.10V,

Error due to reading $= \pm 0.5\%$ of 0.1

$= \frac{0.5 \times 0.1}{100} = \pm 0.0005V$

and 1 digit error $= \pm 0.01V$

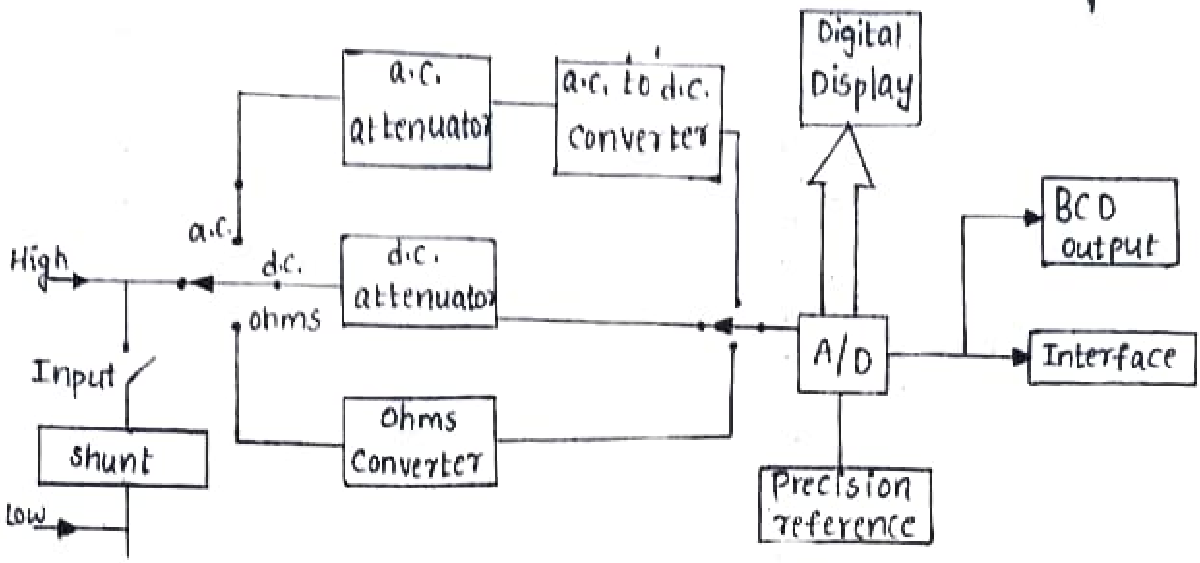
total error $= \pm 0.0105V$

Error as % of reading $= \frac{0.0105}{0.1} \times 100$

$= 10.5\%$

* Digital Multimeters :

The digital multimeter is an instrument which is capable of measuring a.c. voltages, d.c. voltages, a.c and d.c currents and resistances over several ranges.



→ The current is converted to voltage by passing it through low shunt resistance.

→ The a.c. quantities are converted to d.c. by employing various rectifier and filtering circuits.

→ For the resistance measurements the meter consists of a precision low current source that is applied across the unknown resistance while gives d.c. voltage.

→ All the quantities are digitised using analog to digital converter and displayed in the digital form on the display.

Advantages over analog multimeters :

i) The accuracy is very high

ii) The input impedance is very high hence there is no loading effect.

iii) An unambigious reading of greater viewing distances is obtained

iv) The output available is electrical which can be used for interfacing with external equipment.

v) Due to improvement in the integrated technology, the prices are going down

vi) These are available in very small size.

Disadvantages :

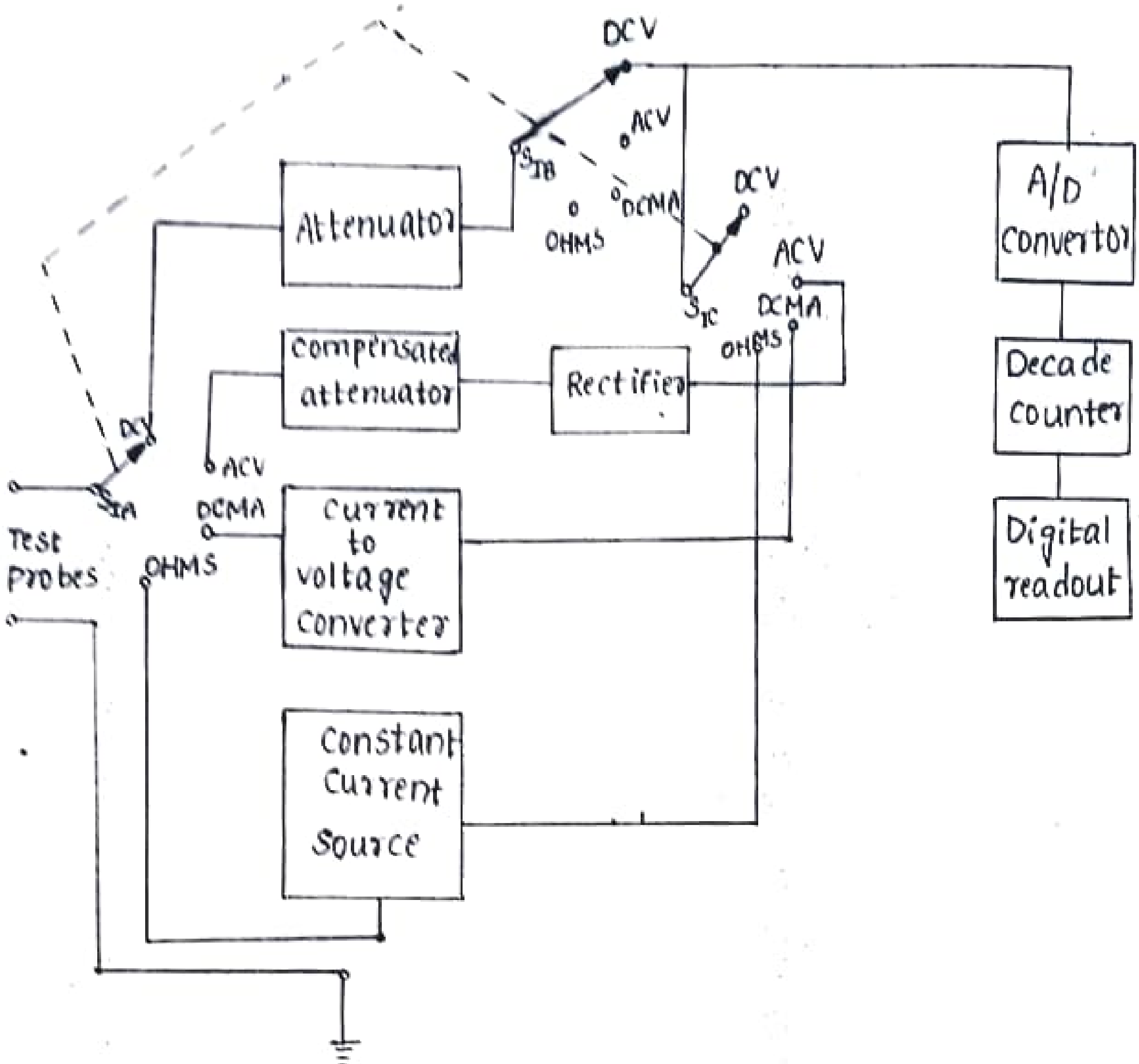
The requirement of power supply . electric noise and isolation problems.

Block diagram of a digital multimeter :

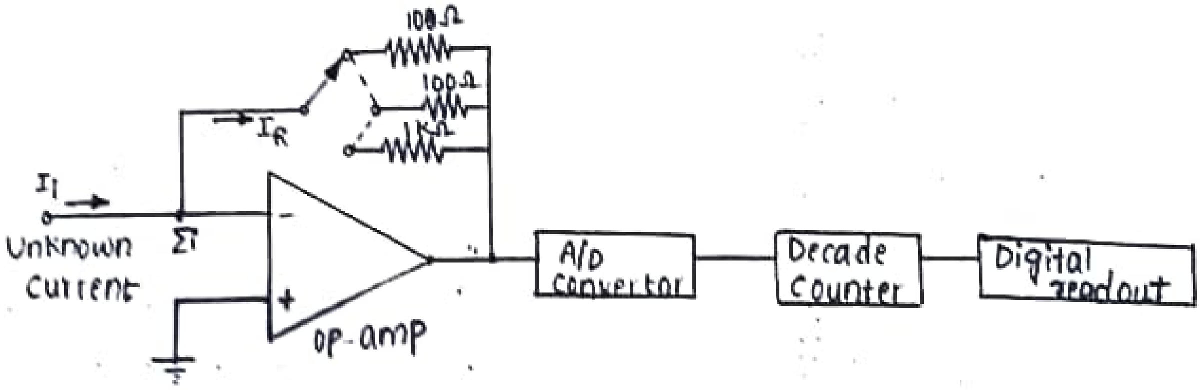
The basic building blocks of digital multimeter are several A/D converters, counting circuitry and an attenuation circuit.

⟶ A single attenuator circuit is used for both a.c and d.c measurements in many commercial multimeters.

⟶ The Block diagram is given below.



→ As mentioned above basically it is a d.c. voltmeter. In Order to measure unknown currents, current to voltage converter circuit is implemented. This is shown below.



→ The unknown current is applied to the summing junction Σi at the input of OP-amp.

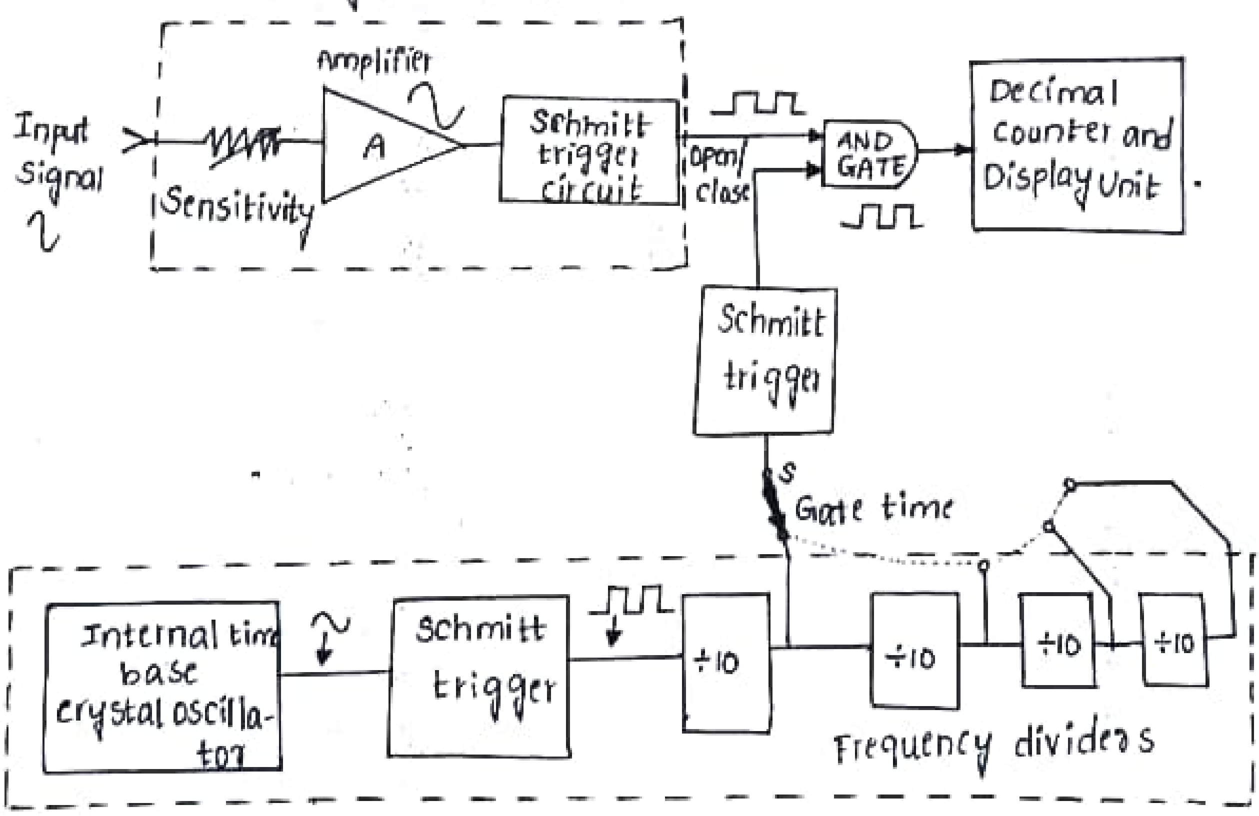
→ This current I_R causes a voltage drop, which is proportional to the current to be measured. This voltage drop is the analog input to the analog to digital convertor, thus providing a reading that is proportional to the unknown current.

→ To measure the a.c. voltages, the rectifiers and the filters are used. The a.c. is converted to d.c. and then applied to the analog to digital converter.

* Digital Frequency meter :

For the unknown frequency measurements the digital frequency counter is the most accurate and reliable instrument available.

As the most of the events now a days can be converted into an electrical signal consisting train of pulses the digital frequency counter can be used for counting heart beats, passing of radioactive particles, revolutions of motor shaft, light flashes etc.



The major components of the digital frequency counter are as given below.

1. Input signal conditioning circuit.
2. Time base generator
3. Gating circuit.
4. Decimal counter and display unit.

1. Input signal conditioning circuit :

In this circuit, an amplifier and schmitt trigger are included. The threshold voltage of the schmitt trigger can be controlled by sensitivity control on the control panel.

→ The input signal of unknown frequency is fed into input signal conditioning circuit.

→ There the signal is amplified and then it is converted into square wave by schmitt trigger circuit.

2. Time base generator :-

The crystal oscillator produces a signal of 1 MHz or 100 MHz depending upon the requirement.

→ The accuracy of the digital frequency counter depends on the accuracy of the time base signals produced.

→ The output of the oscillator produces square wave output then it is fed to frequency dividers connected in cascade.

→ Thus the train of pulses are obtained after each frequency divider section.

→ Using time base selector switch 's' the "Gate Time" is adjusted.

3. Gating circuit :

The gating circuit consists of AND gate. when the enable signal is provided to the AND gate, it allows a train of pulses to pass through the gate for the time Period by the time base circuit. The pulses are Counted and then the second pulse generated from the time base generator disables AND gate and thus closes it.

4. Decimal Counter and display unit :

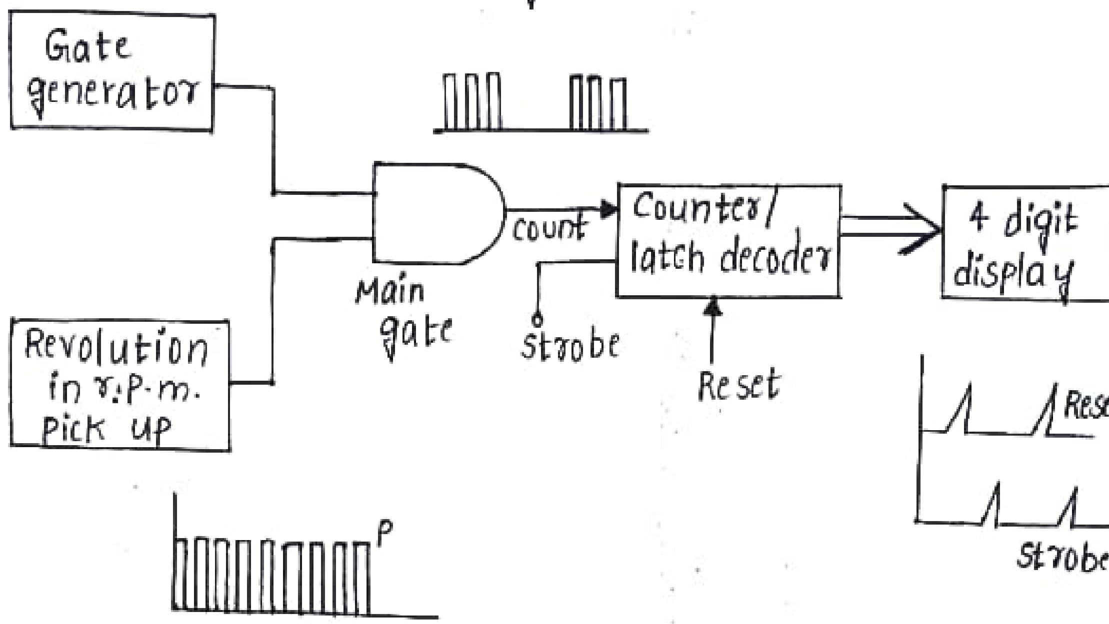
In this unit, decade counters are connected in the cascade. The output of the AND gate is connected to the clock input of the first decade counter. Then the output of this counter to the clock input of next and so on. Using these counters the number of pulses are counted and are displayed by the display unit.

* Digital Tachometer :

The digital tachometer is used to measure speed of a motor. The technique used for the measurement of a speed of a rotating shaft of a running motor. is same as that used in the conventional frequency counter.

In conventional frequency counter, the gate pulses are obtained in accordance with the schmitt trigger output while in the digital tachometer the gate period is selected in accordance with r.p.m. calibration.

Digital tachometer circuitary :-



→ Consider that the revolution per minute of a shaft be 'R'.

→ Assume that the no. of pulses produced in one revolution of rotating shift be 'P'.

→ Then in one minute the no. of pulses from the revolution pick up can be calculated as RXP.

→ And the frquency of the signal is given by $(R \times P / 60)$.

→ Suppose the gate period is 'G' measured in second, then the pulses counted are $[R \times P \times G / 60]$.

→ Now the direct reading is possible in rpm if only the gate period is $(60/P)$ and the pulses counted by the counter are R.

i.e, $\boxed{R \times P \times \left(\frac{60}{P}\right) / 60 \doteq R}$

* **Resolution:** If 'n' is the number of full digits then the resolution of a DVM is given by

$$\boxed{R = \frac{1}{10^n}}$$ where R = Resolution

EX:- for 3 digit display, n=3

$$R = \frac{1}{10^3} = 10^{-3} = 0.001$$

* **Sensitivity:-** sensitivity is the smallest change in input which a digital meter should be able to detect.

$$\boxed{S = (Fs)_{min} \times R}$$

where S = sensitivity, $(Fs)_{min}$ = full scale value on minimum range

R = Resolution

① What is the resolution of a 3½ digit display on 1V & 50V ranges?

Sol:- $n = 3$, $R = \frac{1}{10^3} = 0.001$

For 1V range, the resolution is $1 \times 0.001 = 0.001$ V

For 50V range, the resolution is $50 \times 0.001 = 0.05$V

② A Voltmeter uses a 4½ digit display i) Find its resolution ii) How would the 11.87 V be displayed on a 10V range? How would 0.5573 be displayed on 1V & 10V ranges?

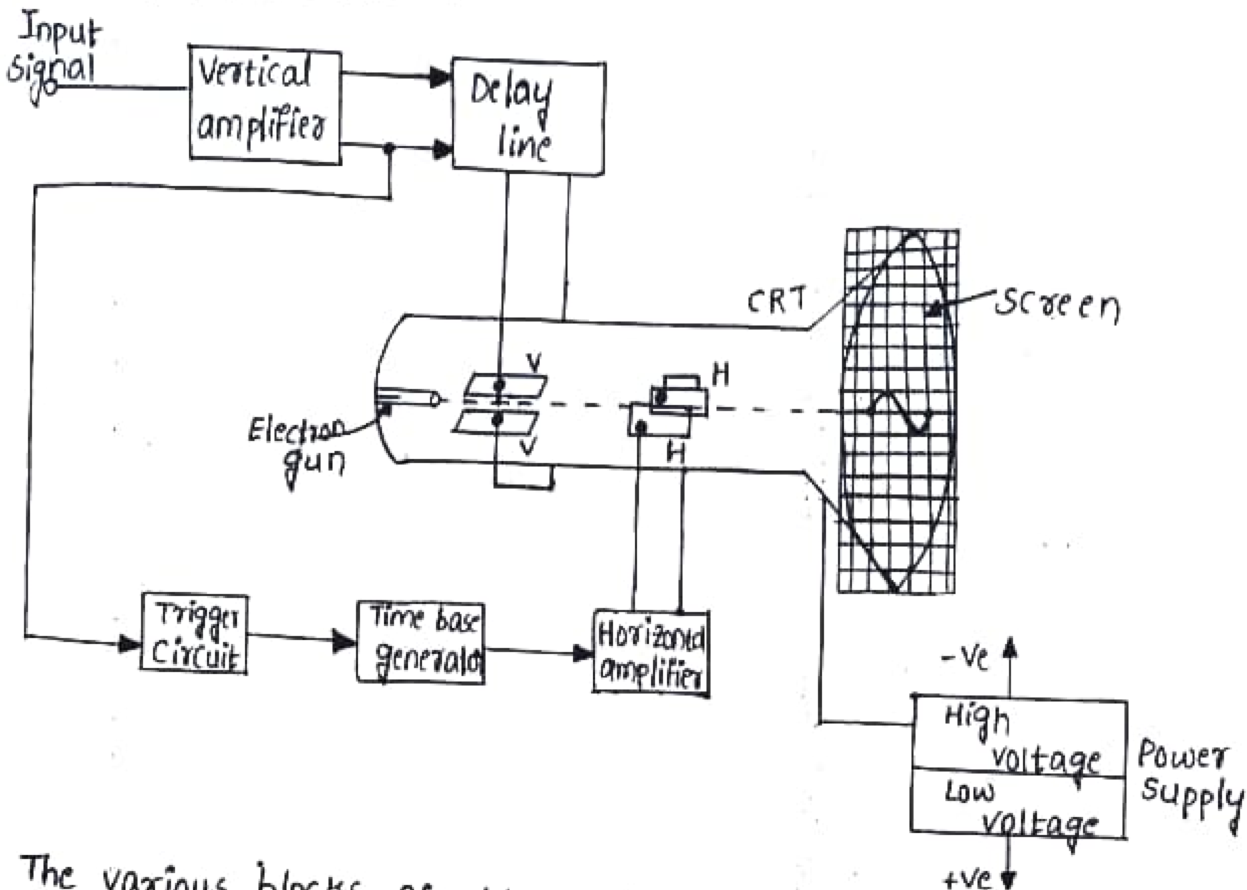
Sol:- $n = 4$, $R = \frac{1}{10^4} = 0.0001$

→ on 10V range, 11.87 is displayed as 11.870 V

→ on 1V range, 0.5573 is displayed as 0.5573V

→ on 10V range, 0.5573 is displayed as 0.557 rather than 0.5573.

* Simple Oscilloscope :-



The various blocks of block diagram of simple oscilloscope are as follows :-

CRT :-

This is the cathode ray tube which is the heart of C.R.O. It is used to emit the electrons required to strike the phosphor screen to produce the spot for the visual display of the signals.

Vertical Amplifier :-

The input signals are generally not strong to provide the measurable deflection on the screen.

→ It is used to amplify the input signals.

→ Amplifier stages are wide band amplifiers.

→ It also contains attenuator stages. These attenuators are used when very high voltage signals are examined to bring the signals within proper range of operation.

Delay line :-

The delay line is used to delay the signal for some time in the vertical sections. When the delay line is not used, the part of the signal gets lost.

Trigger circuit :-

It is necessary that horizontal deflection starts at the same point of the input vertical signal, each time it sweeps. Hence to synchronize horizontal deflection with vertical deflection a synchronizing or triggering circuit is used.

⟶ It converts the incoming signal into the triggering pulses.

Time Base Generator :-

The time base generator is used to generate the saw-tooth voltage, required to deflect the beam in the horizontal section.

⟶ Thus the X-axis on the screen can be represented as time, which helps to display and analyze the time varying signals.

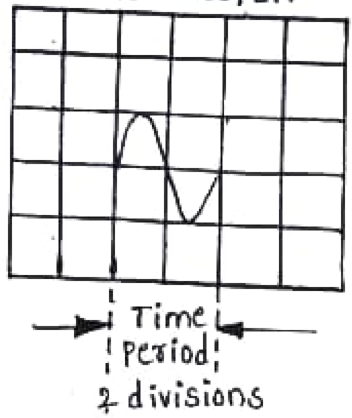
Horizontal Amplifier :-

The sawtooth voltage produces the (voltage) time base generator may not be of sufficient strength. Hence before giving it to the horizontal deflection plates, it is amplified using the horizontal amplifier.

Time measurement :-

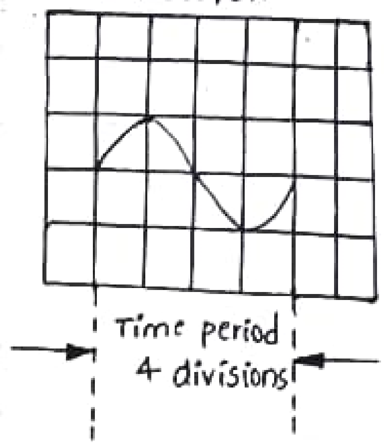
If a signal has time period of 20msec then with two different time base control selections, it can be displayed as shown in below figures.

10msec/div



$\therefore T = 10 \times 2 = 20$msec

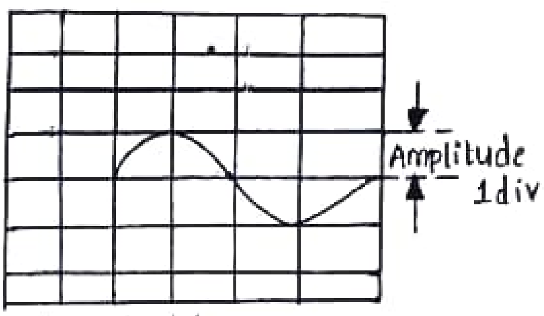
5msec/div



$\therefore T = 5 \times 4 = 20$ msec

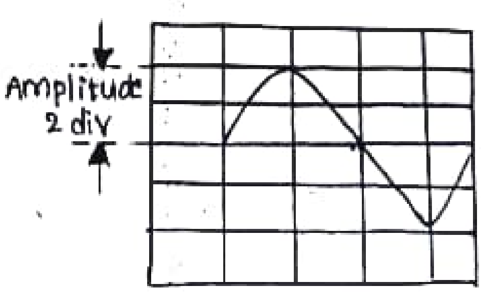
Voltage Measurement :-

Suppose the alternating voltage signal of amplitude 10V is to be displayed. Then if volts/division are selected as 10 then it will be displayed as the below figure. And also if volts/division =5 is selected, as shown in below figure.



10V/div

Amplitude $= 1 \times 10 = 10$V



5 V/div

Amplitude $= 2 \times 5 = 10$V

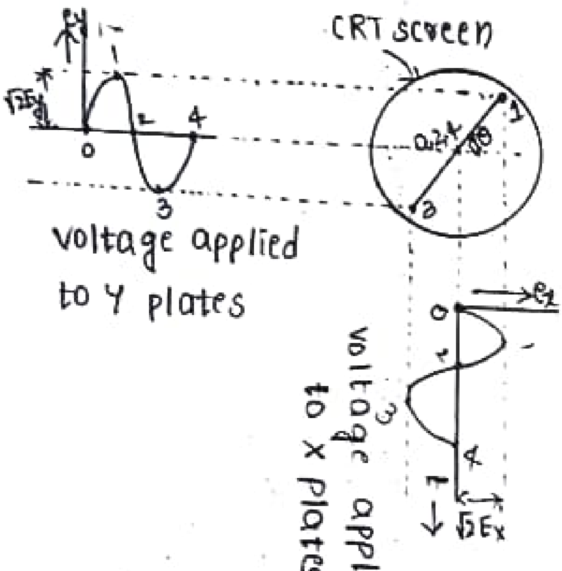
Frequency Measurement :-

- It is reciprocal of time period.

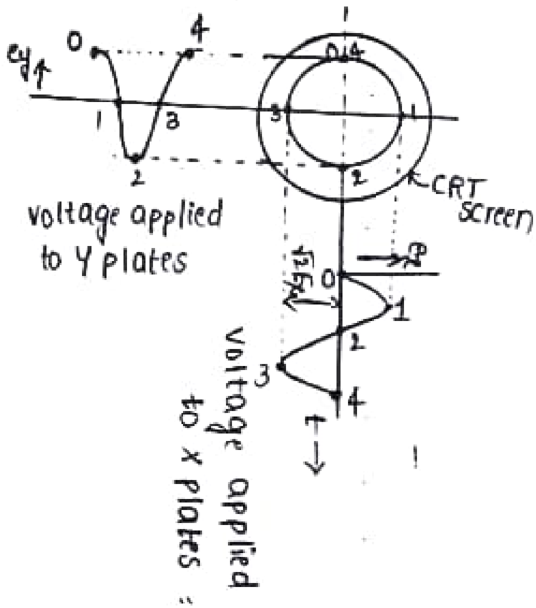
$$\boxed{f = 1/T}$$

Lissajous Patterns :-

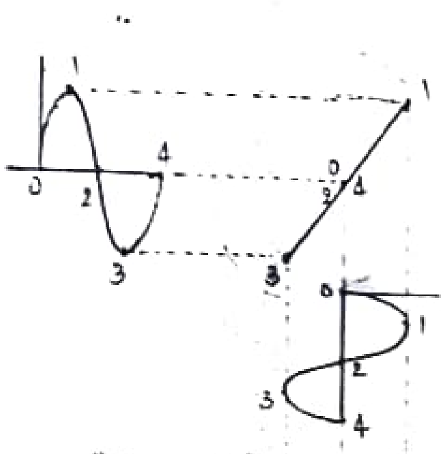
It is interesting to consider the characteristics of patterns that apper on the screen of a CRT when sinusoidal voltages are simultaneously applied to horizontal and vertical plates. These patterns are called "Lissajous patterns".

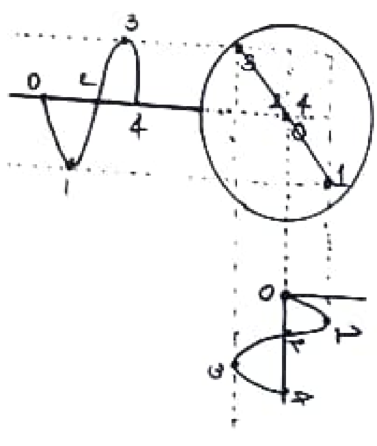


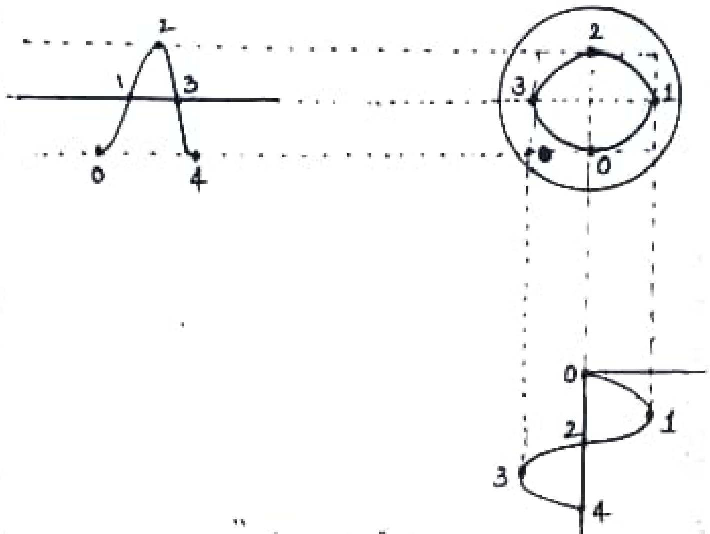
"θ = 0°"



"θ = 90°"


"θ = 360°"


"θ = 180°"



$\underline{\underline{\theta = 270^\circ}}$

When two equal voltages of equal frequency but with a Phase shift ϕ (not equal to 0° or 90°) are applied to a CRO we Obtain an ellipse as in the above figure. An ellipse is also obtained when unequal voltages of same frequency are applied to the CRO.

→ A straight line results when the two voltages are equal and are either in phase with each other or 180° out of phase with each other. The angle formed with the horizontal is 45° when the magnitudes of voltages are equal.

→ Two sinusodial waveforms of the same frequency produce a Lissajous pattern,

→ A circle can be formed only when the magnetude of the two signals are equal & phase difference between them is either 90° or 270°.

→ The sine of the phase angle between the voltages is given by :-

$$\boxed{\sin\phi = \frac{Y_1}{Y_2} = \frac{X_1}{X_2}}$$

$\phi = 30^\circ$ ⇒ Small ellipse

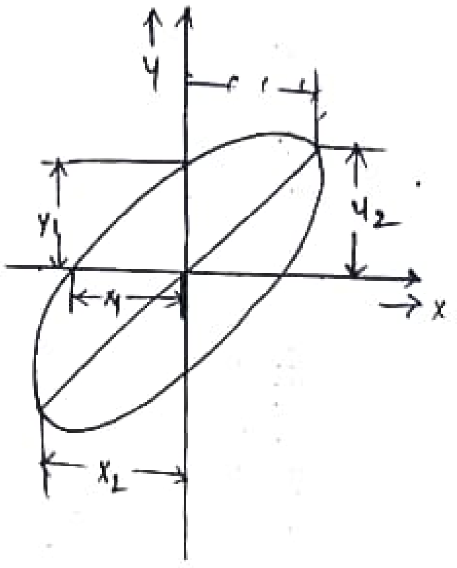
$\phi = 60^\circ$ ⇒ Big ellipse

$\phi = 120^\circ$ ⇒ Big ellipse

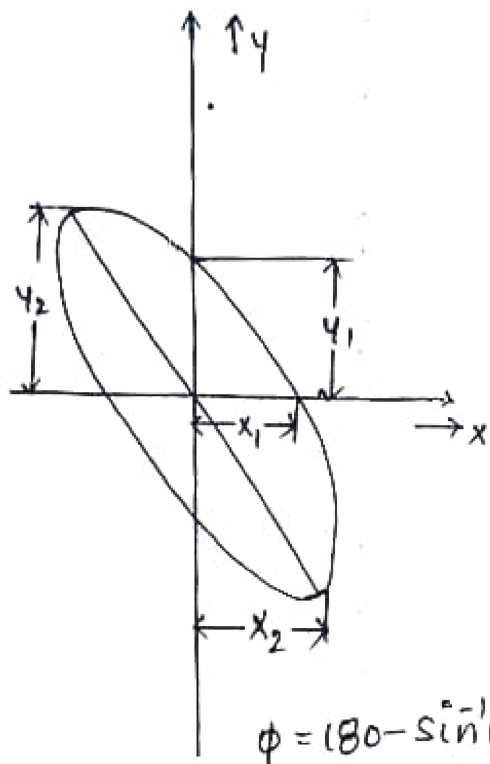
$\phi = 150^\circ$ ⇒ Small ellipse

Phase measurement :-

Curve in between 0 to 90°



Curve in between 90 to 180°



$$\sin\phi = \frac{Y_1}{Y_2} = \frac{X_1}{X_2}$$

$$\boxed{\phi = \sin^{-1}\left(\frac{Y_1}{Y_2}\right) \quad \text{or} \quad \sin^{-1}\left(\frac{X_1}{X_2}\right)}$$

$$\phi = 180 - \sin^{-1}\left(\frac{y_1}{y_2}\right)$$

(or)

$$\phi = 180 - \sin^{-1}\left[\frac{x_1}{x_2}\right]$$

Frequency Ratio measurement :-

$$\frac{f_y}{f_x} = \frac{\text{number of times tangent touches top or bottom}}{\text{number of times tangent touches either side}}$$

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

f_y = frequency of signal applied to Y plates.

f_x = Frequency of signal applied to X plates

Frequency Ratio measurement problems:-

(1) 

$$\frac{f_y}{f_x} = \frac{1}{2}$$

(2) 

$$\frac{f_y}{f_x} = \frac{2}{1}$$

(3) 

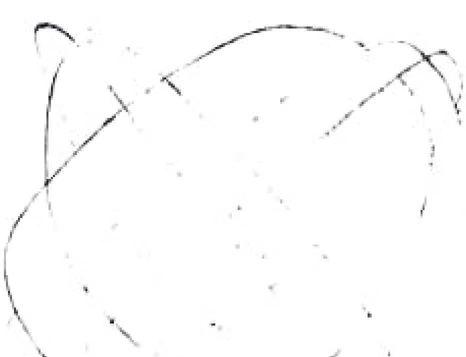
$$\frac{f_y}{f_x} = \frac{3}{2}$$

(4) 

$$\frac{f_y}{f_x} = \frac{2}{2} = \frac{1}{1}$$

(5) 

$$\frac{f_y}{f_x} = \frac{5}{3}$$

(6) 

$$\frac{f_y}{f_x} = \frac{5}{4}$$