MODULE 3

PRINCIPLES OF MEASUREMENT

PERFORMANCE CHARACTERISTICS

Knowledge of the performance characteristics of an instrument is essential for selecting the most suitable instrument for specific measuring jobs. It consists of two basic characteristics-static and dynamic.

STATIC CHARACTERISTICS

The static characteristics of an instrument are, in general, considered for instruments which are used to measure an unvarying process condition. All the static performance characteristics are obtained by one form or another of a process called calibration. There are a number of related definitions (or characteristics), which are described below, such as accuracy, precision, repeatability, resolution, errors, sensitivity, etc.

1. Instrument

   A device or mechanism used to determine the present value of the quantity under measurement.

2. Measurement

   The process of determining the amount, degree, or capacity by comparison (direct or indirect) with the accepted standards of the system units being used.

3. Accuracy

   The degree of exactness (closeness) of a measurement compared to the expected (desired) value.

4. Resolution

   The smallest change in a measured variable to which an instrument will respond.

5. Precision

   A measure of the consistency or repeatability of measurements, i.e. successive reading do not differ. (Precision is the consistency of the instrument output for a given value of input).

6. Expected value

The design value, i.e. the most probable value that calculations indicate one should expect to measure.

7. Error

The deviation of the true value from the desired value.

8. Sensitivity

The ratio of the change in output (response) of the instrument to a change of input or measured variable.

ERROR IN MEASUREMENT

Measurement is the process of comparing an unknown quantity with an accepted standard quantity. It involves connecting a measuring instrument into the system under consideration and observing the resulting response on the instrument. The measurement thus obtained is a quantitative measure of the so-called "true value" (since it is very difficult to define the true value, the term "expected value" is used). Any measurement is affected by many variables; therefore, the results rarely reflect the expected value. For example, connecting a measuring instrument into the circuit under consideration always disturbs (changes) the circuit, causing the measurement to differ from the expected value. Some factors that affect the measurements are related to the measuring instruments themselves. Other factors are related to the person using the instrument. The degree to which a measurement nears the expected value is expressed in terms of the error of measurement. Error may be expressed either as absolute or as percentage of error.

Absolute error may be defined as the difference between the expected value of the variable and the measured value of the variable, or

$$e = Y_n - X_n$$

where $\quad e$ = absolute error

Y_n = expected value

X_n = measured value

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

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

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

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

where A is the relative accuracy.

Accuracy is expressed as % accuracy

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

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

where a is the % accuracy.

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

Solution

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

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

(iii) Relative Accuracy

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

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

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

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

Example 1.1 (b) *The expected value of the current through a resistor is 20 mA. However the measurement yields a current value of 18 mA. Calculate (i) absolute error (ii) % error (iii) relative accuracy (iv) % accuracy*

Solution

Step 1: Absolute error

$$e = Y_n - X_n$$

where $\quad e$ = error, Y_n = expected value, X_n = measured value

Given $\quad Y_n = 20$ mA $\quad$ and $\quad X_n = 18$ mA

Therefore $\quad e = Y_n - X_n = 20 \text{ mA} - 18 \text{ mA} = 2 \text{ mA}$

Step 2: % error

$$\% \text{ error} = \frac{Y_n - X_n}{Y_n} \times 100 = \frac{20 \text{ mA} - 18 \text{ mA}}{20 \text{ mA}} \times 100 = \frac{2 \text{ mA}}{20 \text{ mA}} \times 100 = 10\%$$

Step 3: Relative accuracy

$$A = 1 - \left|\frac{Y_n - X_n}{Y_n}\right| = 1 - \left|\frac{20 \text{ mA} - 18 \text{ mA}}{20 \text{ mA}}\right| = 1 - \frac{2}{20} = 1 - 0.1 = 0.90$$

Step 4: % accuracy

$$a = 100\% - \%\text{error} = 100\% - 10\% = 90\%$$

and $$a = A \times 100\% = 0.90 \times 100\% = 90\%$$

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

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

where X_n = value of the nth measurement
$\bar{X}_n$ = average set of measurement

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

Table 1.1

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

Solution The average value for the set of measurements is given by

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

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

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

For the 6th reading

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

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

The static error of a measuring instrument is the numerical difference between the true value of a quantity and its value as obtained by measurement, i.e. repeated measurement of the same quantity gives different indications. Static errors are categorised as gross errors or human errors, systematic errors, and random errors.

GROSS ERRORS

These errors are mainly due to human mistakes in reading or in using instruments or errors in recording observations. Errors may also occur due to incorrect adjustment of instruments and computational mistakes. These errors cannot be treated mathematically. The complete elimination of gross errors is not possible, but one can minimize them. Some errors are easily detected while others may be elusive. One of the basic gross errors that occurs frequently is the improper use of an instrument. The error can be minimized by taking proper care in reading and recording the measurement parameter. In general, indicating instruments change ambient conditions to some extent when connected into a complete circuit.

Systematic Errors

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

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

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

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

(II) ENVIRONMENTAL ERROR

Environmental errors are due to conditions external to the measuring device, including conditions in the area surrounding the instrument, such as the effects of change in temperature, humidity, barometric pressure or of magnetic or electrostatic fields. These errors can also be avoided by (i) air conditioning, (ii) hermetically sealing certain components in the instruments, and (iii) using magnetic shields.

(III) OBSERVATIONAL ERRORS

Observational errors are errors introduced by the observer. The most common error is the parallax error introduced in reading a meter scale, and the error of estimation when obtaining a reading from a meter scale. These errors are caused by the habits of individual observers. For example, an observer may always introduce an error by consistently holding his head too far to the left while reading a needle and scale reading. In general, systematic errors can also be subdivided into static and dynamic errors. Static errors are caused by limitations of the measuring device or the physical laws governing its behavior. Dynamic errors are caused by the instrument not responding fast enough to follow the changes in a measured variable.

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

Solution

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

(Neglecting the resistance of the milliammeter.)

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

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

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

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

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

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

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

Solution

1. The total circuit resistance is given by

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

2. The voltmeter resistance R_v equals

$$R_v = 1000\ \Omega/\text{V} \times 150 = 150\ \text{k}\Omega$$

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

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

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

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

Random Errors

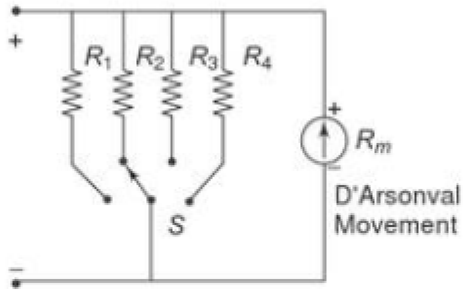
These are errors that remain after gross and systematic errors have been substantially reduced or at least accounted for. Random errors are generally an accumulation of a large number of small effects and may be of real concern only in measurements requiring a high degree of accuracy. Such errors can be analyzed statistically. These errors are due to unknown causes, not determinable in the ordinary process of making measurements. Such errors are normally small and follow the laws of probability. Random errors can thus be treated mathematically. For example, suppose a voltage is being monitored by a voltmeter which is read at 15 minutes intervals. Although the instrument operates under ideal environmental conditions and is accurately calibrated before measurement, it still gives readings that vary slightly over the period of observation. This variation cannot be corrected by any method of calibration or any other known method of control.

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

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

MULTI RANGE AMMETERS

The current range of the dc ammeter may be further extended by a number of shunts, selected by a range switch, such a meter is called a multirange ammeter, shown in Fig. The circuit has four shunts RI, R2, R3 and R4, which can be placed in parallel with the movement to give four different current ranges. Switch S is a multiposition switch, (having low contact resistance and high current carrying capacity, since its contacts are in series with low resistance shunts). Make before break type switch is used for range changing. This switch protects the meter movement from being damaged without a shunt during range changing. If we use an ordinary switch for range changing, the meter does not have any shunt in parallel while the range is being changed, and hence full current passes through the meter movement, damaging the movement. Hence a make before break type switch is used. The switch is so designed that when the switch position is changed, it makes contact with the next terminal (range) before breaking contact with the previous terminal. Therefore the meter movement is never left unprotected. Multirange ammeters are used for ranges up to 50A. When using a multirange ammeter, first use the highest current range, then decrease the range until good upscale reading is obtained. The resistance used for the various ranges are of very high precision values, hence the cost of the meter increases



Example 3.2 *A 1 mA meter movement having an internal resistance of 100 Ω is used to convert into a multirange ammeter having the range 0–10 mA, 0–20 mA and 0–50 mA. Determine the value of the shunt resistance required.*

Solution Given $I_m = 1$ mA and $R_m = 100\ \Omega$

Case 1: For the range 0 – 10 mA

$$\text{Given } R_{sh1} = \frac{I_m \cdot R_m}{I - I_m} = \frac{1\text{ mA} \times 100}{10\text{ mA} - 1\text{ mA}} = \frac{100}{9} = 11.11\ \Omega$$

Case 2: For the range 0 – 20 mA

$$\text{Given } R_{sh2} = \frac{I_m \cdot R_m}{I - I_m} = \frac{1\text{ mA} \times 100}{20\text{ mA} - 1\text{ mA}} = \frac{100}{19} = 5.2\ \Omega$$

Case 3: For the range 0 – 50 mA

$$\text{Given } R_{sh3} = \frac{I_m \cdot R_m}{I - I_m} = \frac{1\text{ mA} \times 100}{50\text{ mA} - 1\text{ mA}} = \frac{100}{49} = 2.041\ \Omega$$

Example 3.3 *Design a multirange ammeter with range of 0–1 A, 5 A and 10 A employing individual shunt in each A D'Arsonval movement with an internal resistance of 500 Ω and a full scale deflection of 10 mA is available.*

Solution

Given $I_m = 10$ mA and $R_m = 500\ \Omega$

Case 1 : For the range 0 – 1A, i.e, 1000 mA

$$\text{Given } R_{sh1} = \frac{I_m \cdot R_m}{I - I_m} = \frac{10\text{ mA} \times 500}{1000\text{ mA} - 10\text{ mA}} = \frac{5000}{990} = 5.05\ \Omega$$

Case 2 : For the range 0 – 5A, i.e, 5000 mA

$$\text{Given } R_{sh2} = \frac{I_m \cdot R_m}{I - I_m} = \frac{10\text{ mA} \times 500}{5000\text{ mA} - 10\text{ mA}} = \frac{5000}{4990} = 1.002\ \Omega$$

Case 3 : For the range 0 – 10A, i.e, 10000 mA

$$\text{Given } R_{sh3} = \frac{I_m \cdot R_m}{I - I_m} = \frac{10\text{ mA} \times 500}{10000\text{ mA} - 10\text{ mA}} = \frac{5000}{99990} = 0.050\ \Omega$$

Hence the values of shunt resistances are 5.05 Ω , 1.002 Ω and 0.050 Ω.

Multirange Voltmeter:

As in the case of an ammeter, to obtain a multirange ammeter, a number of shunts are connected across the movement with a multi-position switch. Similarly, a dc voltmeter can be converted into a multirange voltmeter by connecting a number of resistors (multipliers) along with a range switch to provide a greater number of workable ranges.

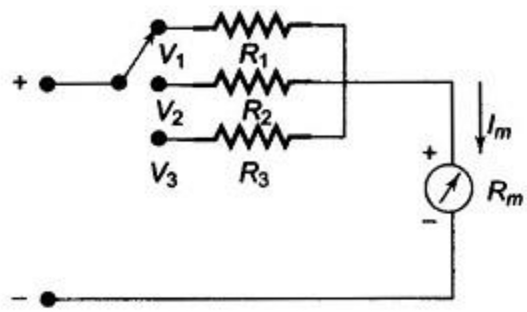


Fig. 4.2 ▬ Multirange Voltmeter

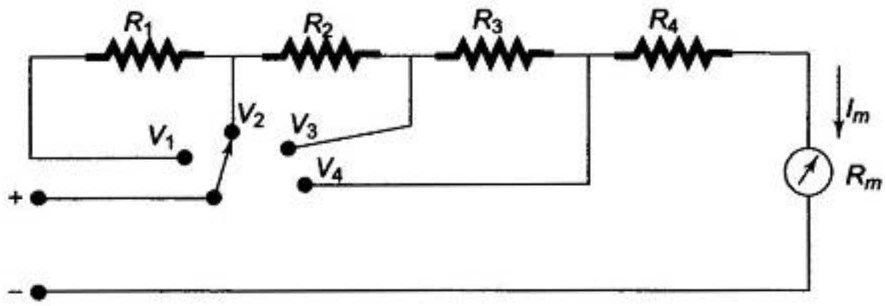


Fig. 4.3 ▬ Multipliers Connected in Series String

Figure 4.2 shows a multirange voltmeter using a three-position switch and three multipliers R_1, R_2, and R_3 for voltage values V_1, V_2, and V_3. Figure 4.2 can be further modified to Fig. 4.3, which is a more practical arrangement of the multiplier resistors of a multirange voltmeter.

In this arrangement, the multipliers are connected in a series string, and the range selector selects the appropriate amount of resistance required in series with the movement.

This arrangement is advantageous compared to the previous one, because all multiplier resistances except the first have the standard resistance value and are also easily available in precision tolerances:

The first resistor or low range multiplier, R_4, is the only special resistor which has to be specially manufactured to meet the circuit requirements.

Digital voltmeters (DVMs) are measuring instruments that convert analog voltage signals into a digital or numeric readout. This digital readout can be displayed on the front panel and also used as an electrical digital output signal. Any DVM is capable of measuring analog de voltages. However, with appropriate signal conditioners preceding the input of the DVM, quantities such as ac voltages, ohms, dc and ac current, temperature, and pressure can be measured. The common element in all these signal conditioners is the de voltage, which is proportional to the level of the unknown quantity being measured. This de output is then measured by the DVM. DVMs have various features such as speed, automation operation and programability.

There are several varieties of DVM which differ in the following ways:

1. Number of digits

2. Number of measurements

3. Accuracy

4. Speed of reading

5. Digital output of several types.

The DVM displays ac and de voltages as discrete numbers, rather than as a pointer on a continuous scale as in an analog voltmeter. A numerical readout is advantageous because it reduces human error, eliminates parallax error, increases reading speed and often provides output in digital form suitable for further processing and recording. With the development of IC modules, the size, power requirements and cost of DVMs have been reduced, so that DVMS compete with analog voltmeters in portability and size. Their outstanding qualities are their operating and performance characteristics, as detailed below.

1. Input range from + 1.000 V to + 1000 V with automatic range selection and overload indication
2. Absolute accuracy as high as ±0.005% of the reading

3. Resolution 1 part in million (1 Jl,Vreading can be read or measured on 1 V range)

4. Input resistance typically 10 MQ, input capacitance 40 pF

5. Calibration internally from stabilised reference sources, independent of measuring circuit

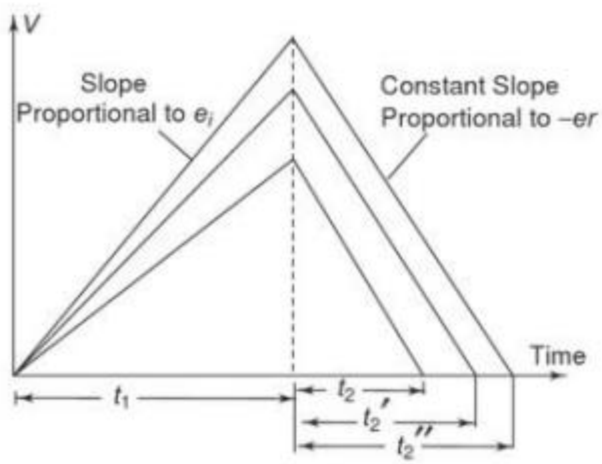
6. Output in BCD form, for print output and further digital processing.

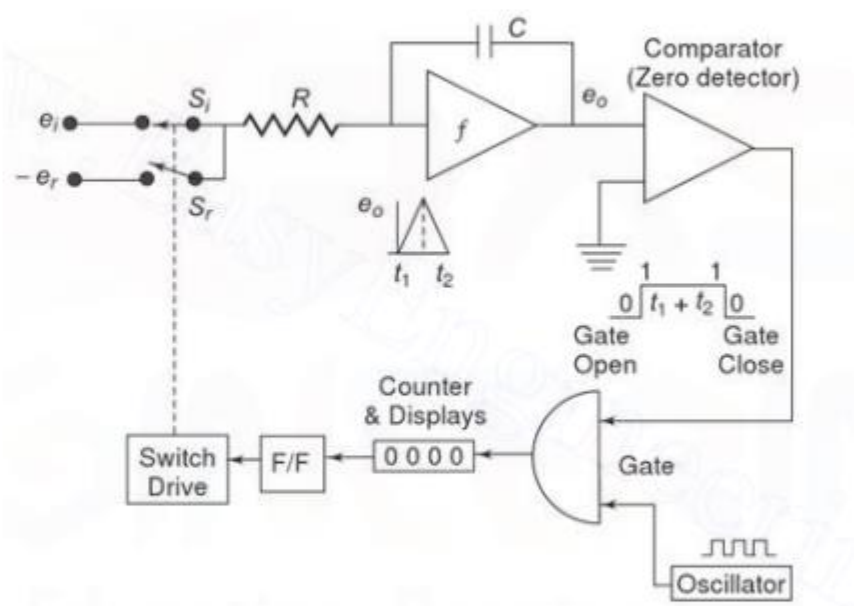
Optional features may include additional circuitry to measure current, ohms and voltage ratio.

DUAL SLOPE INTEGRATING TYPE DVM (VOLTAGE TO TIME CONVERSION)

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

Principle of Dual Slope Type DVM As illustrated in Fig. 5.3, the input voltage 'e/ is integrated, with the slope of the integrator output proportional to the test input voltage. After a fixed time, equal to t., the input voltage is disconnected and the integrator input is connected to a negative voltage -er. The integrator output will have a negative slope which is constant and proportional to the magnitude of the input voltage. The block diagram is given in Fig. 5.4.





At the start a pulse resets the counter and the FIF output to logic level '0'. S, is closed and S, is open. The capacitor begins to charge. As soon as the integrator output exceeds zero, the comparator output voltage changes state, which opens the gate so that the oscillator clock pulses are fed to the counter. (When the ramp voltage starts, the comparator goes to state 1, the gate opens and clock pulse drives the counter.) When the counter reaches maximum count, i.e. the counter is made to run for a time 't)' in this case 9999, on the next clock pulse all digits go to 0000 and the counter activates the FIF to logic level '1'. This activates the switch drive, ei is disconnected and -er is connected to the integrator. The integrator output will have a negative slope which is constant, i.e. integrator output now decreases linearly to 0 volts. Comparator output state changes again and locks the gate. The discharge time t2 is now proportional to the input voltage. The counter indicates the count during time t2• When the negative slope of the integrator reaches zero, the comparator switches to state 0 and the gate closes, i.e. the capacitor C is now discharged with a constant slope. As soon as the comparator input (zero detector) finds that eo is zero, the counter is stopped. The pulses counted by the counter thus have a direct relation with the input voltage. During charging

$$e_o = -\frac{1}{RC}\int_0^{t} e_i\,dt = -\frac{e_i\,t_1}{RC}$$

During discharging

$$e_o = \frac{1}{RC}\int_0^{t_2} -e_r dt = -\frac{e_r\,t_2}{RC}$$

Subtracting Eqs 5.2 from 5.1 we have

$$e_o - e_o = \frac{-e_r\,t_2}{RC} - \left(\frac{-e_i\,t_1}{RC}\right)$$

$$0 = \frac{-e_r\,t_2}{RC} - \left(\frac{-e_i\,t_1}{RC}\right)$$

$$\Rightarrow \qquad \frac{e_r\,t_2}{RC} = \frac{e_i\,t_1}{RC}$$

$$\therefore \qquad e_i = e_r\frac{t_2}{t_1}$$

t_1

If the oscillator period equals T and the digital counter indicates n_1 and n_2 counts respectively,

$$\therefore \quad e_i = \frac{n_2 T}{n_1 T} e_r \text{ i.e. } e_i = \frac{n_2}{n_1} e_r$$

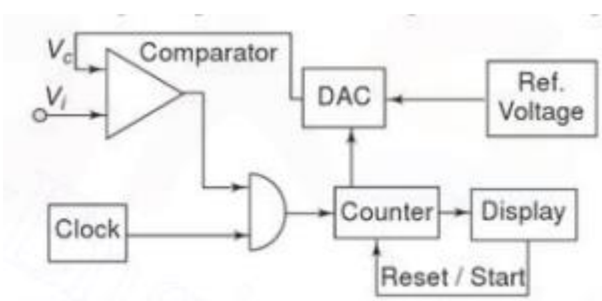
Now, n_1 and e_r are constants. Let $K_1 = \frac{e_r}{n_1}$. Then $e_i = K_1 n_2$

From Eq. 5.3 it is evident that the accuracy of the measured voltage is independent of the integrator time constant. The times tI and t2 are measured by the count of the clock given by the numbers nl and n2 respectively. The clock oscillator period equals T and if n, and e, are constants, then Eq. 5.4 indicates that the accuracy of the method is also independent of the oscillator frequency. The dual slope technique has excellent noise rejection because noise and superimposed ac are averaged out in the process of integration. The speed and accuracy are readily varied according to specific requirements; also an accuracy of ± 0.05% in 100 ms is available.

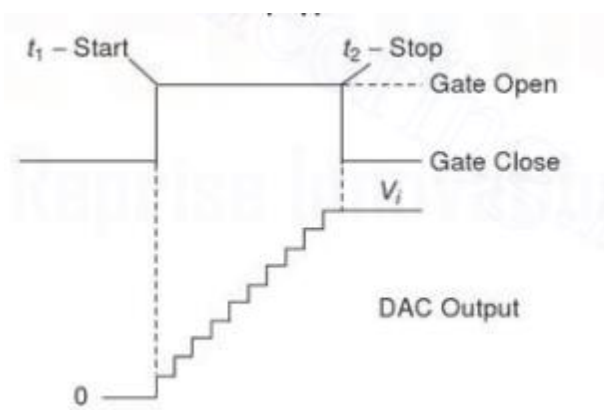
Direct Compensation:

The input signal is compared with an internally generated voltage which is increased in steps starting from zero. The number of steps needed to reach the full compensation is counted. A simple compensation type is the staircase ramp

The Staircase Ramp The basic principle is that the input signal ~ is compared with an internal staircase voltage, Vc> generated by a series circuit consisting of a pulse generator (clock), a counter counting the pulses and a digital to analog converter, converting the counter output into a de signal. As soon as Vc is equal to ~, the input comparator closes a gate between the clock and the counter, the counter stops and its output is shown on the display. The basic block diagram is shown in Fig.



Operation of the Circuit The clock generates pulses continuously. At the start of a measurement, the counter is reset to 0 at time f 1 so that the output of the digital to analog converter (DAC) is also O.If ~ is not equal to zero, the input comparator applies an output voltage that opens the gate so that clock pulses are passed on to the counter through the gate. The counter starts counting and the DAC starts to produce an output voltage increasing by one small step at each count of the counter. The result is a staircase voltage applied to the second input of the comparator, as shown in Fig.



This process continues until the staircase voltage is equal to or slightly greater than the input voltage ~. At that instant f2' the output voltage of the input comparator changes state or polarity, so that the gate closes and the counter is stopped.

The display unit shows the result of the count. As each count corresponds to a constant dc step in the DAC output voltage, the number of counts is directly proportional to Vc and hence to Vi. By appropriate choice of reference voltage, the step height of the staircase voltage can be determined. For example, each count can represent l mV and direct reading of the input voltage in volts can be realised by placing a decimal point in front of the 10 decade.

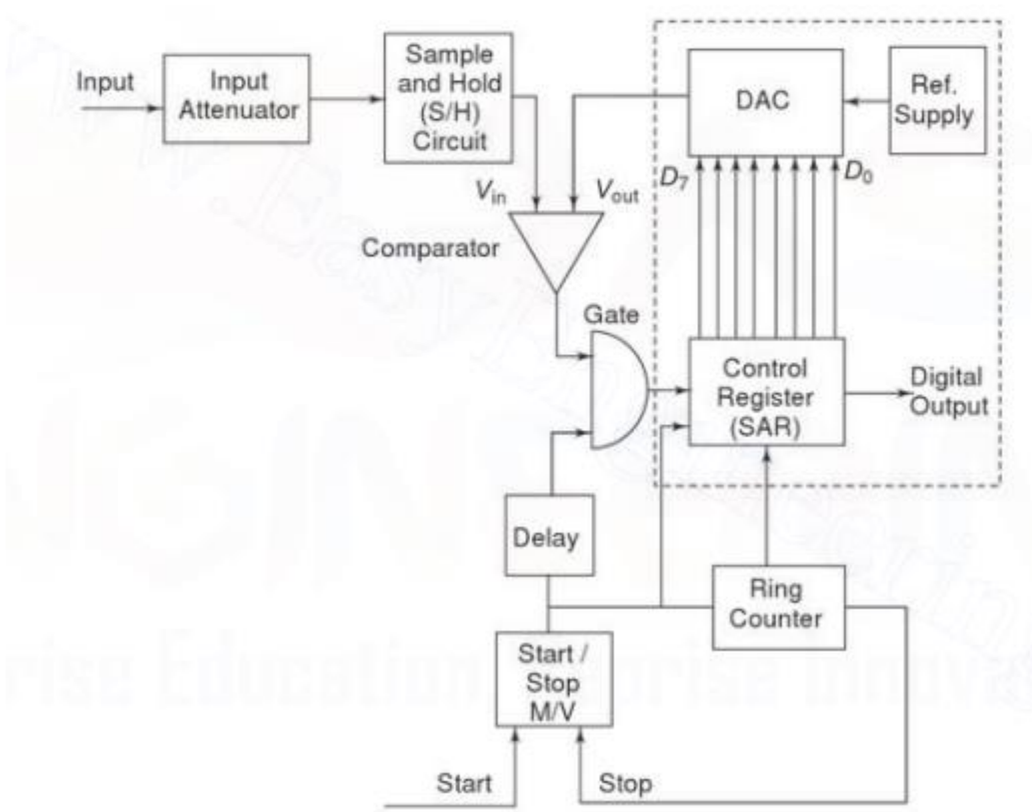
The advantages of a staircase type DVM are as follows: 1. Input impedance of the DAC is high when the compensation is reached. 2. The accuracy depends only on the stability and accuracy of the voltage and DAC. The clock has no effect on the accuracy.

The disadvantages are the following: 1. The system measures the instantaneous value of the input signal at the moment compensation is reached. This means the reading is rather unstable, i.e. the input signal is not a pure de voltage. 2. Until the full compensation is reached the input impedance is low, which can influence the accuracy.

SUCCESSIVE APPROXIMATION

The successive approximation principle can be easily understood using a simple example; the determination of the weight of an object. By using a balance and placing the object on one side and an approximate weight on the other side, the weight of the object is determined. If the weight placed is more than the unknown weight, the weight is removed and another weight of smaller value is placed and again the measurement is performed. Now if it is found that the weight placed is less than that of the object, another weight of smaller value is added to the weight already present, and the measurement is performed. If it is found to be greater than the unknown weight the added weight is removed and another weight of smaller value is added. In this manner by adding and removing the appropriate weight, the weight of the unknown object is determined. The successive approximation DVM works on the same principle. Its basic block diagram is shown in Fig. 5.10. When the start pulse signal activates the control circuit, the successive approximation register (SAR) is cleared. The output of the SAR is 00000000. VOU! of the DIA converter is o. Now, if Vin > VOU! the comparator output is positive. During the first clock pulse, the control circuit sets the D7 to 1, and Voutjumps to the half reference voltage. The SAR output is 10000000. If VOll!is greater than Vin, the comparator output is negative and the control circuit resets D7. However, if Vin is greater than VOU!' the comparator output is positive and the control circuits keeps D7 set. Similarly the rest of the bits beginning from D7 to Do are set and tested. Therefore, the measurement is completed in 8 clock pulses.

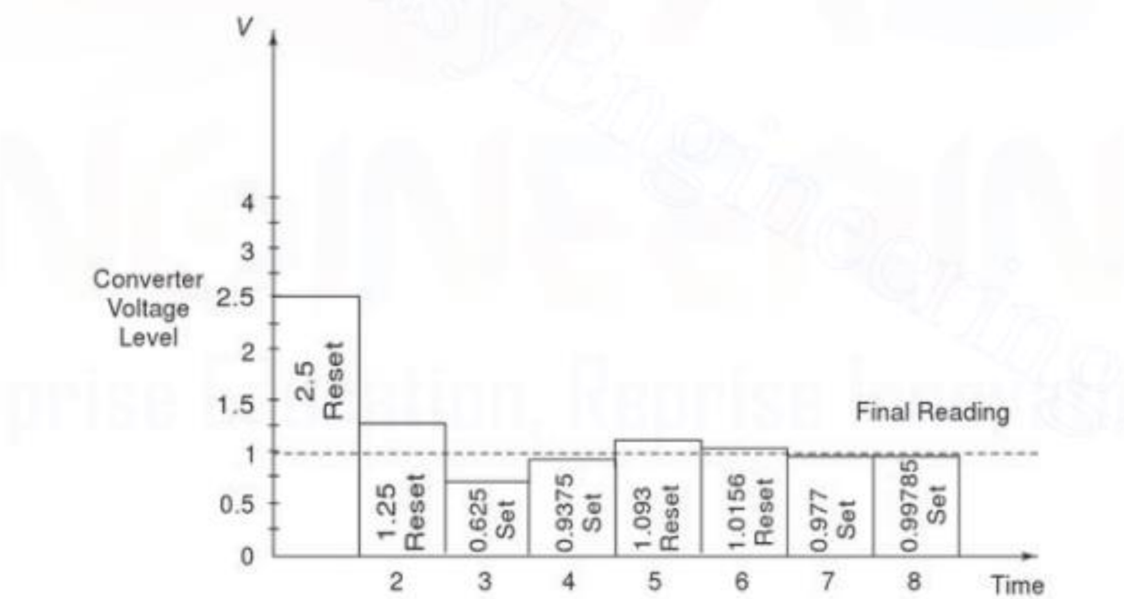
$V_{in} = 1\ V$	Operation	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Compare	Output	Voltage
00110011	D_7 Set	1	0	0	0	0	0	0	0	$V_{in} < V_{out}$	D_7 Reset	2.5
"	D_6 Set	0	1	0	0	0	0	0	0	$V_{in} < V_{out}$	D_6 Reset	1.25
"	D_5 Set	0	0	1	0	0	0	0	0	$V_{in} > V_{out}$	D_5 Set	0.625
"	D_4 Set	0	0	1	1	0	0	0	0	$V_{in} > V_{out}$	D_4 Set	0.9375
"	D_3 Set	0	0	1	1	1	0	0	0	$V_{in} < V_{out}$	D_3 Reset	0.9375
"	D_2 Set	0	0	1	1	0	1	0	0	$V_{in} < V_{out}$	D_2 Reset	0.9375
"	D_1 Set	0	0	1	1	0	0	1	0	$V_{in} > V_{out}$	D_1 Set	0.97725
"	D_0 Set	0	0	1	1	0	0	1	1	$V_{in} > V_{out}$	D_0 Set	0.99785



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

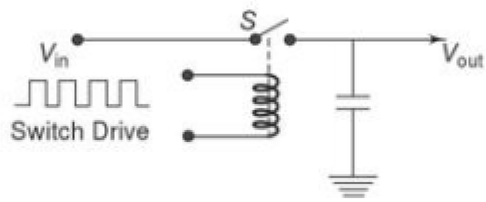
The ring counter then advances one count, shifting a 1 in the second MSB of the control register and its reading becomes 11000000. This causes the DIA converter to increase its reference output by 1 increment to 1/4 V, i.e. 1/2 V + 1/4 V, and again it is compared with the unknown input. If in this case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

Example *Suppose the converter can measure a maximum of 5 V, i.e. 5 V corresponds to the maximum count of 11111111. If the test voltage V_{in} = 1 V the following steps will take place in the measurement. (Refer to Table 5.1 and Fig. 5.11.)*



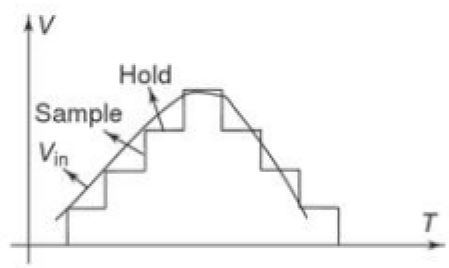
Various output levels for each bit (a-Bit shows the voltage level very nearly equal to I V)

Therefore, Vin nearly equals VOUI' i.e. Vin = 1 Vand Vout = 0.99785. The main advantage of this method is speed. At best it takes n clock pulses to produce an n bit result. Even if the set, test, set or reset operation takes more than 1 clock pulse, the SAR method is still considerably faster than the counter method. However the control circuit is more complex in design and cost is enhanced. This digital voltmeter is capable of 1000 readings per second. With input voltages greater than de, the input level changes during digitisation 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. Switch Drive In its simplest form, the sample and hold (S/H) circuit can be represented by a switch and a capacitor, as shown in Fig. 5.12.



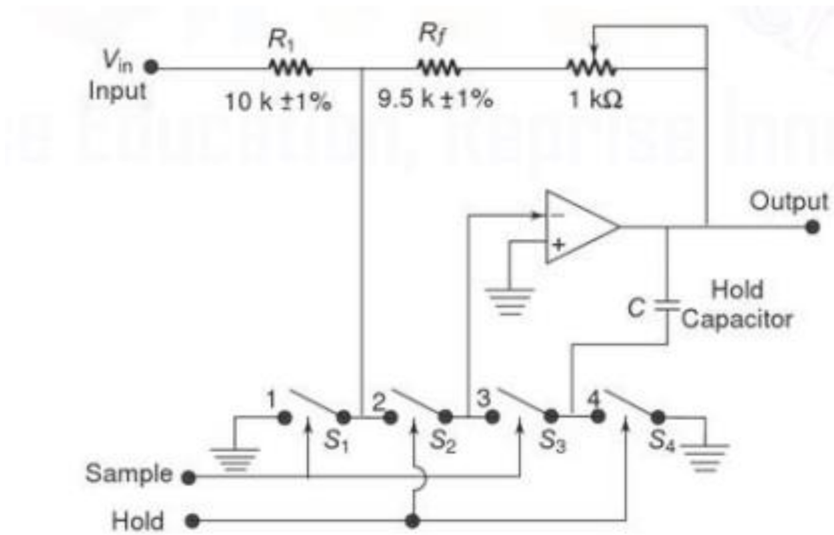
Simple sample hold circuit

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 SIR circuit is in the Hold mode. The output waveform of a sample and hold circuit is shown in Fig. 5.13.



Output wavwform of a sample and hold circuit

An actual sample and hold circuit is shown in Fig. 5.14. The sample pulse operates switches 1 and 3. The hold pulse operates switches 2 and 4. The samplehold pulses are complementary. In the sample mode the hold capacitor is charged up by the Opamp. Inthe hold mode, the capacitor is switched into the feedback loop, while input resistors R I and Rfare switched to ground. Opamps are used to increase the available driving current into the capacitor or to isolate the capacitor from an external load on the output.



Practical sample and hold circuit

The SIH circuit is basically an Op amp that charges the capacitor during the Sample mode and retains the charge during the Hold mode.