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CHAPTER 73

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CONTENTS

ELECTRONIC INSTRUMENTS

The Digital Voltmeter

73.1. Introduction

Electronic instrumentation is such an interesting field that it combines elements of technologies ranging from the nineteenth to the twenty first centuries. Modern computer-based instrumentation is now evident in every reasonably equipped laboratory and workshop and in catalogs and advertisements of all of the manufacturers. Yet at the root of many space-age instruments is circuitry, such as the wheatstone bridge that is found in nineteenth-century textbooks. Although newer techniques are still in widespread use in new as well as old instruments. In this chapter on electronic instruments you will find both types discussed.

The scientific and technological progress of any nation depends on its ability to measure, calculate and finally, estimate the unknown. Also, the success of an engineer or technician is judged by his ability to measure precisely and to correctly interpret the circuit performance. There are three ways of making such measurements :

(*a*) **by mechanical means**–like measuring gas pressure by Bourdon pressure gauge.

(*b*) **by electrical means**–like measuring potential difference with an electrical voltmeter.

(*c*) **by electronic means**–which is a very sensitive way of detecting the measured quantity because of amplification provided by the active electron device.

The electronic instruments generally have higher sensitivity, faster response and greater flexibility than mechanical or electrical instruments in indicating, recording and, where required, in controlling the measured quantity.

73.2. Analog and Digital Instruments

The deflection type instruments with a scale and movable pointer are called ***analog*** instruments. The deflectiion of the pointer is a function of (and, hence, analogous to) the value of the electrical quantity being measured.

Digital instruments are those which use logic circuits and techniques to obtain a measurement and then display it in numerical-reading (digital) form. The digital readouts employ either *LED* displays or liquid crystal displays (*LCD*).

Some of the advantages of digital instruments over analog instruments are as under :

1. easy readability

2. greater accuracy

3. better resolution

4. automatic polarity and zeroing

73.3. Functions of Instruments

Functionally, different instruments may be divided into the following three categories :

1. Indicating instruments

These are the instruments which indicate the instantaneous value of quantity being measured, at the time it is being measured. The indication is in the form of pointer deflection (analog instruments) or digital readout (digital instruments). Ammeters and voltmeters are examples of such instruments.

2. Recording instruments

Such instruments provide a graphic record of the variations in the quantity being measured over a selected period of time. Many of these instruments are electromechanical devices which use paper charts and mechanical writing instruments such as an inked pen or stylus.

Electronic recording instruments are of two types :

(*a*) **null type**–which operate on a comparison basis.

(*b*) **galvanometer type**–which operate on deflection type.

3. Controlling instruments

These are widely used in industrial processes. Their function is to control the quantity being measured with the help of information feed back to them by monitoring devices. This class forms the basis of automatic control systems (automation) which are extensively employed in science and industry.

73.4. Electronic Versus Electrical Instruments

Both electrical and electronic instruments measure electrical quantities like voltage and current etc. Purely electrical instruments do not have any built-in amplifying device to increase the amplitude of the quantity being measured. The common dc voltmeter based on moving-coil meter movement is clearly an electrical instrument.

The electronic instruments always include in their make-up some active electron device such as vacuum tube, semiconductor diode or an integrated circuit etc.

As seen, the main distinguishing factor between the two types of instruments is the presence of an electron device in the electronic instruments. Of course, movement of electrons is common to both types, their main difference being that control of electron movement is more effective in electronic instruments than in electrical instruments.

Although electronic instruments are usually more expensive than their electrical counterparts, they offer following advantages for measurements purposes :

1. since electronic instruments can amplify the input signal, they possess very high sensitivity *i.e.* they are capable of measuring extremely small (low-amplitude) signals,
2. because of high sensitivity, their input impedance is increased which means less loading effect when making measurements,
3. they have greater speed *i.e.* faster response and flexibility,
4. they can monitor remote signals.

73.5. Essentials of an Electronic Instrument

As shown Fig. 73.1, an electronic instrument is made up of the following three elements :

1. Transducer

It is the first sensing element and is required only when measuring a non-electrical quantity, say, temperature or pressure. Its function is to convert the non-electrical physical quantity into an electrical signal.

Of course, a transducer is not required if the quantity being measured is already in the electrical form.

2. Signal Modifier

It is the second element and its function is to make the incoming signal suitable for application to the indicating device.

For example, the signal may need amplification before it can be properly displayed. Other types of signal modifiers are : voltage dividers for reducing the amount of signal applied to the indicating device or wave shaping circuits such as filters, rectifiers or chopper etc.

3. Indicating Device

For general purpose instruments like voltmeters, ammeters or ohm meters, the indicating device is usually a deflection type meter as shown in Fig. 73.1. In digital readout instruments, the indicating device is of digitial design.

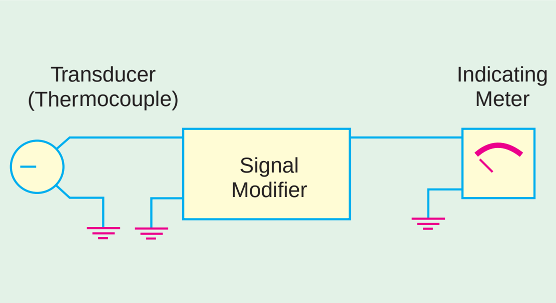


Fig. 73.1

73.6. Measurement Standards

All instruments, whether electrical or electronic, are calibrated at the time of manufacture against a measurement standard.

1. International Standards

These are defined by international agreement and are maintained at the international Bureau of Weights and Measurements in Paris.

2. Primary Standards

These are maintained at national standards laboratories in each country. They are not available for use outside these laboratories. Their principal function is to calibrate and verify the secondary standards used in industry.

3. Secondary Standards

These are the basic reference standards used by industrial laboratories and are maintained by the particular industry to which they belong. They are periodically sent to national laboratory for calibration and verification against primary standards.

4. Working Standards

These are the main tools of a measurement laboratory and are used to check and calibrate the instrument used in the laboratory.

73.7. The Basic Meter Movement

It is also called D' Arsonval meter movement or a permanent-magnet moving-coil (PMMC) meter movement. Since it is widely used in electronic instruments, it is worthwhile to discuss its construction and principle of operation.

1. Construction

As shown in Fig. 73.2, it consists of a permanent horse-shoe magnet with soft iron pole pieces attached to it. Between the two pole-pieces is situated a cylinder-shaped soft iron core around which moves a coil of fine wire wound on a light metal frame. The metal frame is mounted in jewel bearings so that it can rotate freely. A light pointer attached to the moving coil moves up-scale as the coil rotates when current is passed through it. The rotating coil is prevented from continuous rotation by a spring which provides restoring torque.

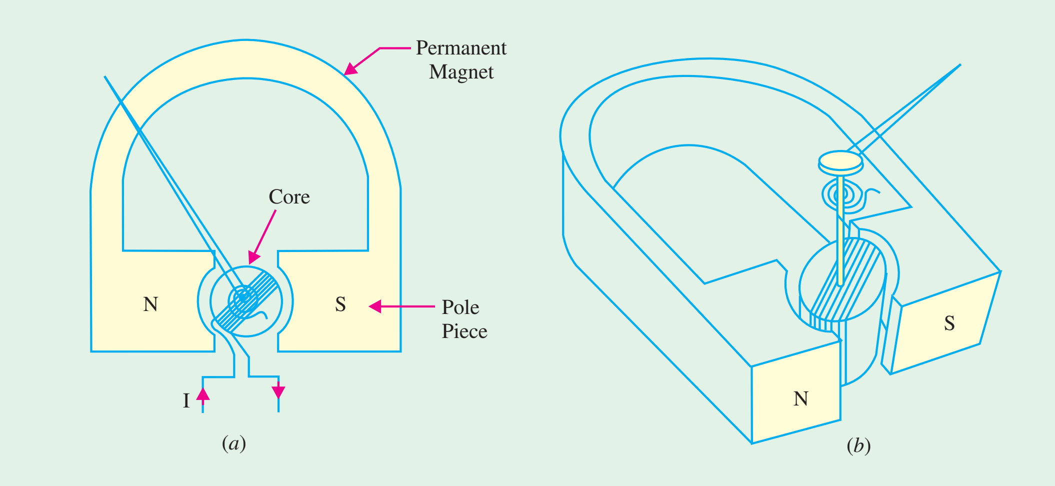


Fig. 73.2

The moving coil movement described above is being increasingly replaced by tautband movement in which the moving coil and the pointer are suspended between bands of spring metal so that the restoring force is torsional. The bands perform two functions ***(i)*** they support the coil and ***(ii)*** they provide restoring torque thereby eliminating the pivots and jewels used with coil spring movement.

As compared to pivoted movement, the taut-band has the advantages of

1. greater sensitivity *i.e.* small full-scale deflection current

2. ruggedness,

3. minimal friction,

4. easy to manufacture.

2. Principle of Operation

This meter movement works on the ***motor*** principle and is a current-responding device. The deflection of the pointer is directly proportional to the amount of current passing through the coil.

When direct current flows through the coil, the magnetic field so produced reacts with the field of the permanent magnet. The resultant force turns the coil alongwith its pointer. The amount of deflection is directly proportional to the amount of current in the coil. Hence, their scale is linear. With correct polarity, the pointer reads up-scale to the right whereas incorrect polarity forces the pointer off-scale to the left.

73.8. Characteristics of Moving Coil Meter Movement

We will discuss the following three characteristics :

(i) full-scale deflection current (I_m),

(ii) internal resistance of the coil (R_m),

(iii) sensitivity (S).

1. Full-scale Deflection Current (I_m)

It is the current needed to deflect the pointer all the way to the right to the last mark on the calibrated scale. Typical values of I_m for D' Arsonval movement vary from 2 μA to 30 mA.

It should be noted that for smaller currents, the number of turns in the moving coil has to be ***more*** so that the magnetic field produced by the coil is strong enough to react with the field of the permanent magnet for producing reasonable deflectin of the pointer. Fine wire has to be used for reducing the weight of the moving coil but it increases its resistance. Heavy currents need thick wire but lesser number of turns so that resistance of the moving coil is comparatively less. The schematic symbol is shown in Fig. 73.3.

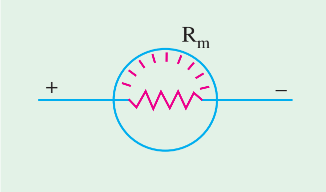


Fig. 73.3

2. Internal Resistance (R_m)

It is the dc ohmic resistance of the wire of the moving coil. A movement with smaller I_m has higher R_m and *vice versa*. Typical values of R_m range from 1.2 Ω for a 30 mA movement to 2 kΩ for a 50 μA movement.

3. Sensitivity (S)

It is also known as ***current sensitivity* or *sensitivity factor.*** It is given by the reciprocal of full-scale deflection current I_m.

$$\therefore \qquad S = \frac{1}{I_m} \text{ ohm/volt.}$$

For example, the sensitivity of a 50-μA meter movement is

$$S = \frac{1}{50\,\mu A} = \frac{1}{50 \times 10^{-6}}\ \Omega/\text{V} = 20{,}000\ \Omega/\text{V} = 20\ \text{k}\Omega/\text{V}$$

The above figure shows that a full-scale deflection of 50 µA is produced whenever 20,000 Ω of resistance is present in the meter circuit ***for each volt of applied voltage.*** It also represents the ohms-per-volt rating of the meter. The sensitivity of a meter movement depends on the strength of the permanent magnet and number of turns in the coil. Larger the number of turns, smaller the amount of current required to produce full-scale deflection and, hence, higher the sensitivity. A high current sensitivity means a high quality meter movement. It also determines the lowest range that can be covered when the meter movement is modified as an ammeter (Art 73.10) or voltmeter (Art 73.12)

73.9. Variations of Basic Meter Movement

The basic moving-coil system discussed in Art 73.7 can be converted into an instrument to measure dc as well as ac quantities like current, voltage and resistance etc. Without any modification, it can carry a maximum current of I_m can withstand a maximum dc voltage $v = I_m R_m$.

1. **DC instruments**
   - **(*a*)** it can be made into a dc ammeter, milliammeter or micrommeter by adding a suitable shunt resistor R_{sh} in parallel with it as shown in Fig. 73.4 (*a*),
   - **(*b*)** it can be changed into a dc voltmeter by connecting a multiplier resistor R_{mult} in series with it as shown in Fig. 73.4 (*b*),

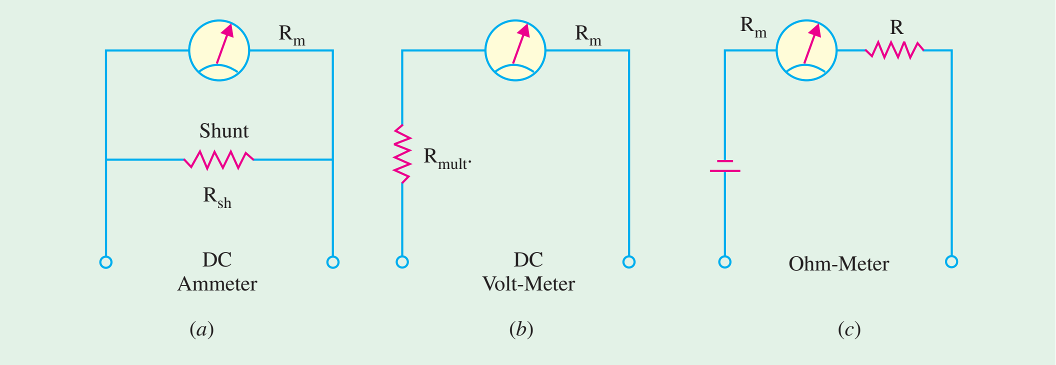


Fig. 73.4

   - **(*c*)** it can be converted into an ohmmeter with the help of a battery and series resistor *R* as shown in Fig. 73.4 (*c*).

2. **AC Instruments**
   - **(*a*)** it can be changed into an ac audio-frequency ammeter or voltmeter by simply adding an extra rectifier as shown in Fig. 73.5 (*a*).

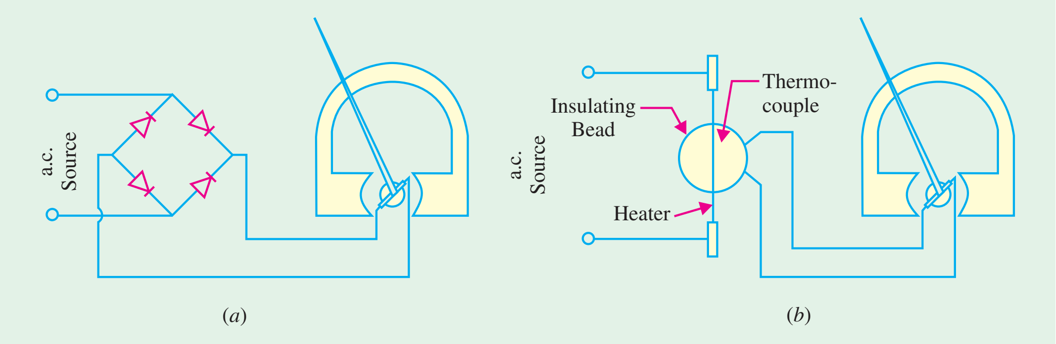


Fig. 73.5

(*b*) it can be converted into a radio frequency ammeter or voltmeter by adding a thermocouple as shown in Fig. 73.5 (*b*).

The above modifications of the basic meter movement have been tabulated below :

- Basic Meter Movement
  - DC Instruments
    - dc ammeter by using a shunt resistor
    - dc voltmeter by using series multiplier resistor
    - ohmmeter by using battery and series resistor
  - AC Instruments
    - audio-frequency ac ammeter or voltmeter by using a rectifier
    - radio-frequency ammeter or voltmeter by using a thermocouple

73.10. Converting Basic Meter to DC Ammeter

As stated earlier and again shown in Fig. 73.6 (*a*), the basic meter movement can carry a maximum current of I_m *i.e.* its full-scale deflection current. However, its current range can be increased (*i.e.* multiplied) to any value by connecting a low resistance (called shunt resistance R_{sh}) in parallel with it as shown in Fig. 73.6 (*b*). The shunted meter works as an ammeter ***with an extended range.***

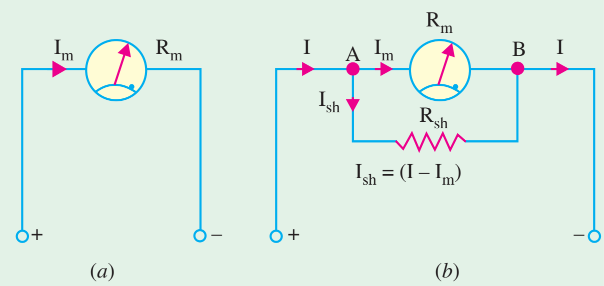


Fig. 73.6

Suppose, we want to measure a line current of I with the help of this meter movement. Obviously, the value of R_{sh} should be such as to shunt or bypass a current of $(I - I_m)$. As seen, range extension is from I_m to I. The ratio $I/I_m = n$ is known as the ***multiplying power or multiplying factor*** of the shunt. It means that a shunt allows the meter to measure current I which is n times larger than I_m.

Value of R_{sh}

In Fig. 73.6 (*b*), voltage across the meter and the shunt is the same because they are joined in parallel.

$$\therefore \quad I_m R_m = I_{sh} \, . \, R_{sh} = (I - I_m)\, R_{sh}$$

$$\therefore \quad R_{sh} = \frac{I_m}{(I - I_m)} \, . \, R_m = \frac{1}{(I/I_m - 1)} \, . \, R_m \quad \therefore \quad R_{sh} = \frac{R_m}{(n-1)}$$

Hence, n is the multiplying factor of the shunt. It is seen that larger the value of n *i.e.* greater the range extension required, smaller the shunt resistance needed. Incidentally, it may be noted that the resistance of the ***shunted*** meter is

$$= R_m \,||\, R_{sh} = \frac{R_m \, R_{sh}}{R_m + R_{sh}}$$

It is much less than either R_m or R_{sh}

Example 73.1. *It is required to convert a 5-mA meter with 20 Ω internal resistance into a 5-A ammeter. Calculate*

(*a*) *the value of shunt resistance required*

(*b*) *multiplying factor of the shunt.*

Solution. Here, $I = 5\text{A}$, $I_{sh} = 5\text{ mA} = 0.005\ A$, $R_m = 20\ \Omega$

(*a*)
$$R_{sh} = \frac{I_m}{(I - I_{sh})} \cdot R_m = \frac{0.005}{(5 - 0.005)} \times 20 = \mathbf{0.02\ \Omega\ (approx)}$$

(*b*)
$$n = \frac{I}{I_{sh}} = \frac{5}{0.005} = \mathbf{1000}$$

Note.
$$R_{sh} = \frac{R_m}{(n-1)} = \frac{20}{(1000-1)} = \frac{20}{999} = 0.02\ \Omega \qquad \text{—as found above}$$

Fig. 73.7 shows such an ammeter connected in a load circuit.

73.11. Multirange Meter

The shunt resistance discussed above gives only a single range ammeter. By using universal shunt (also called Ayrton shunt), we can obtain a multirange ammeter as shown in Fig. 73.8.

It is seen that by changing the switch position from *A* to *B* to *C* and finally to *D*, the current range can be extended as desired.

1. Switch at A

Here, the meter is unshunted and so can read up to its full-scale deflection current of 1 mA only.

2. Switch at B

In this case, R_1 shunts the meter and extends its range to 10 mA *i.e.* increases it ten times.

$$\text{Since} \quad n = 10 \qquad \therefore \quad R_1 = \frac{R_m}{(n-1)} \cong \frac{100\ \Omega}{(10-1)} = 11.11\ \Omega$$

3. Switch at C

Here, R_2 shunts R_m and extends meter range from 1 mA to 0.1 A *i.e.* to 100 mA. Obviously,

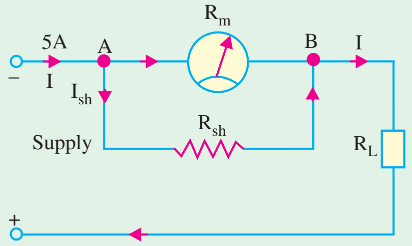


Fig. 73.7

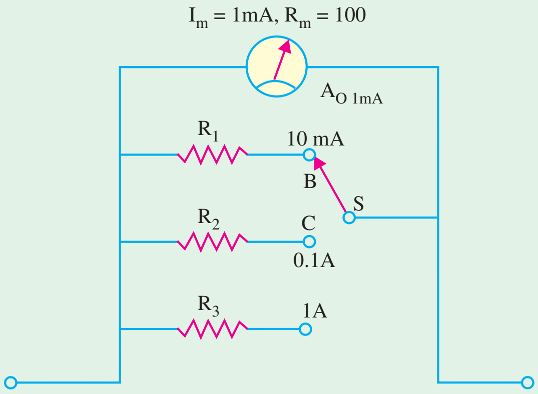


Fig. 73.8

$$n = \frac{100}{1} = 100 \qquad \therefore \qquad R_2 = \frac{100\ \Omega}{(100-1)} = 1.01\ \Omega$$

4. Switch at D

In this case, R_3 shunts R_m and extends the current range of the meter from 1 mA to 1.0 A *i.e.* 1.0 A to 1000 mA. Hence $n = 1000/1 = 1000$.

$$\therefore \qquad R_3 = \frac{100\ \Omega}{(1000-1)} = 0.1001\ \Omega$$

Incidentally, it may be noted that greater the range extension, smaller the shunt resistance.

Alternative Method

An alternative circuit for range extension is shown in Fig. 73.9. It is called 'add on' method of shunting the meter because resistances can be added one after another for changing the range. Unlike in Fig. 73.8, there is no possibility of the meter being in the circuit without any shunt.

As seen, the universal, shunt consists of three resistances R_1, R_2 and R_3. How they are connected as a shunt is determined by the switch position. When S is at position A, the combination $(R_1 + R_2 + R_3)$ becomes connected across R_m. When S is at position B, $(R_2 + R_3)$ become connected in parallel across $(R_1 + R_m)$ and so on.

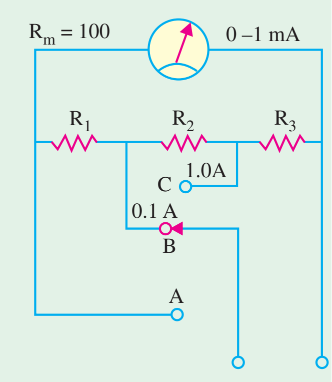


Fig. 73.9

1. Switch at A

In this case, multiplying factor n = 10 mA/1 mA = 10

$$\therefore \qquad (R_1 + R_2 + R_3) = \frac{R_m}{(n-1)} = \frac{100}{9}\ \Omega \qquad \text{...}(i)$$

2. Switch at B

Here, $(R_2 + R_3)$ become in parallel with $(R_1 + R_m)$ or $(R_1 + 100)$. Also, $n = 100/1 = 100$

$$\therefore \qquad R_2 + R_3 = \frac{R_1 + 100}{99} \qquad \text{...}(ii)$$

3. Switch at C

In this position, R_3 is in parallel with $(R_1 + R_2 + 100)$ and $n = 1000/1 = 1000$

$$\therefore \qquad R_3 = \frac{R_1 + R_2 + 100}{999} \qquad \text{...}(iii)$$

Solving for R_1, R_2 and R_3 from Eq. (i), (ii) and (iii) we have

$$R_1 = 10\ \Omega,\ R_2 = 1\ \Omega \text{ and } R_3\ 1/9\ \Omega$$

73.12. Measurement of Current

While measuring current flowing in a circuit, following two points must be kept in mind :

1. The current meter must be connected in series with the circuit where current is to be measured (Fig. 73.7). The full circuit current cannot flow through the meter unless it is made a series component.
2. The dc meter must be connected with the correct polarity for the pointer to read up-scale to the right. Reversed polarity deflects the pointer down-scale to the left forcing it against the stop which can sometime bend the pointer.

73.13. Converting Basic Meter to DC Voltmeter

The basic meter movement can measure a maximum voltage of $I_m R_m$ which is very small [Fig. 73.10 (a)]. However, its voltage range can be extended to any value by connecting a large resistance in series with it as shown in Fig. 73.10 (b). The series resistance is also called ***multiplier resistance*** because it multiplies the voltage reading capability of the meter many times. It is usually connected inside the voltmeter case.

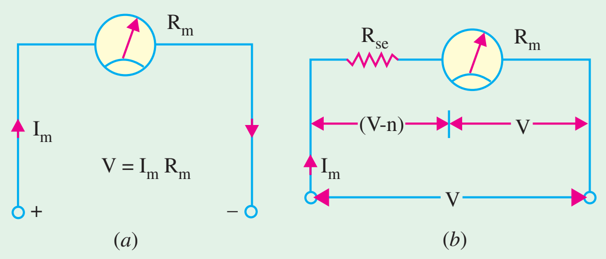


Fig. 73.10

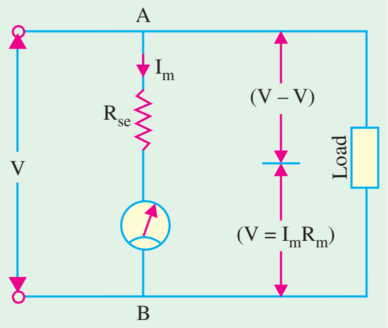


Fig. 73.11

But it should be noted that the voltmeter is connected in parallel with the load across which the voltage is to be measured (Fig. 73.11).

Value of R_{sc}

Suppose, it is desired to extend the voltage range of the meter from *v* to *V*. The ratio *V*/*v* is known as the ***voltage multiplication.*** As seen from Fig. 73.11, drop across R_{se} is (*V* – *v*) and current through it is the same as meter current *i.e.* I_m

$$\therefore \qquad I_m R_{se} = (V - \nu) \qquad \text{...}(i)$$

$$\therefore \qquad R_{se} = \frac{V - \nu}{I_m} = \frac{V - I_m R_m}{I_m} = \frac{V}{I_m} - R_m$$

The voltage multiplication (*m*) can be found from Eq. (*i*) above,

Dividing both sides by ν, we get

$$\frac{I_m R_{se}}{\nu} = V_\nu - 1$$

$$\therefore \qquad \frac{V}{\nu} = 1 + \frac{I_m R_{se}}{\nu} = 1 + \frac{I_m R_{se}}{I_m R_m}$$

$$\therefore \qquad V_\nu = \left(1 + \frac{R_{se}}{R_m}\right) \qquad \therefore \quad m = \left(1 + \frac{R_{se}}{R_m}\right)$$

It is seen that for a given meter, higher the series resistance, greater the voltage range extension.

Example 73.2. *A 50-μA meter movement with an internal resistance of k*Ω *is to be used as dc voltmeter of range 50 V. Calculate the*

(*a*) *multiplier resistance required and* **(*b*)** *voltage multiplication.*

Solution. (*a*)

$$R_{se} = \frac{V}{I_m} - R_m$$

$$= \frac{50}{50 \times 10^{-6}} - 1000$$

$$= 10^6 - 1000 = 999{,}000\ \Omega = \mathbf{999\ k\Omega}$$

73.14. Multirange DC Voltmeter

A multirange voltmeter with ranges of 0–5 V. 0–25 V and 0–50 V is shown in Fig. 73.12. Different values of resistors R_1, R_2 and R_3 can be found in the same way as in Art. 73.11. It would be found that for the meter movement shown in figure

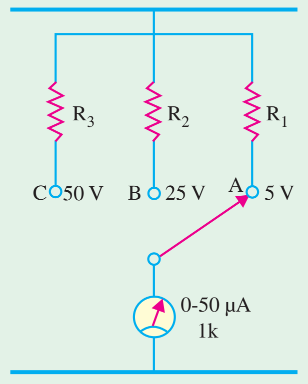


Fig. 73.12

$$R_1 = 99\text{ K},\ R_2 = 499\text{ K},\ R_3 = 999\text{ K}$$

It is seen that higher the voltage range greater the multiplier resistance required (in almost the same proportion as the ranges).

73.15. Loading Effect of a Voltmeter

When the voltmeter resistance is not high as compared to the resistance of the circuit across which it is connected, the measured voltage becomes less. The decrease in voltage may be negligible or it may be appreciable depending on the sensitivity (ohms-per-volt rating) and input resistance of the voltmeter. It is called voltmeter ***loading effect*** because the voltmeter loads down the circuit across which it is connected. Since input resistance of electronic voltmeter is very high (10 M Ω or more), loading is not a problem in their case.

Consider the circuit shown in Fig. 73.13 in which two 15-K resistors are connected in series across a 100-V dc source. The drop across each is 50V. Now, suppose, that a 30-K voltmeter is connected across R_2 to measure voltage drop across it. Due to loading effect of the voltmeter, the reading is reduced from 50V to 40V as explained below. As seen from Fig. 73.13 (*b*), combined resistance of R_2 and voltmeter is 15 K || 30 K = 10 K.

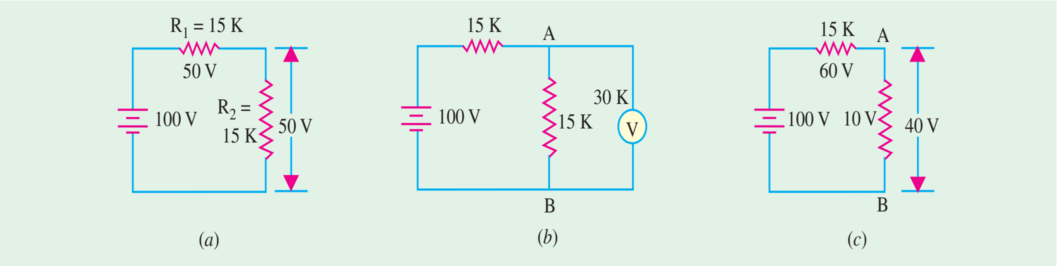


Fig. 73.13

$$\text{drop across 10 K} = \frac{10}{10+15} \times 100 = 40V$$

Loading effect can be minimized by using a voltmeter whose resistance is as high as possible as compared to that of the circuit across which it is connected.

Correction Formula

The loading effect can be neutralized by using the following formula :

$$V_{corr} = V_{means} + \frac{R_1 R_2}{R_v (R_1 + R_2)} . V_{means}$$

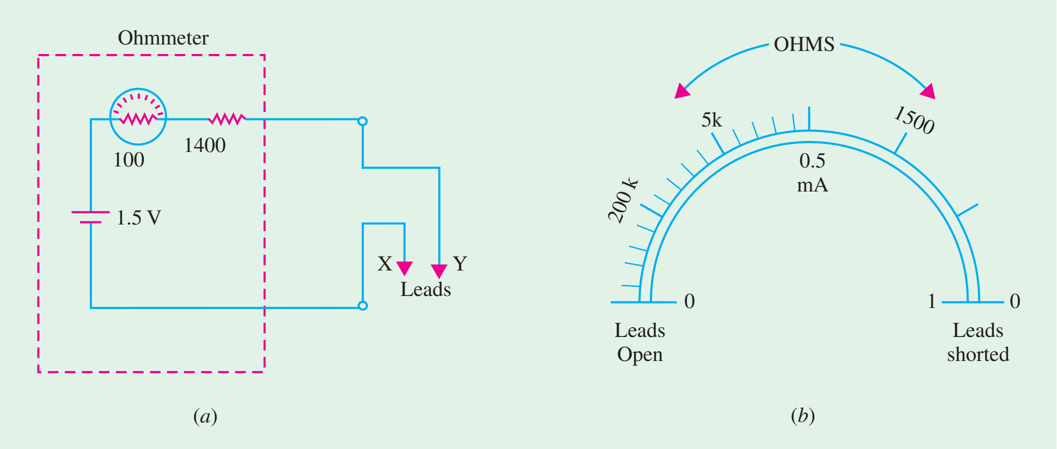
where V_{corr} = corrected voltage reading
V_{meas} = measured voltage reading
R_V = voltmeter resistance
R_1, R_2 = voltage dividing resistances in the circuit

In the above case,

$$V_{corr} = 40 + \frac{15 \times 15}{30\,(15+15)} \times 40 = 40 + 10 = \mathbf{50\ V}$$

73.16. Ohmmeter

The basic meter movement can be used to measure resistance it is combined with a battery and a current-limiting resistance as shown in Fig. 73.14 (*a*). In that case, it is known as an ohmmeter.



(*a*) (*b*)

Fig. 73.14

For measuring resistance, the ohm-meter leads *X-Y* are connected across the unknown resistance after switching off the power in the circuit under test. Only in that case, the ohmmeter battery can provide current for the meter movement. Since the amount of current depends on the amount of external resistance, the meter scale can be calibrated in ohms (instead of mA).

When the leads *X-Y* are shorted, meter current is $1.5V/(100 + 1400)\,\Omega = 1$ mA. The meter shows full-scale deflection to the right. The ohmmeter reading corresponds to 0 Ω because external resistance is zero. When leads *X-Y* are open *i.e.* do not touch each other, meter current is zero. Hence, it corresponds to infinite resistance on the ohmmeter scale.

Following points about the ohmmeter are worth noting :

1. the resistance scale is non-linear *i.e.* it is expanded at the right near zero ohm and crowded at the left near infinite ohm. This nonlinearity is due to the reciprocal function $I = V/R$.;
2. the ohmmeter reads up-scale regardless of the polarity of the leads because direction of current is determined by the internal battery;
3. at half-scale deflection, external resistance equals the internal resistance of the ohmmeter.
4. the test leads should be shorted and 'ZERO OHMS' control adjusted to bring the pointer to zero on each range.

Fig. 73.15. Digital micro-ohmmeter

Fig. 73.16. Digital milli-ohmmeter

Fig. 73.15 shows a digital micro-ohmmeter having a range of 1μΩ – 2 kΩ with 3½ digit, 7-segment *LED* display. It has a basic accuracy of ± 0.2% ± 1 digit and is based on a design using *MOS LSI ICs* and glass epoxy *PCB.*

Fig. 73.16 shows a battery-operated portable digital milli-ohmmeter having a measurement range of 200 mΩ – 2 kΩ with an accuracy of ± 0.5% ± 1 digit. It has a 3½ digit 7-segment *LED* display.

73.17. The Multimeter

It is extensively used in cable industry, motor industry, transformer and switchgear industry. It is also called volt-ohm-milliammeter (VOM). It is a general purpose instrument having the necessary circuitry and switching arrangement for measuring ac/dc voltage or ac/dc current or resistance. It is simple, compact and portable because the only power it uses is the battery for the ohm-meter.

Multimeters may be of analog type (Fig. 73.17) or digital type (Fig. 73.18). The analog type is of the pointer and scale type *i.e.* it uses the basic *D*' Arsoval meter movement. However digital multimeters (*DMMs*) are becoming increasingly popular because of their easy readability, numerical display and imporved accuracy.

Fig. 73.17. A digital multimeter

Fig. 73.18
Courtesy : Fluke Corporation

Fig. 73.17 shows the photograph of an analog multimeter designed primarily for electrical, electronic, radio and TV engineers and technicians. It sells under the brand name of Motwane Multimeter 8 X Mark-III.

It is a 5-function, 30-range meter which measures high ac/dc voltages from 0 to 2.5 kV and ac/dc currents from 0 to 10 A. Its three resistance ranges cover from 0 to 20 MΩ. It is reputed for its excellent reliability, operational simplicity and easy portability.

Fig. 73.18 depicts a digital multimeter which can measure dc voltage upto 1000 V, ac voltages upto 750 V, ac/dc currents from 15 μA to 10 A and resistances from 0 Ω to 100 MΩ. It has a 5 digit multifunction vacuum fluorescent display allowing the user to measure two different parameters of the same signal from one test connection. The user can also view both measurements at the same time.

In Fig. 73.19 is shown a hand-held autoranging, digital multimeter (DMM) having high contrast, 4 digit *LCD* readout. It has been designed for speed, accuracy and reliability.

Fig. 73.19. Courtesy : Fluke Corporation

73.18. Rectifier Type AC Meter

The D' Arsonval meter movement can be used for measuring alternating quantities provided a rectifier is added to the measuring circuit. A similar rectifier arrangement is found as part of *AC VOLTS* function in multimeters (Art. 73.17). Such as meters are more widely used than either (costly but more accurate) dynamometer type or more delicate thermal and hotwire type.

(*a*) With Half-Wave Rectifier

The circuit of an ac Voltmeter using half-wave diode recifier is shown in Fig. 73.20. Here, a half-wave rectifier has been combined in series with a dc meter movement.

When used as a dc voltmeter (*i.e.* without rectifier) it would have (say, for example) a range of $10V$. However, if an ac voltages of rms value $10V$ is applied across input terminals AB, it would read $4.5\,V$.

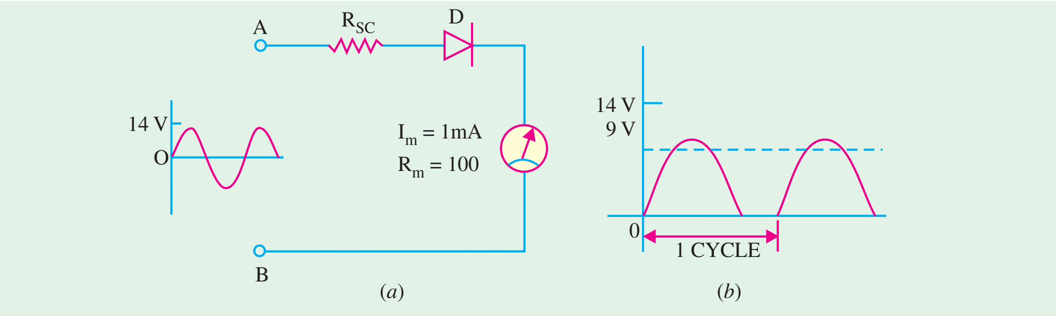
It is so because an *ac* voltage of rms value 10 V has a peak value of $10 \times \sqrt{2} = 14\ V$ and an average value of $0.636 \times 14 = 9V$. Since in the half-wave rectified output, one half-cycle is absent, the average for the full cycle is $9/2 = 4.5\ V$. The meter movement will, therefore read 4.5 V *i.e.* 45% of the dc value. It may also be noted that ac sensitivity of a half-wave ac meter is only 45 per cent of the dc sensitivity.

(*b*) With Full-Wave Rectifier

The circuit is shown in Fig. 73.21. In this case, the meter reading would be 90% of rms input voltage *i.e.* 90% of the dc value.

73.19. Electronic Voltmeters

A *VOM* can be used to measure voltages but it lacks both sensitivity and high input resistances. Moreover, its input resistance is different for each range. The electronic voltmeter (*EVM*), on the other hand, has input resistance ranging from 10 $M\ \Omega$ to 100 $M\Omega$, thus producing less loading of the circuit under test than the *VOM*. Another advantage of *EVM* is that its input resitance remains constant over all ranges.



(*a*) (*b*)

Fig. 73.20

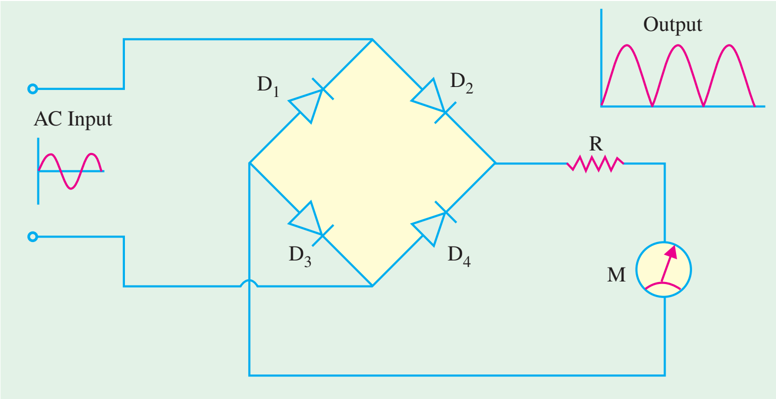


Fig. 73.21

Two types of voltmeters are in use today (*i*) analog and (*ii*) digital. However, a distinction must be made between a digital instrument and an instrument with digital readout. A digital instrument is one which uses internal circuitry of digital design. A digital readout instrument is one whose measuring circuitry is of analog design but the indicating device is of digital design.

The electronic voltmeters go by a variety of nemes reflecting the technology used.

(*i*) vacuum-tube voltmeter (*VTVM*)–it uses vacuum tubes with deflection meter movement,

(*ii*) digital voltmeters like transistor voltmeter (*TVM*) and *FET* voltmeter (*FETVM*).

73.20. Direct Current *FET VM*

The schematic diagram of a *FET VM* using difference amplifier is shown in Fig. 73.22. The two *FETs* are identical so that increase in the current of one *FET* is offset by corresponding decrease in the source current of the other. The two *FETs* form the lower arms of the balanced bridge circuit whereas the two drain resistors R_D form the upper arms. The meter movement is connected across the drain terminals of the *FETs*.

The circuit is balanced under zero-input-voltage condition provided the two *FETs* are identical. In that case, there would be no current through *M*. Zero-Adjust potentiometer is used to get null deflection in case there is a small current through *M* under zero-signal condition.

Full-scale calibration is adjusted with the help of variable resistor *R*.

When positive voltage is applied to the gate of F_1, some current flows through *M*. The magnitude of this current is found to be proportional to the voltage being measured. Hence, meter is calibrated in volts to indicate input voltage.

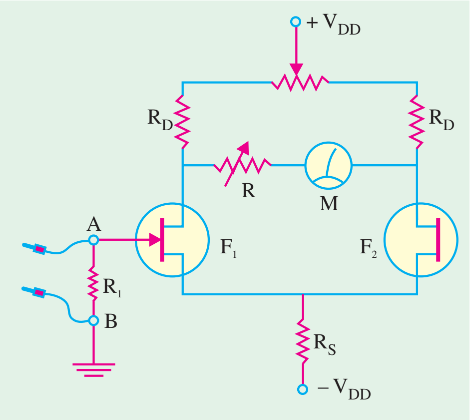


Fig. 73.22

73.21. Electronic Voltmeter for Alternating Currents

The block diagram of such an *EVM* for ac measurements is shown in Fig. 73.23 where voltage divider allows range selection. The amplifier provides the necessary gain to establish voltmeter sensitivity as well as high input impedance. The negative feed-back ensures stability and accurate overall gain.

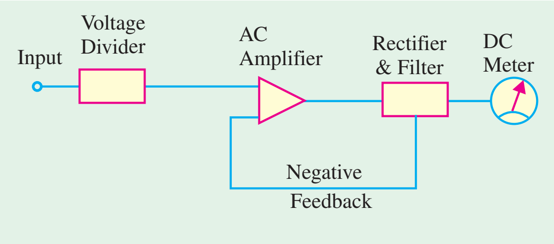


Fig. 73.23

73.22. The Digital Voltmeter (DVM)

Such a voltmeter displays measurements of dc or ac voltages as discrete numerals instead of pointer deflections on a continuous scale as in analog instruments. As compared to other voltmeters, a *DVM* offers the advantages of :

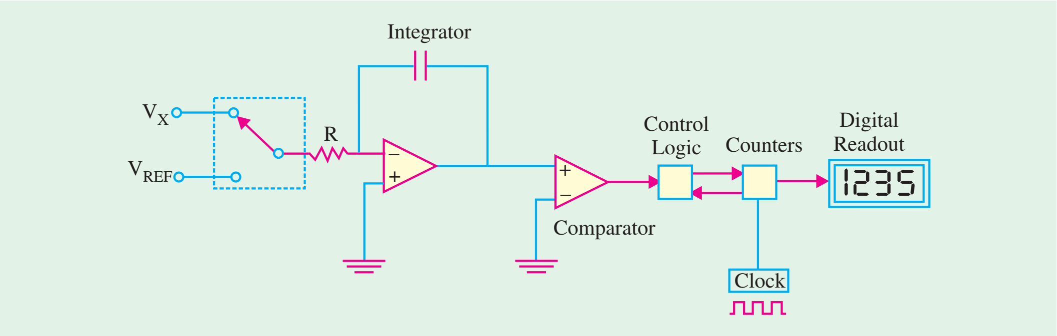


Fig. 73.24

1. greater, speed, **2.** higher accuracy and resolution, **3.** no parallax, **4.** reduced human error, **5.** compatibility with other digital equipment for further processing and recording.

With the development and perfection of IC modules, the size and power requirement of *DVMs* have reduced to a level where they can compete with conventional analog instrument both in price and portability.

The block diagram of a *DVM* based on dual-slope technique is shown in Fig. 73.24. The dual-slope analog-digital (*A - D*) converter consists of five basic blocks : an Op-Amp used as an integrator, a level comparator, a basic clock (for generating timing pulses), a set of decimal counters and a block of logic circuitry.

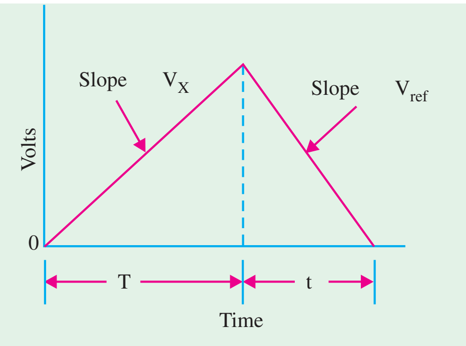


Fig. 73.25

The unknown voltage V_x is applied through switch *S* to the integrator for a known period of time *T* as shown in Fig. 73.25. This period is determined by counting the clock frequency in decimal counters. During time period *T*, *C* is charged at a rate proportional to V_x.

At the end of time interval *T*, *S* is shifted to the reference voltage V_{ref} of ***opposite*** polarity. The capacitor charge begins to decrease with time and results in a down-ward linear ramp voltage. During the second period a known voltage (*i.e.* V_{ref} is observed for an unkown time (*t*). This unknown time *t* is determined by counting timing pulses from the clock until the voltage across the capacitor reaches its basic reference value (reference may be ground or any other basic reference level). From similar triangles of Fig. 73.25.

$$\frac{V_x}{T} = \frac{V_{ref}}{t} \qquad \therefore \quad V_x = \frac{V_{ref}}{t} \times V_{ref}$$

Fig. 73.26. Digital Voltmeter

The count after *t* which is proportional to the input voltage V_x is displayed as the measured voltage.

By using appropriate signal conditioners, currents, resistances and ac voltages can be measured by the same instrument.

DVMs are often used in data processing systems or data logging systems. In such systems, a number of analog input signals are scanned sequentially by an electronic system and then each signal is converted into an equivalent digital value by the *A/D* converter in the *DVM*. The digital value is then transmitted to a printer alongwith the information about the input line from which the signal has been derived. The whole data is then printed out. In this way, a large number of intput signals can be automatically scanned or processed and their values either printed or logged.

Fig. 73.26 shows a portable digital dc micro-voltmeter (Agronic-112). It has a measurement range of 1 μV - 1000 V with an accuracy of ± 0.2% ± 1 digit. It uses latest *MOS LSI ICs* and glass epoxy *PCB*. It has 3½ digit, 7-segment *LED* display and is widely-used by the testing and servicing departments of industries, research laboratories, educational institutions and service centres.

73.23. Cathode-Ray Oscilloscope (*CRO*)

It is generally referred to as oscilloscope or scope and is the basic tool of an electronic engineer and technician as voltmeter, ammeter and wattmeter are those of an electrical engineer or electrician.

The *CRO* provides a two-dimensional visual display of the signal waveshape on a screen thereby allowing an electronic engineer to 'see' the signal in various parts of the circuit. It, in effect, gives the electronic engineer an eye to 'see' what is happening inside the circuit itself. It is only by 'seeing' the signal waveforms that he/she can correct errors, understand mistakes in the circuit design and thus make suitable adjustments.

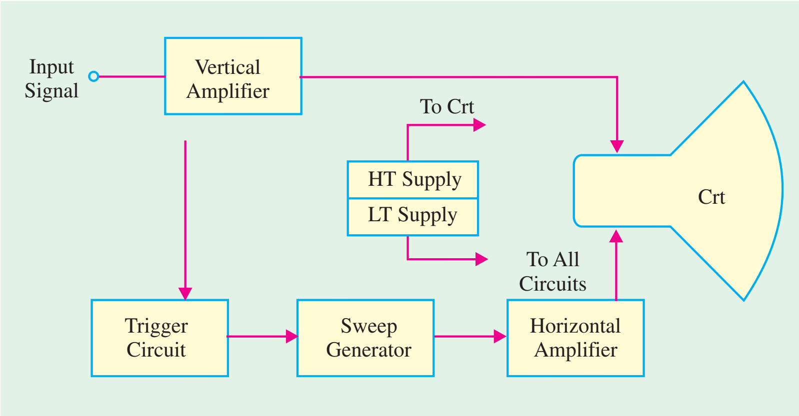


Fig. 73.27

An oscilloscope can display and also measure many electrical quantities like ac/dc voltage, time, phase relationships, frequency and a wide range of waveform characteristics like rise-time, fall-time and overshoot etc. Non-electrical quantities like pressure, strain, temperature and acceleration etc. can also be measured by using different transducers to first convert them into an equivalent voltage.

As seen from the block diagram of an oscilloscope (Fig. 73.27), it consists of the following major sub-systems :

1. **Cathode Ray Tube (*CRT*)**–it displays the quantity being measured.
2. **Vertical amplifier**–it amplifies the signal waveform to be viewed.
3. **Horizontal amplifier**–it is fed with a sawtooth voltage which is then applied to the *X*-plates.
4. **Sweep generator**–produces sawtooth voltage waveform used for horizontal deflection of the electron beam.
5. **Trigger circuit**–produces trigger pulses to start horizontal sweep.
6. **High and low-voltage power supply.**

The operating controls of a basic oscilloscope are shown in Fig. 73.28.

The different **terminals** provide.

1. horizontal amplifier input,
2. vertical amplifier input,
3. sync. input,
4. Z-axis input,
5. external sweep input.

As seen, different **controls** permit adjustment of

1. **Intensity**–for correct brightness of the trace on the screen,
2. **Focus**–for sharp focus of the trace.
3. **Horizontal centering**–for moving the pattern right and left on the screen.
4. **Vertical centering**–for moving the pattern up and down on the screen.
5. **Horizontal gain (also Time/div or Time/cm)**–for adjusting pattern width.
6. **Vertical gain (also volt/div or volt/cm)**–for adjusting pattern height.
7. **Sweep frequency**–for selecting number of cycles in the pattern.
8. **Sync. voltage amplitude**–for locking the pattern.

The different **switches** permit selection of :

1. sweep type,
2. sweep range,
3. sync. type

A *CRO* can operate upto 500 MHz, can allow viewing of signals within a time span of a few nanoseconds and can provide a number of waveform displays simultaneously on the screen. It also has the ability to hold the displays for a short or long time (of many hours) so that the original signal may be compared with one coming on later.

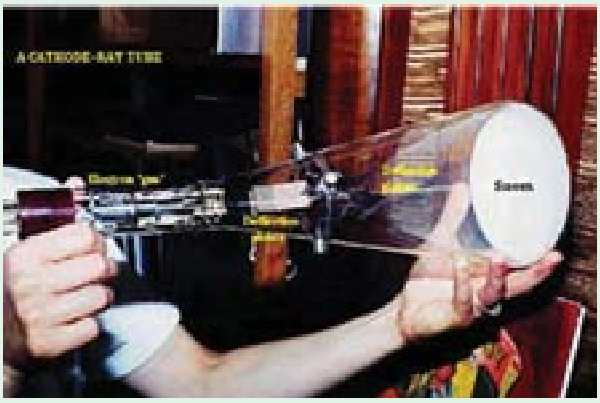
73.24. Cathode Ray Tube (CRT)

It is the 'heart' of an oscilloscope and is very similar to the picture tube in a television set.

Construction

The cross-sectional view of a general-purpose electrostatic deflection *CRT* is shwon in Fig. 73.29. Its four major components are :

1. an electron gun for producing a stream of electrons,
2. focussing and accelerating anodes-for producing a narrow and sharply-focussed beam of electrons,
3. horizontal and vertical deflecting plates-for controlling the path of the beam,
4. an evacuated glass envelope with a phosphorescent screen which produces bright spot when struck by a high-velocity electron beam.



A photography of Cathode ray tube

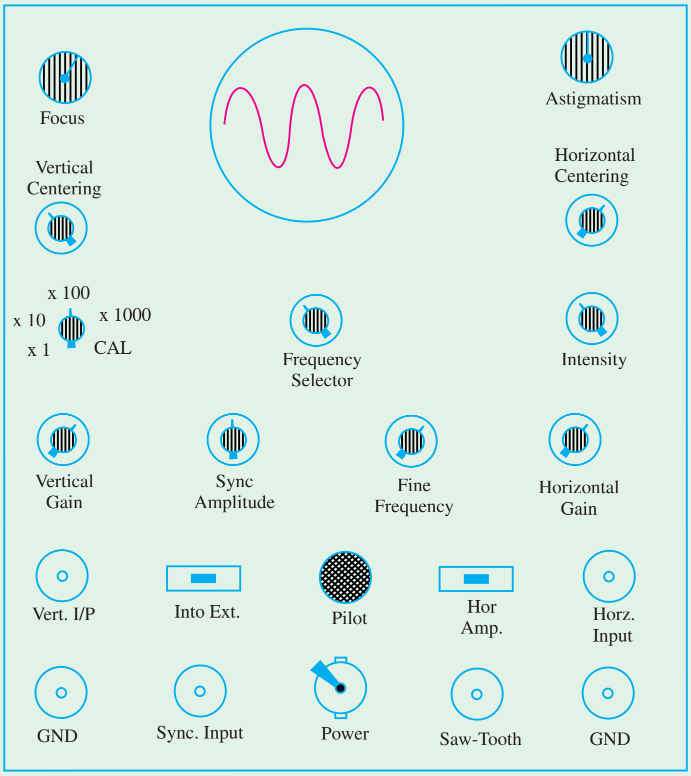


Fig. 73.28

As shown, a *CRT* is a self-contained unit like any electron tube with a base through which leads are brought out for different pins.

1. Electron Gun Assembly

The electron gun assembly consists of an indirectly-heated cathode K, a control grid G, a pre-accelerator anode A_1, focussing anode A_2 and an accelerating anode A_3. The sole function of the electrons gun assembly is to provide a focussed beam of electrons which is accelerated towards the flourescent screen. The electrons are given off by thermionic emission from the cathode. The control grid is a metallic cylinder with a small aperture in line with the cathode and kept at a negative potential with respect to K. The number of electrons allowed to pass through the grid aperture (and, hence, the beam current) depends on the amount of the control grid bias. Since the intensity (or brightness) of the spot S on the screen depends on the strength of beam current, the knob controlling the grid bias is called the ***intensity control.***

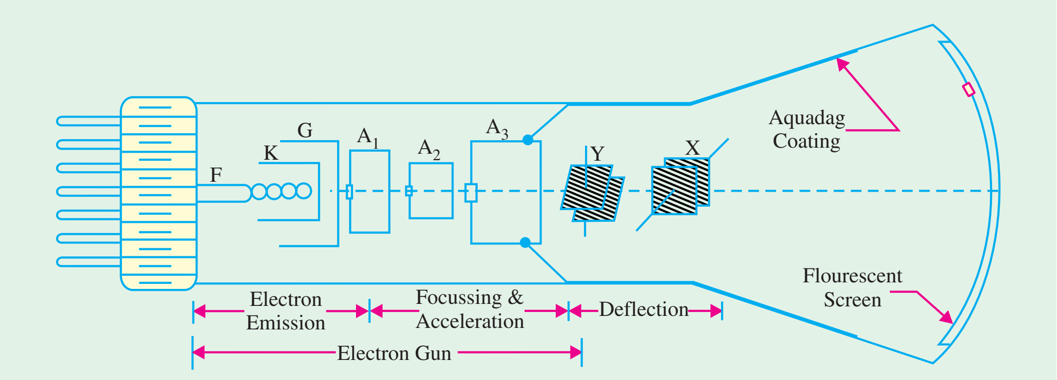


Fig. 73.29

The anodes A_1 and A_3, which are both at positive potential with respect to K, operate to accelerate the electron beam (Fig. 73.30). The cylindrical focussing anode A_2, being at negative potential, repels electrons from all sides and compresses them into a fine beam. The knob controlling the potential of A_2 provides the ***focus control.***

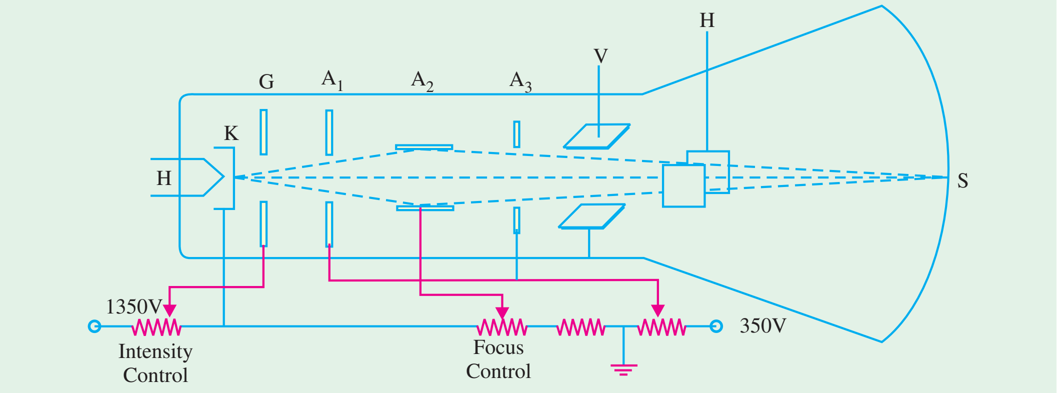


Fig. 73.30

2. Deflecting Plates

Two sets of deflecting plates are used for deflecting the thin pencil-like electronic beam both in the vertical and horizontal directions. The first set marked Y (nearer to the gun) is for vertical deflection and X-set is for horizontal deflection. When no potential is applied across the plates, beam passes between both sets of plates undeflected and produces a bright spot at the centre of the screen.

If upper Y-plate is given a positive potential, the beam is deflected upwards depending on the value of the applied potential. Similarly, the beam (and hence the spot) deflects downwards when lower Y-plate is made positive. However, if an ***alternating*** voltage is applied across the Y-plates, the spot keeps moving up and down thereby producing a vertical luminous trace on the screen due to persistance of vision. The maximum displacement of the spot from its central position is equal to the amplitude of the applied voltage.

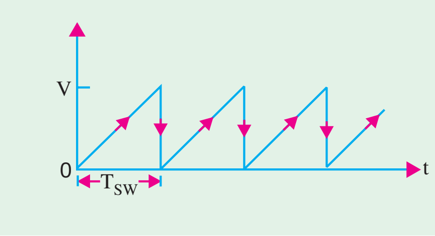


Fig. 73.31

The screen spot is deflected horizontally if similar voltages are applied to the X-plates. The dc potentials on the Y-and X-plates are adjustable by means of ***centring controls.***

It must be remembered that the signal to be displayed on the screen is always applied across the Y-plates. The voltage applied across X-plates is a ramp voltage *i.e.* a voltage which increases linearly with time. It has a sawtooth wave-form as shown in Fig. 73.31. It is also called horizontal time-base or sweep voltage. It has a sweep time of T_{sw}.

3. Glass Envelope

It is funnel-shaped having a phosphor-coated screen at its flared end. It is highly-evacuated in order to permit the electron beam to traverse the tube easily. The inside of the flared part of the tube is coated with a conducting graphite layer called Aquadag which is maintained at the same potential as A_3. This layer performs two functions ***(i)*** it accelerates the electron beam after it passes between the deflecting plates and ***(ii)*** collects the electrons produces by secondary emission when electron beam strikes the screen. Hence, it prevents the formation of negative charge on the screen.

The screen itself is coated with a thin layer of a flourescent material called phosphor. When struck by high-energy electrons, it glows. In other words, it absorbs the kinetic energy of the electrons and converts it into light-the process being known as ***flourescence.*** That is why the screen is called ***flourescent screen.*** The colour of the emitted light depends on the type of phosphor used.

73.25. Deflection Sensitivity of a *CRT*

Fig. 73.32 shows the upward deflection of an electron beam when it passes between the vertical or Y-plates of a CRT. The beam deflects upwards because the upper Y-plate has been made positive with respect to the lower plate. Reversing the polarity of the **applied** voltage would, obviously, cause the beam to deflect downwards.

The vertical deflection of the beam is

$$y = \frac{1}{2} \cdot D \cdot \frac{l}{D} \cdot \frac{V_d}{V_A}$$

where V_A is the accelerating voltage applied to the electrons which make up the electron beam.

The deflection sensitivity of a CRT is definition as the vertical deflection of the beam on the screen per unit deflecting voltage.

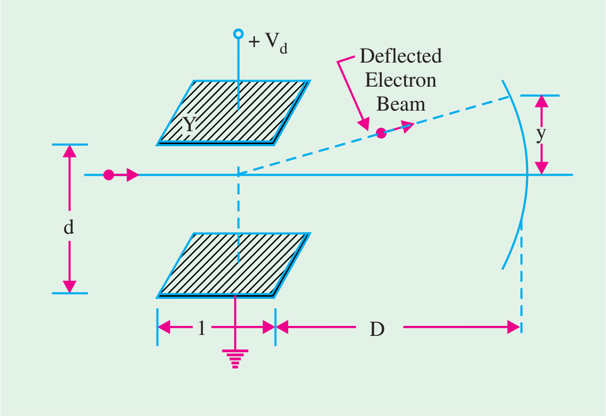


Fig. 73.32

$$\therefore \qquad S = \frac{y}{V_d}$$

Using the above equation, we get $S = \dfrac{lD}{2dV_A}$

The deflection factor which is defined as the reciprocal of deflection sensitivity is given by $G = 1/S$.

Substituting the value of S from above

$$G = 2 \cdot \frac{d}{l} \cdot \frac{V_A}{D} \text{ volt/metre}$$

73.26. Normal Operation of a *CRO*

The signal to be viewed or displayed on the screen is applied across the Y-plates of a *CRT*. But to see its waveform or pattern, it is essential to spread it out horizontally from left to right. It is achieved by applying a sawtooth voltage wave (produced by a time base generator) to X-plates. Under these conditions, the electron beam would move uniformly from left to right thereby graphic vertical variations of the input signal versus time. Due to repetitive tracing of the viewed waveform, we get a continuous display because of persistence of vision. However, for getting a stable stationary display on the screen, it is essential to synchronize the horizontal sweeping of the beam (sync) with the input signal across Y-plates. The signal will be properly synced only when its frequency equals the sweep-generator frequency.

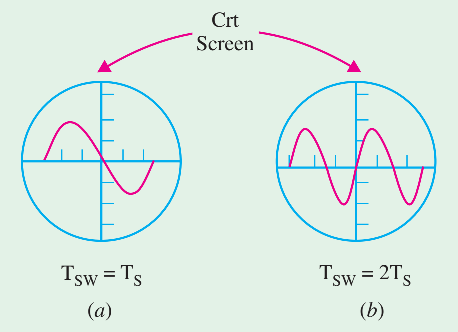


Fig. 73.33

In general, for proper synchronization of time-base with the signal, the condition is

$$T_{sw} = n\,T_s$$

where T_s the time-period of the signal and n is an integer.

If $n = 1$, then $T_{sw} = T_s$ *i.e.* time-periods of the sweep voltage and input signal voltage are equal, then one cycle of the signal would be displayed as shown in Fig. 73.33 (*a*).

On the other hand, if T_{sw} is twice T_s, then two cycles of the signal voltage would be displayed as shown in Fig. 73.33 (*b*). Obviously, three full cycles of the input voltage would be spread out on the screen when $T_{sw} = 3\,T_s$.

Internal Synchronization

The periodic sawtooth voltage which is applied to X-plates for horizontal sweep (or scan) of the beam across the screen is usually provided by the unijunction relaxation oscillator. When the sawtooth voltage falls abruptly to zero, the beam experience no horizontal deflection and hence flies back almost instantly to the original (central) position.

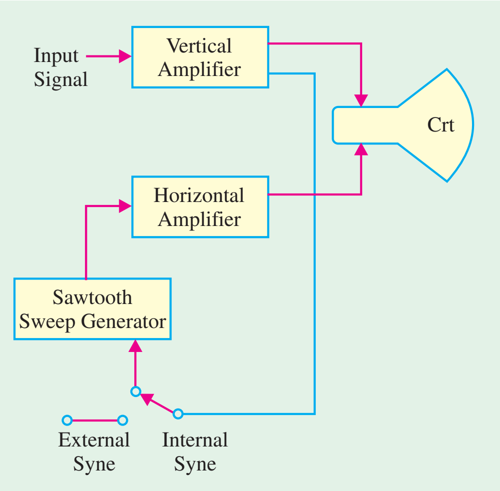


Fig. 73.34

The usual method of synchronizing the input signal is to use a portion of the input signal to trigger the sweep generator so that the frequency of the sweep signal is locked or synchronized to the input signal. It is called internal sync. because the synchronization is obtained by internal wiring connection as shown in the block the diagram of Fig. 73.34.

73.27. Triggered and Non-Triggered Scopes

Oscilloscopes may be classified into two basic types :

1. triggered sweep type.

2. recurrent sweep (free-running) type.

Triggered oscilloscopes, being more sophisticated, are generally used in industrial laboratories and plants, in engineering and technical school laboratories and in all those applications which require study of low- and high-frequency waveforms, for accurate measurement of time and timing relationships etc.

A non-triggered oscilloscope is generally used in servicing work where a certain amount of waveform error can be tolerated and bandwidth requirements are limited to a few MHz.

The sweep (or ramp) generator which produces sawtooth voltage for *X*-deflection plates is prresent in both types of scopes. In non-triggered oscilloscopes, this generator runs continuously (recurrent sweep) and the control and calibration of the sweep is based on the repetition freqeuncy of the sweep. For producing a stable stationary display, the sweep frequency has to be forced into synchronization with the input signal on the *Y*-plates. This is done by manually adjusting the free-running sweep freqeuncy to a value very close to signal frequency (or some submultiple of it) and then depending on the internal sync signal (derived from the input) for locking the sweep generator into exact step. Unfortunately, this method is limited to the display of signals which have contant frequency and amplitude. Hence voice or music signals from a microphone cannot be displayed on this scope because it has to be readjusted for each for new change in frequency. Moreover, a free-running or recurrent time base cannot display less than one complete cycle of the input signal on the scope screen. On the other hand, triggered time base can be adjusted to pick out a small part of a waveform which can then be expended horizontally for evaluation of waveform details.

Fig. 73.35. A non-triggered oscilloscope

The triggered oscilloscope is provided with a triggered (or driven) sweep. Here the input signal is caused to generate pulses that trigger the sweep thereby ensuring that the sweep is necessarily in step with the trigger that drives it. Hence, screen display remains stable in spite of variations in the frequency or amplitude of the input signal. It means that there is automatic mode of triggering in such scopes. Consequently, input signals of very short duration can be displayed for the simple reason that sweep is initiated by a trigger pulse derived from the waveform under observation.

Fig. 73.35 illustrates a triggered oscilloscope having a bandwidth 0-6 MHz, vertical sensitivity of 10 mV/div and horizontal sweep rate varying from 0.2 μs/div to 0.1 s/div.

73.28. Dual Trace CRO

Such oscilloscopes are used extensively by industrial firms and research laboratories. They produce a dual-trace display by means of electronic switching of two separate input signals. As shown in the block diagram of Fig. 73.36, there are two vertical input circuits marked channel *A* and *B* with identical pre-amplifiers. The outputs of the these preamplifiers are fed to an electronic switch which alternately connects them to the main vertical amplifier of the oscilloscope. In this type of scope, ther is only one electron beam. The electron switch is also capable of selecting a variety of display modes.

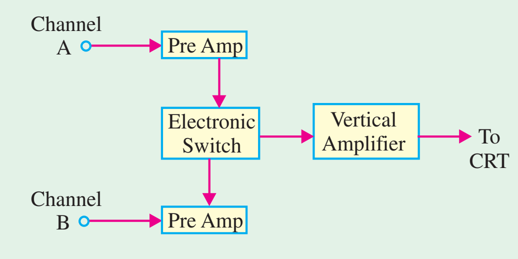


Fig. 73.36

In Fig. 73.37 is shown a dual trace oscilloscope (type *VOS*-26) which has a band-width of 5-15 MHz, vertical sensitivity of 10 mV/cm to 30 V/cm and calibrated sweep speed from 0.3 μs/cm to 10 ms/cm. It is a very sensitive yet simple oscilloscope which assures long life and easy maintenance.

73.29. Dual Beam CRO

Such a *CRO* has two sets of vertical deflection plates and has two electronic beams which produce two separate traces on the scope screen by using the same set of horizontal deflection plates. This scope makes it possible to observe two time-related wave forms at different points *i.e.* the electronic circuit.

Such a scope does not have the same number of display modes as the dual-trace scope yet it is ideally suited for different input signals.

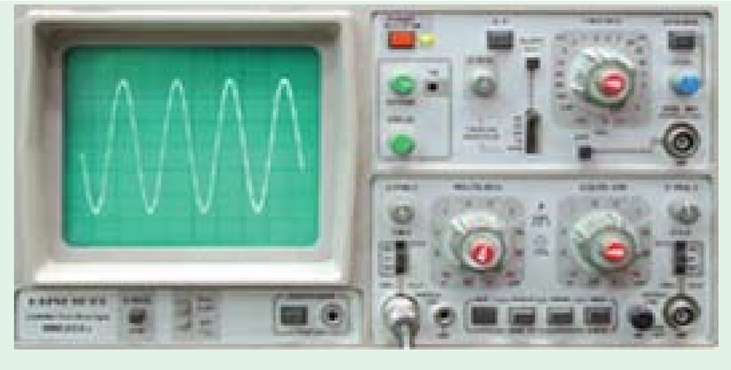


Fig. 73.37. Dual Beam CRO

73.30. Storage Oscilloscope

It can retain a *CRT* display for 10 to 150 hours after the pattern is first produced on the screen. It uses the phenomenon of secondary electron emission to build up and store electrostatic charges on the surface of an insulated target. Such oscilloscopes are especially useful.

1. For real-time observation of events that occur only once.

2. For displaying the waveform of a very low-frequency signal.

Fig. 73.38 shows a 4 channel storage oscilloscope with 400 MHz bandwidth. It has a standard floppy disk drive which makes the saving of screen images or data to a disk, simple. The disk can then be inserted into your personal computer (*PC*) for importing to desk top publishing or spreadsheet programs. The storage oscilloscopes finds their application in biophysics/biomedical research, audio system measurement and analysis, power supply and power-related design, electrophysical and electromechanical system design etc.

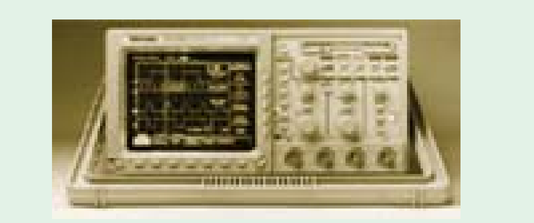


Fig. 73.38. 4 channel storage oscilloscope

73.31. Sampling CRO

It is specifically meant to observe very high frequency repetitive electric signals by using the sampling technique. Such high-frequency signals cannot be viewed by conventional oscilloscopes because its frequency range is limited by the gain-bandwidth product of its vertical amplifier. The sampling technique 'slows down' the signal frequency many thousands of times thereby making it easier to view it on the screen.

The oscilloscope shown in Fig. 73.38 is a sampling cathode ray oscilloscope. Its sample rate is 100 M samples per second.

73.32. Digital Readout CRO

It provides digital readout of the signal information such as voltage or time etc. in addition to the conventional *CRT* display. It consists of a high-speed laboratory *CRO* and an electronic counter, both contained in one cabinet.

73.33. Handheld Battery Operated Oscilloscope

Fig. 73.39 shows a handheld battery operated oscilloscope Model THS 720 P manufactured by Tektronix Corporation. It has built in 3-3/4 digit digital multimeter (DMM) with *data logger and power analyser. It has a bandwidth of over 100 MHz and the sampling rate is as high as 500 M samples per second. The oscilloscope and power analyser can operate simultaneously and independently on the same or separate signals. This type of an oscilloscope is extremely useful for electric/power electronics measurements. Examples of such measurements are : **(1)** testing and verifying correct operation of motors **(2)** checking transformer efficiency, **(3)** verifying power supply performance, **(4)** measuring the effect of neutral current etc.

Fig. 73.39. Courtesy : Tektronix Corporation

73.34. Lissajous Figures

Lissajous figures (or patterns) are named in honour of the French scientist who first obtained them geometrically and optically. They illustrate one of the earliest uses to whch the *CRO* was put.

Lissajous patterns are formed when two sine waves are applied simultaneously to the vertical and horizontal deflecting plates of a *CRO*. The two sine waves may be obtained from two audio oscillators as shown in Fig. 73.40. Obviously, in this case, ***a sine wave sweeps a sine-wave input signal***. The shape of the Lissajous pattern depends on

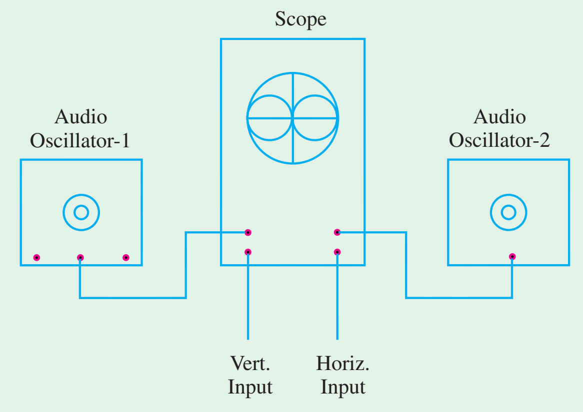


Fig. 73.40

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* Data logger is a system which can acquire data and store it in a memory.

the frequency and phase relationship of the two sine waves.

Two sine waves of the ***same*** frequency and amplitude may produce a straight line, an ellipse or a circle depending on their phase difference (73.41).

In general, the shape of Lissajous figures depends on ***(i)*** amplitude, ***(ii)*** phase difference and ***(iii)*** ratio of frequency of the two waves.

Lissajous figures are used for ***(i)*** determining an unknown frequency by comparing it with a known frequency (*ii*) checking audio oscillator with a known-frequency signal and ***(iii)***checking audio amplifiers and feedback networks for phase shift.

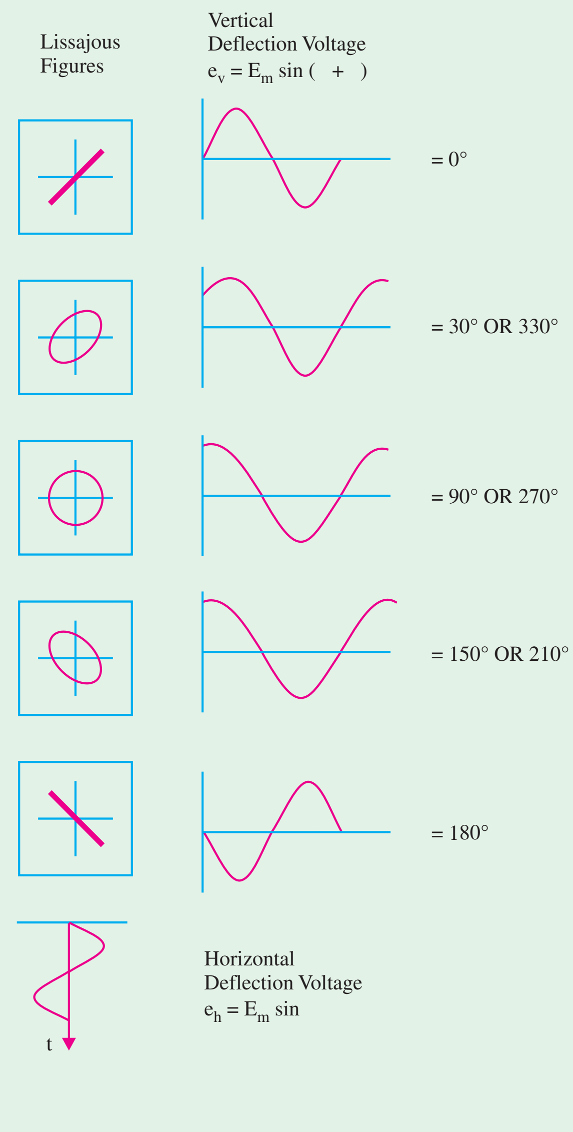


Fig. 73.41

73.35. Frequency Determination with Lissajous Figures

The unknown signal is applied across one set of deflecting plates and a known signal across the other. By studying the resultant Lissajous pattern, unknown frequency can be found.

Depend on the frequency ratio, the various patterns obtained are shown in Fig. 73.42. The ratio of the two frequencies is given by

$$\frac{f_H}{f_v} = \frac{\text{No. of points of horizontal tangency}}{\text{No. of points of vertical tangency}}$$

In Fig. 73.41 (*a*), there is one point of tangency along the horizontal as well as vertical axis. Hence, $f_H = f_v$ *i.e.* the signals have the same frequency. In Fig. 73.42 (*e*) f_H/f_v = 3/2. In other words $f_H = 1.5\, f_v$.

It should be noted in passing that this method of frequency determination has limitations and is being discarded gradually because low-cost digital frequency counters are becoming increasingly available in the market Fig. 73.43. The two main limitatioins of this method are as under :

(i) the numerator and denominator of the frequency ratio must be whole numbers,

(ii) the maximum ratio of frequencies that can be used is 10 : 1. Beyond that, the Lissajous patterns become too complex to analyse.

Fig. 73.43 shows a 10-digit digital frequency counter Model No. PM 6685 manufactured by Fluke Corporation. This can measure frequencies from 10 Hz to 300 MHz. This is an ideal instrument for *R* and *D* laboratories, testing, servicing and even outside the lab environment such as in base station transmitters of large telecommunication networks like *GSM*.

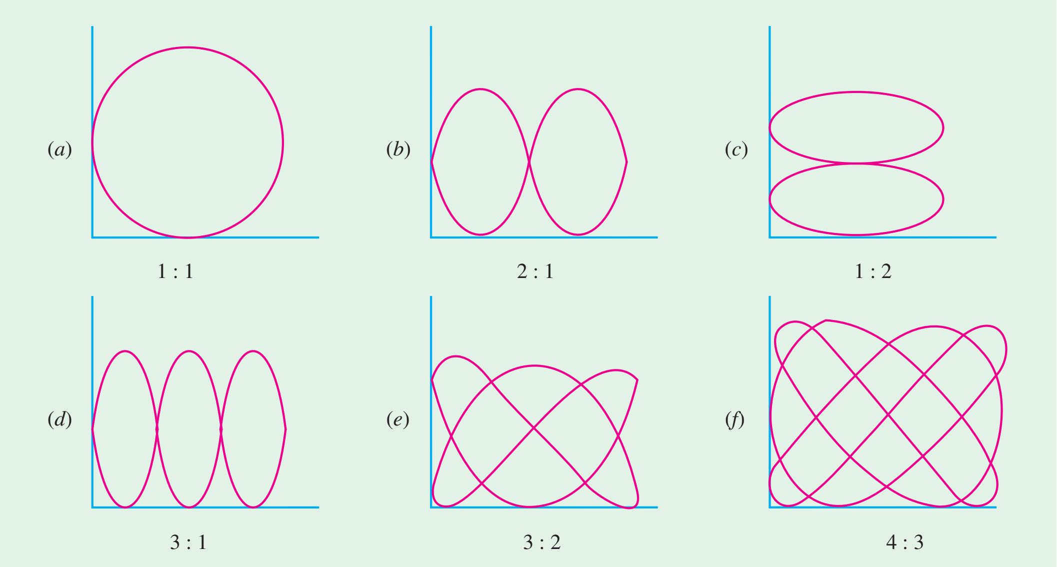


Fig. 73.42

73.36. Applications of a CRO

As stated earlier, no other instrument in electronic industry is as versatile as a *CRO*. In fact, a modern oscilloscope is the most useful single piece of electronic equipment that not only removes guess work from technical troubleshooting but makes it possible to determine the trouble quickly. Some of its uses are as under :

Fig. 73.43

(Courtesy : Fluke Corporation)

(*a*) In Radio Work

1. to trace and measure a signal throughout the *RF*, *IF* and *AF* channels of radio and television receivers.
2. it provides the only effective way of adjusting *FM* receivers, broadband high-frequency *RF* amplifiers and automatic frequency control circuits;
3. to test *AF* circuits for different types of distortions and other spurious oscillations;
4. to give visual display of waveshapes such as sine waves, square waves and their many different combinations;
5. to trace transistor curves
6. to visually show the composite synchronized TV signal
7. to display the response of tuned circuits etc.

(*b*) Scientific and Engineering Applications

1. measurement of ac/dc voltages,
2. finding B/H curves for hysteresis loop,
3. for engine pressure analysis,
4. for study of stress, strain, torque, acceleration etc.,
5. frequency and phase determination by using Lissajous figures,
6. radiation patterns of antenna,
7. amplifier gain,

8. modulation percentage,
9. complex waveform as a short-cut for Fourier analysis,
10. standing waves in transmission lines etc.

73.37. The Q Meter

This instrument is designed to measure some of the electrical properties of coils and capacitors by measuring the *Q*-value of an *R*-*L*-*C* circuit.

1. Construction

As shown in Fig. 73.44, it essentially consists of

(i) a frequency-calibrated continuously-variable *RF* oscillator,
(ii) a calibrated variable capacitor *C*,
(iii) *VTVM* which is calibrated to read *Q* directly.

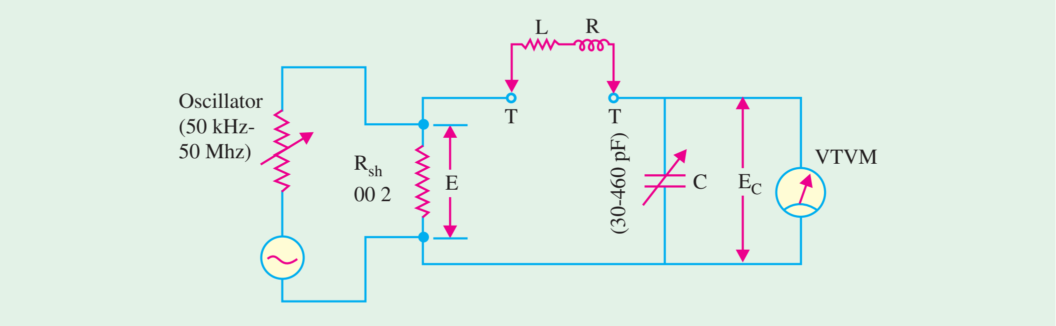


Fig. 73.44

2. Principle of Operation

The basic principle used in *Q*-meter is the resonant rise of the voltage across the capacitor in an *R.L.C* circuit. The condition for series resonance (Art. 14.10) is

$$X_L = X_C \quad \text{and} \quad E = IR$$

The value of circuit *Q* is

$$Q = \frac{X_L}{R} = \frac{X_C}{R} = \frac{E_C}{E}$$

If the applied voltage *E* is constant, then $Q \propto E_C$. Hence, by measuring voltage drop across *C* under resonant conditions, *Q* can be found. Alternatively, *VTVM* can be calibrated directly in terms of *Q* (rather than voltage).

As seen from Fig. 73.44, the oscillator delivers current to a very small (0.02 Ω) shunt resistance R_{sh} thereby developing a voltage *E* across it. It becomes the applied voltage for the *RLC* circuit and corresponds to the source voltage *E* of Fig. 73.45.

It is measured by a thermocouple meter marked 'Multiply *Q* by'. The voltage E_C across variable *C* is measured by the *VTVM*. The value of *Q*-factor is given by $Q = E_C/E$.

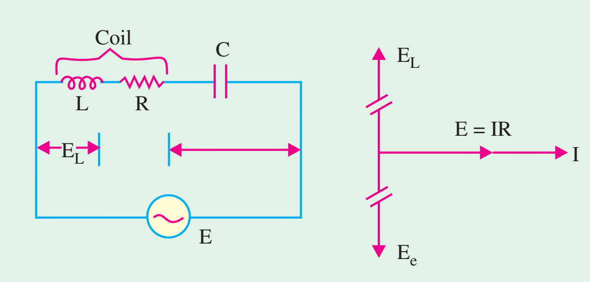


Fig. 73.45

For making measurement, the unknown coil is connected to the test terminals *TT* of the instrument and the circuit is tuned to resonance (Fig. 73.44)

(i) either by setting the oscillator to a given frequency and varying *C*,

(ii) or by keeping value of *C* constant and adjusting the oscillator frequency.

The reading on the *VTVM* must be multiplied by the index setting of the 'Multiply *Q* by' meter in order to obtain the actual value of *Q*.

3. Applications

Some of the specialized uses of this instrument are to measure

1. *Q* of a coil,
2. inductance and capacitance,
3. distributed capacitance of a coil,
4. *Q* and *p.f.* of a dielectric material,
5. mutual inductance of coupled circuits,
6. coefficient of coupling,
7. critical coupling,
8. reactance and effective resistance of an inductor at operating frequency,
9. bandwidth of a tuned circuit etc.

The above list does not exhaust the number of its possible applications. It has been very truly said that if ever an *RF* problem exists, a *Q* meter can always provide the answer.

73.38. Logic Analysers

The oscilloscope is probably the best tool for the development of analog or digital system design. It can be used to examine the waveforms and determine the voltage and rise time of the analog or digital signals. But the oscilloscope has two limitations especially when used in digital system design : **(1)** high speed random pulses can not be observed easily **(2)** oscilloscope cannot monitor a few signal lines simultaneously. For example, in a commonly available oscilloscope, the maximum number of inputs are four.

For these reasons, the logic analysers has been developed. It operates on a slightly different principle than that of an oscilloscope. Because there are many signal lines in a digital system (such as a microprocessor based system), the data is changing rapidly on each line, a logic analyser must take a ***snap shot*** of the activities on the lines and store the logic state of each signal in memory for each cycle of the system clock. The conditions under which the snapshot is taken are determined by triggering circuits, which can respond to various combinations of events.

The logic analyser enables the activity of many digital signal points to be recorded simultaneously and then examined in detail. The information is recorded with respect to a clock signal to determine whether they are HIGH or LOW with respect to a defined threshold voltage. This information is stored in memory and is then available for detailed analysis via the logic analyser's display. The clock signal can be internally or externally generated.

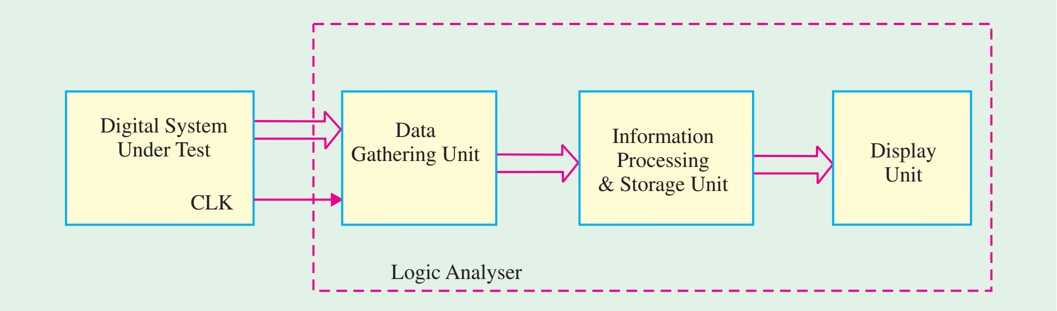


Fig. 73.46

Fig. 73.46 shows a block diagram of a typical logic analyser. It has a data gathering unit, information processing and storage unit and a display unit. The data gathering unit has (1) a pod slots for carrying data from the digital system under test to the logic analyser and (2) a key pad. The key pad is used to enter commands and set up the parameters that the logic anayser will use. The display unit is a cathode ray tube (*CRT*) that displays the command menu for the operator and also displays the output data.

Fig. 73.47. Logic analysers

Applications

- hardware/software debugging
- parametric/mixed signal testing
- hardware simulation and stimulus-response testing
- complex debugging with deep memory.

Fig. 73.47 shows a family of logic analysers, available from Tektronix corporation. Each logic analyser has at least 34 channels, 4-channel digitizing oscilloscope, off-line analysis capability for viewing data and creating setups on a separate PC.

Applications.

Logic analyser is a very powerful tool in the field of microprocessor based system development. Some of its major applications in this area are :

1. Hardware debug and verification.
2. Processor/bus debug and verification.
3. Embedded software integration, debug and verification.

73.39. Spectrum Analysers

The spectrum analyser is an instrument that brings together a superhetrodyne radio receiver with a swept frequency local oscillator and an oscilloscope to present a display of amplitude versus frequency.

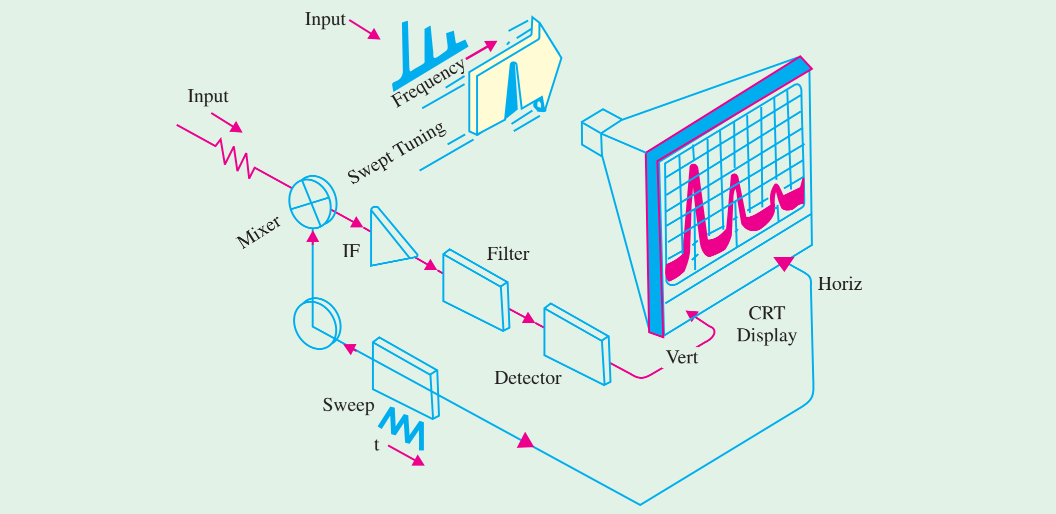


Fig. 73.48

(Courtesy Hewlett Packard)

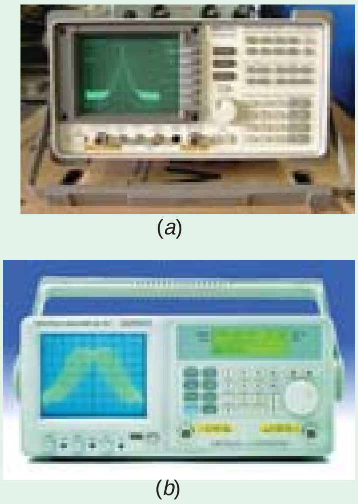
Fig. 73.48 shows a simple block diagram of a spectrum analyser. As seen, the spectrum analyser is actually a superhetrodyne receiver in which local oscillator is a sweep generator. A low frequency saw-tooth wave is applied to both the sweep oscillator and the horizontal deflection plates of the *CRT*, producing a horizontal deflection that is a function of frequency. The lowest frequency is represented by left side of the trace while the highest frequency is represented by the right side of the trace. The sweep is from left to right.

The input signal is mixed with local oscillator to produce the *IF* (*i.e.* intermediate-frequency or difference) signal. The bandwidth of the *IF* amplifier is relatively narrow. so the output signal at the detector will have a strength that is proportional to the frequency that the local oscillator is converting to the *IF* at that instant. The display will then contain "poles" that represent the amplitudes of the various input frequency components.

There are several spectrum analysers available in the market manufactured by the companies like Rhode & Schwarz (Tektronix), Hewlett Packard (now called Agilent Technologies), and so on. Fig. 73.49 shows two commercially available spectrum analyses.

The spectrum analyser shown in Fig. 73.49 (*a*) is Model *FSE* 30 manufactured by Rhode & Schwarz but marked by Tektronix Corporation.

It has a frequency range from 20 Hz to 76.5 GHz, a bandwidth from 1 Hz to 10 MHz. Another spectrum analyser Model No. 3066 shown in Fig. 73.49 (*b*) is a real-time instrument. It has a frequency range from *DC* to 5 MHz, a bandwidth from *DC* to 3 GHz. The real-time spectrum analyser take a very different approach compared to traditional sweeping spectrum analysers. Rather than acquiring one frequency step at a time, the real time spectrum analyser captures a block of frequencies all at once.


(*a*)

(*b*)

Fig. 73.49

(Courtesy : Rhode & Schwarz and Tektronics Corporation)

It is possible to use computers to do spectrum analysis of the signals. There is a variety of software available over the internet from several companies. Some softwares can be downloaded free of cost from the companies web-sites.

Applications

The spectrum analyser is used to :

1. check the spectral purity of signal sources.
2. evaluate local electromagnetic interference (*EMI*) problems.
3. do site surveys prior to installing radio receiving or transmitting equipment.
4. test transmitters.
5. analyse signatures.

73.40. Signal Generators

A signal generator is an instrument that provides a controlled output waveform or signal for use in **testing, aligning** or in **measurements** on other circuits or equipment. The signal generators can be classified into the following categories :

1. Audio generators
2. Function generators
3. Pulse generators
4. *RF* generators
5. Frequency synthesizers
6. Other signal generators.

73.41. Audio Generators

The audio generators covers the frequency range 20 Hz to 20 kHz, although few models produce signals up to 100 kHz. Audio generators always produce ***pure sine*** waves and most also produce square waves. They uses a 600 Ω output impedance and produce output levels from –40 dB mW to + 4 dB mW.

Two methods of frequency selection are typically used in audio signal generators. ***continuous*** and ***step***. On the continuous type of a dial, we turn a knob to the desired frequency. Many such audio generators have a scale that reads 20 to 200 (or alternatively 2 to 20) and a *range* selector switch determines whether the output frequencies will be 20 to 200 Hz, 200 to 2000 Hz or 2000 to 20,000 Hz. In a step-tuned generator, these controls are replaced by a ***rotary*** or ***pushbutton*** switch bank. As many as four decode switches might be used, although three is a more common number. These will be marked 0 through 100, 0 through 10 and 0.1 through 1.0 in decade steps. A multiplier switch determines whether the actual frequency will be X1, X10, X100 or X1000 the frequency indicated on the selector switches.

Audio signal generator

Fig. 73.50 shows a block diagram of an audio signal generator. The audio oscillator section is usually an *RC* phase-shift oscillator (or a Wien Bridge oscillator) circuit. A power amplifier stage provides buffering between the load and the oscillator and it develops the output signal amplitude. The ac voltmeter at the output is strictly optional, but in some models it is used with a ***level control*** to set precisely the input signal to the attenuator. Not all quality audio signal generators use this feature. So the lack of an ac output meter is not, in itself, indication of quality. In some models, an audio digital frequency counter is used ahead of the attenuator to provide digital display of the output frequency.

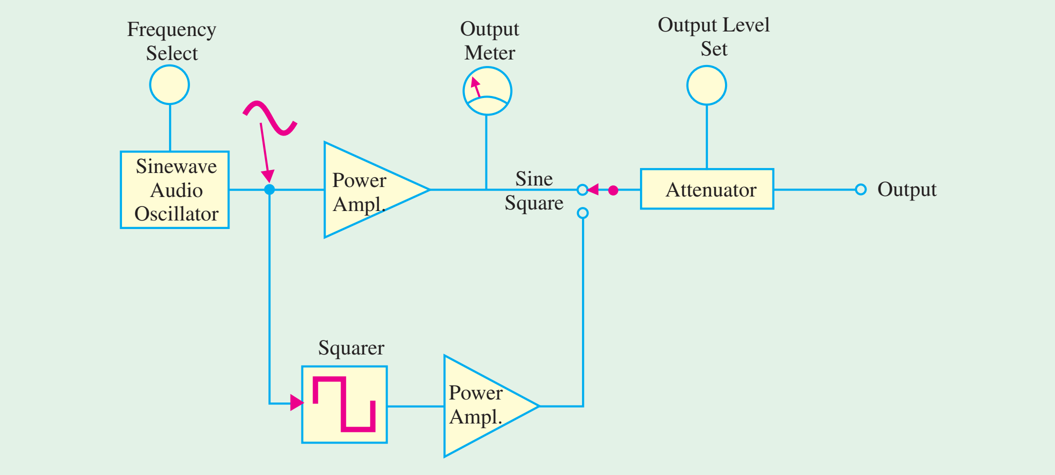


Fig. 73.50

Applications

The audio generators are basically used to test the amplitude and frequency response of audio amplifiers.

73.42. Function Generators

These generators typically, cover at least the same frequency range as audio signal generators (*i.e.* 20 Hz to 20 kHz) but most modern designs have extended frequency ranges. A very common frequency range for function generators is 0.01 Hz to 3 MHz.


Fig. 73.51

The major difference between a function generator and an audio generator is in the number of output waveforms. The audio signal generator produces only sine waves and square waves. While almost all function generators produce these basic waveforms plus triangular waves. Besides this, some function generators also produce sawtooth, pulse and non-symmetrical square waves. Fig. 73.51 shows the controls of a typical function generator.

Fig. 73.52 shows a simple block diagram of a function generator. The major parts of a function generator are schmitt trigger, integrator, sine-wave converter and an attenuator. The schmitt trigger converts a slowly varying input signal to a square wave signal. This square wave signal is available at the output as well as it is also connected to the integrator as an input through a potentiometer (*R*). The potentiometer is used to adjust the frequency of the output signal. The frequency range is adjusted by selecting the appropriate capacitor connected in the integrator circuit.

The sine-wave converter is a six-level (or more) diode-resistor loading circuit.

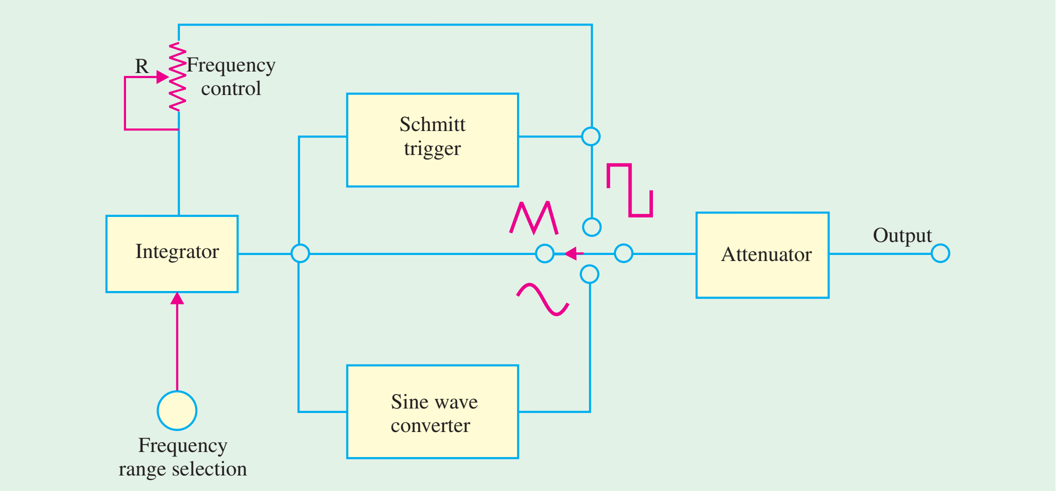


Fig. 73.52

Let us see how a simple diode-resistor circuit shown in Fig. 73.53 (*a*) is used to convert a triangular wave into a square wave.

Note that if diodes D_1 and D_2 and resistors R_3 and R_4 were not present in the circuit, of Fig. 73.53 (*a*), R_1 and R_2 would simply behave as a voltage divider. In this case the output from the circuit would be an attenuated version of the triangular wave :

$$V_0 = V_i \frac{R_2}{R_1 + R_2}$$

With diodes D_1 and R_3 in the circuit, R_1 and R_2 still behave as a simple voltage divider until the voltage drop across R_2, VR_2 exceeds $+ V_1$. At this point D_1 becomes forward biased, and R_3 is effectively in parallel with R_2. Now,

$$V_0 = V_i \frac{R_2 \parallel R_3}{R_1 + R_2 \parallel R_3}$$

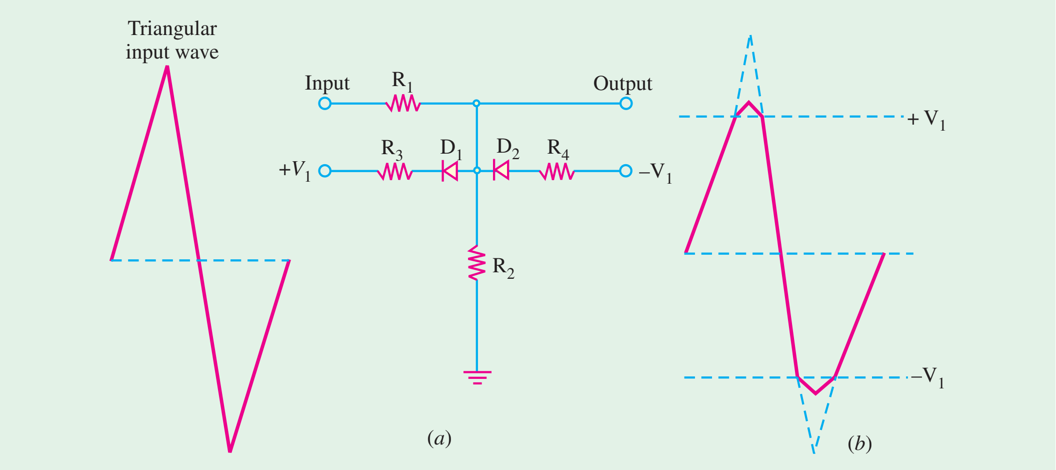


Fig. 73.53

Output voltage levels above + V_1 are attenuated to a greater extent than levels below + V_1. Consequently, the output voltage rises less steeply than without D_1 and R_3 in the circuit (refer to Fig. 73.53 (*b*). When the output falls below + V_1, the diode D_1 is reverse biased. As a result of this, R_3 is no longer in parallel with R_2, and the attenuation is once again $R_2/(R_1 + R_2)$. Similarly during the negative half cycle of the input, the output voltage,

$$V_0 \quad = \quad V_i \frac{R_2}{R_1 + R_2}$$

until V_0 goes below – V_1. Then D_2 becomes forward biased, putting R_4 in parallel with R_2 and making,

$$V_0 \quad = \quad V_i \frac{R_2 \parallel R_4}{R_1 + R_2 \parallel R_4}$$

With $R_3 = R_4$, the negative half-cycle of the output is similar in shape to the positive half-cycle. If we employ six or more diodes, all connected via resistors to different bias voltage levels (refer to Fig. 73.54 (*a*), a good sine-wave approximation can be achieved. With six diodes, the three positive bias voltage levels and three negative bias voltage levels, the slope of the output wave changes three times during each quarter cycle. Assuming correctly selected bias voltages and resistor values, the output wave shape is as shown in Fig. 73.54 (*b*).

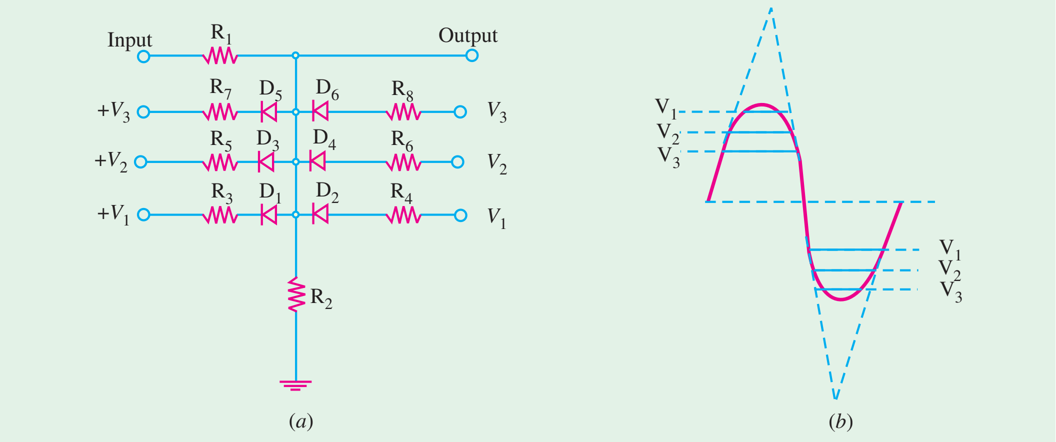


Fig. 73.54

Applications

The function generator is an essential equipment for an electronic laboratory to generate signals to test a variety of analog and digital system during the design phase as well as to trouble shoot such systems.

Fig. 73.55 shows the picture of a Tektronix function generators Model No. CFG 253. This model has a frequency range form 0.03 Hz to 3 MHz. In addition to sine, square and triangular waves it can also produce *TTL* signals. Another function generator from Tektronix (Model No. CFG280 has a wide frequency range form 0.01 Hz to 11 MHz. It has a built in frequency counter with a range from 1 Hz to 100 MHz.

Fig. 73.55
(Courtesy : Tektronix Corporation)

Applications

The function generators can be employed in a variety of applications in the area of product design, training, manufacturing production test, field repair, bench calibration and repair, laboratory and research, and education. Mainly they are used for testing amplifiers, filter and digital circuits.

73.43. Pulse Generators

Fig. 73.56 shows the block diagram of a pulse generator. As seen, an astable multivibrator generates square waves. This is used to trigger monostable multivibrator (*i.e.* one-shot). The pulse repetition rate is set by the square-wave frequency. The one-shot triggers on the leading edge of the square-wave and produces one output pulse for each input cycle. The duration of each output pulse is set by the on-time of the one-shot. It may be very short or may approach the period of the square wave. The attenuator facilities output amplitude control and dc level shifting.

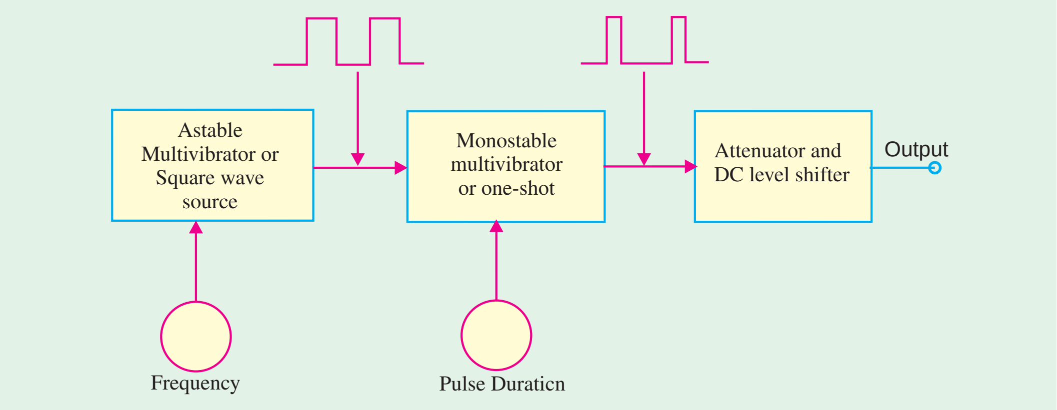


Fig. 73.56

A typical pulse generator will allow the user to select the repetition rate, duration, amplitude and number of output pulses to be output in a given burst. The most common frequency range is from 1 Hz to 50 MHz. The pulse width is adjustable from 10 ns to over 10 ms and the output is variable from 3 mV to 30 V.

Fig. 73.57 shows a pulse generator from Fluke Corporation Model No. PM5786. This instrument has a frequency range from 1 Hz to 125 MHz. The output pulse width can

Fig. 73.57. (Courtesy Fluke Corporation)

be varied from 8 ns to 100 ms. The instrument can also be used to generate pulse bursts. The output voltage level can be adjusted up to 10 V.

Applications

The pulse generators are used extensively to test :

1. Memory circuits
2. Shift registers
3. Counters
4. Other digital components, subsystems and systems.

73.44. RF Generators

A radio frequency (*RF*) signal generator has a sinusoidal output with a frequency somewhere in the range of 100 kHz to 40 GHz region. Fig. 73.58 shows the block diagram of an *RF* generator. As soon, the instrument consists of an *RF* oscillator, an amplifier, a calibrated attenuator and an output level meter.

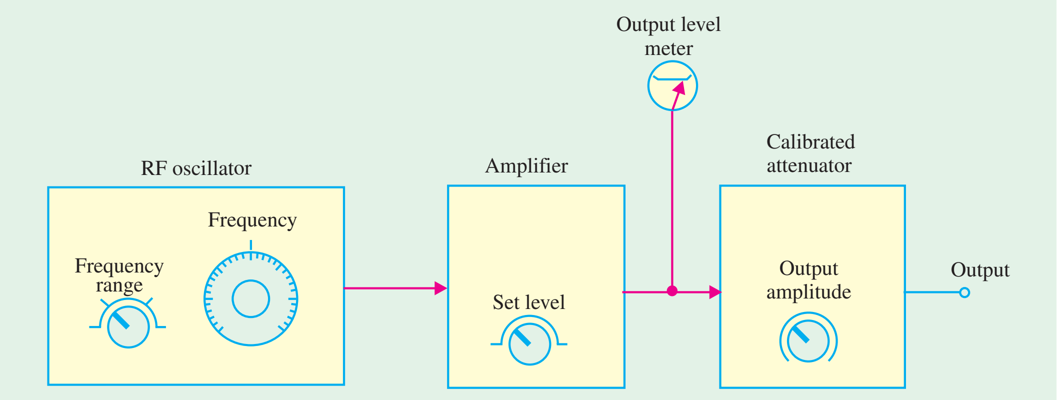


Fig. 73.58

The *RF* oscillator has a continuous frequency control and a frequency range switch, to set the output to any desired frequency. The amplifier includes an output amplitude control. This allows the voltage applied to the attenuator to be set to a calibration point on the output level meter. The output level must always be ***reset*** to this calibration point everytime the frequency is changed. This is necessary to ensure that the output voltage levels are correct, as indicated on the calibrated attenuator.

The oscillator circuit used in an *RF* generator is usually either a Hartley Oscillator or Colpitts oscillator. Most RF signal generators include facilities for amplitude modulation and frequency modulation of the output. Switches are provided on the front panel to allow the user to select no modulation as well as internal or external *A M* or *FM* modulation. It may be noted that each section of the RF generator is ***shielded*** by enclosing it in a metal box. The whole system is then completely shielded. The purpose of shielding is **(1)** to prevent RF interference between the components and **(2)** to prevent the emission of RF energy from any point except the output terminals. As a matter of fact, even the power line is decoupled by means of RF chokes and capacitors to prevent RF emission from it.

Fig. 73.59 (*a*) shows an analog RF generator Model No. SML01 manufactured by Tektronics Corporation. This

Fig. 73.59

(Courtesy Fluke Corporation)

instrument is a general purpose signal generator and is available at low cost. It has a wide frequency range from 9 kHz to 3.3 GHz. Another RF generator Model No. SMP04 shown in Fig. 73.59 (*b*) from Tektronix Corporation is a high precision signal source. It has a wide frequency range from 0.01 GHz to 40 GHz. This instrument can produce, AM–, FM–, phase– and pulse modulated signals as well.

Applications

The RF signal generators are widely used in the area of radar and communication, research and development laboratories, education and training, electromagnetic interference (*EMI*) testing and material testing. Their main applications are :

1. To perform variety of tests on radio transmitters and receivers.

2. To test the amplitude and frequency response of RF amplifiers during the design phase.

73.45. Frequency Synthesizer

It is another type of RF generator that uses ***phase-locked loop*** (*PLL*) to generate output frequencies over a wide range. The most common range is from 1 MHz to 160 MHz. Fig. 73.60 shows a simple block diagram of a frequency synthesizer. As seen, the major components of the frequency synthesizer are : voltage controlled oscillator (*VCO*), divide-by-N counter, phase detector, crystal oscillator, low-pass filter and a square-wave circuit.

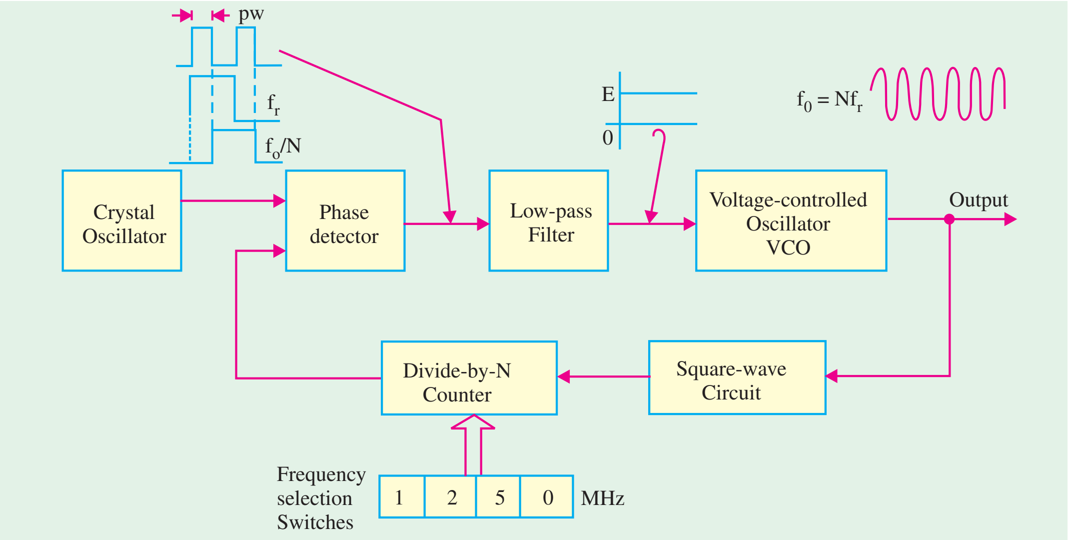


Fig. 73.60

The output of the crystal oscillator (a reference frequency, *fr*), is fed into one input of a phase detector. The other input of a phase detector has another square-wave applied to it as shown in the figure. The frequencies of these two square waves is identical but there is a phase difference (ϕ) between them. The output of the phase detector is a pulse waveform with pulse width controlled by the phase difference. The output of the phase detector is applied to the low-pass filter which converts it into a dc voltage, *E*. The dc voltage, *E* is used as the control voltage for the *VCO* and it determines the output frequency of *VCO*. The output of *VCO* is fed to a circuit that converts it into a square wave for triggering a digital divide-by-N counter. The divide-by-N counter divides the *VCO* frequency by a number set by a bank of switches. These switches may be push buttons with digital readouts or they may be thumb-wheel type which indicate their position numerically. The switches are connected in such a way that the displayed number is the factor *N* by which the output frequency is divided before being applied to the phase detector. The switches allow the user to obtain frequency which is any integer multiple of the crystal oscillator frequency.

Applications

The frequency synthesizer is used in almost same areas as the RF signal generators.

73.46. Other Signal Generators

There are some signal generators that do not fit well in various pres-etabilished categories. Some of these signal generators are as discussed below :

1. RF Markers : These devices are usually crystal controlled and have a fixed output frequency for use as a reference. These are used to calibrate TV signals.

2. Digitally Programmable Test Oscillators : These instruments can have extremely wide frequency range although some versions have much narrow range also. The set frequency can be programmed through the front panel keypad or via a computer interface input such as IEEE-488 general purpose interface bus (commonly known as GPIB).

3. Arbitrary Waveform Generators : These instruments allow the user to design and generate virtually any desired waveform. The arbitrary waveform generator is quite useful to perform a variety of tests on communication equipment. For example, a modulated signal that varies over the entire bandwidth and amplitude range of the equipment shown in Fig. 73.61 could be created for testing purpose. Noise could also be superimposed upon the signal and gaps might be introduced between waveform bursts, to investigate the response of the system. Once such a waveform has been designed, it could be stored in the instrument memory and can be recalled repeatedly for production testing.

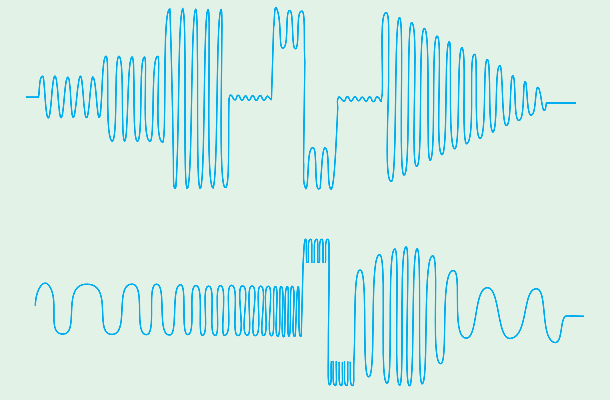


Fig. 73.61

Fig. 73.62 shows an arbitrary waveform generator from Agilent Technologies Model No. 33250A. This instrument can generate real world signals up to 80 MHz. It has a capability to display the waveforms in colour. It can be used as a function generator/pulse generator as well. The instrument has a GPIB/LAN interfaces.

Applications

The arbitary waveform generators are used extensively in the following areas :

1. Communications design and test for producing (*a*) arbitrary IF based signals and (*b*) standard waveforms for communication.
2. Mixed signal design and test.
3. Disk drive read/write design and test.
4. Real word simulations.
5. High-speed low filter data and clock pulse generation.

Fig. 73.62 (Courtesy : Agilent Technologies)

73.47. IEEE-488 General Purpose Interface Bus (GPIB) Instruments

These days automatic test equipment (*ATE*) is one of the leading methods for testing electronic equipment in factory production and troubleshooting situations. The basic method is to use a programmable digital computer to control a bank of test instruments. The bank of instruments can be configured for a special purpose or for general use. For example, we could select a particular line-up of equipment needed to test a broadcast audio console and provide a computer program to do a variety of measurements such as gain, frequency response, total harmonic distortion etc. The other possibility could be to do a generalized test set. This method is adopted by number of industries who have many electronic devices or systems to test. There is a main bank of electronic test equipment adapters to make the devices (or systems) under test interconnect with the system and a computer program to do a variety of measurements such as gain, frequency response, total harmonic distortion etc. The other possibility could be to do a generalized test set. This method is adopted by number of industries who have many electronic devices or systems to test. There is a main bank of electronic test equipment adapters to make the devices (or systems) under test interconnect with the system and a computer program for each type of equipment. Such an approach reduces the test equipment cost drastically.

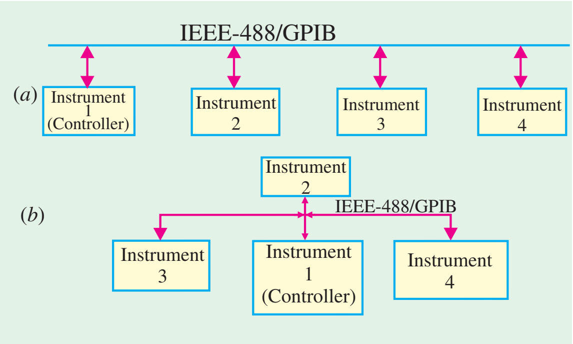


Fig. 73.63

The Institution of Electrical and Electronic Engineers (*IEEE*) has laid out a specification titled *IEEE* standard Digital Interface for programmable instrumentation or *IEEE*-488. This specification provides details for a standard interface between a computer and instruments. The *IEEE*-488 bus or General purpose interface bus (*GPIB*) is a tool that is based on the *IEEE* specifications. The Hewlett-Packard interface bus (*HPIB*) is a proprietary version of the *IEEE*-488 bus.

The digital signals on the *IEEE*-488 bus are generally similar to *TTL* (transistor-transistor logic), *i.e.* a logic LOW is less than 0.8 V and a logic *HIGH* is greater than 2.0 V. The digital signals can be connected to the instruments through a multiconductor cable up to 20 metres in length provided that an instrument load is placed every 2 metres. Most *IEEE*-488/*GPIB* systems operate unrestricted to 250 kilobytes per second or faster with some restrictions.

There are two basic configurations for the *IEEE*-488/*GPIB* system : **(1)** linear and **(2)** star. In the linear configuration shown in Fig. 73.63 (*a*), a tap-off to the next instrument is taken from the previous one in series. On the other hand, in star configuration shown in Fig. 73.63 (*b*), the instruments are connected from a central point.

Fig. 73.64 shows the basic structure of *IEEE*-488/*GPIB* system. The figure indicates four different devices (*i.e.* computer, frequency counter, signal generator and digital multimeter) connected to the bus. The *IEEE*-488/*GPIB* system itself consists of three major buses : **(1)** general interface management (*GIM*) bus. **(2)** data *I*/*O* (*DIO*) bus and **(3)** data byte transfer (*DBT*) bus.

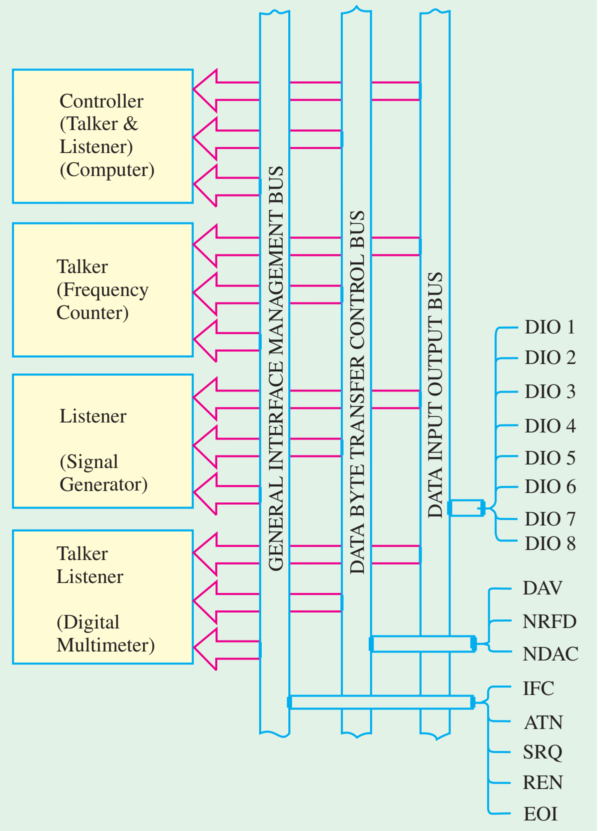


Fig. 73.64

1. General Interface Management (*GIM*) bus : This bus coordinates the whole system and ensures an ordely flow of data over the data input/output (*DIO*) bus. This bus has a number of signals explained below.

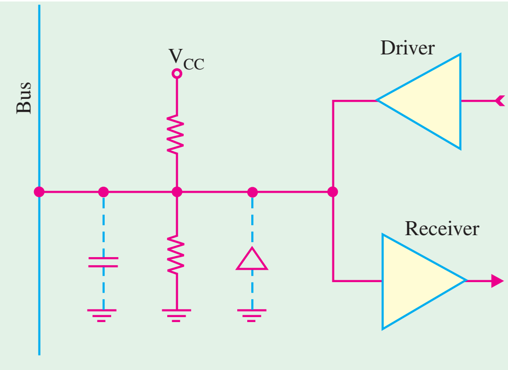


Fig. 73.65

***IFC* (Interface Clear Signal) :** This signal is used by the controller to place all devices in a predefined quiescent or standby condition.

***ATN* (Attention Signal) :** This signal is used by the computer/controller to let the system know how data on the *DIO* bus lines are to be interpreted and which device is to respond to the data.

***SRQ* (Service Request Signal) :** This signal is used by a device on the system to ask the controller for attention. It is basically an interupt request signal.

***REN* (Remote Enable Signal) :** This signal is used by the controller to select between two alternate sources of device programming data.

***EOI* (End or Identify Signal) :** This signal is used by talkers for the following two purposes : (1) it will follow the end of a multiple byte sequence of data in order to indicate that the data are now finished. (2) It is also used in conjunction with the *ATN* signal for polling the system.

2. Data *I/O* (*DIO*) bus : This bus is a bidirectional 8-bit data bus that carries data, interface messages and device-dependent messages between the controller, talkers and listeners. This bus sends asynchronously in byte-serial format.

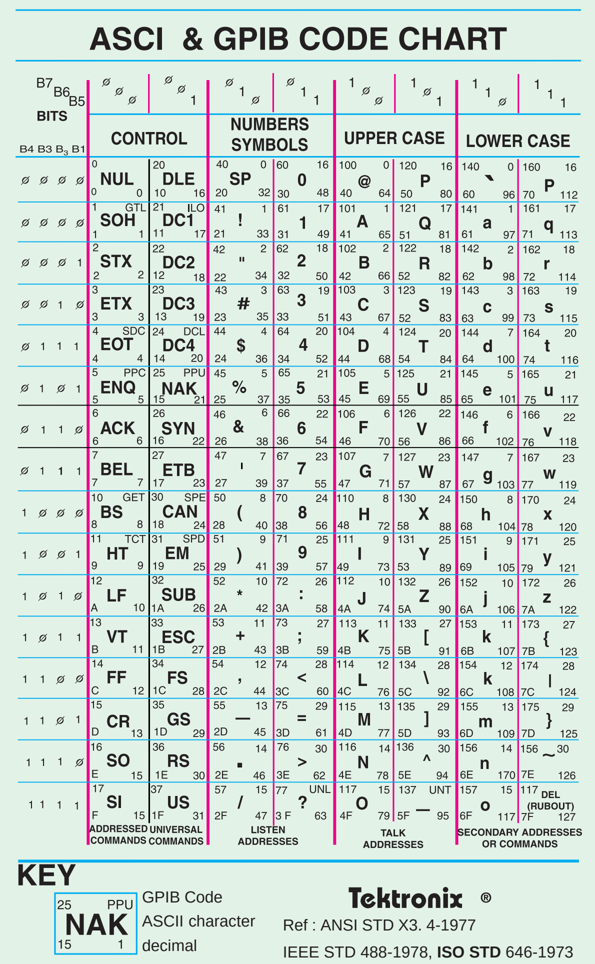
3. Data Byte Transfer (*DBT*) bus: This bus controls the sending of data along the *DIO* bus. There are three signals on this bus as explained below :

***DAV* (Data Valid Signal) :** This signal indicates the availability and validity of data on the line. If the measurement is not finished, for example, the *DAV* signal will be false.

***NRFD* (Not Ready For Data Signal) :** This signal lets the controller know whether or not the specific device addressed is in a condition to receive data.

***NDAC* (Not Data Accepted Signal) :** This signal is used to indicate to the controller whether or not the device accepted the data sent to it over the *DIO* bus.

Each signal line in the bus has a circuit similar to the one shown in Fig. 73.65. As seen from this circuit, each signal line has a pull-up and pull-down resistors, receiver, and driver-circuits. Besides this each signal line has also a shunt protection diode and a stray capacitance.



ASCI & GPIB CODE CHART

B7 B6 B5 BITS	0 0 0	0 0 1	0 1 0	0 1 1	1 0 0	1 0 1	1 1 0	1 1 1
B4 B3 B3 B1	CONTROL		NUMBERS SYMBOLS		UPPER CASE		LOWER CASE	
0 0 0 0	0 NUL 0 0	20 DLE 10 16	40 0 SP 20 32	60 16 0 30 48	100 0 @ 40 64	120 16 P 50 80	140 0 ` 60 96	160 16 P 70 112
0 0 0 0	1 GTL SOH 1 1	21 ILO DC1 11 17	41 1 ! 21 33	61 17 1 31 49	101 1 A 41 65	121 17 Q 51 81	141 1 a 61 97	161 17 q 71 113
0 0 0 1	2 STX 2 2	22 DC2 12 18	42 2 " 22 34	62 18 2 32 50	102 2 B 42 66	122 18 R 52 82	142 2 b 62 98	162 18 r 72 114
0 0 1 0	3 ETX 3 3	23 DC3 13 19	43 3 # 23 35	63 19 3 33 51	103 3 C 43 67	123 19 S 52 83	143 3 c 63 99	163 19 s 73 115
0 1 1 1	4 SDC EOT 4 4	24 DCL DC4 14 20	44 4 $ 24 36	64 20 4 34 52	104 4 D 44 68	124 20 T 54 84	144 7 d 64 100	164 20 t 74 116
0 1 0 1	5 PPC ENQ 5 5	25 PPU NAK 15 21	45 5 % 25 37	65 21 5 35 53	105 5 E 45 69	125 21 U 55 85	145 5 e 65 101	165 21 u 75 117
0 1 1 0	6 ACK 6 6	26 SYN 16 22	46 6 & 26 38	66 22 6 36 54	106 6 F 46 70	126 22 V 56 86	146 6 f 66 102	166 22 v 76 118
0 1 1 1	7 BEL 7 7	27 ETB 17 23	47 7 ' 27 39	67 23 7 37 55	107 7 G 47 71	127 23 W 57 87	147 7 g 67 103	167 23 w 77 119
1 0 0 0	10 GET BS 8 8	30 SPE CAN 18 24	50 8 (28 40	70 24 8 38 56	110 8 H 48 72	130 24 X 58 88	150 8 h 68 104	170 24 x 78 120
1 0 0 1	11 TCT HT 9 9	31 SPD EM 19 25	51 9) 29 41	71 25 9 39 57	111 9 I 49 73	131 25 Y 53 89	151 9 i 69 105	171 25 y 79 121
1 0 1 0	12 LF A 10	32 SUB 1A 26	52 10 * 2A 42	72 26 : 3A 58	112 10 J 4A 74	132 26 Z 5A 90	152 10 j 6A 106	172 26 z 7A 122
1 0 1 1	13 VT B 11	33 ESC 1B 27	53 11 + 2B 43	73 27 ; 3B 59	113 11 K 4B 75	133 27 [5B 91	153 11 k 6B 107	173 27 { 7B 123
1 1 0 0	14 FF C 12	34 FS 1C 28	54 12 , 2C 44	74 28 < 3C 60	114 12 L 4C 76	134 28 \ 5C 92	154 12 k 6C 108	174 28 | 7C 124
1 1 0 1	15 CR D 13	35 GS 1D 29	55 13 — 2D 45	75 29 = 3D 61	115 13 M 4D 77	135 29] 5D 93	155 13 m 6D 109	175 29 } 7D 125
1 1 1 0	16 SO E 15	36 RS 1E 30	56 14 . 2E 46	76 30 > 3E 62	116 14 N 4E 78	136 30 ^ 5E 94	156 14 n 6E 170	156 30 ~ 7E 126
1 1 1 1	17 SI F 15	37 US 1F 31	57 15 / 2F 47	77 UNL ? 3 F 63	117 15 O 4F 79	137 UNT — 5F 95	157 15 o 6F 117	117 DEL (RUBOUT) 7F 127
	ADDRESSED COMMANDS	UNIVERSAL COMMANDS	LISTEN ADDRESSES		TALK ADDRESSES		SECONDARY ADDRESSES OR COMMANDS	

KEY

25 PPU	GPIB Code
NAK	ASCII character
15 1	decimal

Tektronix ®

Ref : ANSI STD X3. 4-1977

IEEE STD 488-1978, **ISO STD** 646-1973

Fig. 73.66

Fig. 73.66 shows the 7-bit binary signals used in the *IEEE*-488/*GPIB* system for *ASCII* and

GPIB message codes.

The signals defined for the three buses in the *IEEE*-488/*GPIB* systems are implemented as conductors in a system interface cable. Each *IEEE*-488/*GPIB* compatible instrument will have a female 36-pin Amphenol-style connector on the rear panel. The pin-out definitions are given in Table 73.1.

The devices connected to *IEEE*-488/*GPIB* system (*i.e.* computer, frequency counter, signal generator and digital multimeter) are categorised as controller, listener and/or talker.

Table 73.1

Pin No	*Signal Lin*	*Pin No*	*Signal Line*
1	*DIO* 1	13	*DIO* 5
2	*DIO* 2	14	*DIO* 6
3	*DIO* 3	15	*DIO* 7
4	*DIO* 4	16	*DIO* 8
5	*EOI*	17	*REN*
6	*DAV*	18	Ground (6)
7	*NRFD*	19	Ground (7)
8	*NDAC*	20	Ground (8)
9	*IFC*	21	(Ground 9)
10	*SRQ*	22	(Ground 10)
11	*ATN*	23	(Ground 11)
12	Shield	24	Digital Ground

1. Controller : Its function is to communicate device addresses and other inface buses to instruments in the system.

2. Listener : Its function is to receive commands from other instruments (usually the controller) when the correct address is placed on the bus. The listener acts on the message received but does not send back any data to the controller. The signal generator shown in Fig. 73.22 is an example of a listener.

3. Talker : Its function is to respond to the message sent to it by the controller. The frequency counter shown in Fig. 73.62 is an example of a talker.

Fig. 73.67

There is also a combination device that accepts commands from the controller to set up ranges, tasks etc. and then returns data back over the *DIO* bus to the controller. The digital multimeter shown in Fig. 73.62 is an example of this category.

The *IEEE*-488 was introduced to the electronic industry in 1977. Since then it has evolved to *IEEE*-488.1 in 1987 and further to *IEEE*-488.2 in 1990. At present the system allows the control upto 14 instruments and it has data transfer rate greater than 1 M bytes/s.

73.48. VXI bus

The *VXI* bus is another fast growing platform for instrumentation systems. It was introduced in 1987 and since then it has experienced tremendous growth and acceptance around the world. *VXI* uses a mainframe chassis with a maximum of 13 slots to hold ***modular instruments* on *plug-in boards.*** Fig. 73.67 shows an example of system using *VXI* instruments. The *VXI* backplane includes the 32-bit *VME* data bus, high performance instrumentation buses for precision timing and synchronization between instrument components, standarized initialization and resource management to ease configuration.

OBJECTIVE TESTS – 73

1. Digital instruments are those which
(*a*) have numerical readout
(*b*) use *LED* or *LCD* displays
(*c*) have a circuitry of digital design
(*d*) use deflectioin type meter movement.

2. The main difference between the electronic and electrical instruments is that an electronic instrument contains
(*a*) an electronic device (*b*) a transducer
(*c*) a digital readout (*d*) electrons.

3. The essential elements of an electronic instrument are
(*a*) transducer (*b*) signal conditioner
(*c*) indicating device (*d*) all of the above.

4. The current sensitivity of a meter is expressed in
(*a*) ampere (*b*) ohm/ampere
(*c*) ohm/volt (*d*) ampere/division.

5. The basic meter movement can be converted into an ohmmeter by connecting a .....with it.
(*a*) high resistance in series
(*b*) low resistance in parallel
(*c*) battery in series
(*d*) battery and a variable resistance in series

6. The D' Arsonval meter movement can be converted into an audio-frequency ac ammeter by adding a ...... to it.
(*a*) thermocouple (*b*) rectifier
(*c*) chopper (*d*) transducer.

7. In a linear meter, half-scale deflection occurs when there is ... per cent of the rated current through its coil
(*a*) 100 (*b*) 25
(*c*) 50 (*d*) 75

8. A 0-1 mA meter has a sensitivity of
(*a*) 1 k Ω/V (*b*) 1 mA
(*c*) 1 k Ω (*d*) 1000 A.

9. A moving coil instrument has a resistance of 10 Ω and takes 40 mA to produce full-scale deflection. The shunt resistance required to convert this instrument for use as an ammeter of range 0 to 2 A is
(*a*) 0.1021 Ω (*b*) 0.2041 Ω
(*c*) 0.2561 Ω (*d*) 0.4210 Ω

10. A moving coil ammeter has a fixed shunt of 0.02 ohm resistance. If the coil resistance of the meter is 1000 Ω, a potential difference of 500 mV is required across it for full-scale deflection. Under this condition, the current in the shunt would be
(*a*) 2.5 A (*b*) 25 A
(*c*) 0.25 A (*d*) 0.025 A

11. It is desired to convert a 0-1000 μA meter movement, with an internal resistance of 100 Ω into a 0-100 mA meter. The required value of shunt resistance is about
(*a*) 1 Ω (*b*) 10 Ω
(*c*) 99 Ω (*d*) 100 Ω

12. Loading effect is principally caused by... instruments
(*a*) high resistance (*b*) low-sensitivity
(*c*) high-sensitivity (*d*) high-range

13. A multimeter is used to measure
(*a*) resistance (*b*) current
(*c*) voltage (*d*) all of the above

14. A sinusoidal voltage of rms value 10 V is applied to a D' Arsonval movement connected in series with a half-wave rectifier. It will show a reading of... volt
(*a*) 9 (*b*) 4.5
(*c*) 10 (*d*) 7.7

15. A *VTVM* produces negligible loading effect on a circuit under test primarily because
(*a*) it virtually drawn no current from the circuit
(*b*) of its very high internal resistance
(*c*) it uses high vacuum tubes
(*d*) it is a null deflection instrument.

16. In a 3½ digit voltmeter, the largest number that can be read is
(*a*) 0999 (*b*) 1999
(*c*) 4999 (*d*) 9999

17. A 3½ digit voltmeter having a resolution of 100 mV can be used to measure maximum voltage of
(*a*) 100 V (*b*) 200 V
(*c*) 1000 V (*d*) 5000 V

18. The signal to be observed on the screen of an oscilloscope is applied
(*a*) across its *X*-plates (*b*) across its *Y*-plates
(*c*) to the horizontal amplifier
(*d*) to the trigger circuit.

19. When a 30 V dc is applied to the vertical deflection plates of a cathode ray tube, the bright spot moves 1 cm away from the centre. If 30 V (rms) ac is applied, then the movement of the spot will be nearly

(*a*) 1 cm (*b*) 1.5 cm
(*c*) 2 cm (*d*) 3 cm

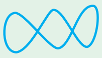
20. Production of a steady stationary display of a signal waveform on the scope screen is due to

(*a*) persistence of vision
(*b*) flourescent material of the screen
(*c*) proper sync. between the signal and the sweep generator
(*d*) electrostatic focussing of the electron beam.

21. Two sinusoidal signals of frequency *f* and 3*f* are applied at *x* and *y* inputs respectively to an oscilloscope. Which one of the following patterns can be observed on the screen ?

(*a*)


(*b*)


(*c*)


(*d*)


22. The *X*- and *Y*-inputs of a *CRO* are respectively *V* sin *wt* and –*V* sin *wt*. The resulting Lissajous pattern will be

(*a*) a straight line (*b*) a circle
(*c*) an elipse (*d*) a figure of eight

23. The deflection sensitivity of a *CRT* depends inversely on the

(*a*) length of the vertical deflecting plates
(*b*) distance between screen and deflecting plates
(*c*) deflecting voltage
(*d*) separation between *Y*-plates.

24. Two complete signal cycles would be displayed on the screen of a scope when time-period of the sweep generator is ...... the signal time period.

(*a*) half (*b*) twice
(*c*) equal (*d*) thrice

25. A non-triggered oscilloscope is one which

(*a*) has no sweep generator
(*b*) cannot produce a stable stationary screen display
(*c*) has a continuously running time-base generator
(*d*) can display a portion of the input signal wave form.

26. A dual-trace *CRO* has

(*a*) one electron gun (*b*) two electron guns
(*c*) one electron gun and one two-pole switch
(*d*) two electron guns and one two-pole switch

27. The operation a *Q*-meter is based on

(*a*) self-induction (*b*) series resonance
(*c*) mutual induction (*d*) eddy currents.

28. The resolution of a logic analyser is

(*a*) maximum number of input channels
(*b*) the minimum duration of the glitch it can capture
(*c*) its internal clock period
(*d*) the minimum amplitude of the input signal it can display

29. A spectrum analyser can be described as

(*a*) voltage selective frequency meter
(*b*) current selective frequency meter
(*c*) frequency selective voltmeter
(*d*) None of these

ANSWERS

1. (*c*)	**2.** (*a*)	**3.** (*d*)	**4.** (*c*)	**5.** (*d*)	**6.** (*b*)	**7.** (*c*)	**8.** (*a*)	**9.** (*b*)	**10.** (*b*)
11. (*a*)	**12.** (*b*)	**13.** (*d*)	**14.** (*b*)	**15.** (*b*)	**16.** (*a*)	**17.** (*c*)	**18.** (*a*)	**19.** (*a*)	**20.** (*c*)
21. (*b*)	**22.** (*a*)	**23.** (*d*)	**24.** (*b*)	**25.** (*c*)	**26.** (*c*)	**27.** (*b*)	**28.** (*a*)	**29.** (*d*)	

GO To FIRST