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Cathode Ray Oscilloscope

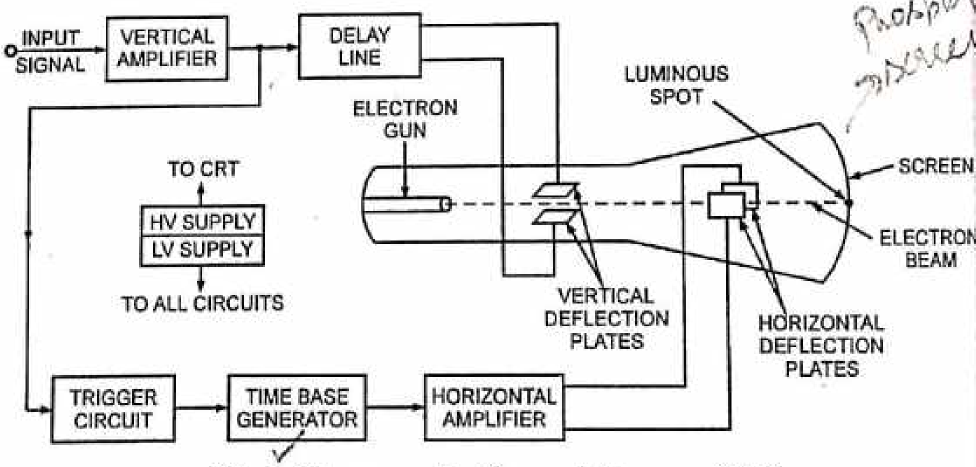
Introduction—Block Diagram—Cathode Ray Tube—Basic Controls—Measurement of Electrical Quantities With CRO—Measurement of Phase Difference—Measurement of Frequency of a Voltage Signal—Measurement of Voltage and Current—Solved Examples—Exercises and Problems.

36.1. INTRODUCTION

The cathode ray oscilloscope is an extremely useful and versatile laboratory instrument used for studying wave shapes of alternating currents and voltages as well as for measurement of voltage, current, power and frequency, in fact, almost any quantity that involves amplitude and waveform. It allows the user to see the amplitude of electrical signals as a function of time on the screen. It is widely used for trouble shooting radio and TV receivers as well as laboratory work involving research and design. It can also be employed for studying the wave shape of a signal with respect to amplitude distortion and deviation from the normal. In true sense the cathode ray oscilloscope has been one of the most important tools in the design and development of modern electronic circuits.

36.2. BLOCK DIAGRAM

The instrument employs a cathode ray tube (usually abbreviated as CRT), which is the heart of the oscilloscope. It generates the electron beam, accelerates the beam to a high velocity, deflects the beam to create the image, and contains a phosphor screen where the electron beam eventually becomes visible. For accomplishing these tasks various electrical signals and voltages are required, which are provided by the power supply circuit of the oscilloscope. Low voltage supply is required for the heater of the electron gun for generation of electron beam and high voltage, of the order of few thousand volts, is required for cathode ray tube to accelerate the beam. Normal voltage supply, say a few hundred volts, is required for other control circuits of the oscilloscope.



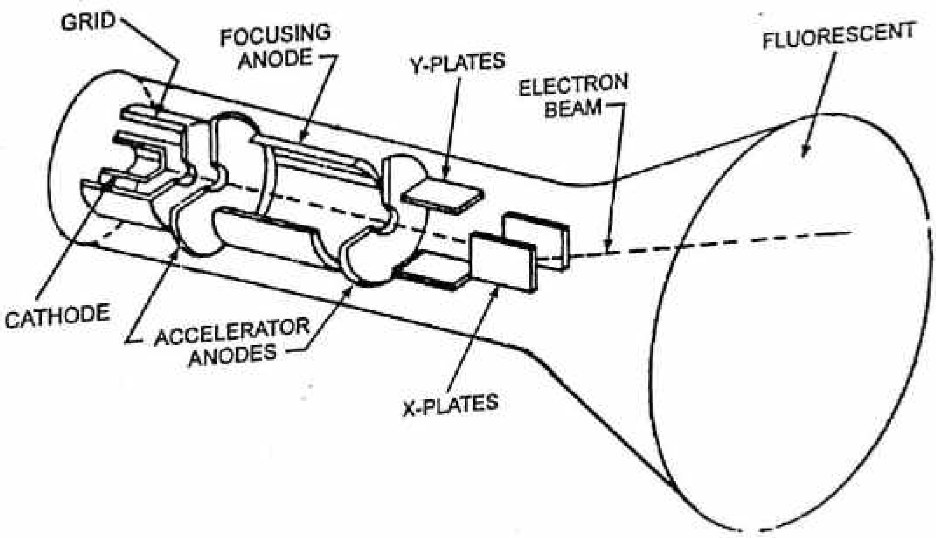
Block Diagram of a General Purpose CRO
Fig. 36.1

Horizontal and vertical deflection plates are fitted between electron gun and screen to deflect the beam according to input signal. Electron beam strikes the screen and creates a visible spot. This spot is deflected on the screen in horizontal direction (X-axis) with constant time dependent rate. This is accomplished by a time base circuit provided in the oscilloscope. The signal to be viewed is supplied to the vertical deflection plates through the vertical amplifier, which raises the potential of the input signal to a level that will provide usable deflection of the electron beam. Now electron beam deflects in two directions, horizontal on X-axis and vertical on Y-axis. A triggering circuit is provided for synchronizing two types of deflections so that horizontal deflection starts at the same point of the input vertical signal each time it sweeps. A basic block diagram of a general purpose oscilloscope is shown in fig. 36.1. Cathode ray tube and its various components will be discussed in the following Arts.

36.3. CATHODE RAY TUBE

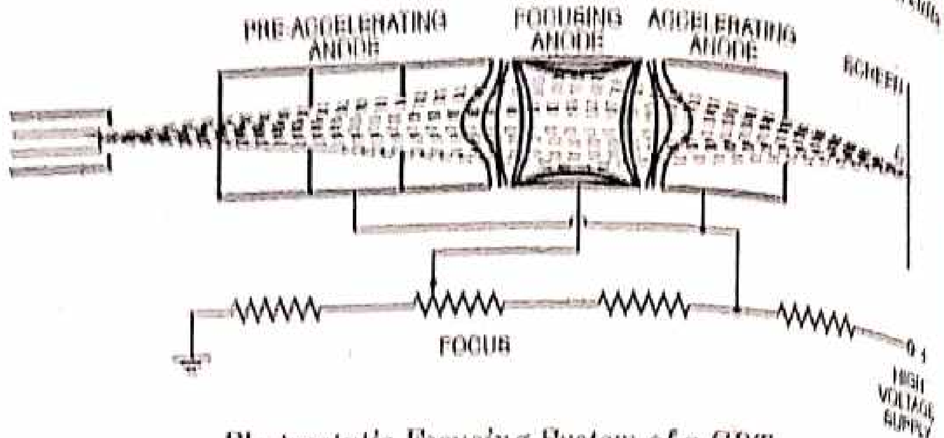
Cathode ray tube essentially consists of an electron gun for producing a stream of electrons, focusing and accelerating anodes for producing a narrow and sharply focused electron beam, horizontal and vertical deflection plates for controlling the beam path and an evacuated glass envelope with phosphorescent screen giving bright spot when struck by a high velocity electron beam.

A cutaway view of an early CRT is shown in fig. 36.2.



Cathode Ray Tube
Fig. 36.2

1. Electron Gun Assembly. The electron gun assembly consists of an indirectly heated cathode, a control grid surrounding the cathode, a focusing anode and an accelerating anode. The sole function of the electron gun assembly is to provide a focused electron beam which is accelerated towards the phosphor screen. The cathode is a nickel cylinder coated with an oxide coating and emits plenty of electrons, when heated. The emitting surface of the cathode should be as small as possible, theoretically a point. Rate of emission of electrons or say the intensity of electron beam depends on the cathode current, which can be controlled by the control grid in a manner similar to a conventional vacuum tube. The *control grid* is a metal cylinder covered at one end but with a small hole in the cover. The grid is kept at negative potential (variable) with respect to cathode and its function is to vary the electron emission and so the brilliancy of the spot on the phosphor screen. The hole in the grid is provided to allow passage for electrons through it and concentrate the beam of electrons along the axis of tube. Electron beam comes out from the control grid through a small hole in it and enters a pre-accelerating anode, which is a hollow cylinder in shape and is at a potential of few hundred volts more positive than the cathode so as to accelerate the electron beam in the electric field. This accelerated beam would be scattered now because of variations in energy and would produce a broad ill-defined spot on the screen. This electron beam is focused on the screen by an electrostatic lens consisting of two more cylindrical anodes called the *focusing anode* and *accelerating anode* apart from the pre-accelerating anode. The focusing and accelerating anodes may be open or close at both ends and if covered, holes must be provided in the anode cover for the passage of electrons. The function of these anodes is to concentrate and focus the beam on the screen and also to accelerate the speed of electrons.



Electrostatic Focusing System of a CRT
Fig. 36.3

An electrostatic focusing system is shown in fig 36.3. Electrostatic lens consists of three anodes, with the middle anode at a lower potential than the other two electrodes.

In fig. 36.4 two anodes and its electrostatic lines and equipotential surfaces are shown. A pd is kept between these two electrodes so that an electric field is generated between them. Spreading of electric field is caused because of repulsion between electric lines. If equipotential lines are drawn, as shown in fig. 36.4, they would bulge at the centre of the two anodes.

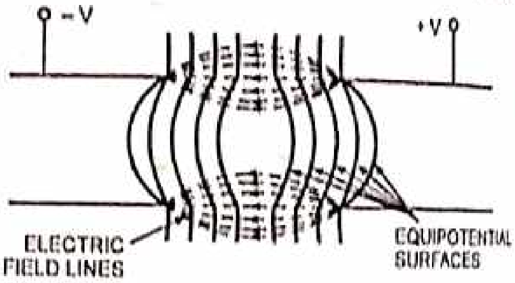
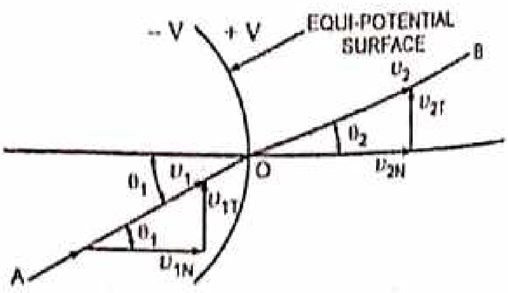


Fig. 36.4

As we know that electrons move in a direction opposite to that of electric field lines and equipotential surfaces are perpendicular to the electric field lines so force on the electron is exerted in the direction normal to the equipotential surface.

Electrons entering at the centre line of the two anodes experience no force but electrons displaced from the centre line experience a force normal to the direction of equipotential surface and deflects, as shown in fig. 36.5. In fig. 36.5 an equipotential surface is shown, in which an electron with velocity υ_1 and at an angle θ_1 to the normal of equipotential surface enters and experiences a force in a direction normal to the equipotential surface. Thus the velocity of the electron increases to υ_2. This force on the electron is exerted in the direction normal to equipotential surface so only the normal component of electron velocity υ_{1N} increases to υ_{2N} and the tangential component of velocity υ_{1T} remains the same.



Refraction of an Electron Ray at an Equipotential Surface
Fig. 36.5

From fig. 36.5 $\upsilon_{1T} = \upsilon_1 \sin\theta_1$

$$\upsilon_{2T} = \upsilon_2 \sin\theta_2$$

$$\text{but} \quad v_{1T} = v_{2T}$$

$$\text{so} \quad v_1 \sin \theta_1 = v_2 \sin \theta_2$$

$$\text{or} \quad \frac{v_2}{v_1} = \frac{\sin \theta_1}{\sin \theta_2}$$

From the above expression it is obvious that equipotential surface acts as a concave lens in geometrical optics. That is why, this focusing system is named as an *electrostatic lens.*

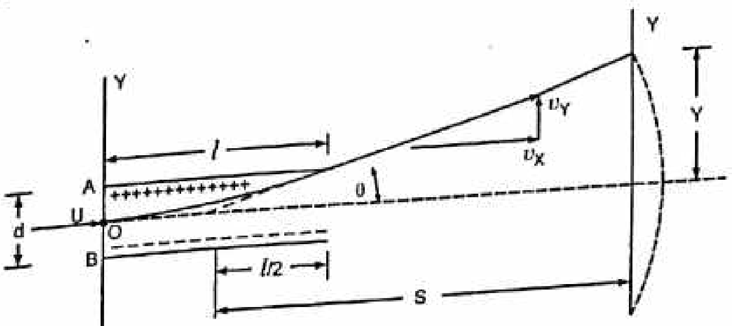
Now if we go back and refer figure 36.3, it can be seen that because of middle anode at a lower potential, electron beam coming from the cathode and passing through the first concave electrostatic lens tends to become more aligned with the axis of CRT and when it enters at the second concave electrostatic lens, formed between two anodes at different potentials, it is focused at the phosphor screen. Focal length of the electrostatic lens can be adjusted by varying potential of middle anode with respect to other two anodes. Thus the electron beam can be made to focus at the screen very precisely.

2. Deflection Plate Assembly. Electron beam, after leaving the electron gun, passes through the two pairs of deflection pates. One pair of deflection plates is mounted vertically and deflects the beam in horizontal or X-direction and so called the *horizontal* or *X-plates* and the other pair is mounted horizontally and deflects the beam in vertical or Y-direction and called the *vertical* or *Y-plates*. These plates are to deflect the beam according to the voltage applied across them. For example if a constant *pd* is applied to the set of Y-plates, the electron beam will be deflected upward if the upper plate is + ve. In case the lower plate is + ve then the beam will be deflected downward. Similarly if a constant *pd* is applied to the set of X-plates, the electron beam will be deflected to the left or right of the tube axis according to the condition whether the left or right plate is + ve. When a sinusoidal voltage is applied to Y-plates, the beam will be moved up and down according to the variation of plate potential. If the frequency of variation is more than 16 Hz the deflection will be a vertical line in the centre of the screen. In case the sinusoidal voltage is applied to X-plates and frequency of variation is more than 16 Hz the deflection will be a horizontal line. If potentials are applied to both sets of plates simultaneously, the deflection will be an oblique line. The amount of deflection is in proportion to the voltage applied to the pair of plates.

Deflection of Moving Electrons in CRO Tubes. We know that a force is experienced by an electron when it is kept in a uniform electric field. This principle is the basis for the deflection of electron beam owing to deflection plates.

Let us consider an electron having initial velocity of u m/s along X-axis at point O in the space between the plates A and B, each of length l metres and separated by a distance of d metres. Let the *pd* across the plates be of V volts. For simplicity, let us assume that the field is uniform and does not extend beyond the ends of the plates.

Axial velocity of electron remains unchanged and is equal to u as there is no axial force and, therefore, no axial acceleration.



Deflection of Cathode Ray Beam
Fig. 36.6