15

Principles of Television

15.1. Introduction

By television is meant transmission of a scene or picture over long distance through electrical means. Television technique consists in the following stages : (*i*) successively evaluating light values of different portions of the scene to be reproduced and converting these light values into corresponding electrical signals. This is done by television camera (*ii*) amplifying television signals and made to modulate an R.F. carrier (*iii*) radiating this modulated carrier from a television antenna (*iv*) catching the TV signal in TV receiver antenna, amplifying and detecting it to get back the original vision signal and (*v*) feeding this vision signal to a TV picture tube (a C.R. tube) to reproduce the original scene on the fluorescent screen of the picture tube. In the picture tube, the cathode ray spot moves over successive portions of the reproduced scene in exactly the same fashion as the scanning of the original scene. Simultaneously the brightness of the spot varies according to the instantaneous value of the vision signal obtained at the output of the detector for the TV receiver. One scanning of the complete picture is completed typically in 1/48 second and then the process is repeated. Thus the changing scenes are evaluated continuously and reproduced continuously. Because of the rapid scanning of the complete scene, the illusion of continuous motion is achieved.

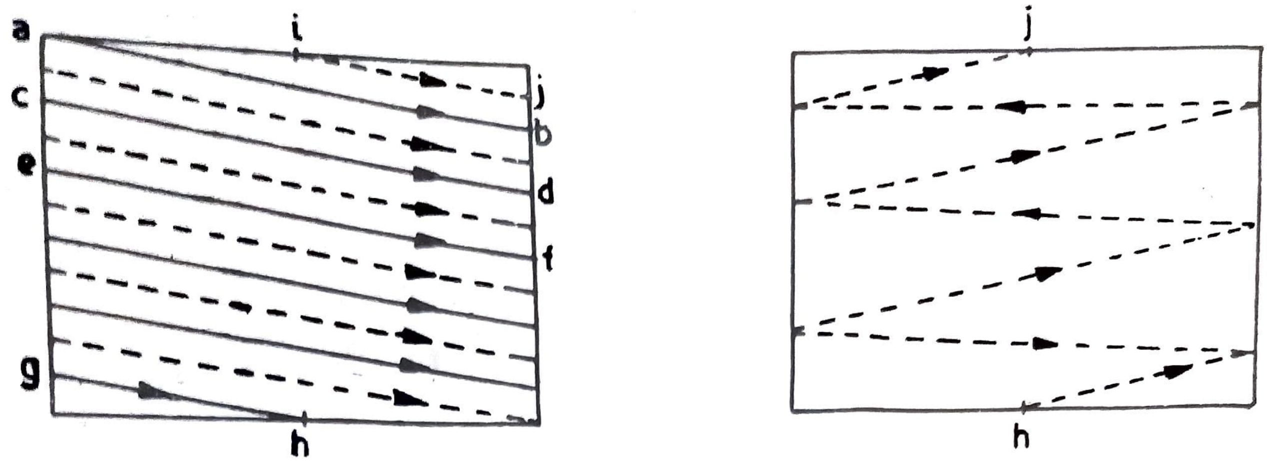
In television broadcast, in order that any receiver may receive from any of the several TV transmitters, the following conditions must be met : (*i*) same picture shape be used, (*ii*) same scanning procedure be used at transmitter and receivers and (*iii*) same means of synchronization be used. Standards for TV broadcast transmitters are accordingly laid down by the appropriate authorities.

15.2. Aspect Ratio

It has been found that for best viewing comfort, panoramic effect and artistic appreciation, the scanned picture should have a rectangular format with aspect ratio, *i.e.* width-to-height ratio of 4 : 3. In motion picture industry, aspect ratio of 4 : 3 has been generally accepted. In TV system also, aspect ratio of 4 : 3 has been accepted.

15.3. Rectangular Switching

For rectangular picture frames, rectilinear scanning is used. This rectilinear scanning involves two scanning simultaneously (*i*) horizontal scanning and (*ii*) vertical scanning. Fig. 15.1 depicts the rectilinear scanning of the interlaced type. In horizontal scanning, the scanning spot starts at the upper left hand corner and moves from left to right along a straight line at the uniform rate. But since there is simultaneously a relatively slow vertical downward movement also, the spot reaches the right hand edge at a slightly lower point. Thus in Fig. 15.1, *ab* represents one such horizontal scanning line. When the end of the line *ab* is reached, the horizontal scanning suddenly reverses and the scanning spot quickly returns to the left, *i.e.* from *b* to *c*. This point *c* is almost at the same height as *b* since the retrace is extremely quick. During the retrace from *b* to *c*, the spot is blanked out. Hence the retrace line is not visible. However, it is shown dotted. At the left hand point *C*, forward horizontal scanning again begins producing a new scanning line *Cd*. However, as the scanning point moves to and fro across the frame, the spot also moves downward at a constant but slow rate. Hence the scanning lines are slightly sloped and each forward scanning line is a little below the preceding line. This continues until the bottom of the picture is reached at point *h*, the point at which only half the horizontal scanning has completed. This instant of time represents completion of relatively slow vertical downward scanning and now quick vertical upwards flyback begins bringing the spot from point *h* to *i*. The horizontal to and fro scanning, however, continues. The time interval of travel of the spot from *h* to *i* is an integral multiple of the time of to and fro horizontal travel. This is shown in Fig. 15.1 (*b*). During this interval, the spot is blanked out so that the return pattern is not visible to the eye.



(*a*) Interlaced scanning pattern. (*b*) Schematic representation of vertical retrace.

Fig. 15.1. Interlaced scanning pattern. In (*a*) solid lines represent first field while dotted lines represent second field.

Persistence of Vision and Flickers. The eye has the so-called *persistence of vision, i.e.* the image formed on the retina is retained on it for a short period of time. This property of the eye has been used both in cinema and television to create the illusion of continuity by using rapidly flashing picture frames. If the number of frames is large enough, the flicker is not observed and the flashes appear continuous. The minimum repetition rate of flashes at which flicker disappears, called the *critical flicker frequency* (CFF), depends on the image brightness and the colour spectrum of the light. Motion picture uses 24 frames/second with each frame illuminated twice during the interval it is shown. The resulting effective flicker rate becomes 48 frames/second at which rate flicker is hardly noticeable.

In TV, the picture frame rate is usually the same as the mains power supply frequency namely 50 or 60 cycles/second.

Vertical Resolution. By vertical resolution is meant the ability of a scanning system to resolve or identify separately vertical details in a scene. This depends upon the number of scanning lines used per frame. Useful limit to the maximum number of lines is, however, determined by the resolving capability of the human eye which is typically about 1 minute of visual angle. For a comfortable continuous viewing, the visual angle should be 10° and 15°. Taking visual angle of 10°, the best viewing distance *D* for watching television is about 6 times the height *H* of the picture. In practice, the viewing distance may be kept 4 to 8 times the picture height *H*.

Let n_v indicate the number of lines of vertical resolution. This number n_v then gives the maximum number of dark and white elements which may be resolved by the human eye in the vertical distance *H* of the TV screen. Then

$$\frac{H}{D} = n_v \times \alpha_0 \qquad \ldots(15.1)$$

where α_0 is the minimum angle of vertical resolution in radians and *D* is the distance of the viewer from the screen.

Fig. 15.2 (*a*) shows n_c white and black lines in the height *H* of the screen while Fig. 15.2 (*b*) schematically represents the angle α_0.

From Eq. (15.1)

$$n_v = \frac{H}{\alpha_0 D}$$

15.4. Interlaced Scanning

In order to avoid flicker, the number of picture frames/second should be at least 50. For 625 line system, this corresponds to horizontal line scanning frequency of $50 \times 625 = 31{,}250$ lines/second. This corresponds to line period of 32 μs. For the requisite horizontal resolution of $546/2 = 273$ pairs of black and white alterations in one horizontal line, the bandwidth requirement is given by,

$$BW = \frac{273}{(32-6)} \text{ MHz} \approx 10 \text{ MHz}$$

where 6 alterations out of 32 are lost in horizontal retrace.

This frequency bandwidth of 10 MHz is needed in simple sequential scanning. This bandwidth requirement is rather large and may be reduced by using interlaced scanning instead of sequential scanning. In interlaced scanning, already depicted in Fig. 15.1 (*a*), the entire picture is divided into two sets of fields each containing half the total number of lines per picture frame and the two fields are scanned alternately. This picture frame containing 625 lines is divided into two fields of 325.5 lines each.

The first field of 312.5 lines constitutes the odd field and is scanned sequentially as shown by the solid scanning lines in Fig. 15.1 (*a*). This odd field starts from point *a* and terminates at point *i*. The second field of 312.5 lines, called the even field begins at point *i* and terminates at point *a*.

Each field of 312.5 lines is completed in 1/50 second so that the complete picture frame is scanned in 1/25 second. Thus through interlaced scanning using a frame rate of only 25 frames/sec. an effective flicker rate of 50 cycles/sec is achieved. This rate of 60 fields/second is high enough to avoid perceptible flicker.

In this technique of interlaced scanning, since 312.5 lines are scanned in 1/50 second, the bandwidth requirement reduces to half, *i.e.* to about 5 MHz.

The flyback from bottom of a field to the top is not instantaneous and requires a time interval equal to about 20 lines. Thus out of 625 lines, only about $(625 - 40) = 585$ lines effectively carry the picture information and are referred to as the active lines.

In interlaced scanning, however, the number of lines per picture must be odd. Further the flyback periods in odd and even fields must be exactly the same, failing which pairing of lines of adjacent fields may result causing marked reduction in vertical resolution. This difference in flyback period must in no case exceed 0.1 μ s.

15.5. Composite Video Signal

By video signal is meant the electrical signal corresponding to the picture information at the output of TV camera which scans the picture. To this video signal, we add (*i*) horizontal blanking pulses (*ii*) horizontal synchronizing pulses (*iii*) vertical blanking pulses (*iv*) vertical synchronizing pulses and (*v*) equalising pulses. The resulting video signal is referred to as the *composite video signal.*

The horizontal synchronizing pulses are needed at the end of the horizontal scan when horizontal flyback is desired. Similarly vertical sync pulses are needed at the end of the vertical scan. During the forward scan, the video signal changes depending upon the picture brightness in the scanned area. The sync pulses occupy amplitude level corresponding to blacker than black level in the video signal.

Different television standards are used in different countries. These TV signal standards completely specify the technical details of the video and audio signal waveforms such as the number of scanning lines, scanning frequency, interlace, amplitude and time dimensions of the composite video waveform, characteristics of video and sound modulation, channel bandwidth etc. The CCIR system-B standard is used in India, Pakistan, Australia and various other countries and is the one discussed here. U.S.A., on the other hand, uses 525 lines, 60 frames/sec system.

The CCIR system-B uses 625 lines interlaced scanning with field frequency of 50 Hz (picture frequency of 25 Hz). Accordingly the horizontal line frequency is $625 \times 25 = 15{,}625$ Hz. The maximum deviation permitted is 0.1%. The aspect ratio is 4 : 3.

Blanking Pulses. The picture tube is made inoperative during the horizontal and vertical retrac intervals by means of *blanking pulses.* These blanking pulses are generated at the transmitting station and a added to the video signal. These pulses are thus included in the composite video signal and they modulat the transmitter carrier. At the receiving end, after the detector stage, these blanking pulses are separated ou from the composite video signal and used for blanking the picture tube.

The actual horizontal retrace takes a small fraction of the line interval *H*. However, there get producec damped oscillatory current in the deflection coil as shown in Fig. 15.4 resulting in light and dark stripes at the left of the picture tube screen. The horizontal blanking pulses at the black level (75% Blank) extending for 0.19 H takes care of this effect also.

Vertical blanking pulse of duration 0.065 V (about 20 H) in each field at the end of each field serves to (*i*) make inoperative the picture tube during oscillatory conditions in the frame and the line time bases.

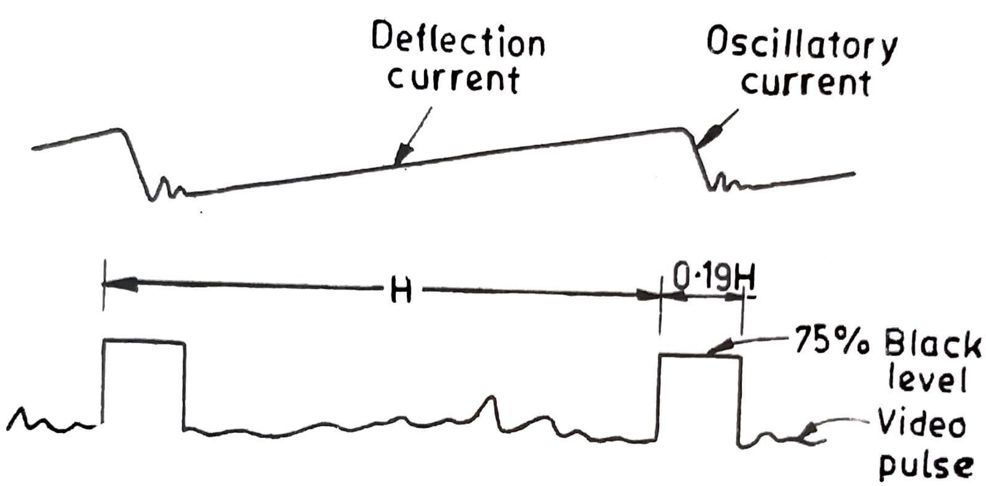


Fig. 15.4. Blanking signal.

Horizontal Synchronizing Pulse and Blanking Pulse Standard. Fig. 15.5 shows the amplitude levels and time durations involved in horizontal synchronizing and blanking pulses as per CCIR system-B standards. Two consecutive pulses are shown in this diagram. As per CCIR system-B standard followed in India, the line frequency f_H is 625 × 25 = 15,625 lines/second. Hence the line period

$$H = \frac{1}{f_H} = \frac{1}{15.625} \text{ sec} = 64\ \mu\text{s}$$

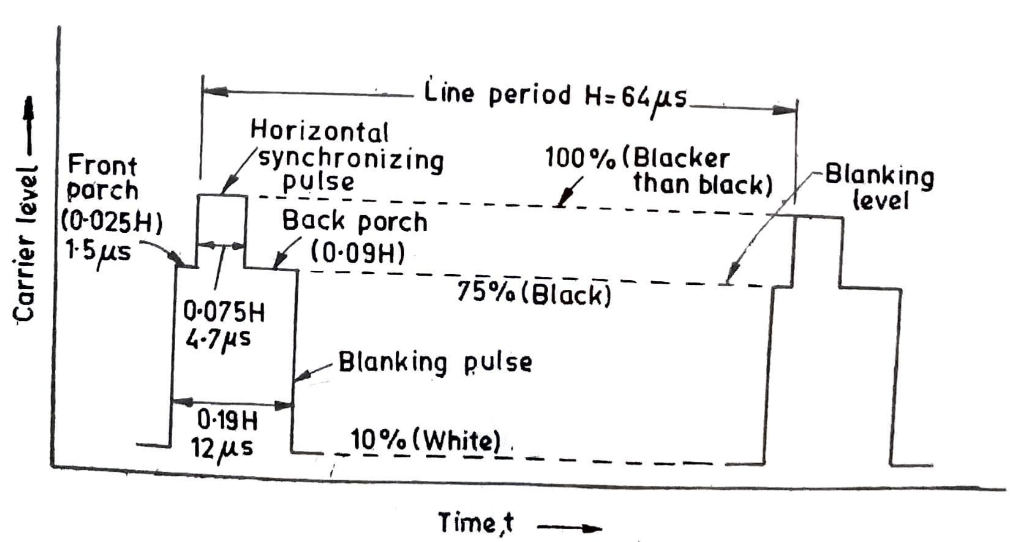


Fig. 15.5. Horizontal sync and blanking pulse.

Line Blanking period (LB). It is kept 0.19 H (≈ 12 μs) with a tolerance of + 3 μs to –2 μs.

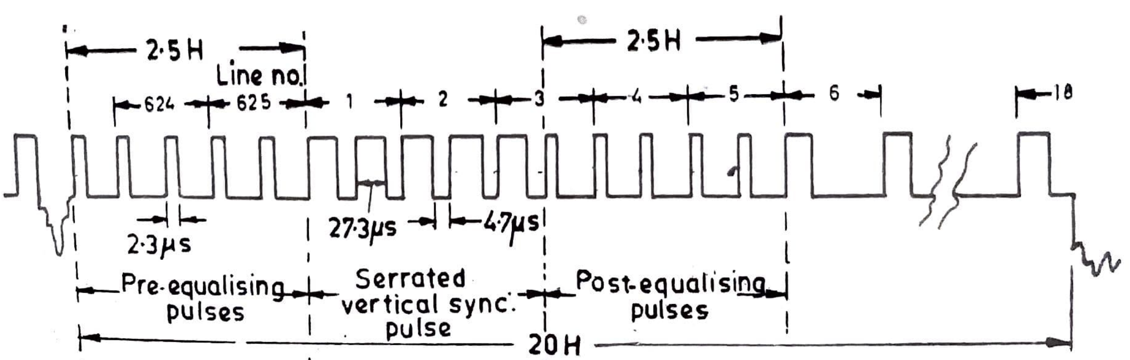
Line Synchronizing Pulse. It is sent from the transmitter to maintain the horizontal scanning rate at the TV receiver in synchronism with that at transmitter. As per CCIR system-B standard, its length is $HS = 0.075$ H ≈ 4.7 µs with a tolerance of ± 2 µs. Its maximum rise time at the transmitter is 0.25 µs.

Front porch. The horizontal sync pulse starts about 0.025H ($\approx$ 1.5 µs) later than the blanking pulse. This period of 0.025 H, called the front porch, permits every sync pulse to build up in the positive direction starting from fixed black level (75% black) of the blanking pulse. In the absence of this front porch, the sync pulse may build-up from the varying brightness levels in the video signal. Thus the front porch acts as a buffer region between the video signal and the sync pulse. The duration of the front porch is kept 0.025 H ($\approx$ 1.5 µs) with a tolerance of -0.2 µs to $+ 0.3$ µs.

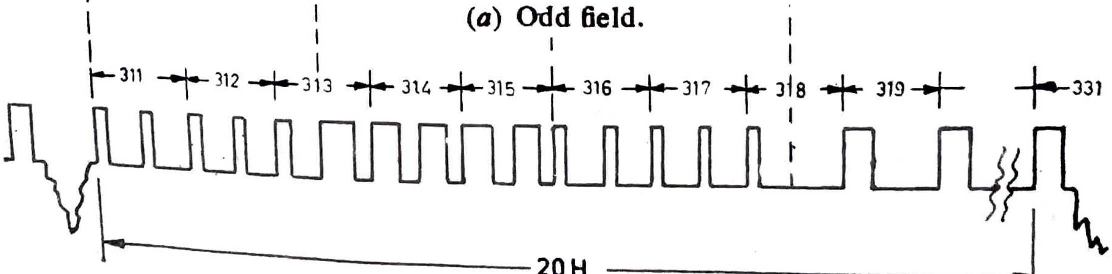
Back porch. The sync pulse ends about 0.09 H before the end of the blanking pulse. This period, called the back porch, permits the line retrace to complete itself and all oscillations in the deflection circuit current to die down before the next forward deflection begins. Another function served by the back porch is to provide a reference level in preserving the d.c. component of the video signal. Further, back porch voltage is used to produce in the AGC circuit of the TV receiver an AGC voltage proportional to the carrier strength. In colour TV system, this back porch serves to accommodate the burst of colour sub-carrier. The duration of back porch is kept about 0.09 H $\approx$ 5.8 µs.

Levels in the composite Video Signal. The various levels in the composite video signal are generally prescribed as the modulated carrier levels. Using negative modulation, the tips of the sync pulses are 100% level (blacker than black), the blanking level is 75% (Black level) and the peak white level in the video signal is limited to 10%. These levels are shown in Fig. 15.5.

Vertical Sync and Blanking Pulse Standard. A vertical sync waveform is inserted in the composite video signal at the end of each field of 312.5 lines. Figs. 15.6 (*a*) and (*b*) shows these waveforms of the odd and even fields respectively. Each vertical sync complex consists of (*a*) pre-equalising pulses (*b*) field sync pulses and (*c*) post-equalising pulses as shown in Fig. 15.6.



(*a*) Odd field.



(*b*) Even field.

Fig. 15.6. Field sync equalising and blanking pulses as per CCIR B-system.

Field Blanking Period (VB). During this period, video signal is suppressed and field retrace is completed. In CCIR B-system, the field blanking period VB equals 20 H. Thus VB = 20 H = 1280 µs. Since there are two fields per picture frame, the number of active lines becomes (625 – 40) = 585 lines.

Field Sync Pulses. The vertical sync pulses may be distinguished from the horizontal sync pulses by their larger duration, being about 2.5 H long in CCIR B-system. Further in order to maintain the horizontal synchronization during the vertical sync-pulse, the latter is split up by serrations each 4.7 µs wide into five narrow pulse occurring at 0.5 H interval and width equal to (32 –4.7) = 27.3 µs. These serrations are so timed that the leading edges of alternate half line pulses coincides with the leading edges of horizontal sync pulse had they existed. The extra half-line pulses, other than those coinciding with the horizontal sync pulses serve no useful purpose during the pertinent field but they do not influence the line time base which is insensitive to these intermediate pulses. The half-line rhythm becomes necessary since the field retrace begins at the middle of horizontal scanning line in the case of an odd field and at the end of a horizontal scanning line in the case of an even field.

Equalising Pulses. In TV receiver, field sync pulses are separated out from the line sync pulses. The serrated vertical sync pulses are then integrated to produce a composite single field pulse which is then used for triggering and synchronizing the vertical oscillator. These integrated vertical sync pulses so produced at the ends of odd and even fields must be identical for perfect interface. But the line periods preceding the vertical sync pulses for odd and even fields are unequal, being $H/2$ before an odd field and H before an even field. As a result of this, the integrated vertical sync pulses so formed are slightly different. This interval preceding the vertical sync pulse can be made $H/2$ in both the cases by using 5 narrow pulses each 2.3 µs wide occurring at H/2 rythm preceding the field sync pulses. These 5 pulses constitute the *pre-equalising pulses* and they equalise the integrated vertical sync pulses in cases of odd and even fields.

The width of these equalising pulses is kept small, being half that of the horizontal sync pulses in order to maintain the electrical conditions preceding the vertical retrace in odd and even fields.

The vertical blanking starts from first pre-equalising pulse and extends for duration 20 H in each field.

Post-equalising Pulses. Just beyond the final field sync pulse, there is $H/2$ period for the odd field and H period for the even field, before the next line sync pulse results. In order to maintain the horizontal sync continuously, there are introduced five equalising pulses of $H/2$ rhythm at the end of field sync pulses. For accurate interlacing of lines, the vertical retrace must start regularly and its duration should be regular. Any sudden change from full-line ryhthm to the half-line rhythm occurring between two fields may disturb the horizontal time base. Introduction of these post-equalising pulses resulting in shifting this half-line and full-line discrepancy away from the field pulses and thus result in producing identical electrical conditions in the TV receiver field pulse circuit on odd and even fields, both before and after the field pulse.

The synchronising, blanking and equalising pulses of the composite video signal are produced by *synchronising generators* which comprise of oscillators, pulse generators, frequency dividers, clippers, gates etc.

15.6. Video Modulation

The composite video signal amplitude modulates the video carrier using either positive modulation or negative modulation. In the positive modulation, an increase of brightness in the video signal results in increase in carrier amplitude. In this positive modulation, the peak white corresponds to 100% modulation, the black has lower modulation and the sync pulses have minimum modulation.

In negative modulation, on the other hand, the tips of sync pulses result in 100% modulation. The blanking level (or the black level) is at 75% modulation and any increase in brightness results in decreasing carrier amplitude. The peak white corresponds to 10% modulation. The CCIR B-system, used in India, utilizes negative modulation.

The negative modulation has the drawback that an impulsive interference causes a sudden random increase in the modulated signal level and causes serious interference with the sync pulses. An impulsive interference further causes visible interference on the picture tube screen in the form of black spots. These black spots in the negative modulation system are, however, less annoying than the white blocks cau'sed in positive modulation system.

The more significant and desirable feature of a zoom lens system is that it maintains constant the spacing of the focused image plane from the stationary lens element while focal length is varied. Fig. 15.9 (*a*) shows a three-element zoom lens. Here convex lens *X* and concave lens *Y* are movable while convex lens *Z* is stationary. In this system movement of concave element *Y* relative to *X* causes change in the focal length. Simultaneously a very small movement of element *X* from the normal position provides image shift compensation mechanically and the position of the image plane remains at the same constant distance from the plane of stationary element *Z*. This simultaneous unequal movement of elements *X* and *Y* requires use of a non-linear or cam control.

Zoom lens has, however, the drawback that it is not a fast lens. With poor light conventional turret mounted fixed focus lenses are preferred. Another limitation of a zoom lens is that it is subject to greater abberation since several movable lenses are involved.

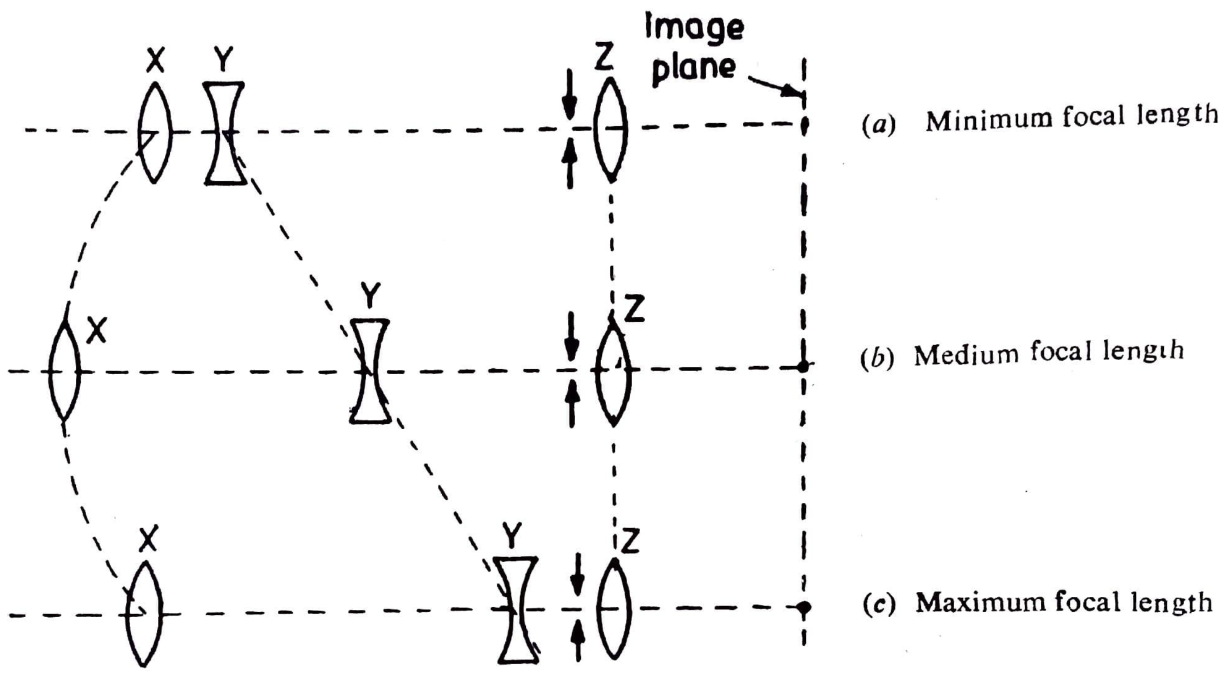


Fig. 15.9. Zoom lens assembly using mechanical compensation of image shift.

15.15. Television Camera Tubes

A camera tube develops an output voltage which varies in accordance with the light intensity of the successive elements of the image formed on its photosensitive surface. Basically TV camera tubes may be of two types : (*i*) those utilizing photo-emission principle, typical example being image orthicon (*ii*) those utilizing photo-conduction principle, typical examples being vidicon and plumbicon tubes.

Camera Tube Characteristics. The following are the main characteristics of camera tubes :

(*i*) *Transfer characteristic.* This plots on log-log scale the output current against illumination of the face plate. The slope of transfer characteristic is called the *gamma* of the tube.

(*ii*) *Sensitivity.* This is defined as the output current per lumen using a standard light source generally a tungsten filament lamp at 2870°K.

(*iii*) *Spectral response.* Ideally, for monochrome TV, the tube should have the same spectral response as that of the eye. Colour TV tube, however, has greater response to primary colour of the tube.

(*iv*) *Dark current.* This is the output current with zero illumination of the face plate and is caused by the flow of electrons and holes generated in the photo-sensitive surface due to thermal energy or otherwise. The dark current tends to limit the low illumination sensitivity of the camera tube.

(*v*) *Time lag.* The output current does not truly follow the fast changes in illumination. As the illumination drops suddenly from a high value, the electrons and holes so caused by the illumination take a finite time to recombine. This results in a decayed memory of the earlier bright illumination and presents a smear or sort of comet tail in the case of moving objects.

(*vi*) *Resolution.* As the number of alternate black and white lines of resolution in the image increases, the output current magnitude during the white line reduces. This output current expressed as a fraction of the current for wide white strip is referred to as the resolution. Then this percentage resolution reduces with the increase of number of lines. Different camera tubes have different percentage resolution versus number of lines curves.

The three most widely used camera tubes are : (*i*) image orthicon (*ii*) vidicon and (*iii*) plumbicon. Image orthicon is mostly used for studio broadcast since it has high sensitivity, stability and high picture quality. Vidicon has the merits of small size, simplicity and low cost. It is, therefore, used for (*i*) industrial applications (*ii*) educational purpose (*iii*) aerospace application (*iv*) broadcasting of still and telecine projections.

Plumbicon is superior to vidicon in respect of (*i*) faster response (*ii*) higher sensitivity and (*iii*) better frequency response. Accordingly it is used in black and white and also colour CCTV (closed circuit television) systems in broadcast studios and for industrial and medical applications.

Silicon multidiode vidicon is a modified version of vidicon using modified target.

15.16. Image Orthicon

It was first produced in the year 1945 and because of its superior performance it soon replaced all earlier TV camera tubes like image dissector, iconoscope and orthicon. It has the following qualities :

(*i*) it has high photographic sensitivity
(*ii*) it provides a very dependable service
(*iii*) it provides an excellent response over a wide range of illumination level varying from bright sunlight to dark shadows.

As a result of this, image orthicon remained in popular TV studio use for a long period but it is now being replaced by plumbicon.

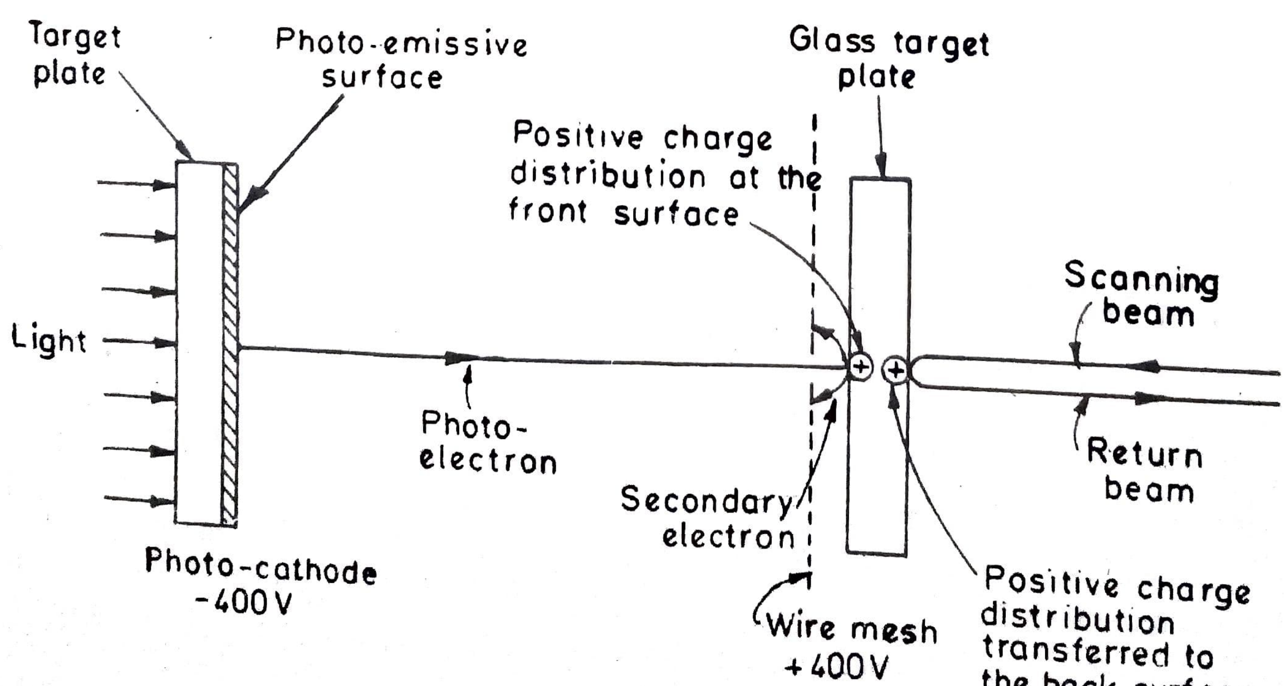


Fig. 15.10. Formation of positive charge pattern on the target plate.

Principle of working. A lens system focuses light from the scene on to a translucent photocathode. Electrons get emitted from the various points on photocathode surface in proportion to the illumination. These photo-electrons travel to a thin glass target causing secondary emission from it. These secondary electrons get collected by a fine mesh placed close to the glass target plate as shown in Fig. 15.10. This causes electron deficiency distribution or positive charge distribution on the target plate proportional to the light distribution on the photocathode. This positive charge distribution originally on the front surface of the target plate leaks through thin plate to the back surface.

A low velocity scanning beam from an electron at the other end of the image orthicon (I.O.) tube scans the back surface of the target plate following a predetemined scanning pattern. This electron is slowed down to a non-zero velocity as it approaches the target. From a dark element (*i.e.* no positive charge), the scanning electron beam is returned unaffected. However, at a lighted element (positively charged element), the scanning beam is deprived of some of its electrons to neutralise the positive charge so that the returning electron beam contains lesser electrons. This varying density returning beam is fed to an electron multiplier.

The entire image orthicon thus consists of the following three sections :

(*a*) *Image Section*. Here the optical image focused on the photocathode is converted into corresponding electron image and is transferred to the target plate. Fig. 15.10 shows this section.

(*b*) *Scanning Section*. Here the low velocity electron beam scans the target plate in accordance with predetermined scanning pattern to convert the electron deficiency image positive charge (image) into a time-varying electrical signal in the form of a time-varying return beam current.

(*c*) *Multiplier Section*. Here the return beam current is magnified through the process of electron multiplication (using secondary emission principle) thereby providing amplification without introduction of noise. Thus the signal-to-noise ratio remains high.

The image orthicon may be two types :

(*i*) Non-field mesh type
and (*ii*) Field mesh type.

Non-field mesh Image Orthicon. Fig. 15.11 shows the basic construction of a non-field mesh I.O. (Image orthicon).

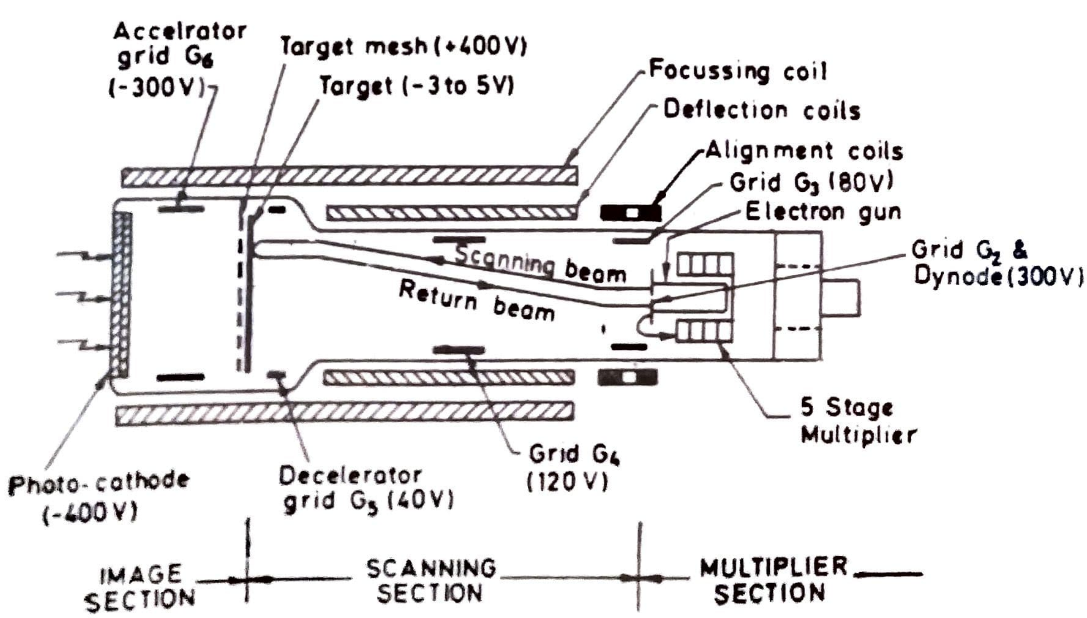


Fig. 15.11. Schematic diagram of non-field mesh image orthicon.

Image Section The image section consists of a photocathode, accelerator grid, the target plate and the target screen-mesh.

An optical lens system (not shown in Fig. 15.11) focuses the scene on the semi-transparent photocathode formed on the inner surface of the face plate of the camera tube and kept negative (–400 V) relative to the target. Electrons get emitted from every point on the photocathode in proportion to the intensity of light. The photoelectrons so emitted from the photocathode are accelerated towards the target due to the target potential and by the accelerator grid G_6 potential. Focusing is done by magnetic field produced by the focusing coil external to the tube and by the electrostatic field of the accelerator grid and the target. The photoelectrons emitted from any individual point on the photocathode can be brought to sharp focus at the corresponding point on the target by varying the photocathode potential.

The photocathoae material is chosen to have spectral response extremely close to that of human eye. Modern I.O. tube use bismuth-silver-cesium.

The accelerator grid G_6 (–300 V) serves to accelerate the photoelectron and to cause uniform landing of photoelectrons on the target. The target mesh is made extremely thin with 750 holes/inch so as to inercept very few photoelectrons. Thus almost all the photoelectrons pass through the target mesh and hit the target.

Modern target plate use special glass plate using glass doped with *n*-type semiconductor. Such a construction reduces the phenomenon of *sticking* of picture in the case of stationary objects image persisting even after the camera focus has been shifted. Such a phenomenon occurs specially when the I.O. tube has been operated without adequate warming up *i.e.* with lower operating temperature. Higher operating temperature, on the other hand, causes loss of resolution.

The primary electrons on striking the target produce secondary electrons which are drawn to the screen leaving the positive charges on the target, producing thereby a charge distribution similar to light distribution of the optical image projected on the photocathode.

The scanning Section. The back side of the target plate is scanned, as per standard scanning sequence, by a low velocity electron beam produced by an electron gun. This electron gun consists of an indirectly heated thermionic cathode which emits electrons, a control grid G_1 (not shown in Fig. 15.11) for controlling the beam current and an accelerating grid G_2 (+ 300 V).

The electron beam on leaving grid G_2 is first aligned parallel to the axis of the tube by two beam alignment coils, the magnetic fields of which is at right angles to the tube axis. The beam on leaving the electron gun passes through grid G_3 (+ 80 V) remaining practically unaffected because of its high velocity. The beam is then focused on the target by the magnetic field of the focus coil and by the electrostatic field of grid G_4 (+ 120 V). This grid G_4 is usually in the form of a conductive coating on the inner wall of the tube. Focus coil current provides the coarse focus control while G_4 potential forms the fine focus control. As the electron beam approaches the target, it is slowed down by decelerator grid G_5 (+ 40 V).

The electron beam scanning the target deposits just enough electrons at each point on the back of the target to neutralize the positive charge of the image. The return beam becomes deficient in electrons proportional to the positive charges on the back of the plate and thus gets amplitude modulated proportional to the light variation of the original scene.

Deflection of the electron beam for scanning as per standard pattern is achieved by use of horizontal and vertical deflection coils causing saw tooth current. These deflection coils are just outside the tube but within the focus and run almost the full scanning section of the tube.

The Multiplier Section. The modulated return beam passing through the field of grid G_4 (+ 120 V) tends to spread out. This *fringing* is reduced by varying G_3 potential. Thus grid G_3 serves as multiplier focus. The return beam then strikes the surface of grid G_2 causing high secondary emission. Thus G_2 serves as the first dynode of the electron multiplier. The surface of G_2 is coated with material having high secondary emission. The secondary electrons from G_2 are deflected into the electron multiplier system consisting of several dynodes of progressively higher potentials (300 V per stage) each dynode having been treated to give high secondary emission. These dynodes are in the form of flat vanes inclined at angle of 40° to the axis. Grid G_3 also serves to control the motion of the secondary electrons produced by the returning beam in such a way as to guide them into the electron multiplier.

The overall magnification of beam current is 1000 or so. The final output current is of the order of several micro-amps. This current flowing through a load resistor of say 20 kΩ, produces the output signal is 100 mV or more.

The lowest permissible illumination for I.O. tube is less than that required for fast motion picture film This lowest level is determined by the shot noise in the output current of the electron multiplier.

Field-mesh Image Orthicon. Fig. 15.12 gives the schematic circuit of field-mesh image orthicon. Here a field mesh (+ 15 to + 25 V) is added close to the target on the rear side. This field mesh overcomes (*a*) the halo effect and (*b*) I.O. ghost.

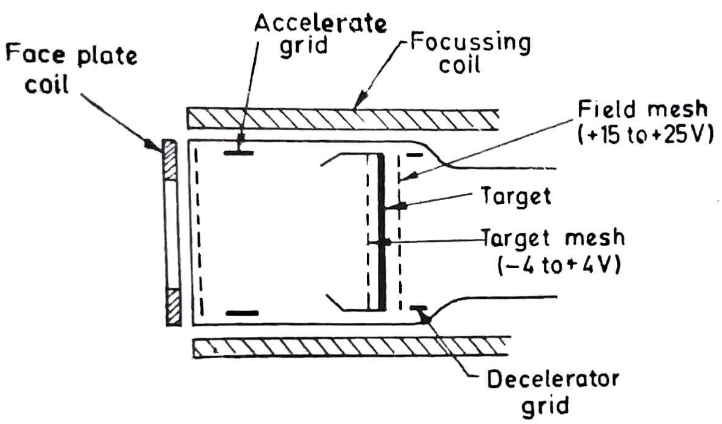


Fig. 15.12. Schematic diagram of field-mesh image orthicon.

Halo Effect. Photoelectrons emitted from highly illuminated areas produce large number of secondary electrons which tend to nullify the potential difference between the target and the target mesh. Hence all the secondary electrons are not collected by the target mesh. The uncollected low velocity secondary electrons fall back on the glass target plate in areas surrounding the high illumination spots, causing lowering of potentials of these areas. The full electron beam secondary emission then takes place from these areas causing black areas in regions around high illumination spots in Fig. 15.13. Thus a halo effect is created. This phenomenon results when the tube is operated a little above the knee of its transfer characteristics. This halo effect gets reduced materially by the use of field mesh.

The field mesh placed between the target and the decelerating electrode stiffens the electrostatic field and prevents beam bending due to the charge pattern on the target and thus secures more perpendicular landing of the beam on the scanned surface.

The addition of face plate coil, a pan-cake shaped coil in series with the main focusing coil results in graded magnetic field such that the image on the photo-cathode gets increased by a factor of 1.7. Hence the area of high illumination gets increased about 3 times while the area of excess secondary electrons causing the halo effect remains the same because of the target capacitance. Hence the ratio of halo to high illumination gets reduced considerably.

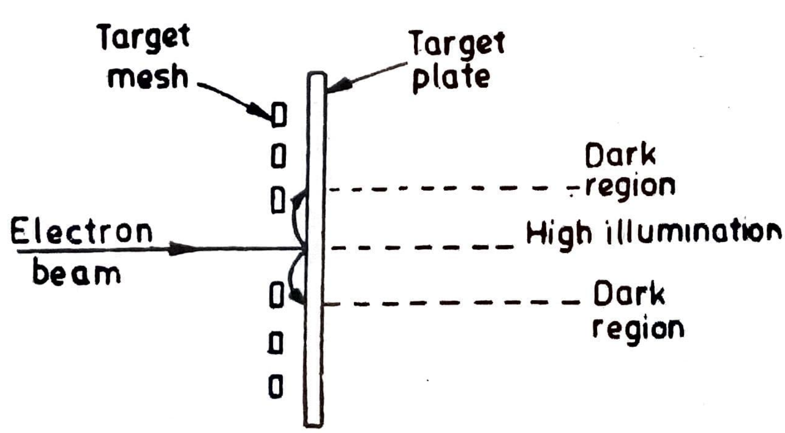


Fig. 15.13. Halo effect in image orthicon.

Image orthicon ghost. By image orthicon ghost is meant an image of the same polarity displaced from the high illumination image. This becomes more evident when there exists high contrast between dark background and the high light. The phenomenon is caused by high velocity secondary electrons from the target which escape the target mesh and travel towards the photocathode. These electrons slow down, stop and then return to the target with high velocities and produce a ghost-like image of the high-illumination objects, somewhat displaced from the main image. This effect has been eliminated in modern I.O. tube by anti-ghost image section design consisting in modification of the accelerator grid shape relative to the target.

Spectral response of I.O. A wide variety of spectral responses of modern I.O. tubes has become possible through use of bi-alkali and multi-alkali photocathode materials. Thus while it is possible to have spectral response very close to that of human eye, on the other hand it is possible to have very high sensitivity in near infra-red region.

15.17. Vidicon

This camera tube was developed by RCA in the early 1950's. It has the merits of (*i*) low cost (*ii*) small size (1" dia) (*iii*) simplicity and (*iv*) ease of operation. Accordingly it has become popular is CCTV applications.

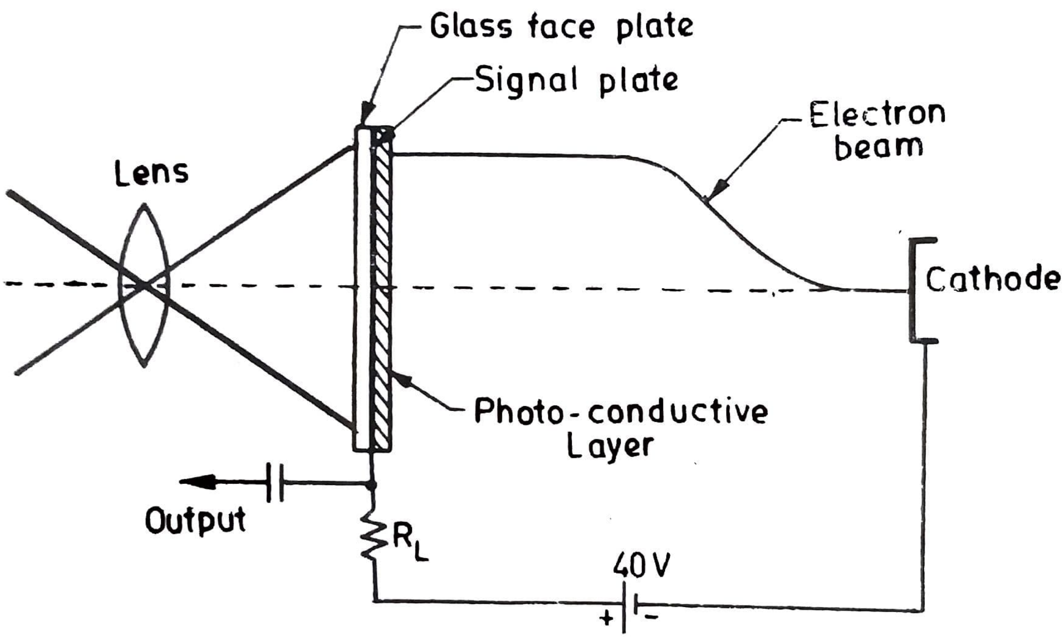


Fig. 15.14. Schematic diagram explaining signal production in vidicon.

Vidicon camera tube utilizes a target plate of a photoconductive material such as amorphous selenium. Fig. 15.14 gives the schematic diagram explaining signal production in vidicon. The signal plate is a conducting metallic film, so thin that it is transparent. This metallic film is deposited on the interior surface of the glass face plate. The other surface of the metallic signal plate is coated with a very thin layer (0.0002") of the photo-conductive material. The optical image is focussed on the exterior surface of the signal plate and the interior surface of the signal plate (*i.e.* the photoconductive material layer) is scanned by an electron beam originating at the cathode which is kept at a potential of –40 V with respect to the signal plate. A load resistor R_L (50 kΩ) is connected in series with the signal plate. The output voltage is developed across the load resistor R_L.

The photoconductive material has thickness less than a micron. Its resistance is high being about at 20 MΩ in dark and it falls to about 2 MΩ for high intensity light. The semiconductor layer is capable of storing charge across small elemental areas without appreciable lateral spreading and may, therefore, be considered to form a mosaic structure of isolated elements each equal to light dependent resistor in parallel with a capacitor.

Charge Image. When the scanning beam is incident on any picture element (pixel), the capacitance of the pixel gets charged by the beam (*i.e.* the beam deposits electrons on the pixel) with the result that the potential of the scanned side of the pixel reduces to the cathode potential. Thus immediately after having been scanned, the potential difference across a given pixel approximates 40 volts. However during the 1/25 second interval between the successive scans, the change leaks through the resistance of the pixel which resistance depends on the intensity of illumination of that element. More the intensity of light, less is the resistance of pixel, more is the charge leakage and less is the charge remaining on the pixel when the scanning beam arrives next time. Thus on the target surface, a potential or charge image gets created corresponding to the optical image focused on it.

When the electron beam scans any pixel next time, the beam deposits enough electrons to replenish the deficiency of charge to bring back the inner surface of pixel to cathode potential. The result is that as the electron beam scans the surface of the photoconductive material, the charge it deposits varies from element to element in accordance with the variation in the illumination of the successive elements. Hence the current through the load resistor R_L and hence the output voltage, reproduces the variation in the light intensity of successive element of the optical image being scanned.

Typically the signal peak current of 300 to 400 nA flowing through the 50 kΩ load resistor R_L produces output signal of 50 to 20 mV. The dark current is typically 20 nA.

Dark current. Even with zero illumination of the face plate, the photo-conductive layer has a large but finite resistance resulting in a slight discharge of the pixel capacitors and hence a small recharging signal current in the dark condition, called the *dark current*. This dark current increases with the increase of target voltage. It also varies with the nature of photoconductive layer and with its age.

Construction of Vidicon. Fig. 15.15 shows the construction of vidicon and also typical operating voltages at the various electrodes.

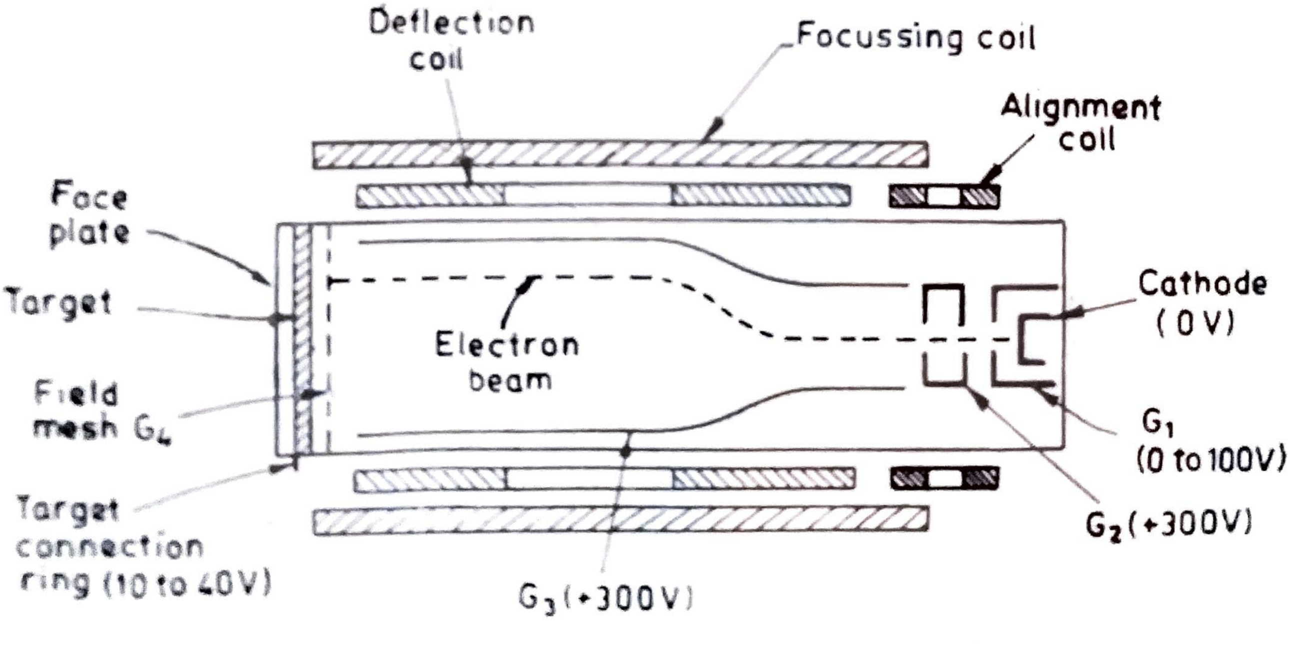


Fig. 15.15. Schematic diagram of vidicon camera tube.

In a commercial vidicon tube, the signal plate is deposited directly on the glass face plate. The scanning beam is obtained by suitable combination of the cathode, control grid G_1, accelerating grid G_2 and the anode grid G_3. The beam velocity within grid G_3 corresponds to about 300 V. The electrostatic field of G_3 (+ 300 V) and the magnetic field of the external focussing coil cause focus of the electron beam on the target. The vertical and horizontal deflection of the electron beam is obtained by sending saw-tooth currents through the deflection coils which produce transverse horizontal and vertical magnetic fields respectively. The alignment coil permits control of the initial direction of the electron beam. The field mesh grid G_4, having 300 to 1000 meshes per inch and usually connected to the grid G_3, serves to cause uniform deceleration of the electron beam in the region between the wire mesh and the target plate. Thus the electron beam approaches the target perpendicularly and at a low velocity so as to deposit electrons on the charge image without causing any secondary emission of the photoconductive surface.

Light Transfer Characteristics. Fig. 15.16 shows for vidicon tube the signal output versus illumination characteristics with dark current or the target voltage V_T as the parameter.

The gamma, *i.e.* the slope of the transfer characteristic on log-log scale lies in the range 0.4 to 0.6 for low target voltage and high illumination and in the range 0.8 to 0.9 for high target voltage and low illumination. The average value is thus only 65% of the linear gamma. This signifies that the transfer characteristics are noncritical of input lighting. Further such characteristics enhance the low-level details.

It is interesting to note that the gamma of vidicon tube is complement of the gamma of the receiving picture tube so that the two taken together produce light tone rendition without any gamma correcting circuit.

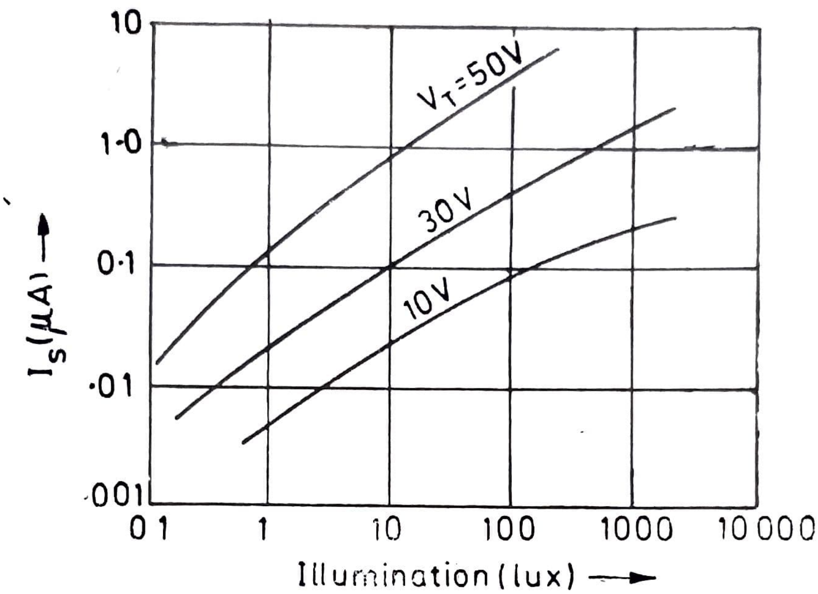


Fig. 15.16. Light transfer characteristic of a vidicon.

The remarkable feature of vidicon tube is that it may be used at different levels of illumination simply by changing the target voltage. Thus we may use the target voltage V_T for three categories of application as shown in Table 15.2.

Table 15.2. Values of Target Voltage V_T for Different Applications

Application	*Illumination obtainable (Lux)*	*Target Voltage V_T used*	*Resulting gamma*
Industrial	Low 0.1 to 10	40 V to 60 V	0.8 to 0.9
Studio	Medium 10 to 100	25 V to 40 V	0.6 to 0.8
Telecine	High 100 to 1000	10 V to 20 V	0.4 to 0.6

Vidicon lag. A major limitation of vidicon is its lag *i.e.* response not varying instantaneously with changes in light intensity; rather it takes time to adjust itself to the new level of illumination. Thus very rapid motion is not reproduced very satisfactorily. Fig. 15.17 shows typical lag or persistence characteristic of vidicon. For comparison, lag characteristic of plumbicon is also shown.

The overall vidicon lag is caused by the following two :

(*a*) beam lag
(*b*) photoconductive lag.

Beam Lag in Vidicon. This is caused by the slow recharging of the target elements by the beam and is determined by the time constant $C_T R_B$ where C_T is the element capacitance and R_B is the beam resistance.

The beam resistance

$$R_B = \frac{\text{Scanning face potential}}{\text{Landed beam current}}$$

Beam resistance R_B lies in the range 1 to 10 MΩ.

Photoconductive lag in Vidicon. This is caused by the slow response of photoconductive target elements to the changes in brightness. This causes smear or comet tail following a fast moving object in the scene. This lag may be minimized by using high illumination and limited contrast at the lowest target voltage necessary for the video signal.

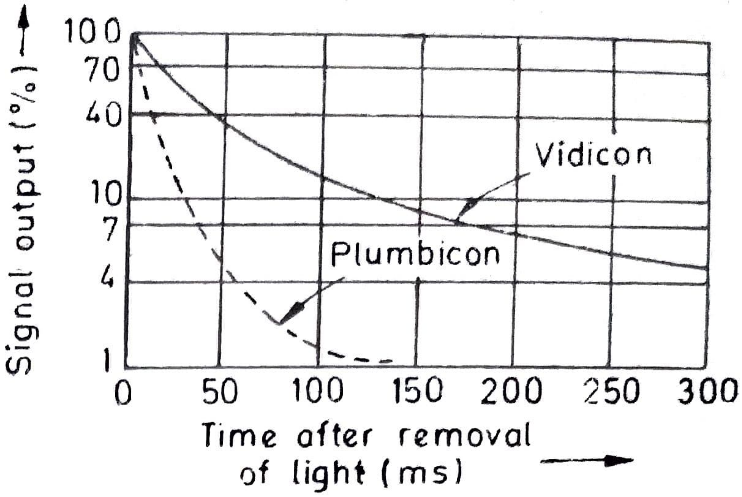


Fig. 15.17. Lag characteristic of vidicon and plumbicon.

Spectral Response. The spectral response of a vidicon is quite close to that of human eye. However, the spectral response may be modified to extend suitably into the infra-red or ultra-violet regions, by proper choice of target material.

Resolution. Typically vidicon has 400 lines or resolution for 55% modulation.

15.18. Plumbicon

The original plumbicon introduced by Philips in 1963 suffered from poor red response, contrast ratio limitations etc. The modern plumbicon has overcome these limitations. Modern plumbicon has the following merits :

(*i*) High sensitivity.

(*ii*) High signal to noise ratio of 50 dB.

(*iii*) Reduced lag.

(*iv*) High resolution of 40—50% at 400 lines (5 MHz).

(*v*) Gamma close to unity (0.9 to 1.0).

(*vi*) Simple and quick operation.

and (*vii*) Medium size, 16 mm ; 25 mm.

Fig. 15.18 gives schematic diagram showing the construction of the plumbicon. Plumbicon has electron gun and the scanning system similar to vidicon. Further plumbicon, in similarity with vidicon, uses the principle of photoconductivity. The photoconductive material used in plumbicon is lead monoxide (PbO) which has the merit of lower dark current, improved sensitivity and lower photoconductive lag as shown in Fig. 15.18. Directly on the interior surface of front glass plate is deposited a thin layer of tin oxide (SnO_2). This layer constitutes the signal plate. On the tin oxide layer is deposited a layer of intrinsic PbO. Finally a thin layer of *p*-doped PbO is deposited on the intrinsic PbO layer. The SnO_2 layer forms an *n*-type semiconductor. We thus have an intrinsic PbO layer sandwiched between *n*-type and *p*-type layers. These three layers together form a *pin diode*. The overall width of the target including all the layers is small being 10 to 20 μM. The size of the target is 20 mm (16 mm) diagonal in 30 mm (25 mm) plumbicon.

Scanning. The photo-electric conversion and scanning are similar to vidicon. The difference lies i the structure of each target element. In plumbicon, each element of target constitutes a small capacitor i series with a light controlled pin diode. With zero incident light, the pin diode is reverse biased and hen there is no conduction. Few electron-hole pairs are generated within the intrinsic PbO layer at normal operatin temperature because of the large forbidden energy gap. With usual bias of 30 V at the target, the dark curre