Preliminary Handout

The Plumbicon Camera Tube

Introduction

The target structure of the Plumbicon is significantly different from that of the Vidicon. These notes describe the composition of the Plumbicon target and the resulting electrical characteristics. Comparisons are made with the Vidicon to demonstrate the effects of the different target materials in the two tubes.

These notes are intended for use by students who have a basic understanding of photo-conductive tube operation including the scanning and focusing processes. The first section however is included as a brief revision of signal generation in photo-conductive ~~tubes~~.

Basic operation of photo-conductive tubes.

In the absence of light, the beam scans the target and maintains the scanned surface at about cathode potential. In this condition the target acts as a dielectric and the entire target becomes charged to the bias potential (say 45V) When the target is fully charged the beam no longer lands on the target but returns back down the tube to be collected by the anodes. There is no output signal current.

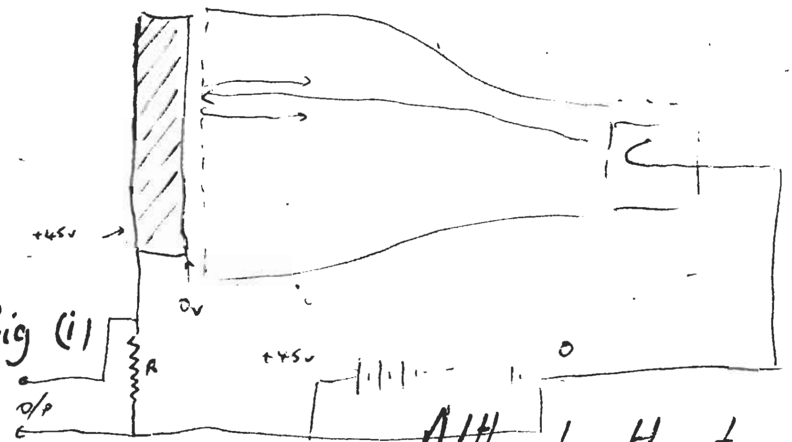


fig (i)

Although the target is deposited as a continuous layer on the signal plate, it is usually considered as a very large number of small elements. This is not unreasonable because leakage of charge from one part of the target to another is almost negligible. These elements all consist of part of the signal plate one one side, the semi-conductor in the middle and the scanned surface of the target as the other side of the element. The equivalent circuit of a part of the target is shown in fig(ii)

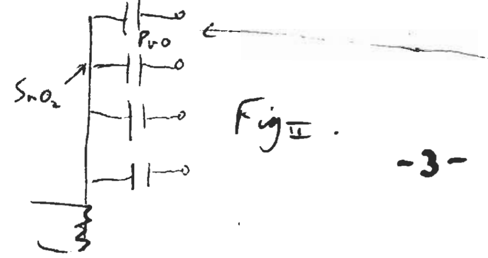
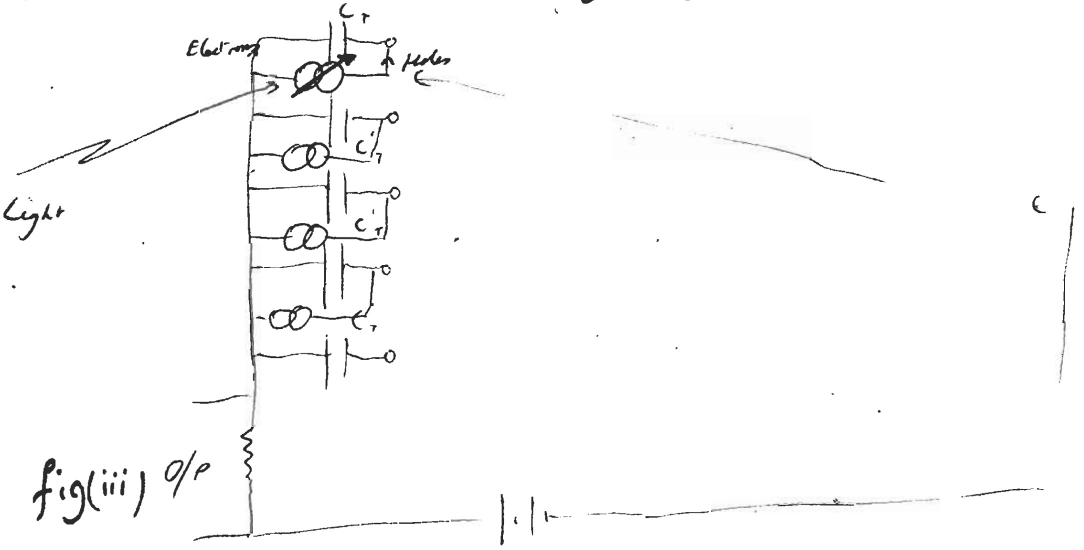


Fig II.

In fig (ii) the elements are shown as 'elemental capacitors' C'_T and the beam is represented by a switch which closes as the element is scanned.

The arrival of light energy at the target releases charge carriers within the target material. The potential (45 v) across the target causes the released electrons to flow to the signal plate and the holes to the scanned surface. The equivalent circuit is thus extended to include the mechanism of current generation by light energy:-

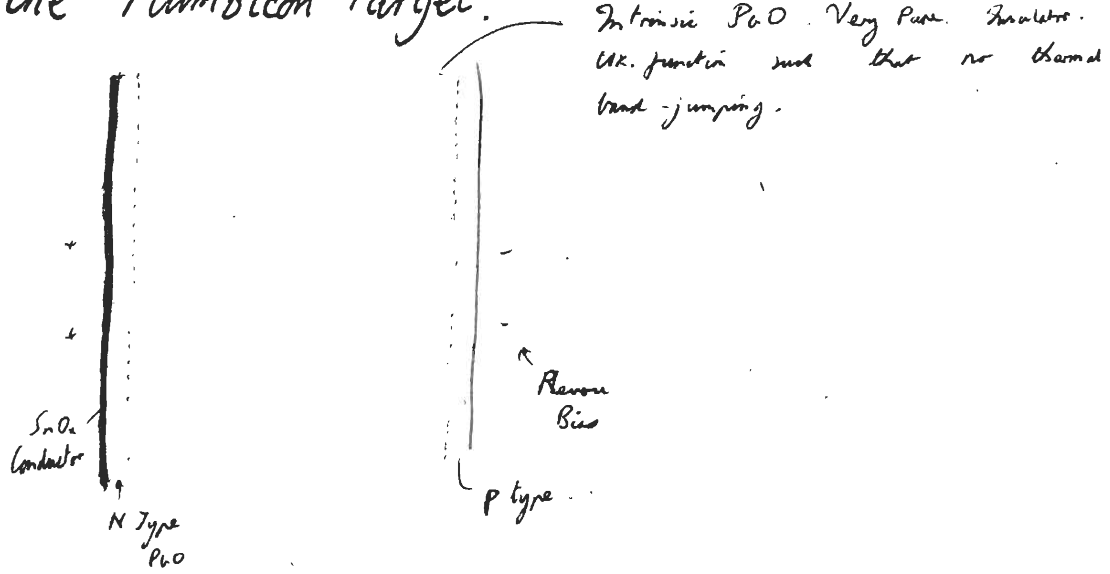


fig(iii) O/P

In this circuit the top element is shown illuminated. The photo-current i' is discharging the elemental capacitor.

When the beam next scans the element it will re-charge the capacitor thus causing a current flow in the load resistor. An output signal is therefore available.

Detail of the Plumbicon target.



fig(iv)

The NIP sandwich construction gives the Plumbicon a number of characteristics which differ significantly from those of the Vidicon (The Vidicon target is usually a layer of N type Antimony Trisulphide $Sb_2 S_3$).

The characteristics to be considered are:-

(i) Dark currents
(ii) Photo conductive lag.
(iii) Transfer Characteristic
(iv) Highlight beam lag. (Comets tails)
(v) Low light beam lag.
(vi) Resolution
(vii) Spectral response
(viii) Sensitivity
(ix) Ageing.

Dark Currents.

Current which flows through the target causes discharge of the elemental capacitors. If any of this current is caused by other than light energy it creates spurious signals on the reproduced picture. Such unwanted currents are known as 'dark currents'.

If current carriers are liberated - for instance by thermal energy - within the target, they will flow through the target under the influence of the bias voltage and cause elemental discharge. In the vidicon such currents can cause serious picture degradation.

In the Plumbicon, dark currents are kept to a very low level for the reasons given below.

(i) Intrinsic lead monoxide has a relatively high work function & thus considerable thermal energy would be required to produce electron-hole pairs within the I layer. At normal operating temperatures thermally generated carriers within the I layer are almost non-existent.

(ii) The doped N & P layers have a lower work-function than the I layer & thermally generated carriers are normally present. However only minority carriers can enter the I layer because of the diode action at both junctions. These are reverse biassed by the applied target potential. The dark currents in a Plumbicon thus exhibit the characteristics of the reverse current through a diode:-

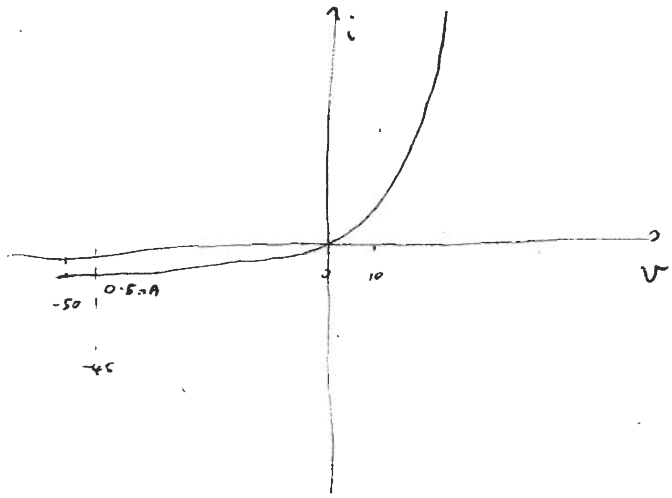


fig (v)

fig (vi)

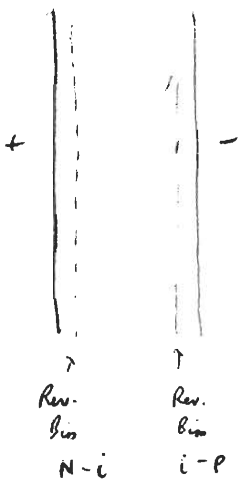


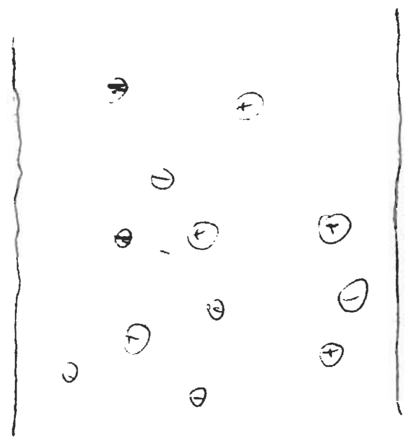
Photo-conductive lag

This defect is ~~or~~ one of the principal disadvantages of a vidicon. Unless a scene is very highly illuminated, and is of low contrast ratio, objectionable smearing will occur on moving objects. The reason is that the tube retains a 'memory' of the object. This memory continues to be read out (at rapidly decreasing amplitude) after the object has moved.

Another manifestation of p.c. lag is "print-through". If an actor moves in front of furniture, windows etc., the tube retains a memory of the background which is thus superimposed upon the actor. This gives the appearance that he is semi-transparent, i.e. the background "prints-through" the foreground.

The lag is produced by holes arriving at the scanned surface some considerable time after the energising light is removed. This 'trapping' of charge carriers & their subsequent release is explained below.

Consider a slice of doped (& hence impure) N type semi-conductor as in fig (vii)



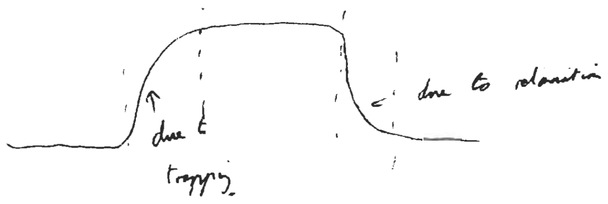


fig (vii)

The holes reach the negative plate either directly or after having been captured and released (probably many times) by the impurities. The capturing effect is not very strong & at normal temperatures there is a constant interchange between holes trapped and holes actually flowing through the crystal. The steady state relationship between holes actually generated + holes trapped is indicated approximately by the curve in fig (viii).

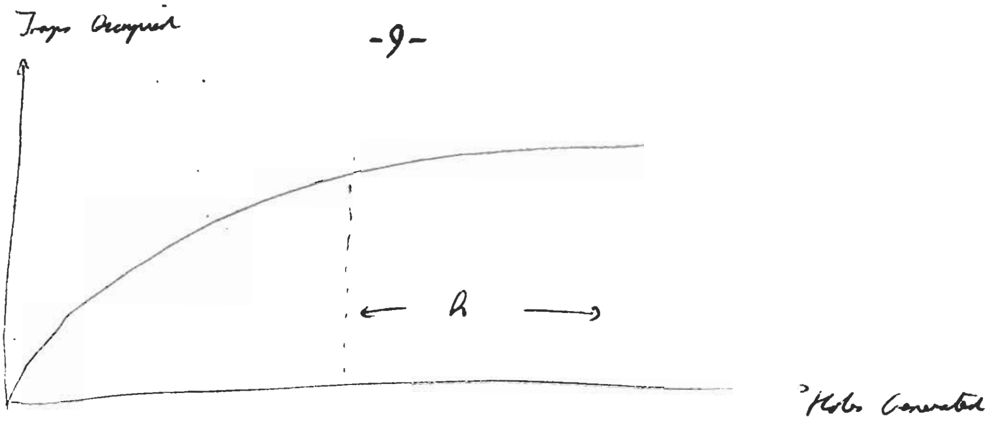


fig (viii)

As the light input is increased the number of trapped holes increases. If the light is removed the traps empty or 'dry out'. Unfortunately this drying out takes time & holes continue to arrive at the surface after the light is removed.

This is photo conductive lag.

If a camera tube target can be operated in region 'h' then p.c. lag will be negligible because the concentration of trapped holes does not alter – there is no effective filling up & drying out.

The vidicon has an impure target – many traps – & thus must be worked at very high light levels with low contrast to remain in the region h, thus reducing p.c. lag. This condition can only be satisfactorily met in telecine installations handling low density film; at studio lighting levels lag is almost inevitable

The plumbicon I layer which constitutes most of the target thickness is pure, – it has very few traps. Thus even at comparatively low light levels e.g. poorly lit corners of floodlit football grounds, the few traps which do exist are full. The tube is thus operated in region 'h' & p.c. lag does not occur.

Transfer characteristic.

The number of charge carriers released is proportional to the intensity of the incoming light. If all these carriers were to reach the target surface, & so discharge the target capacitance, then the steady state output signal would be directly proportional to the light input. (Trapping does not affect this argument since its effect is only evident during <u>changes</u> of light level).

In the vidicon such a linear relationship does not hold. A proportion of the released electrons & holes re-combines thus preventing them from contributing to the output signal.

The probability of recombination taking place is dependant upon:-

(i) The density of carriers being generated
(ii) The length of time they remain in the target
(iii) The crystal structure of the target material

Recombination in the Vidicon.

The probability of recombination in the vidicon target is high primarily because of the impurity of the target material. An impure crystal structure contains many discontinuities & it is at these discontinuities that recombination is most likely to take place. The probability is further increased as the light input increases because the carrier density ~~is~~ increases. The result is a transfer characteristic of the form shown in figs (ix) & (x)

fig (ix)

fig (x)

The gamma is typically around 0·6 in normal studio conditions.

The amount of recombination can be reduced by reducing the time spent by the carriers in the target. This is effected by increasing the target bias voltage as in fig (xi)

fig (xi)

Thus target bias may be used as a video gain control within the range giving acceptable dark currents.

Recombination in the Plumbicon.

The probability of recombination in the Plumbicon is low because the I layer contains very few discontinuities. Even at high light levels the loss in output due to recombination is very small. The output is therefore very nearly directly proportional to the input.

fig (xii)   fig (xiii).

The gamma is typically around 0·9 in normal studio conditions.

The Signal out/Target bias characteristic saturates at a very much lower voltage than the vidicon:

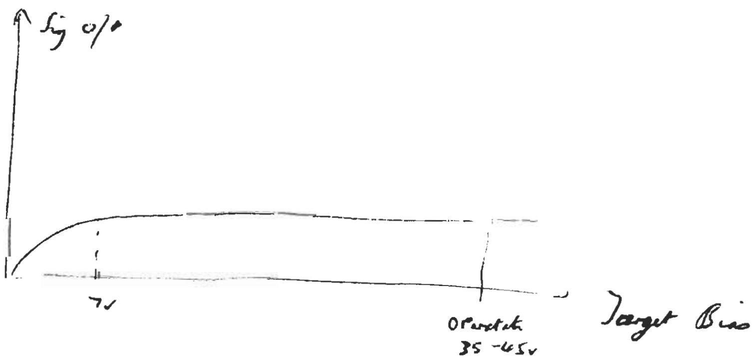


fig (XIV).

The Plumbicon is usually worked around $V_T = 45$ Volts + thus variation of V_T has little effect on the output signal.

PTO

The reason is that at biasses in excess of about 20V recombination becomes insignificant because all generated carriers are being swept quickly through the target. The tube is then said to be operating in the "photo-saturated" mode. At voltages ~~in excess~~ below 20V the carrier density increases and the probability of recombination becomes significant.

Highlight Beam Lag (Comets tails)

Since recombination in the Plumbicon is insignificant this implies that as the input light level continues to increase so the target capacitance will be more & more rapidly discharged between scans. At very high light levels, e.g. speculars from musical instruments etc, the recharging requirement for the beam will be so great that the beam will be unable to re stabilise the target in one scan. Once this condition occurs the scanned face will continue to rise in potential until it reaches target bias potential. The elemental capacitor is then completely discharged. Thus even if the highlight is removed it may take an appreciable number of fields to remove its effect from the target.

This is highlight beam lag.

It is especially noticeable on moving speculars which produce a trailing image or 'comets tail'. Stationary speculars produce a washed out appearance & beam pulling or 'ballooning' on highlights.

In order to reduce this effect Plumbicons are operated with as much beam current as possible - consistent with good resolution and geometry. This precaution is however only effective for slight overexposure & speculars will still create problems. One solution appears to be the 'Anti Comets Tail Gun'.

The recombination which occurs at high light levels in the Vidicon renders the effect negligible for normal values of beam current.

Low light beam lag.

In order to understand this form of lag it is necessary to reconsider the mechanism of cathode potential stabilisation.

It has been assumed that when the target falls to cathode potential no further landing of elections will take place. This would only occur if all electrons in the beam had left the cathode with zero initial velocity – in which case all electrons would be decelerated to zero velocity just before reaching the target. In practice the velocities vary as indicated in fig (xv) below.

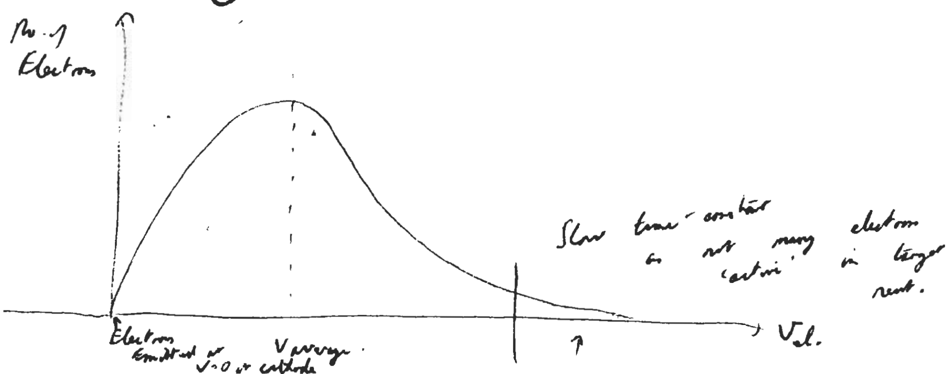


fig (xv)

The elections which left the cathode with greater than zero velocity will not be prevented from landing on the target when the target is at zero volts. The landing of the higher velocity (i.e. higher energy) electrons will thus quickly take the target slightly below cathode potential. However as the target continues to fall negatively so there are fewer & fewer electrons able to land & the rate at which the target goes more negative decreases.

It seems likely that a Plumbicon target can in practice fall to about ~~—~~ 0.75 volts negative under suitable conditions. A Vidicon target does not appear to fall significantly below cathode potential because the continuous dark currents provide a constant flow of holes to the scanned surface offsetting the effect of the high energy electrons in the beam. The Plumbicon does not have these dark currents.

At normal lighting levels the hole flow through a Plumbicon target is always sufficient to prevent the scanned face falling far below cathode potential.

At very low levels of scene illumination, however, most of the target does become significantly negative. Black parts of the scene are represented by perhaps −0.75 volts & lighter parts by some more positive value. Thus in order to remove the image of a moving 'highlight' the target must be restored ~~back~~ to black level i.e. −0.75 volts. This removal will take a long time because it can only be completed by the comparatively rare high energy electrons. Therefore in a scene with a poorly lit background — e.g. the corner of a floodlit football ground — lag will occur. This is clearly a form of beam lag.

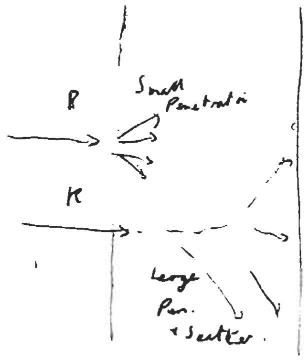
Plumbicons do therefore exhibit a low light lag but this is not photo conductive lag & is not nearly as significant as the photo-conductive lag of vidicons.

A technique involving bias lighting may soon be employed to reduce the effects of low light beam lag. See Appendix II.

Resolution.

The resolution of a Plumbicon is sufficient to give about 50% modulation at 5 MHz (625 line standard). This is appreciably worse than a vidicon which typically gives 60 - 65% modulation.

The principal reason for the difference appears to be light scatter within the target. The Plumbicon target is up to twenty times as thick as that of the vidicon. The effects of light scatter are much more serious :-



PbO → Brown

∴ Blue Absorb.

fig (xvi).

Separation of the field mesh from the wall anode was effective in improving vidicon resolution but has little or no effect in the Plumbicon because the poor resolution is much more a function of target thickness than of beam cross-section. Separate mesh Plumbicons do not have inherently better resolution than integral mesh types.

The Plumbicon target cannot be made thinner unless reduced response to red light can be accepted — see next section.

Spectral Response.

For every photo conductive material there is a threshold wavelength beyond which photons have insufficient energy to create electron-hole pairs. Thus for a given target material there ~~be~~ is a wavelength beyond which there is no response.

The Vidicon threshold is in the infra-red region & thus the Vidicon has adequate response to red light.

Intrinsic lead monoxide however has a threshold wavelength of 620nm (orange). It does not respond to the longer (red) wavelengths. The Plumbicon however does not exhibit a sudden cut-off at 620nm ~~because~~ principally because of the effect of impurities around the I-P junction & the effect of the few traps that do exist even in the I layer. (The lower ~~lower~~ energy photons below 620 nm have sufficient energy to raise electrons from impurities & traps into the conduction band.) There is still therefore considerable response up to 650 nm.

The response can be extended further by increasing the target thickness thus increasing the probability of a photon being absorbed before it passes through the target. The disadvantage is the consequent loss of resolution.

Alternatively the I layer may be doped to increase the number of traps. This however may bring back problems of re-combination and of photo conductive lag.

At the blue end of the spectrum the response falls due to the early absorption of the shorter wavelengths. The shorter the wavelength the shorter the penetration of light into the target. Ultra-violet radiations are absorbed in the N region before they reach the I layer, the carriers are thus not available for conduction through the target.

The overall characteristic is shown in fig (xvii)

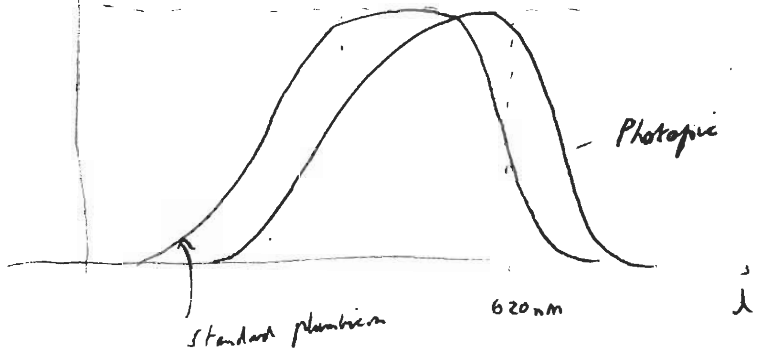


fig (xvii).

Sensitivity.

Under normal operating conditions the sensitivity of the Plumbicon is approximately four times that of a modern vidicon.

Typically a Plumbicon provides 400-550 μA per lumen & a Vidicon 100-150 μA per lumen.

It must be noted however that the number of μAmps per lumen is not the sole criterion of sensitivity. In a Plumbicon a reduced input will produce a reduced output & thus the signal to noise ratio will deteriorate - as would be expected. In a vidicon however it is not possible to 'trade' signal-to-noise ratio against light input because the limit to low light working is invariably imposed by unacceptable photo-conductive lag long before the signal-to-noise ratio becomes unacceptable. Furthermore it is not possible to increase target volts to take the vidicon into photo saturation because of the increase in dark currents.

Thus the Plumbicon not only inherently produces more signal for a given light input but will work at much lower levels than a Vidicon because it does not suffer from photo-conductive lag or appreciable dark currents.

Ageing

Gradual decomposition of the target takes place, particularly in the P region which is subject to ion bombardment. The PbO reverts to lead and gaseous oxygen – the oxygen being absorbed by the barium getter.

The process of losing oxygen gradually renders the ~~region~~ scanned region less P type & the diode action becomes less pronounced. Dark currents increase slowly throughout the tubes life but the rate of increase becomes much greater as the diode barrier disappears.

This barrier breakdown may occur locally considerably ~~E~~ earlier than the breakdown of the whole target. This effect produces small bright specks on the reproduced picture.

Appendix I

Anti Comet Tail (ACT) Gun

Specular highlights cause beam starvation because the charge lost by the incremental capacitors cannot be restored in one pass of the scanning beam. The ACT gun (or Highlight Overload Protection - HOP - gun) ensures that excessive demands are not made of the beam during the forward scan.

In principle the method is simple. Each line is 'pre-scanned' during the flyback from the previous line. The cathode is held at about 6 volts above normal during flyback. Thus any part of the line above 6 volts is stabilised to cathode potential - i.e. +6 volts by the flyback beam. Any parts below 6 volts are unaffected. (6 volts corresponds to normal peak white). During the forward scan any specular - which had produced +45 volts on the scanned surface - will now be represented by about +6 volts i.e. normal peak white.

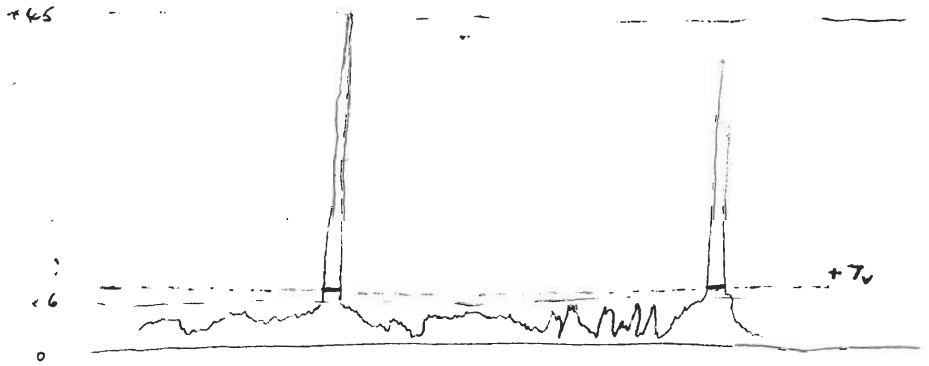
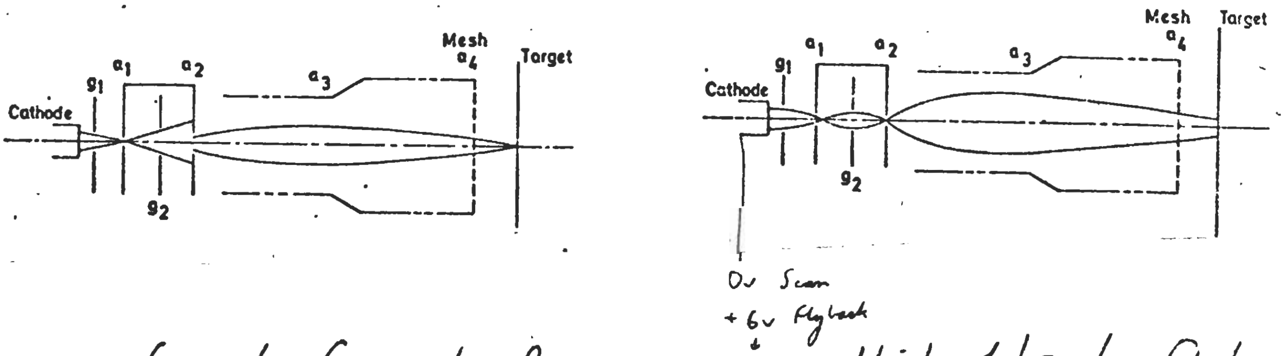


fig (xviii)

During flyback the beam travels approximately ten times as fast as during the forward scan. It is also expected to stabilise potentials more than six times as great. Additionally the beam cannot be as well focussed as the normal beam. In practice the beam current during flyback is in the range 75-100 μA - compared with approximately 0.5 μA for peak white on the forward scan.

The electron gun of the ACT tube is arranged to alter the focus node within the gun during flyback. This has the effect of increasing the beam current by removing the limiting aperture action of second anode.



Normal Forward Scan High Intensity Flyback.

fig (xix).

Flyback is complete before the end of camera blanking & thus clamping may take place before the start of the active line period.

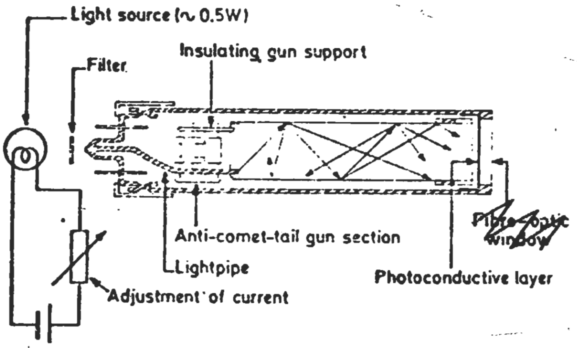
Appendix II

Bias Lighting

The vidicon target does not stabilise to a potential significantly below that of the cathode. The absence of dark currents in the Plumbicon permit the target to be stabilised at some potential negative w.r.t. cathode. As has been explained this produces low light-beam lag.

This form of lag may be prevented by introducing controlled 'dark currents'. The entire target is evenly illuminated from a small light source. This produces an even 'sit-up' on the output signal which may easily be 'sat-out' by the lift control. The target will fall significantly below cathode potential & low light lag will not occur.

One method of light biassing is shown below:



Alternatively a bulb within the tube or the introduction of light through the dichroic block may be employed. The latter technique has the advantage that it may be used with standard tubes.