OPTICAL PERCEPTIONS

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SLATERSVILLE DIVISION • AMPEREX ELECTRONIC CORPORATION • SLATERSVILLE, RHODE ISLAND 02876

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PLUMBICON® APPLICATION BULLETIN NO. 34

LAG AND LIGHT BIAS IN LEAD OXIDE TUBES

INTRODUCTION

The objective of this bulletin is to acquaint you with the phenomenon that occurs in camera tubes whose effect can cause picture smear, color fringing errors and at times a measurable loss in resolution. We will show how the phenomenon called lag can occur under some conditions and not under others, and how simple operating procedures can help to minimize it. Also we will present some clarifications as to what the lag measurements mean. Finally, we will describe how bias lighting, a low level uniform illumination of the photoconductor, will significantly reduce the effect of lag under low lighting conditions.

In order to better understand the concepts of lag, the first section of this bulletin is a brief review of the operating principles of lead oxide tubes.

OPERATING PRINCIPLES OF THE PLUMBICON TELEVISION CAMERA TUBE

In the Plumbicon camera tube, the photosensitive layer is composed of lead oxide, the properties of which are quite different from those of the ordinary antimony trisulfide vidicon. As shown in Figure 1, the cross-sectional appearance of the lead oxide layer takes the form of a P-I-N junction diode reversed biased by the target voltage of approximately 40v. When light strikes the photoconductor, electron-hole pairs are generated within the intrinsic region and are swept toward their respective N and P contacts. This results in the photoconductor being partly discharged. As a consequence of this a pattern of positive charges will be produced on the P material, the amount of charge being directly dependent upon the amount of light. The scanning beam, seeing this positive charge, will deposit enough electrons to replenish the charge lost due to the photocurrent. The current flowing within this series circuit consisting of the P-I-N junction layer, scanning beam and target voltage supply is the signal current. Simply stated, the photoconductor layer is discharged by the photocurrent and recharged **by the beam, resulting in an equilibrium potential close to the cathode potential. Any change in the photocurrent results in a change of the equilibrium potential.**

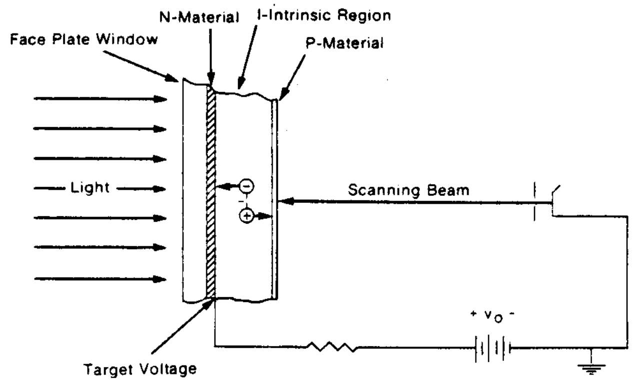

Figure 1: Cross-sectional view of Plumbicon layer

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LIGHT, LAG AND EFFECT IN ANY CAMERA TUBE

We have mentioned in the preceding paragraph that the amount of signal current is directly dependent on the amount of light. Therefore, as the amount of light at the faceplate of the tube changes, the signal current should change at the same rate. It is not uncommon that for a rapid change in light there will be a delay, or lag in the corresponding change in signal current. This rapid change in light can be an increase in light or a decrease in light. The term for lag under the conditions of an increase in light is "build up" or "rise lag" and the term for lag under the conditions of a decrease in light is "decay lag."

The results of this delay of signal current, whether it is rise lag or decay lag, can have an influence on the reproduced picture and is most noticeable at low light levels and when high contrast objects move across a low contrast background. One effect of lag is to produce smearing in the picture and color fringing when only one tube in a color camera is slow in responding to the change in light. This characteristic is also seen as a reduction in the ability to resolve moving objects.

THE CAUSE FOR LAG IN LEAD OXIDE TUBES

We have stated that the delay or lag is the function of the time for the signal current to change. The time required for the signal current to change depends mainly on two characteristics of lead oxide tubes. One is the capacitance of the photoconductive layer. The other is the resistance of the beam which depends on the beam acceptance (inverse of resistance) as a function of the potential of the picture elements, and is determined by the velocity spread of the electron beam. A summation of this can be represented by the formula $t = Rc$ where:

t is the time for the change
R is the resistance of the beam
c is the capacitance of the layer

Remember the formula $c = KA/d$ where:

c is capacitance
K is the constant for the material
A is the Area
d is the thickness of the material (in a capacitor this is the distance between the plates)

We can see from this formula that the target capacitance can be reduced by scanning a smaller area or increasing the thickness of the layer. The limitations here are that in both situations the resolution will become adversely affected. The requirement for an acceptable response at a given frequency, say 5 MHz (400 TV lines) determines what the scan size and layer thickness is for a given tube.

Since the resolution limit is a direct function of the scan size and thickness this leaves the beam resistance or (R) as the main contributing factor to beam discharge lag.

To explain beam resistance we will consider one photo conductive target element from which the light has just been removed.

NOTE:
A similar situation would exist in panning a camera from a light area to a dark one, or having a bright object move across the dark background.

At the instant the light is removed the element will be at a positive potential with respect to the cathode. In the first few scans the electron beam deposits sufficient electrons of both high energy and low energy to lower the target potential close to the cathode potential. Now, because the target potential is lower, only higher energy electrons can be deposited in succeeding scans and the acceptance of the beam decreases or, inversely, the resistance to the beam increases. An equilibrium is reached when the charge deposited in one scan of the element is equal to the charge lost due to dark current.

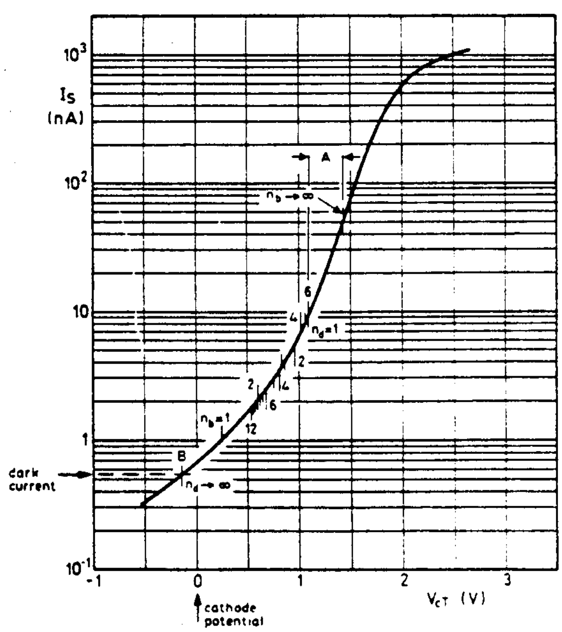
NOTE:
Since no photoconductor is perfect, there will be a small current flowing through the target element in the absence of light. This is referred to as dark current.

Remember that the dark current, like the photocurrent, will discharge the target element requiring the beam to recharge the element.

As we mentioned earlier, when the light is removed the beam acceptance decreases even further with each successive scan. This gradual decrease of beam acceptance, and hence a gradually decreasing signal current after a change in light from white to black, is termed decay lag.

If now the target element is exposed to a small amount of light (the worst condition for lag) the charge potential due to signal current flowing in one frame period will be low (a signal current of 20nA corresponds to only 0.6 volts change in target potential). Since the potential is low during the first scan, only high energy electrons will play a role in reaching the new equilibrium level. But as the signal current continues, the potential of the element will increase and the lower energy electrons will begin to participate in charging the layer to the new equilibrium level. Therefore, beam acceptance increases or beam resistance decreases. Again an equilibrium will be reached when the beam just replenishes in one scan of the element the charge lost during one frame period due to signal current. The time required for this change is again dependent on the velocity spread of the beam electron which represents the difference between the highest energy and the lowest energy electron. This build up of beam acceptance after a change in light from black to white is termed rise lag.

Figure 2 illustrates the growth and decay of beam acceptance with the switching on and off of a 20nA signal current.



Signal plate current Is as a function of the potential V_{CT} at the cathode side of the target. The points n_b = 1, 2, etc. indicate the level of V_{CT} immediately after the beam has scanned the target in the nth field after switch -on of a 20 nA photocurrent: the corresponding points following switch-off are n_d = 1, 2, etc. The equilibrium-state potential swing for A for a 20 nA photocurrent is approximately 0.4 V, and the equilibrium-state potential swing with the photocurrent switched off is approximately 0.011 V. Target capacitance, 1.1 nF; dark current, 0.6 nA; cathode current, 290 uA.

Fig. 2

THE MEASUREMENT OF LAG

In the graph of Figure 3 we illustrate the lag of signal current of a theoretical increase and decrease of light. The usual measure of lag is given in terms of relative output in the 3rd field and 12th field respectively. To state it more simply we will define rise lag and decay lag separately:

Rise Lag:
The percentage of the ultimate signal current reached at a specified time after the light has been applied to the face plate of the tube.

Decay Lag:
The percentage of the original white signal current left at a specified time after the light has been removed.

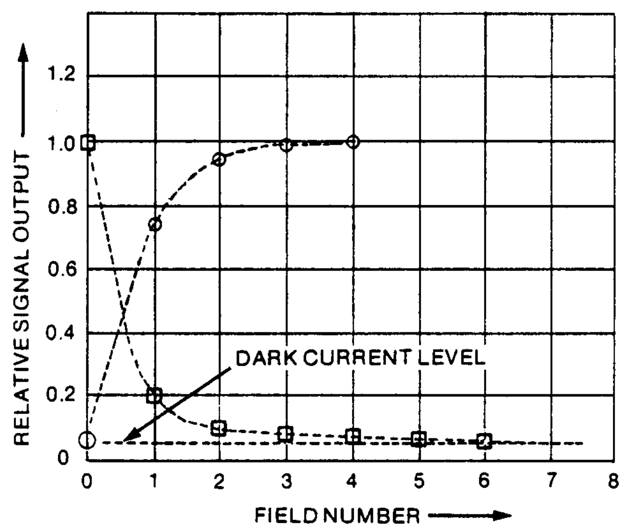


Fig. 3
Rise time and decay of the relative signal output resulting from a change in light on the faceplate of the tube.

HOW TO MINIMIZE LAG

Some operating conditions which can cause an increase in lag are misalignment of the scanning beam, low target voltages, operating with excessive beam (higher energy electrons are present in large quanitities at higher beam currents) and with low signal currents. The first three conditions can be controlled by using a proper set up procedure. However, lighting conditions which produce low signal current or high contrast scenes are less likely to be under you control.

In order to see how we can reduce lag under this condition, we need to consider again the basic problem: the velocity spread of the electron beam has an effect on beam acceptance. Because the dark current is very weak, elements held in the dark are gradually charged to a negative potential with respect to the cathode by the high energy electrons in the beam. If a good level of beam acceptance is to be maintained, this build-up of negative potential must be prevented. One way to do this is to increase the dark current by introducing bias lighting to the tube. Figure 4 shows that below a certain value, depending on beam current, the dark current has a very pronounced effect on the build-up lag. Ideally, the dark current should be so chosen such that for a given energy distribution of the beam electrons, the beam acceptance of electrons with energies from 0 to a few electron-volts will be sufficient to replenish in one scan of the element the charge lost in one frame period. One of the earliest methods of doing this was to introduce bias lighting into the prism with one or two small lamps. Due to the angle of the light and the intensity distribution of the light, dark current shading could result.

An alternate way of bias lighting is internal tube light biasing. Light from a lamp at the rear of the tube is transmitted to the scan side of the layer via two internal light pipes. This has become the accepted method because of more uniform shading characteristics which result from it.

It has been found that a very small increase of dark current (1 to 8nA) has a pronounced effect on decreasing rise lag. This is shown in Figure 4. As the intensity of the bias light is increased the greater will be the improvement in lag performance. However, an optimum operational point is reached when any further small improvement in lag can be obtained only at the expense of the deterioration of dark current shading.

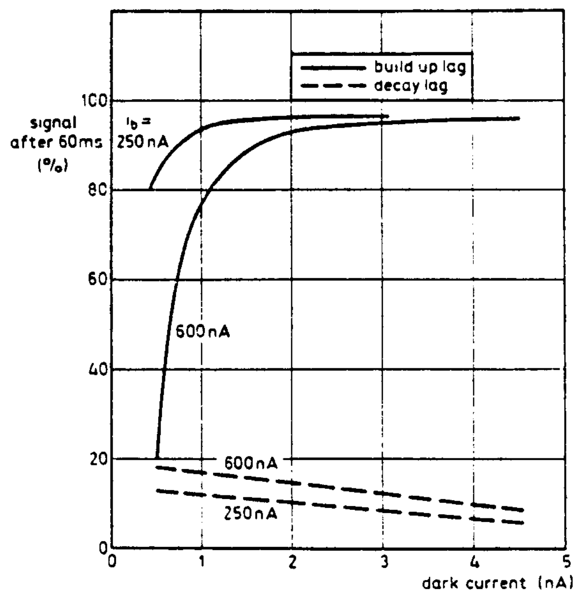


Fig. 4
Lag of a Plumbicon XQ1410 represented as function of bias light with beam current as a parameter. NOTE: reduction in build-up lag with increased dark current. Signal current 20nA; target voltage 45V; target capacitance 0.8 nF.

The Amperex XQ1410 series tubes employ the scan side bias light method of internal light biasing and will be discussed in greater detail in Bulletin No. 35.

Lag and Light Bias in Lead Oxide Tubes

How the new technologies have reduced light lag in camera tubes.

by Gregory Murphy and Robert Heroux

TELEVISION CAMERA tubes are subject to lag, which is most evident as picture smear, color fringing errors, and, at times, a measurable loss in resolution. In many cases, operating procedures can help to minimize lag. But under low-light conditions a surer method to minimize lag is to use bias lighting—a low-level uniform illumination of the photoconductor.

In order to better understand the concepts of lag, let's review the operating principles of lead oxide tubes, a popular type of camera pickup tube.

In the Plumbicon® camera tube, the photosensitive layer is composed of lead oxide, the properties of which are quite different from those of the ordinary antimony trisulfide vidicon. As shown in Figure 1, the cross-sectional appearance of the lead oxide layer takes the form of a P-I-N junction diode reversed bias by the target voltage of approximately 40V. When light strikes the photoconductor, electron-hole pairs are generated within the intrinsic region and are swept toward their respective N and P contacts. This results in the photoconductor being partly discharged. As a consequence of this discharge, a pattern of positive charges will be produced on the P material, the amount of the charge being directly dependent upon the amount of light. The scanning beam, seeing this positive charge, will deposit enough electrons to replenish the charge lost due to the photocurrent. The current flowing within this series circuit, consisting of the P-I-N junction layer, scanning beam and target voltage supply, is the signal current. Simply stated, the photoconductor layer is discharged by the photocurrent and recharged by the beam, resulting in an equilibrium potential. Any change in the photocurrent results in a change of the equilibrium potential.

Light, Lag and Effect in Any Camera Tube

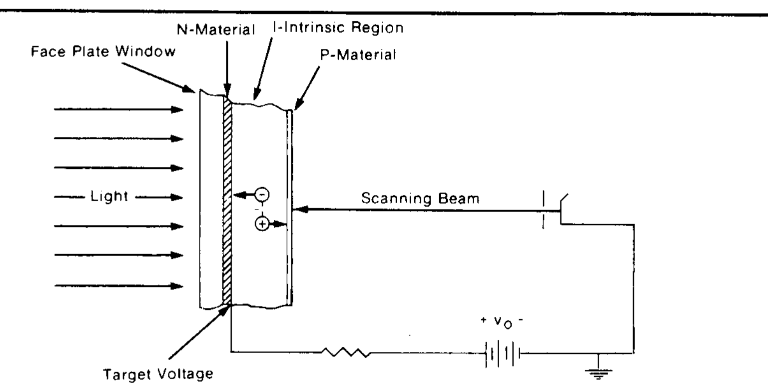
We have mentioned in the preceding paragraph that the amount of signal current is directly dependent on the amount of light. Therefore, as the amount of light at the faceplate of the tube changes, the signal current should change at the same rate. It is not uncommon that for a rapid change of light there will be a delay, or lag, in the corresponding change in the signal current. This rapid change in light can be an increase or a decrease in intensity. The term for lag under the conditions of an increase in light is "build up" or "rise lag", and the term for lag under the conditions of a decrease in light is "decay lag."

This delay of signal current, whether it appears as rise lag or decay lag, can have an influence on the reproduced picture. It is most noticeable at low-light levels and when high contrast objects move across a low-contrast background. One effect of lag is to produce smearing in the picture and color fringing when only one tube in a color camera is slow in responding to the change in light. This characteristic is also seen as a reduction in the ability to resolve moving objects (dynamic resolution).

The Cause for Lag in Lead Oxide Tubes

We have stated that the delay or lag is the function of the time needed for the signal current to change. The time required for the signal current to change depends mainly on two characteristics of lead oxide tubes. One characteristic is the capacitance of the photoconductive layer of the tube. The other is the resistance of the beam. For practical purposes, this is the parameter that can be impaired most readily.

To explain beam resistance let us consider one photoconductive target element from which the light has just been removed (as in panning a camera from a light area to a dark one, or having a bright object move across a dark background). At the instant the light is removed, the target element will be at a positive potential with respect to the cathode. In the first few scans, the electron beam deposits sufficient electrons of both high energy and low energy to lower the target potential to closer that of the cathode potential. Now, because the target potential is lower, only higher energy electrons can be de-



Cross-Section of Plumbicon Layer

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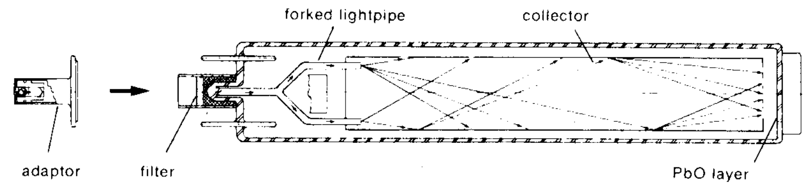

Light Bias in the Plumbicon Tube

posited in succeeding scans and the acceptance of the beam decreases, or inversely, the resistance to the beam increases. An equilibrium is reached when the charge deposited in one scan of the element is equal to the charge lost due to dark current. Since no photoconductor is perfect, there will be a small current flowing through the target element in the absence of light. (This is referred to as dark current.)

How To Minimize Lag

Some operating conditions which can cause an increase in lag are *misalignment* of the scanning beam, *low target voltages*, operating with *excessive beam* (when higher energy electrons are present in large quantities at higher beam currents) and with *low signal currents*. The first three conditions can be controlled by using a proper set-up procedure. However, lighting conditions which produce low signal current or high contrast scenes are less likely to be under your control.

In order to see how we can reduce lag under the condition of low signal current, we need to consider again the basic problem: the velocity spread of the electron beam has an effect on beam acceptance. Because the dark current is very weak, elements held in the dark are gradually charged to a negative potential with respect to the cathode by the high energy electrons in the beam. If a good level of beam acceptance is to be maintained, this build-up of negative potential must be prevented. One way to do this is to increase the dark current by introducing bias lighting to the tube. Below a certain value, depending on beam current, the dark current has a very pronounced effect on the build-up lag. Ideally, the dark current should be chosen so that, for a given energy distribution of the beam electrons, the beam acceptance of electrons with energies from 0 to a few electron-volts will be sufficient to replenish, in one scan of the element, the charge lost in one frame period. One of the earliest methods of doing this was to introduce bias lighting into the prism with one or two small lamps. Due to the angle and the intensity distribution of the light, dark current shading could result. An alternate way of bias lighting is internal tube light biasing, as in the XQ1410 tube.

The XQ1410 family is constructed to provide two balanced light pipes traveling up the tube from the base or tipoff to within the G3 collector assembly. With the light bias adaptor, light is transmitted through the light pipes into the interior of the collector where it is diffused to evenly illuminate the scan side of the target. In the development of internal light biasing, it was determined that two light pipes, rather than one, provide the best overall illumination, thus the optimum uniformity of induced dark current.

When compared to the non-light biased 30mm lead oxide tubes, the XQ1410 shows a 37% improvement in rise time lag and a 50% reduction in decay lag. In terms of differential lag (the difference in lag characteristics between the red, blue, and green in any one camera), with the XQ1410 family it is possible to reduce the differential decay lag to less than 1%. □

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