THE PLUMBICON

A CAMERA TUBE WITH A PHOTOCONDUCTIVE LEAD OXIDE LAYER

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The Plumbicon: A Camera Tube With a Photoconductive Lead Oxide Layer

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The photosensitive layer of the Plumbicon is an evaporated microcrystalline layer of lead monoxide. The most significant advantages of the Plumbicon are the low dark current, the high speed of response, which is independent of light intensity, and the high sensitivity. In the Plumbicon, every picture gives a signal that is dependent solely on the light-intensity projected on that particular picture element within the proper time-limits and is unaffected by disturbing effects known from other pickup tubes. This new tube is expected to prove especially suitable for color television.

THE PLUMBICON* is a small, lightweight television camera tube which utilizes the photoconductive properties of lead-monoxide (PbO) (Figs. 1, 2) instead of Sb_2S_3 or Se as is normal for camera tubes of the vidicon type. The photoconductive layer is applied to a transparent and conductive SnO_2-layer which is deposited on the tube face and is used as a signal electrode. The photoconductor is an evaporated microcrystalline layer of the red, tetragonal modification of PbO, which has a bandgap of 2.0 ev. The thickness of this layer is 10 to 20 microns, and the crystallites are needles with dimensions of about 0.1 to 1.0 micron.

Externally a Plumbicon tube is 20 cm long (8 in.) and 3 cm ($1\frac{1}{4}$ in.) in diameter. The useful sensitive area is 2 cm (0.8 in.) in diameter. From these figures it can be concluded that neither the thickness of the layer nor the dimensions of the crystallites limit the resolution of this camera tube, since the distance between two adjacent television lines is about 20 microns.

The principles of operation of this pickup tube are as follows: Each picture element represents a capacitor, one plate of which is at the positive potential of the signal electrode and the other floating, that discharges as a result of leakage through the layer. The amount of charge which leaks through the layer depends on the illumination; hence there appears on the gun side of the entire layer surface a positive potential pattern composed of the various element potentials, corresponding to the pattern of light whose image is formed on the layer. When this positive potential pattern is scanned by the electron beam, electrons are deposited from the beam on the layer until the surface potential is reduced to that of the cathode of the electron gun. These charging currents of the capacities of individual picture elements constitute the video signal. Complete storage of the information present in the light beam will be achieved if the discharging time constant of the target capacity is greater than the frame period.

From this follows the requirement that the specific resistance of the photoconductor must be greater than 10^{10} ohm/cm. There are of course requirements for all the parameters of this type of camera tube which have necessarily to be fulfilled simultaneously in order to make it a useful pickup tube in practice. The most important parameters are:

(1) dark current or other spurious signals;

(2) resolution;

(3) sensitivity: (a) sensitivity to incandescent light determining to a large extent the signal-to-noise ratio; (b) spectral sensitivity;

(4) speed of response.

It will be obvious that the above parameters are determined to a large extent by the physical properties of the photoconductive layer. The photoconductor of a Plumbicon tube consists in principle of three layers. The layer in the middle is almost pure lead-oxide; in other words, it is an intrinsic semiconductor. In the layer on the gun side the lead-oxide is transformed by an appropriate doping process into a *p*-type semiconductor, and on the side of the signal electrode (SnO_2) into an *n*-type semiconductor. The doped areas are both thin in comparison with the total thickness of the lead-oxide layer.

This means that the photoconductive layer of a Plumbicon tube is, in principle, when the tube is in operation, a *p-i-n*-diode connected in the reverse direction (Fig. 3). The fact that the Plumbicon can satisfy the stringent demands of broadcast television is largely the result of this special *p-i-n*-diode structure of the photoconductive PbO layer.

As expected, the dark current of a Plumbicon has a diode characteristic (Fig. 4), which means that it becomes saturated as target potential increases. As a result of this very low dark current the absolute variation of the dark current will also be small, therefore the black level uniformity is extremely good. This becomes especially important when the Plumbicon tube is used in color-TV cameras.

An ideal pickup tube would be one in which every picture element gave a

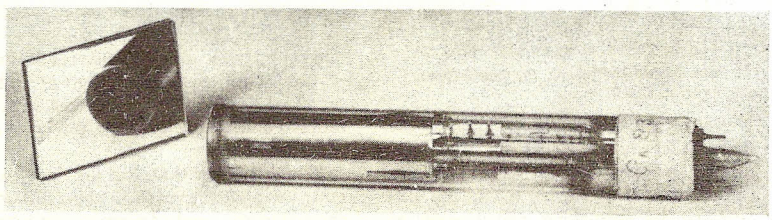

Fig. 1. The Plumbicon tube.

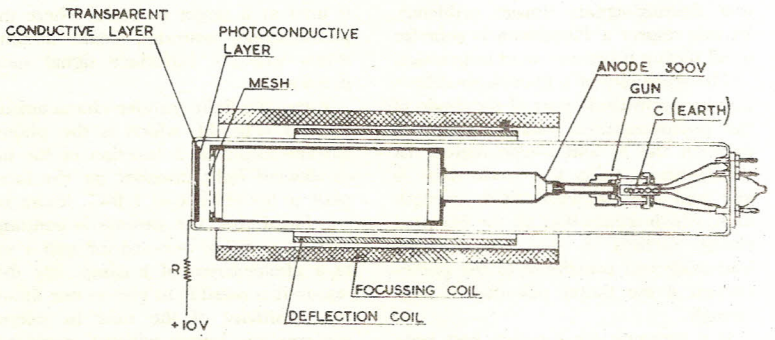

Fig. 2. Diagram of the Plumbicon.

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* E. F. de Haan, A. v. d. Drift and P. P. M. Schampers, *Philips Technical Review*, *25:* 1963/64, no. 6/7.

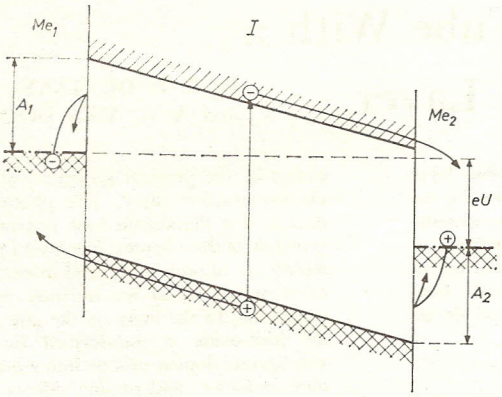

Fig. 3. The p-i-n diode structure of the Plumbicon tube.

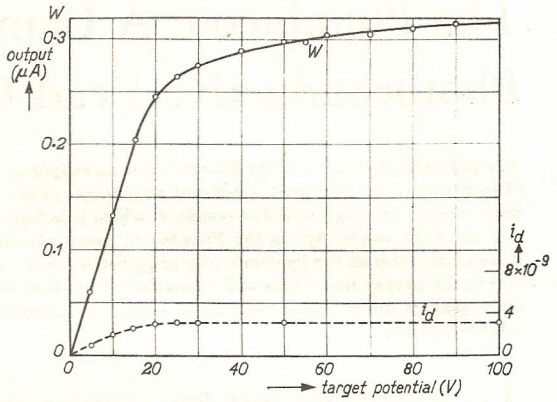

Fig. 4. Photocurrent of a Plumbicon versus target potential (ordinate on the left) exposed to incandescent light of 2870 K (W). Dark current versus target potential (ordinate on the right).

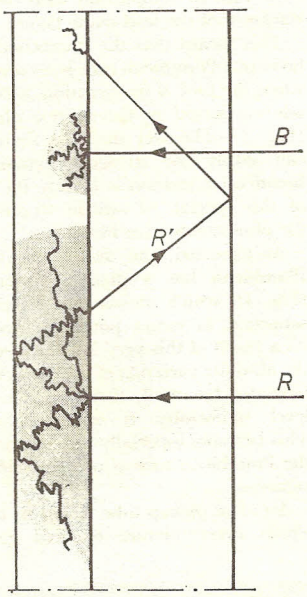

Fig. 5. Effect of light scattering in the photoconductor on resolution.

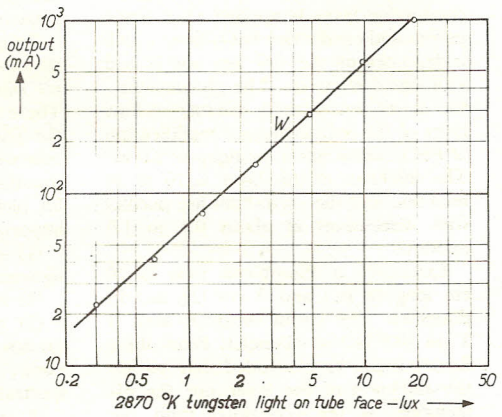

Fig. 6. Light transfer characteristic of an average Plumbicon tube.

signal which was solely dependent on the light intensity projected on that particular picture element in the proper time limits and which would be unaffected by disturbing effects such as dark current and persistence of the photoconductor (Sb_2S_3 vidicon), dark halo and shading-signals (image orthicon). In this respect a Plumbicon is superior to all pickup tubes now used in practice.

The sensitivity of a Plumbicon tube is due to the intrinsic part of the diode of the photoconductor which is situated between the *p*- and *n*-type region. In this intrinsic region the conductivity is low and the electrical field strength high, which means that all the liberated charge carriers in this area of the lead-oxide will contribute to the photocurrent if the target potential is high enough.

If a common *p-n* junction had been used the sensitivity would have been low because the effective intrinsic area would then have been very thin.

A high sensitivity can therefore be obtained by making the *i*-region as thick as possible. The optimal thickness is determined by the desired resolution, especially for red light (Fig. 5). The scattered light will cover an area with a radius comparable with the thickness of the layer.

It will be clear that, like the dark current, the photocurrent will show a diode characteristic and become saturated with increasing target potential (Fig. 4).

It can be understood that, if the tube is used at a target potential where the photocurrent saturates, beam landing errors will not introduce signal nonuniformities.

From the light transfer characteristic ($i = L^{\gamma}$) (Fig. 6), which is the photocurrent-output as a function of the incandescent light intensity on the faceplate in lux (10 lux $\approx$ 1 ft-c), it can be concluded that the gamma is constant and has a value between 0.8 and 1 up to a photocurrent of 1 μamp. For this reason it is possible to give in one figure the sensitivity of the tube in microamperes per lumen without specifying what light-intensity has been used. For the Plumbicon tube a sensitivity of 300 μamp/lm(2870 K) can easily be obtained. This means that even at light levels of 10 to 12 ft-c on the scene high-quality images can be obtained at a lens setting of *f*/2.8, which is comparable to image-orthicon cameras at *f*/5.6 for the same depth of focus. The constant gamma of the Plumbicon tube makes the tube especially suitable for color TV, because excellent color-rendition can be expected over a large range of varying lighting conditions.

The spectral response curve (Fig. 7) is to a large extent determined by the fact that the red modification of PbO (bandgap E = 2.0 ev) is used; this means that the edge wavelength of the red sensitivity is about 6400 A. The maximum sensitivity of a Plumbicon is at 5000 A. The fall-off in sensitivity in the region of shorter wavelength is due to the fact that the absorption of this type light takes place mostly in the thin *n*-type region which is an almost field-free area where the rate of recombination is accordingly high.

The resolution of a TV camera tube is usually defined by expressing the modulation depth at 5 mc/sec (in the European 625-line system corresponding to 400

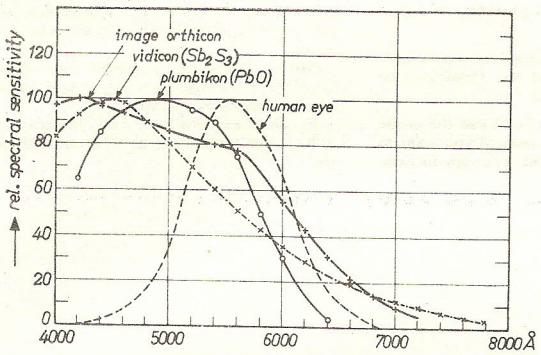

Fig. 7. An equal energy relative spectral response curve of an image orthicon, a Sb_2S_3 vidicon, a Plumbicon tube and the human eye.

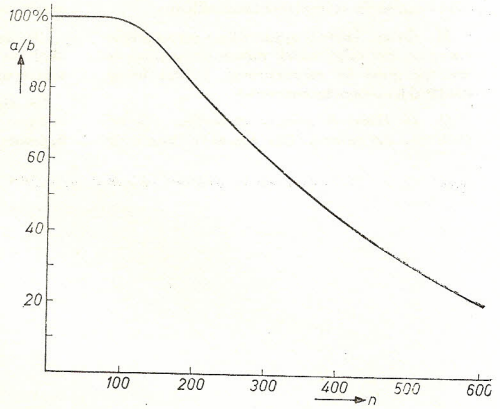

Fig. 8. Modulation depth from a square-wave test pattern as a function of the number of lines.

lines per picture height) as a percentage of the value at 0.5 mc/sec (Fig. 8). A modulation depth of 50% can be obtained with a Plumbicon. This is comparable with the resolution of a standard 3-in. image orthicon. This can only be obtained if the cathode region of the photoconductor, despite being strongly p-type, has a very low conductivity along the surface on the gun side.

In a Plumbicon tube the persistence of the photoconductor is hardly noticeable. This can be shown by the following experimental figures obtained at a target potential such that the photocurrent is saturated. If the light intensity changes from L_I to L_{II}, the photocurrent i will attain the value $i_{II} \pm 0.1$ $(i_I\text{-}i_{II})$ after 3 frames, and after 10 frames the value i_{II}, independent of light intensity. The absence of objectionable persistence is due, first, to the fact that the capacitance of the layer is chosen as low as possible to avoid a slow response due to the beam resistance, and second to the elimination of disturbing trap centers in the intrinsic region; with increasing target potential the persistence of the photoconductor decreases and at 50 v is fully acceptable.

The life of tubes of the Plumbicon type is quite satisfactory. Most characteristics have been found to remain unchanged after the tube has been operated for several thousand hours. It can be concluded that a Plumbicon has the advantage of simple construction and operation, with a high sensitivity and a low dark current together with freedom from objectionable persistence, thus ensuring an excellent final gradation of high-contrast pictures. These properties make this tube suitable for a large number of television applications. Especially for color TV cameras, the Plumbicon tube is almost the ideal pickup tube.

In fact, the reason why development of this tube was started, a few years ago, was the urgent demand for pickup tubes suitable for color television.

Several 3-Plumbicon color TV cameras have been built on a laboratory basis (Fig. 9). These Plumbicon cameras have the advantages of small size, easy operation, excellent stability, good color rendition and a high sensitivity.

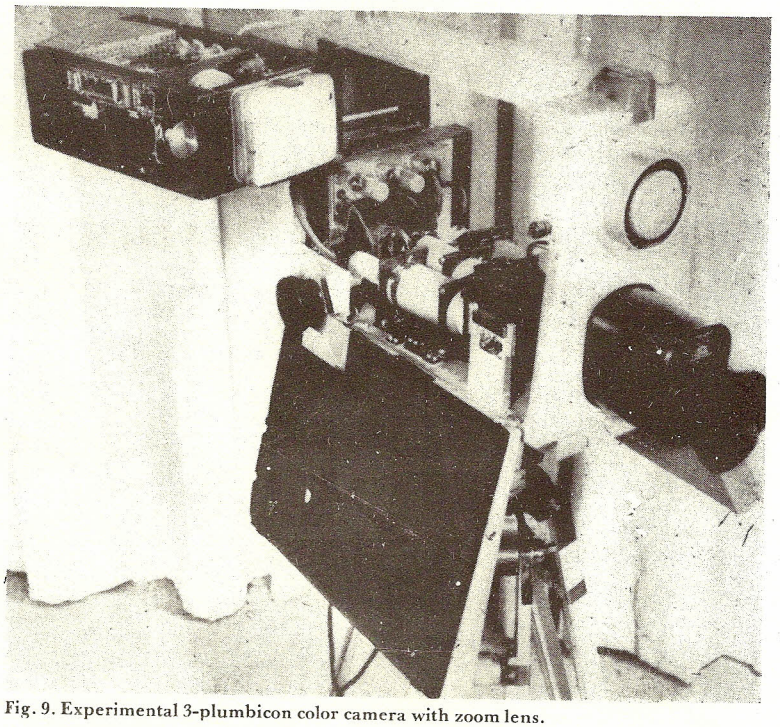

Fig. 9. Experimental 3-plumbicon color camera with zoom lens.

With a lighting level of 100–150 ft-c fully saturated color-pictures can be obtained at a lens setting of f 2.8. In that case, the signal-to-noise ratio in the Y-channel will be better than 40 db.

Discussion

Wayne T. Hogue (General Dynamics Corp.): Are these tubes on the market and how does the cost compare with others?

Dr. De Haan: The Plumbicon will be available at the end of this year. Coming from the Research Laboratories, I can only say that I think it will be cheaper than the image orthicon. The tubes are expected to be available from Amperex and the cameras also are expected to be supplied by North American Philips.

Mr. Hogue: Would there be any trouble from particles if the tube looked straight down?

Dr. De Haan: I would not advise doing it with any pickup tube. The difficulty of operating a camera tube like this is always that if there is, for example, some dust in the tube there is a possibility that this will result in a spot in your pictures. This holds for every camera tube, not only the Plumbicon.

Mr. Hogue: Some tubes have recently been made with a particle catcher.

Dr. De Haan: There is a particle catcher in the Plumbicon; but I would still emphasize that it is very dangerous to use a camera tube upside down.

Joseph Roizen (Ampex Corp.): What is the expected life of the Plumbicon?

Dr. De Haan: In the Research Laboratory we do not know exactly what the guarantee will be. It will be longer than any other pickup tube

now in use. In our laboratory, we have had the tube running for several thousands of hours.

Mr. Roizen: There is apparently a very straight curve on the tube, which means the gamma is not too good for monochrome. Is this being changed for monochrome work?

Dr. De Haan: A gamma correction will be built into the camera. That has to be done with any tube in order to obtain pictures with a good gradation.

Hal Kuerschner (Academic Communications UCLA): Will the anode voltage on the Plumbicon be similar to that of the vidicon?

Dr. De Haan: Yes, you can choose the anode voltage: for example, 300 volts; if you want to increase the resolution a bit, you can increase it to 600 volts. It is the same type of tube as the vidicon as far as the handling of the tube is concerned.

John G. Downes (J. M. Schuller Import-Export): Could you tell us the limits of faceplate temperature for satisfactory operation?

Dr. De Haan: We have used the tube up to 70°C. I don't know exactly what the limitations are.