Narragansett imaging

Technical Information

PLUMBICON IMAGING TUBES: PRINCIPLES OF OPERATION

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PHOTOCONDUCTIVE CAMERA TUBES

General Description

A lens system focuses an image of the scene to be televised onto the faceplate of the camera tube. A photoconductive layer on the faceplate converts this image into a charge distribution which is then scanned line-by-line by an electron beam and transformed into an electrical signal.

Figure 1 illustrates the electron and coil arrangement for a vidicon or Plumbicon tube with magnetic focusing and deflection. An electron gun produces the scanning electron beam, which is directed by the focusing and deflection coils to land upon a target containing the photoconductive layer.

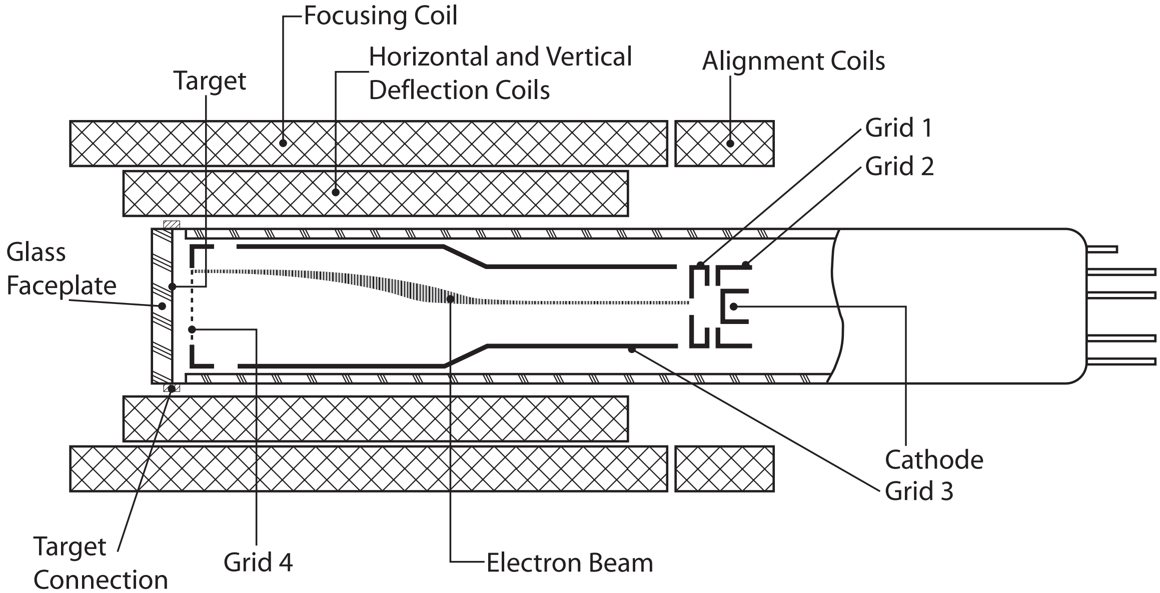

Figure 1. *Electrode and coil arrangement of a vidicon or Plumbicon tube.*

The electron gun comprises an indirectly heated cathode and grids 1 to 4. The voltage on grid 1 controls the electron beam current. Grid 2 (first anode) accelerates the electrons, which subsequently pass through a cylindrical electrode (grid 3) and a fine mesh (grid 4), which establishes a uniform decelerating field in front of the target.

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The focusing coil produces an axial magnetic field that, in combination with an appropriate voltage applied to grid 3, focuses the beam on the target. Focusing can be adjusted by varying wither the grid 3 voltage or the focusing coil current.

Two sets of alignment coils produce an adjustable transverse magnetic field, enabling the beam to be aligned parallel to the tube axis so that it land perpendicularly on the target.

Finally, two sets of deflection coils supply the varying magnetic field needed to deflect the beam for line-by-line scan of the target.

The target section is illustrated in figure 2. It consists of:

- an optically flat faceplate;
- a transparent conductive film on the inner surface of the faceplate, connected electrically to the external signal electrode contact;
- a thin layer of photoconductive material deposited on the conductive film. In darkness this material has a high specific resistance which decreases with increasing illumination.

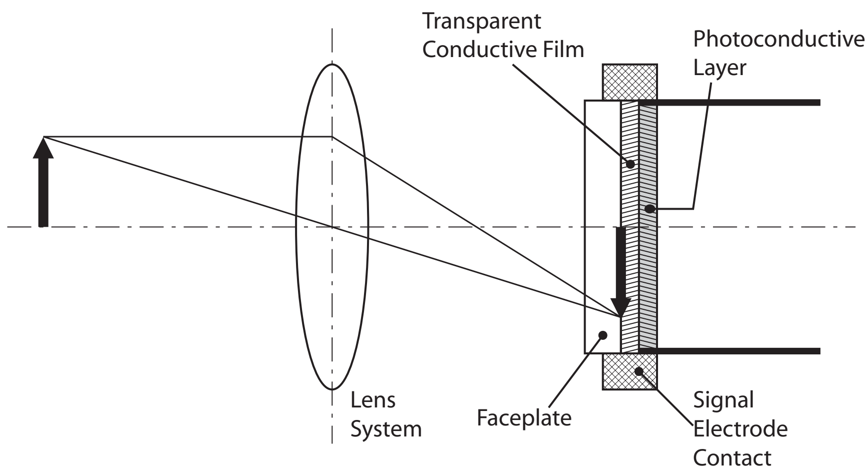

Figure 2. *Target Section.*

Operation

The external signal electrode contact is connected via a load resistor to a positive voltage of e.g. 45V (see figure 3). The target may be assumed to consist of a large number of target elements corresponding to the number of picture elements. Each target element may be represented by a small capacitor C_e, connected on one side to the signal electrode via the transparent conductive film and shunted by a light dependent resistor R_e.

When the target is scanned, beam electrons approaching the target at a low velocity will continue to land until the scanned surface is approximately at the cathode potential. This is called cathode potential stabilization. In this way a voltage difference is established across the layer, with each element capacitor charged to nearly the same potential as that applied to the signal electrode.

In the dark, the photoconductive material is a fairly good insulator, so that only a minute fraction of the charge of the element capacitors will leak away between successive scans. This fraction will be restored by the beam and the resulting current to the signal electrode is called 'dark current'.

When an optical image is focused on the target, those target elements which are illuminated will become conductive and will be partly discharged. As a consequence of this a pattern of positive charges corresponding to the optical image will be produced on the side of the target facing the electron gun.

While scanning this charge pattern, the electron beam will deposit electrons on the positive elements until the latter are restored to their original cathode potential, causing a capacitive current to the signal electrode – and hence a voltage across the load resistor R_l. This voltage is the video signal and is fed to the preamplifier. A camera tube is called 'stabilized' when the magnitude of the beam current is sufficient to restore the scanned surface to the cathode potential. All element capacitors, including those at the highlights of the image, are then completely recharged by the passing electron beam.

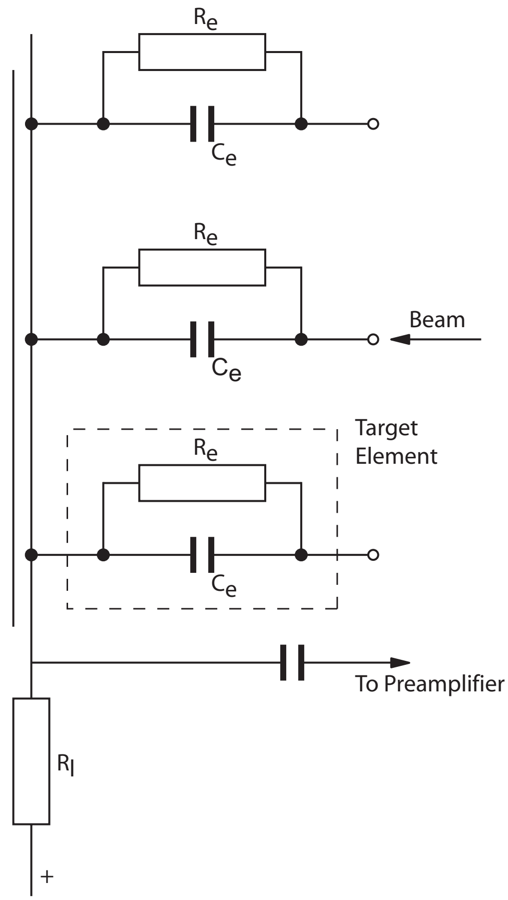

Figure 3. *Equivalent Circuit of tube target*

Separate Mesh Construction

The focusing coils commonly used do not produce an ideal focusing field distribution in the vicinity of the target. The resulting 'landing errors' pf the scanning beam (non-perpendicular landing outside the central area) may cause picture defects such as geometrical distortion and 'stern waves' behind moving objects. An electron-optical lens formed between grids 3 and 4 can correct these landing errors. The grids are electrically separated with grid 4 (the mesh) positive relative to grid 3. Lens action is governed by the ratio of voltage on grids 3 and 4, the optimum ratio depending on factors such as electron gun construction and type of coil assembly used.

Besides eliminating landing errors, separate mesh construction reduces the space charge in the field-free region near the mesh, and so provides the bonus of improved resolution compared with the integral mesh (in which grids 3 and 4 are internally connected). Moreover, since this space charge increases with increasing beam current, separate mesh tubes can operate with higher beam currents than integral mesh tubes.

All currently available Plumbicon tubes have separate mesh construction. Some vidicon tubes, however, have integral meshes.

Electrostatic Focus

Focusing and deflection may both be electrostatic. Figure 4 shows a possible arrangement of electrodes and coils for a camera tube with electrostatic focusing and magnetic deflection.

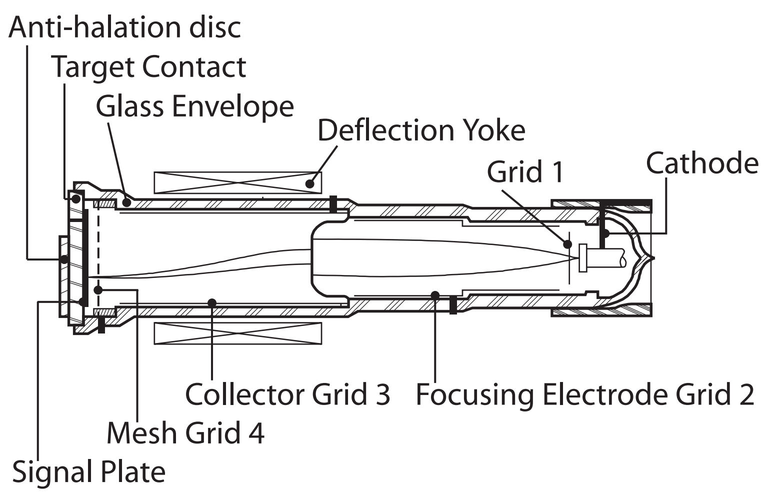

Figure 4. *Schematic electrode and coil arrangement with electrostatic focusing*

In an electrostatically focused tube the electrode gun includes and indirectly heated cathode, a control electrode (grid 1), a focusing electrode (grid 2), a cylindrical electrode (grid 3) and a fine mesh (grid 4). Since this tube uses no focusing coils, it dissipates significantly less power than the magnetically focused tube.

Anti-Comet-Tail Gun

To cope with extreme highlights, which cannot be stabilized with normal beam currents, a special electron gun known as the anti-comet tail (ACT) gun has been developed. The General Operational Notes on Plumbicon tubes give a short description of this gun.

The Diode Gun

In the diode gun, grid 1 is made positive relative to the cathode. This modifies the electron beam and provides larger beam reserve for highlight handling. A brief description of the diode gun will be found in the General Operational Notes on Plumbicon tubes.

MAIN PROPERTIES

Luminous Intensity

The luminous sensitivity, S_L, of a camera tube is defined as the average signal current, I_S, generated per unit luminous flux falling uniformly on the scanned area, *A*, of its target; i.e.

$$S_L = \frac{I_S}{AB_{ph}} \text{ µA/lumen}$$

In which B_{ph} is the illuminance of the photoconductive layer (in lumens/m^2).

Often what is of interest to the camera designer is no the average signal current, but the current, I_P, over the active scanning line, since this is a better indication of the peak signal currents likely to occur in practice. For a camera tube with a blanking period β (given as a percentage of the total line period), the signal current I_P is given by:

$$I_P = \frac{100}{100-\beta} I_S = \alpha I_S \, .$$

For the CCIR system α=1.3.

For a black/white camera, the illuminance, *Bph*, of the photoconductive layer is related to the scene illuminance, B_{SC}, by:

$$B_{ph} = B_{SC} \frac{RT}{4F^2(m+1)^2}$$

in which: *R* is the average scene reflectivity, *T* the lens transmission factor, *F* the lens aperture and *m* the linear magnification from scene to target.

A similar relationship holds for the red, green and blue channels of a color camera, but in this case the situation is complicated by the extra components that must be included in the optical system.

Radiant Sensitivity and Spectral Response

The radiant sensitivity, S_r, of a camera tube is the average signal current generated per unit radiant energy falling uniformly on the scanned area of its target. Radiant energy is commonly expressed in mA/W, and at a given wavelength λ it is related to the luminous sensitivity, S_L, by:

$$S_r(\lambda) = 0.680V(\lambda)S(\lambda)$$

in which *V(λ)* is the normalized spectral sensitivity of the eye at wavelength λ. Note: *V(λ)* is an empirical function that has been internationally agreed; its peak value is unity which occurs at a wavelength of 555nm.

The radiant sensitivity of a camera tube varies with wavelength. The spectral response curves given in figure 5 show this variation for some typical camera tubes; these curves are merely exemplary, and for spectral response details of specific tubes the relevant data sheet should be consulted.

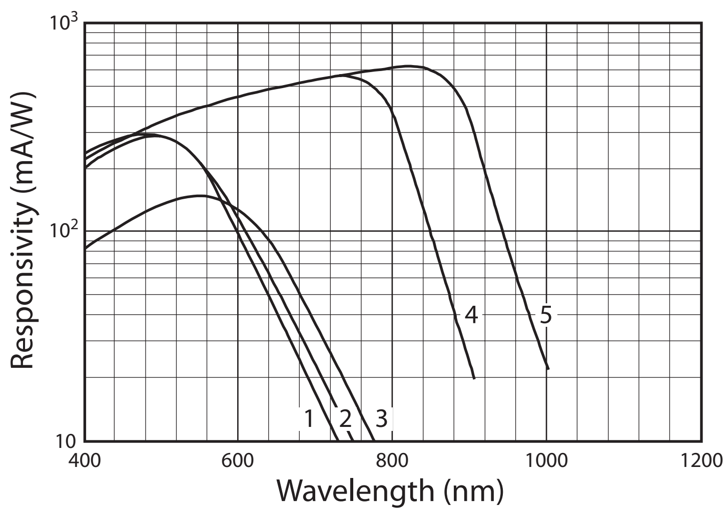

Figure 5. *Spectral response of various camera tubes. (1) Plumbicon tube XQ1073; (2) Sb2S3 vidicon XQ1280; (3)Sb2S3 vidicon XQ1240; (4) Newvicon tube XQ1274; (5) Newvicon tube XQ1276.*

Resolution

The resolution of a camera tube is often expressed in terms of modulation depth, which is defined as the ratio (expressed as a percentage) of the amplitudes of a 5MHz and a 0.5MHz square-wave signal as measured on a waveform monitor.

The square-wave signal can be produced by a test pattern comprising vertical black and white bars of equal thickness. The pattern may be specified in terms of the video frequency, or in terms of the corresponding number of TV lines, i.e. the number of bars that will fill a TV picture when arranged horizontally. For the CCIR system (52µs scan), 5MHz corresponds to about 530 vertical bars or 400 TV lines, and 0.5MHz corresponds to about 40 TV lines.

A pattern can also be specified by the number of line-pairs per mm (lp/mm), a line pair being an adjacent pair of black and white bars. 400 TV lines corresponds to:

- 12.5 lp/mm for a 30mm tube with enlarged scanning (scanned area 15.6mm × 20.8mm);
- 15.6 lp/mm for a 30mm tube (scanned area 12.8mm × 17.1mm);
- 20.8 lp/mm for a 25mm tube (scanned area 9.6mm × 12.8mm);
- 30.3 lp/mm for a 18mm tube (scanned area 6.6mm × 8.8mm);
- 40.6 lp/mm for a 14mm tube (scanned area 4.8mm × 6.4mm).

The modulation depth values given in this book include the slight degradation produced by the camera lens. For the purpose of these measurements, a lens aperture of 5.6 is taken.

Lag

In a camera tube there is always a delay in establishing a new signal current following a rapid change in target illumination. This is the phenomenon of lag. Two type of lag occur in a photoconductive camera tube: photoconductive lag determined principally by the nature of the target, and discharge (or capacitive) lag attributed to the way in which the electron beam discharges the target.

We define two forms of lag for measurement purposes:

- decay lag occurring at the transition for light to dark. This is measured after the target has been illuminated for at least 5s, and is usually given as the ratio (expressed as a percentage) of the residual signal current to the initial current, the residual current being measured 60ms and 200ms (at 50Hz) after the light is cut off.

- build-up lag occurring at the transition from dark to light. This is measured after 10s of darkness, and is given as the ratio (expressed as a percentage) of the intermediate signal current to the final current, the intermediate current being measured 60ms and 200ms (at 50Hz) after restoring the light.

CAMERA TUBE TYPES

Plumbicon Tube – Lead Oxide Photoconductive Layer

The photoconductive layer forms a continuous array of reverse-biased PIN-diodes, giving it an extremely low dark current. Its linear transfer characteristic, high sensitivity, very low photoconductive lag, excellent resolution and low burn in make it pre-eminently suited to color TV. Lead oxide does not respond to wavelengths greater than about 650nm, but a small amount of sulfur included in the layer extends its response to wavelengths in the deep red (extended red Plumbicon tubes).

N.B. Plumbicon tubes do not permit automatic sensitivity control by means of regulation of the signal electrode voltage. Adequate control is therefore to be achieved by other means (iris control and neutral density filters).

When the tube is to be applied to in a camera originally designed for vidicons, the automatic sensitivity control circuitry should, to prevent permanent damage or destruction of the target, be made inoperative and the signal electrode voltage be set to 45V.

Vidicon Tube – Antimony Trisulfide (Sb_2S_3) Photoconductive Layer

The sensitivity of a Sb_2S_3 layer depends on the target voltage (the voltage across the layer), so it is possible to control the sensitivity by varying this voltage. The dark current is strongly dependent upon target voltage as well as temperature.

The Sb_2S_3 layer suffers from photoconductive lag and is prone to burn-in. The layer also has a non-linear transfer characteristic and so is less suited to color TV. However, since the layer is thin its resolution is high.

Standard vidicons are relatively inexpensive to manufacture, so despite their drawbacks they are used extensively in less critical applications. Variants of the standard vidicon have been developed for use in medical X-ray equipment where they are coupled to an X-ray image intensifier.

Newvicon Tube – Heterojunction Photoconductive Layer

The photoconductive layer contains sublayers of zinc selenide (ZnSe) and of a zinc telluride (ZnTe) cadmium telluride (CdTe) mixture. In operation the layer is reversed biased. The layer produces a non-negligible dark current which is temperature dependent.

The Newvicon tube has a very high sensitivity that extends into the near infrared. It is not possible to adjust this sensitivity by varying the target voltage. The tube has a linear transfer characteristic and low burn-in. Its photoconductive layer is thin, so it has high lag and high resolution.

EQUIPMENT DESIGN AND OPERATING CONDITIONS

Signal Electrode Connection

The signal electrode connection should be made by a spring contact that bears against the target connection. The spring contact may be part of the coil assembly.

Deflection Circuitry

The signal current is a function of target illumination and of scanning speed. The deflection circuitry must therefore provide constant scanning speed to ensure that the variation in signal current is a true representation of the intensity profile across the target.

Electrostatic Shielding

To avoid interference on the picture the signal electrode must be electrostatically shielded, e.g. by one grounded shield inside the focusing coil at the faceplate end, and inside the deflection yoke.

Polarity of Focusing Coil

The polarity of the focusing coil should be such that the target will attract (for 30mm tubes, repel) a north seeking pole.

Full Size Scanning

The full scanning area should always be covered during scan; underscanning of the photoconductive layer or failure to scan, even for a short time, can cause permanent damage.

To prevent the electron beam landing on the target during vertical and horizontal flyback (which would remove some picture information from the target), a blanking pulse must be applied – either a negative pulse to the control grid or a positive pulse to the cathode.

In tubes with a separate mesh construction corner resolution can be improved by applying suitable pulses to grid 3 (dynamic focusing or focus modulation).

The resolution of most types of photoconductive camera tube increases with increasing voltage on grids 3 and 4. High voltage operation, however, requires increased power for the deflection and focusing coils.

RECOMMENDATIONS

- When the tube is used in a series heater chain, the heater voltage must not exceed 9.5V (r.m.s.) when the supply is switched on. Preferably, each heater should be shunted by a zener diode.
- If cathode-current stabilization is used to stabilize beam current, the cathode heater should be arranged to operate for at least 1 minute before any beam current is drawn.