

Institut für Plasmaphysik  
KERNFORSCHUNGSANLAGE JÜLICH  
des Landes Nordrhein-Westfalen - e.V.  
ASSOCIATION EURATOM - KFA

**The image orthicon in high-speed photography**

by

W. Hopmann

**Berichte der Kernforschungsanlage Jülich - Nr. 467**

Institut für Plasmaphysik Jül - 467 - PP

Dok.: Image Orthicons  
High-Speed Photography

DK: 621.397.331.22  
778.37

Zu beziehen durch: ZENTRALBIBLIOTHEK der Kernforschungsanlage Jülich  
Jülich, Bundesrepublik Deutschland

# The Image Orthicon in High-speed Photography

W. HOPMANN†

*Institut für Plasmaphysik, Jülich, Nordrhein-Westfalen, Germany*

## INTRODUCTION

Supported by wide commercial applications, television techniques have achieved a high degree of development. It is therefore of interest to investigate if a normal, commercially available television system can be made use of in high-speed photography. As compared with other high-speed photographic systems, the advantages are: the remote presentation of a large and bright picture, if necessary at several locations; the possibility of photometric evaluation by recording of selected lines of the video signal; and the possibility of magnetic or electrostatic storage.

So far, the image orthicon is the most sensitive camera tube of the types in quantity production. Its image section resembles a single-stage image converter with electrical output. Apart from its use as a transducer in conjunction with a high-speed shutter it is also possible to use the tube itself as a high-speed shutter by applying fast pulses to the image section. The restricted picture-frequency allows, of course, only its application as a still camera.

## EQUIPMENT USED

For these investigations, a commercially available closed-circuit television system was chosen, designed for the European CCIR standard with 625 lines at 25 pictures/sec and interlaced scanning. For use as a still camera, it required some modifications. The discontinuous scanning is performed in a cycle of three steps: (a) the stand-by period, which ends with the exposure; (b) the storage period, lasting from the exposure to the next vertical synchronizing pulse, at least 35 msec; (c) the reading period, lasting one full scan, 40 msec. All scanning circuits are running continuously and the cycling is controlled by an additional transistorized circuit called the "storage switch".

Figure 1 shows the modifications in the circuit of the scanning section. During the stand-by period the relay is energized. It increases the grid bias in order to reduce the beam current to a value just sufficient to maintain a constant black-level potential at the target. Moreover, the

† Association EURATOM-KFA.

gun cathode is raised to a slightly positive potential of approximately 0.5 V. This method overcomes the effects of "scanning in the dark".

Controlled by the storage switch, the relay is de-energized at the moment of exposure, and the transistor is switched off. The grid is now at normal potential, but no reading takes place since all beam electrons return before reaching the target, because the gun cathode is raised to approximately 4 V. The transistor is switched on again at the occurrence of the next vertical pulse, and clamps the gun cathode to nearly

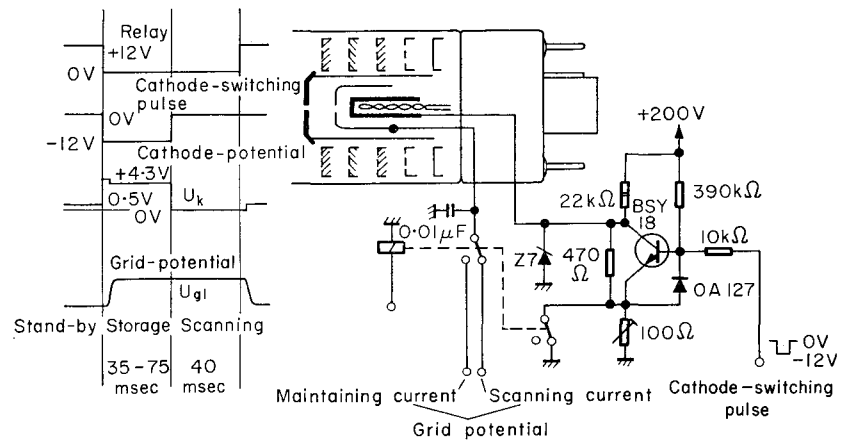


FIG. 1. Scanning beam control circuit.

ground potential, and the reading of the stored charge pattern starts. With the next vertical pulse the relay is energized again, and a new stand-by period begins.

The storage switch furthermore controls a gating circuit in the output stage of the main amplifier, which inhibits the video part of the combined output signal during the stand-by and the storage period. The synchronizing and the blanking parts of the signal are fed continuously to the picture monitor. This gating circuit is useful not only against electrical interference arising from the experiment under observation, for example the high discharge-fields in plasma physics experiments, but it also suppresses the unwanted image orthicon output signals produced by photoelectrons which are released from the tube walls and from the dynodes by the high light intensities of the events under observation.

The large variations in the beam current demand the use of a stable clamping circuit in the pre-amplifier to prevent overloading. The installation of a second clamping circuit in the output stage of the main amplifier is useful though it may not be provided by the manufacturer.

For single frame scanning, it is best to use sequential scanning by halving the vertical sweeping frequency. It is in most cases only a minor modification of the original circuits.

#### IMAGE ORTHICON PERFORMANCE

The most interesting performance data of an electron-optical shutter system are: the sensitivity, the spatial resolution, the shutter efficiency and the dependence of these parameters on the duration of exposure.

##### *Sensitivity*

The sensitivity of an image orthicon with normal-spaced glass target equals 10,000 ASA and is time independent. It can be measured in continuous operation taking into account the scanning period. With these tubes the space-charge limitation of the photoelectron current occurs at shutter times beyond practical interest.

##### *Spatial Resolution*

The spatial resolution, measured in lines per picture height, was determined by means of a test chart projector.<sup>1</sup> At an illumination by a xenon flash of more than 10  $\mu$ sec duration the resolution decreases only to 500 television lines from 625 lines in continuous operation. This is mainly owing to the higher visible amount of noise in single-frame scanning, which is normally averaged out by integration over several scanning periods. At the short storage times used, the leakage of the glass target is practically of no importance. If the duration of the flash is reduced to less than 1  $\mu$ sec, the resolution decreases rapidly because of the finite resistance of the photocathode.<sup>2</sup> A fine cross-hair mesh of 0.03 mm diameter tungsten wire with 1 mm spacing was mounted directly on the outer side of the face-plate of the tube. This cured the effect nearly completely by coupling the photocathode capacitively to a fixed potential. The exposure time was further lowered by use of spark-gap light sources. With a light pulse of 9 nsec half-width the resolution decreases again, but in this case it is due to the high space-charge densities (Fig. 2). Since the exposure time is of the same magnitude as the transit time (approximately 6 nsec), the space-charge density varies within the exposure. This variation causes the rotational distortion in the corners of the picture area (Fig. 2). The effects of cathode resistance and space-charge densities have been calculated.<sup>†</sup>

The resolution capabilities measured with short light-flashes are the optimum values to be expected if the image section is used as a high-speed shutter at comparable shutter times. In the latter case, the resolution is, in addition, affected by the shape of the shutter-pulse.

<sup>†</sup> See p. 591.

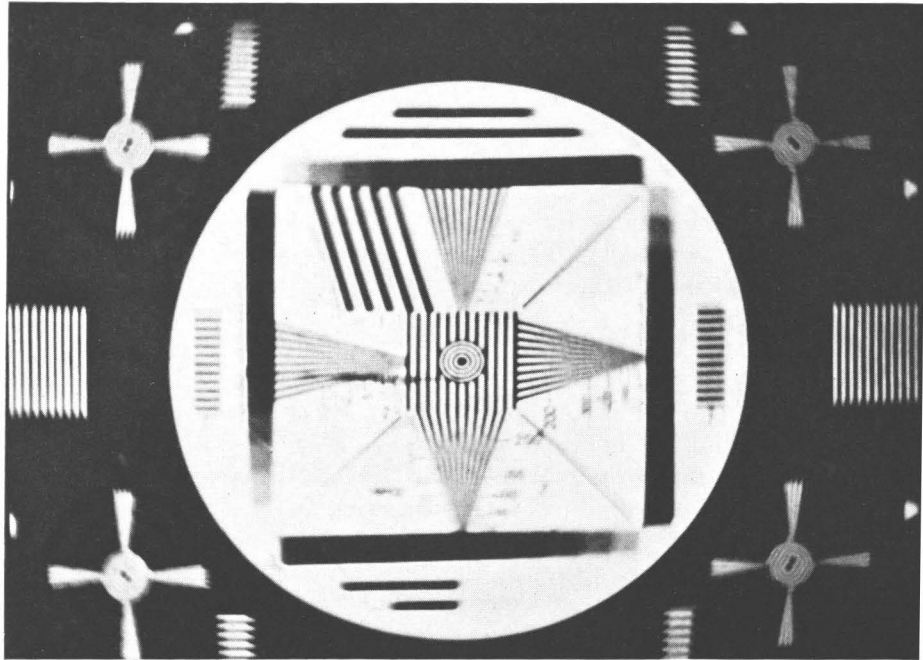


FIG. 2. Test chart illuminated by a 9-nsec flash.

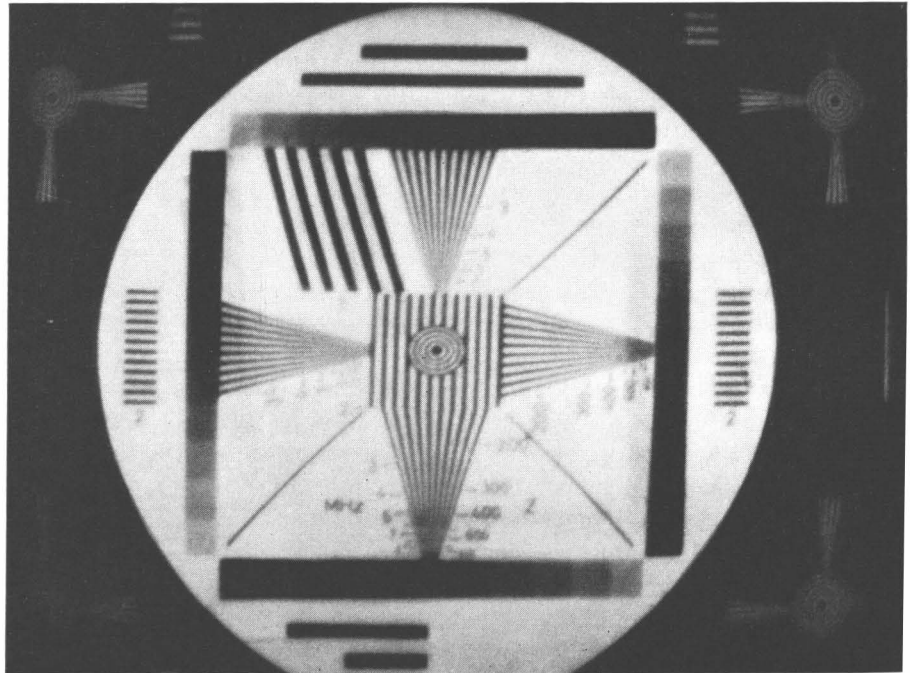


FIG. 3. Test chart projected on the target of the image orthicon.

*Shutter Efficiency*

The shutter efficiency of the image section depends on the photoelectric emission of the target foil. The relative emission of the target is measured by switching off the image section and focusing a normalized image of the flash-illuminated test chart directly on the target. Owing to the lack of demagnification in the image section, the pattern appears 1.25 times enlarged on the monitor (Fig. 3). The amplitude of the image orthicon output signal is measured and the image section is then switched on and the test chart focused on the photocathode. By application of neutral density filters in the projector the light flux is reduced until the output signal amplitude equals the amplitude of the first measurement. The attenuation ratio is then equal to the shutter efficiency.

The relative photoelectric emission from the target is thus measured by comparing the charges produced on the target by direct illumination and the charges produced in normal operation. It is influenced by the light absorption in the photocathode and the contamination of the target with caesium during the processing of the tube on the one hand and the sensitivity of the photocathode, the electron-optical demagnification and the target multiplication on the other hand. During operation ion-conducting target foils develop a second photocathode on the scanning side of the target.<sup>3</sup> This effect raises the photoemission of the target considerably and lowers the shutter efficiency. Consequently, only tubes with electron-conducting target foils are usable for shutter applications.

New glass-target tubes of both kinds show a mean value of shutter efficiency of approximately 1800. With ion-conducting glass targets, the efficiency drops rapidly to approximately 150. By courtesy of the manufacturer,† a 7293/ELCON was specially selected, and this has a shutter efficiency of 14,000.

## SHUTTER CIRCUIT

The image section can be switched off, as in a triode, by applying a high negative potential to the accelerator grid. But the cut-off potential is far beyond the absolute maximum ratings, and the generation of a fast positive shutter pulse involves more problems than that of a negative one. It is better to switch off the image section by applying a low positive potential to the photocathode, as is usually done for electronic image suppression.

The connecting circuit for the shutter pulse is shown in Fig. 4. The negative pulse of approximately 570 V amplitude is generated in a hard-

† English Electric Valve Co. Ltd., Chelmsford, Essex.

tube pulser. The connecting coaxial cable is back-terminated in the pulser. At the image orthicon the pulse amplitude is limited by a transistor and Zener diode combination. If the pulse amplitude goes more negative than the avalanche potential of the diode chain at the base, then the transistor acts as an emitter-follower with a dynamic resistance of a few ohms. The diodes in the collector circuit have an overall avalanche potential 50–60 V lower than the diodes in the base circuit. The pulse amplitude can be fine-controlled by the bias potential.

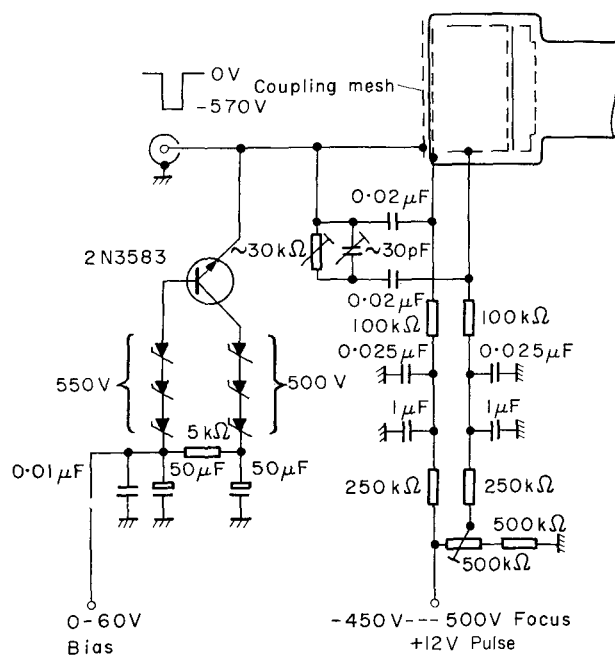


FIG. 4. Shutter pulse circuit.

By these methods the top of the pulse is flat to better than 1%. The rise and fall times are 12 nsec. The shutter pulse is applied directly to the mesh on the face-plate of the tube and capacitively coupled to the photocathode connector. The accelerator grid receives the pulse through a compensated potential divider. The simultaneous pulsing of the accelerator grid has some advantages: the stray capacitance between photocathode and accelerator grid does not have to be charged to the full pulse amplitude and the required pulse amplitude is less critical.

#### RESULTS

Using the 7293/ELCON as a high-speed shutter with a shutter time of 20 nsec, Fig. 5 was taken. It shows the reproduction of a test chart;

the resolution in the original is still over 300 television lines. By use of a line-type pulser a minimum shutter time of 12 nsec was possible with a resolution of approximately 250 television lines.

So far, the high-speed television still-camera has been applied successfully for the observation of the five events given in Table I.

TABLE I

Application	Shutter time
Formation of a plasmoid in a conical coil	20–100 nsec
Plasma compression in a cusp	20– 50 nsec
Ionization of hydrogen in a torus	50–100 nsec
Afterglow of a hydrogen plasma	1–100 $\mu$ sec
Differential interferometry on a theta pinch	20– 50 nsec

Figure 6 shows one picture of the application of the system as a high-speed receiver for a differential interferometer used on a 200 kJ theta-pinch experiment. With a shutter time of 20 nsec, it shows the compressed plasma column observed end-on.

#### CONCLUSIONS

These investigations have shown that it is possible to convert a normal closed-circuit television system to a high-speed camera of high sensitivity and good resolution by means of minor modifications and by use of some auxiliary equipment. Selected image orthicons of standard manufacture with electron-conducting glass targets can be used. Inasmuch as tubes with MgO targets have higher sensitivities due to a higher target multiplication, they may have a better resolution at very short shutter times and a better shutter efficiency. But it might be questionable whether the much higher cost of such tubes is justified by the possible improvements. The conversion of an image orthicon camera to a sweeping camera demands a fast sweeping field in the image section. Magnetic deflexion seems not to be advisable due to the eddy currents in the rigid structures of the target mount and of the accelerator grid. Electrostatic deflexion requires the incorporation of deflecting plates or the splitting of the accelerator grid with symmetrical application of a sweeping potential. Both methods demand the development of special tubes, and the advantages of using equipment produced in quantity are lost.

#### ACKNOWLEDGMENTS

The author is indebted to Prof. Dr. W. Fucks and Dr. H. L. Jordan, directors of the Institute für Plasmaphysics KFA for their permission and support of this work. Dr. K. Frank and Mr. Siepmann of Fernseh GmbH. contributed many

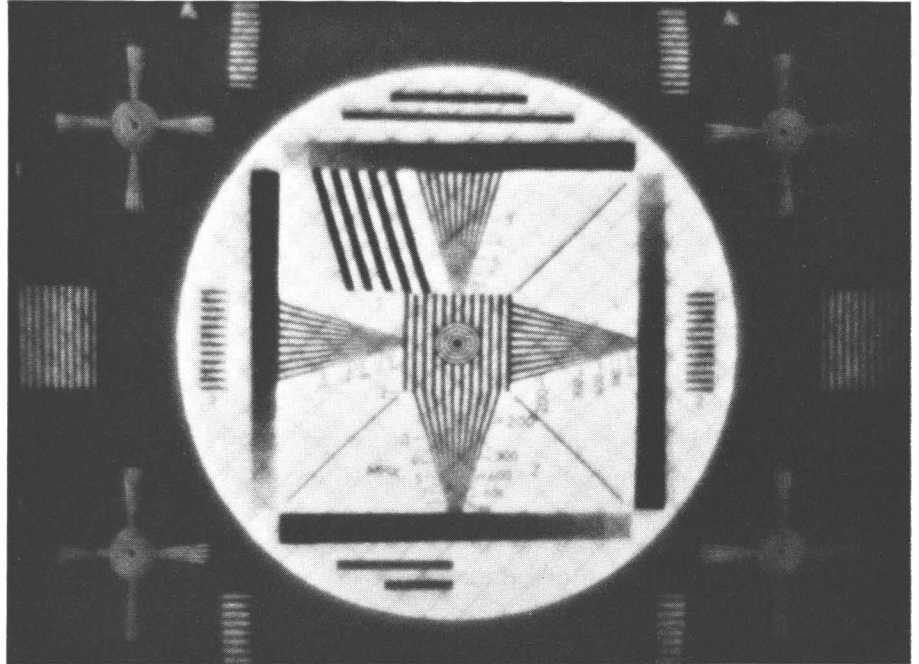


FIG. 5. Test chart, reproduced by the 7293/ELCON. Single scan, 20-nsec shutter pulse applied to the image section.

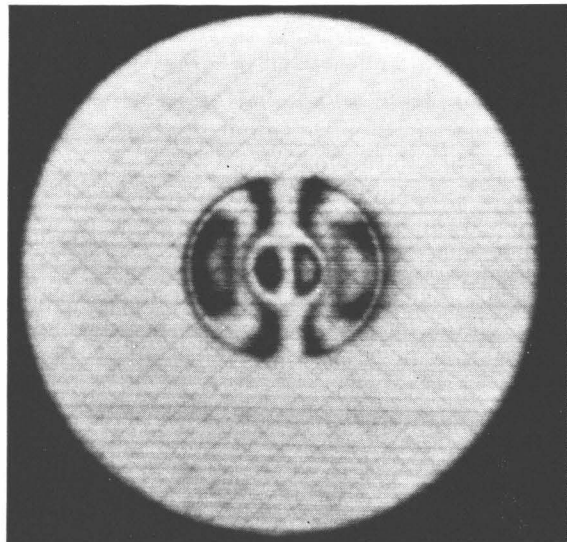


FIG. 6. Differential interferogram of a theta-pinch (20-nsec shutter time).

helpful suggestions for the modifications of the television system. The image orthicon was selected for highest shutter efficiency by the English Electric Valve Co. Ltd.

#### REFERENCES

1. Hopmann, W., *Elektronische Rundschau* **19**, 493 (1965).
2. Stewart, G. W. and Waniek, R. W., *Rev. Sci. Instrum.* **34**, 512 (1963).
3. Hopmann, W., *Electronics Letters* **1**, 25 (1965).

#### DISCUSSION

F. B. MARSHALL: Do I understand correctly that for all exposures, short or (relatively) long, you used a single exposure and a single read-out of the picture? I am thinking of Krittman's paper (*IEEE Trans Electron Devices*, **ED-10**, 404 (1963)) indicating that successive read-outs in repeating frames will have progressively improved resolution.

W. HOPMANN: All the pictures I showed were taken with a single exposure and a single read-out, starting 35-75 msec after exposure. The resolution figures hold for the same mode of operation. The limiting resolution of 500 TV-lines resulted if the time interval between subsequent exposure/read-out cycles was more than 10 sec. When this interval is shortened the resolution increases and approaches the resolution in continuous operation. This effect seems to be caused by the dynamic properties of the charge transport in the target foil and is different for different foil materials. We had the best results when reading out the stored charge in a single scan.

J. A. LODGE: What kind of display unit was used?

W. HOPMANN: We used an ordinary picture monitor with a 17-in. kinescope tube. The only modification was the 25-c/s vertical sweep. The large screen was very convenient for all visual observations during the development of the system. So far we used the same monitor for photographic recording, but a smaller and flat-faced tube would be better.

W. M. WREATHALL: Since the greater part of the transit time delay occurs just in front of the photocathode, is it correct to assume uniform space-charge density when the image has large intensity variations?

W. HOPMANN: Yes, the assumption of uniform space-charge density does not hold exactly at the photocathode. But due to the constant orbital velocity the electron trajectories from adjacent picture points are intermingled very rapidly regardless of the axial acceleration.

A. D. BERG: I believe you quoted a pulse rise-time of 12 nsec and yet obtained 12-nsec exposures.

W. HOPMANN: For shutter times between 100  $\mu$ sec and 20 nsec we used the hard-tube pulser mentioned. The 12-nsec pulse was generated by a bread-board-constructed line-type pulser which produced a pulse of 12 nsec 70% width and a rise and fall time of approximately 3-4 nsec.