A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

LA-UR-84-2598

UCC # 840887-9

NOTICE
PORTIONS OF THIS REPORT ARE UNCLASSIFIED
IT HAS BEEN REVIEWED AND
AVAILABLE TO THE PUBLIC SINCE 1993
POSSIBLE AND INTEREST

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--84-2598

DE94 013023

TITLE: Characterization of Electronic Streak Tubes Including One With
Internal CCD Readout

AUTHOR(S): P.B. Weiss, P. Black, H. Oona, L. Sprouse

SUBMITTED TO: Society of Photo-Optical Instrumentation Engineers
16th International High Speed Photography and Photonics,
Strasbourg, France, August 27-31, 1989.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

MASTER

Characterization of electronic streak tubes including one with internal CCD readout

P. B. Weiss, P. Black,* H. Oona,* and L. Sprouse

Physics Division, Los Alamos National Laboratory
P. O. Box 1663, Los Alamos, NM 87545

Abstract

Measuring techniques for characterizing electronic streak tubes including dynamic range and resolution are described. A particular tube with a CCD imaging device within the envelope is described.

Introduction

The streak tube is becoming of increasing importance in many experimental applications as the experiments can be more quantitative with the device. The possibilities of replacing banks of oscilloscopes for multiple signal recording, to recording many independent fiberoptic channels directly, to tomographic time analysis of a two dimensional event have all lead to increased interest in these devices.

We are currently involved in evaluating different streak tubes from several different manufacturers. In particular our concerns involve achieving more spatial resolution with good dynamic range coupled with large useable photocathodes. The highest time resolution has not been at the forefront of our interest.

Measuring techniques

The following parameters are presently being measured on prototype streak tubes: Dynamic Range, Linearity, Quantum efficiency over wavelength, Photocathode gain, Spatial resolution (Static & Dynamic), Temporal Resolution, and Extinction Ratio.

The measurement of Dynamic Range & Linearity can be usually done simultaneously and refer to the transfer characteristics relating input optical power or intensity to that output at the phosphor.¹

A source of optical power, typically a flashlamp optoliner, is used to focus an image of a pinhole of different sizes onto the photocathode. A series of neutral density filters permits different intensities in a well defined and calibrated fashion to be input into the tube under test. If absolute optical power levels are required then insertion of a calibrated radiometer between the optical source and streak tube is necessary. Stability of the optical source and radiometer need to be verified if the testing is expected to take any substantial time. Dynamic range is measured by relating the input and output intensities. The output intensity (power) measurement will depend on the readout system used. SIT (Silicon Intensified Target Vidicon) or CCD cameras are the systems most commonly used for dynamic range measurements not requiring absolute power measurements. This is accomplished by digitizing a frame of video and performing the required analysis and association of relative intensity levels on the computer and an image processing system. The input intensity levels, if only relative, can be represented in forms of the neutral density filters used for adjusting the input intensity. In this manner the transfer characteristics relating input to output are quantitatively measured and easily related to determine the dynamic range and deviation from linearity. A representative plot is displayed in Figure 1 and refers to the Delli-Delti Picotron tube. Note that in this case, with the available equipment, it was impossible to bring this tube into saturation and was "linear" over at least a dynamic range of 1000:1.

The measurements of Quantum Efficiency & Photocathode Uniformity are most easily performed utilizing a constant intensity optical power source. Generally this is a Tungsten-Halogen lamp running at 1kW input power. The spectral range (350-800 nm) is covered by discrete filters, each of which has approximately 60 nm FWHM bandpass at the center wavelength of each filter. A pinhole aperture is focused onto the photocathode. This image may vary in diameter and normally is not a factor since it is usually about 100 μ m thereby eliminating any question of overfilling the photocathode or radiometer detector. This diameter also permits for easy mapping of the uniformity of photocathode response.

*Energy Measurements Group, EG&G, Los Alamos, NM

The technique is to set up two separate configurations. The first involves biasing of the photocathode to a sufficient potential ($\sim 300\text{V}$) so as to allow collection of all photoelectrons ejected by the photocathode. All electrodes and grounds (other than the photocathode) are connected together. The photoelectron current may be monitored either in the photocathode line or in the return consisting of all other electrodes. The photocurrent is measured with a high impedance picoammeter. The second step is to monitor the amount of optical power incident on the photocathode. An EG&G radiometer has been used and an overall 10-15% error is associated with the quantum efficiency. By allowing for two orthogonal motions, this technique can be used to trace out the uniformity of the photocathode response. Figure 2 is such a map of response. The contour intervals are 10% intervals for the Picotron tube. Figure 3 is a representative plot of quantum efficiency at one particular point in the photocathode.

The determination of spatial resolution is a much more difficult problem. This is primarily due to the limiting resolution of readout system and the fact that the spatial resolution can be different along two orthogonal directions at the same point.

The experimental configuration consists of forming a well defined image of some resolution target onto the photocathode. The resolution target used is usually a PRC-10 or preferably an Air Force test target when it is expected that the resolution will be different in different directions. The limiting resolution of the readout system must be known and understood in order to isolate the response of the streak tube alone. In practice, a SIT or CCD system is optically (proximity) coupled to the output phosphor and the timing of the camera clock adjusted with respect to the system and sweep trigger so as to obtain a maximum signal to noise ratio. The projection of the resolution target is typically performed utilizing a "optoliner" with either a D.C. or flashlamp assembly. The flashlamp assembly with the integrating diffuser is quoted as being uniform to 3% over the field available. Once proper optical and timing adjustments have been performed, the remaining procedure is straight forward, involving digitization of a frame of video, transmitting it to the image processor and thereby computing the MTF for each set of resolution data. The digitization of a frame is accomplished with commercial hardware consisting of a LeCroy digitizer and memory and a CAMAC link to a PDP-11 system. Data is recorded in the same fashion whether the measurement is in the "Static" or the "Streaked" mode. The sweep rate obviously needs to be recorded in concert with the particular frame of video. It has become evident with some streak systems that the resolution can be a strong function of position on the phosphor. The previously quoted refer to the optimum or "best" resolution whether swept or not. Knowledge of the projected line pairs/mm is inferred by combining the measured magnification of the projection system along with the known resolution target size. The accuracy of this determination is much better than the errors involved in the rest of the system, and, is therefore assumed to be exact. A plot of MTF vs spatial frequency is displayed in Figure 4. This again represents measurements performed on the Picotron B streak tube.

Temporal resolution as we attempt to measure it is a measure of the impulse response of the system. A block diagram of the experimental configuration is shown in Figure 5. This measurement requires the generation of "short" optical pulses. "Short" meaning times much less than the expected temporal resolution of the unit under test. The shortest pulses available were 12-15 picoseconds and were generated by driving a spectra physics dye laser (using Rhodamin 6G) with a continuous stream of pulses from a spectra physics Kr^+ laser.

The cavity dumper for the dye laser needs to be synchronized in some way with readout system and the sweep for the streak tube. Each pulse from the dye laser must originate at such a time that upon its arrival at the photocathode, the sweep will position the resulting trace on the phosphor. This is performed by supplying an external trigger to the cavity dumper drive units from a coincidence between the drive to the Kr^+ laser and a divided clock pulse. In this manner it is possible to investigate the characteristics of temporal "spreading" of the 12 psec laser pulse except for the lack of timing information on the streak tube. Timing information was supplied by beam-splitting and delaying the optical pulse from the dye laser. With accurate knowledge of this time delay, two pulses will appear at the phosphor with the spacing between these pulses corresponding to the known time delay. With this timing information the width of each pulse can be related to time. By appropriate "deconvolution" the contribution of the streak tube to the temporal resolution can be determined. As an estimate of this resolution we subtract, in quadrature, the known contributors to the observed pulse width from the observed pulse width. The fundamental contributions are:

- (1) (Δt) streak --- response of streak tubes
- (2) (Δt) pulse --- finite width of laser pulse
- (3) (Δt) spot --- finite width of static image

Contribution (3) is a manifestation of the limit of the system to producing a finite extent image at the phosphor for an infinitesimal (spatial) input image. This width will translate to time, the two being related by the sweep speed used.

Figure 6 displays these two pulses separated in time by 2.7 nanoseconds. A series of such measurements are made in order to compile statistics on the experimental precision. The output of the spectra-physics dye laser pulses was periodically monitored using an auto-correlator in order to measure the width of the optical pulse. The resolution capability of this auto-correlator is ~ 1 picosecond.

The probable limits of error for these pulse width measurements are calculated as approximately 2 picoseconds. Although it is believed that the accuracy and precision of these measurements is more than adequate it should be pointed out that care must be taken to isolate and understand causes of potential pulse widening. One example of this is the possible variation of the temporal scale as a function of position on the phosphor. This is not strictly a spatial resolution problem but a geometric distortion and has resulted in grossly varying temporal resolution measurements. A second problem is the relationship between available optical pulses at a wavelength commensurate with the photocathode response. Optimally the source wavelength should be at or near the peak photocathode response so as to maximize signal to ratio of the measurement.

The extinction ratio is defined for tube with an extraction grid. It is the ratio of measured intensity at the phosphor for the extraction grid biased on and then off. The measurement is made by using either an EG&G 550 radiometer or a photomultiplier. The extraction grid is biased to a value which would prevent any photoelectrons from passing through the cathode to the phosphor. Due to the configuration a small but finite probability exists that some electrons will make it to the phosphor. This measurement is relatively routine and simply yielding a single number of this ratio.

Tube with internal CCD

In the tubes described previously, the incident light from a slit or an array of optical fibers is converted by the photocathode into a ribbon of electrons within the tube. This electron stream is then swept across the output phosphor, and converted to a rectangular visible light image. This is either lens or fiber optically coupled into an optical intensifier which can then output its light image onto film or a vidicon tube. These additional conversions of the output light again into electrons and back to light each add their own noise and distortions.

It is thus quite attractive to put a device sensitive to a few electrons into the original streak tube envelope before any intermediate conversions back into light.^{2,3} One of the benefits of this approach is the geometrical certainty of position. Each element is precisely located within the tube and thus the only possible geometric distortions arise from the electron optics within the streak tube itself. There are significant problem areas, however. Penetration of the electrons into the appropriate charge gathering region without effecting the transfer mechanism is high on the list of potential problems. When the electrons impinge upon the shift registers and output amplifier of the CCD chip some damage is done. The noise will increase. A good match must also be made to the size of the pixel in the CCD to this smallest resolution element of the streak tube. Finally as there is inherent gain in the CCD chip, and a finite capacity to the transfer mechanism, saturation is a real problem at high light levels. We will describe a preliminary attempt at putting a Fairchild CCD imager into the output plane of a Hamamatsu streak tube.

The Fairchild CCD 221 device was prepared by the manufacturer without its surface protective overlayer of SiO₂. Hamamatsu Corporation of Japan mounted the device in place of a phosphor in a streak tube with about a 9mm diameter photocathode and no internal microchannel plate amplifier (Fig. 7). Unfortunately the tube bake out process raised the temperature of the CCD above that of the manufacturer's recommendation and the latter was damaged. Its noise level was raised significantly. However, it was still operable and allowed us to evaluate the system within the limitations of the chip.

It was possible to couple sufficient photons directly through the photocathode and the central anode aperture to directly characterize the chip with its response to light. Then the streak tube could be operated and such characteristics as dynamic range (loss taken 2 orders of magnitude) and resolution (less than 5 lp/mm) were determined. The measuring techniques for these characteristics - as well as for photocathode response, time response, and spot size was described above.

The accompanying plot (Fig. 8) displaying amplitude measured at the CCD output vs ND filters is for explaining the apparent degradation of dynamic range. The basic philosophy was to isolate the effect of the photocathode on the system response. A He, Ne laser was

set up so as to pass through the anode aperture and activate the sensitive CCD elements. The intensity was varied by calibrated neutral density filters. The camera output was digitized and analyzed on an RCI image processing system. The vertical axis on the plot are just the digitized levels. No absolute intensity (i.e. watts/cm²) is inferred by these numbers. The laser beam was then offset from its original orientation and the photocathode biased (it was not in the previous test). The same sets of measurements were performed and recorded. This comparison indicates the dynamic range of the CCD itself is less than 100 and severely limits the overall system dynamic range.

The remaining plots (Figs. 9 and 10) show a monitor picture and an intensity profile output from the streak tube when illuminating the photocathode with a bar chart resolution target. The line spacings were determined by comparison with a known line spacing pair. The measurements were performed with the streak tube in a "static" (not swept mode) and indicate a 15% MTF for 1.9 lp/mm. It is believed that these measurements are affected by the extremely poor signal to noise ratio, but nonetheless indicate the "as is" performance.

The principle of placing a solid state imaging device within a tube is viable. The long term lifetime of the S-20 photocathode has not degraded from the presence of the imaging device. However in situ photocathode processing is apparently incompatible with the preservation of the CCD chip in its nominal state and further experiments in this mode await a remotely processed photocathode.

References

1. Majumdar, S., Dynamic Range of Picosecond Streak Cameras, Proceedings of 12th International Congress on High Speed Photography, 1976, A-5.
2. Savoye, E. D., et al., Design and Performance of a CCD-Streak Tube, SPIE Vol. 203, 1979, 59,65.
3. Cheng, J. C., et al., Intensified CCD Readout System for Ultrafast Streak Cameras, J. Appl. Phys., Vol. 49, 5421-5426.

Fig. 1

FIGURE 2

FIGURE 3

Fig 4

FIGURE 5

FIGURE 6

A00229 71

fig 8

Fig. 10

Hammerston
ced stroke