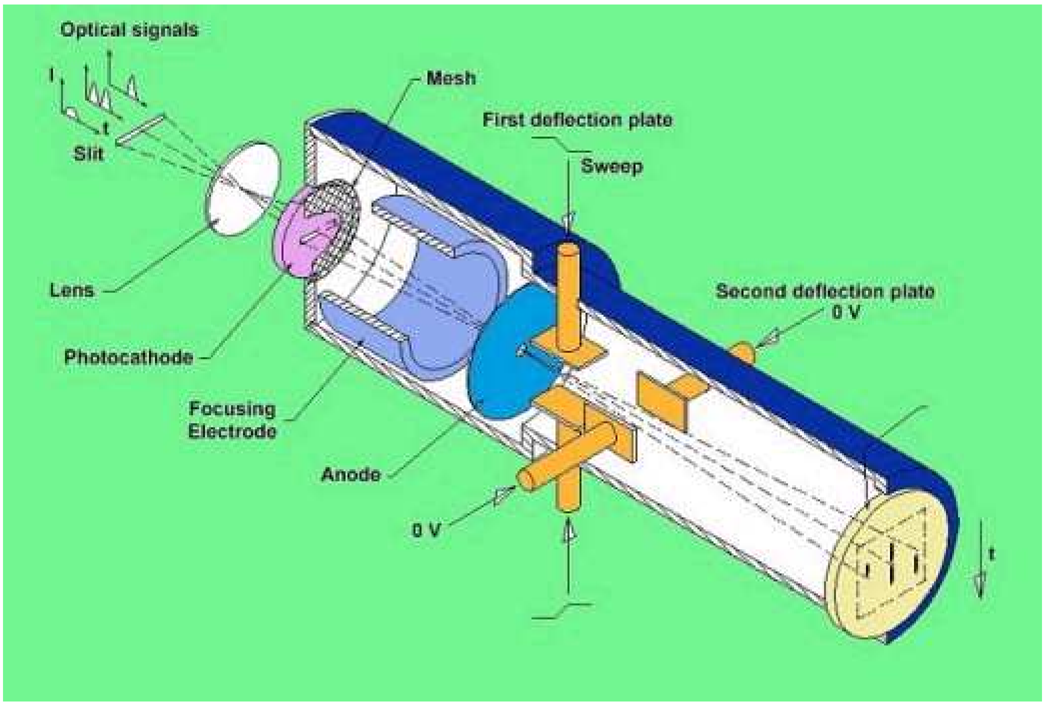
# STREAK CAMERA TUBES

## INTRODUCTION

Streak camera tubes are used to study ultrafast optical phenomena. Streak cameras are sometimes called optical oscilloscopes, because a streak camera functions in much the same way as an oscilloscope.

Light incident on the photocathode is converted to an electron beam, which is then deflected by electrostatic deflection voltage as shown in the schematic diagram below.




This deflection voltage provides the time base.

Since the deflection sensitivity can be as high as 100 volts/cm, it can be seen that a drive pulse with rise time of 2000 volts/ns gives rise to a time base of 50 ps/cm. (The maximum deflection speed is approximately the speed of light.)

The readout system – typically an image intensified CCD camera can clearly resolve 100 microns or less, giving an overall time resolution of 1 ps, or less.

## SPATIAL INFORMATION

The streak image can contain spatial information. In a typical application the spatial information could be spectra, so the image shows intensity/time information over a spectral range of interest.



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## BASIC CONCEPTS

### 1. Basic Design Concept of Streak Tubes

A good introduction to streak tube and camera design was published by Bruce Johnson, Applied Optics, Vol. 19, No. 20 page 3491, October 15, 1980. The following paragraphs attempt to summarise this and a host of more detailed studies:

### 1.1 Slit Width and Readout Pixel Size

In an ideal tube, the light from a slit is imaged onto the photocathode, and faithfully reproduced on a readout medium, almost universally a CCD. Clearly, if for example the CCD pixel is 11 microns, the slit needs to be 11 microns or less to take full advantage of this. If magnification is not one, but say two, then the optimum slit width is smaller (5.5 microns). Generally, the use of slit width of much less than 20 microns leads to optical diffraction patterns and are therefore counter productive. The minimum pixel size at the phosphor screen is therefore 20-30 microns multiplied by electron optical magnification – say 20 –100 micron range.

Realistically the slit image should be covered by 2-3 CCD pixels to define precisely when an event happens, so the CCD pixel size should be in the range of 15-25 microns (factored by the fibre optic taper or optical magnification, if it is not directly coupled).

This leads to a fundamental time resolution given by the pixel size and deflection speed of so many units of length/second.

### 1.2 Tube Spatial Resolution

Clearly there is nothing to be gained by making the slit width and readout pixel size much smaller than the inherent spatial resolution of the tube.

Limiting resolution is generally 30-60 lp/mm at the photocathode, with substantial MTF in the range 15-20 lp/mm. This corresponds to slit width in the range 25-30 microns.

### 1.3 Magnification and Deflection Speed

Increasing the distance between the deflection plates and phosphor screen increases deflection speed and magnification in a linear manner. It also increases magnification in a similar way. Clearly, a long deflector region could have high deflection sensitivity, but also high magnification—resulting in very large pixel size. Conversely, a small magnification can result in a poor deflection speed, and a need for very small CCD pixels to compensate.



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### 1.4 Chromatic Aberration and Space Charge Limitation

Photoelectrons will be emitted into the tube with a characteristic energy (velocity) spread arising from the difference between photon energy and the work function of the photocathode. The electric field within the tube adds to this velocity, but the velocity of an electron at any position in the tube comprises the initial velocity superimposed onto that generated by applied voltages.

Analytically, this chromatic time dispersion predominantly occurs when the imposed acceleration is still small – that is close the photocathode. To a reasonable degree of accuracy, the time dispersion is inversely proportional to the electric field at the photocathode.

Tubes designed for optimum time resolution therefore use a very high field close to the photocathode. This is typically 2 kV/mm in modern metal-ceramic tubes made by Photek, and corresponds to sub-picosecond time resolution

This high field also helps overcome space charge limitations. At first glance, this seems unlikely, but for example 1000 photo-electrons, liberated in less than 1 picosecond, in a 10 micron square pixel corresponds to a current density of over 100 Amps/cm$^2$. This is sufficient to collapse a strong field close to the photocathode; thus increasing chromatic time dispersion, and limiting the signal than can be drawn from a bright event according to Child's Law. Light output is no longer proportional to light input, and the dynamic range, reduces as the optical pulse is made shorter. (References 1 - 7).

## 2. DESIGN FAMILIES OF STREAK TUBES

### 2.1 Large Format Tubes

The RCA (Burle) C73435, Photonis P510, ITT4126 all belong to the same family of large format streak tubes. The photocathode can be as big as 35 x 5mm. The majority of cameras were designed to work in the nanosecond time domain, and the large image input area enables a large number of parallel spatial channels to be analysed. Magnification is typically in the range of 0.8 – 0.9.

Photek equivalents are ST-Y, which is based on electro-optical modelling by Dr Ching Lai. (Reference 9)

The ST-Y has a relatively low field between photocathode and slot, similar to the RCA tube, which limits the photoelectron throughput (Reference 10 ) The Photonis P510 was developed with a closer slot- photocathode separation giving double the electron throughput. An unwanted side effect of operating at high cathode-slot extraction field is that the magnification of the image in the spatial direction increases to 1.2 or higher. This means that although the photocathode is mechanically 35mm long, the useful length may only be 20mm.A similar high throughput version of ST-Y is available (ST- HDR).



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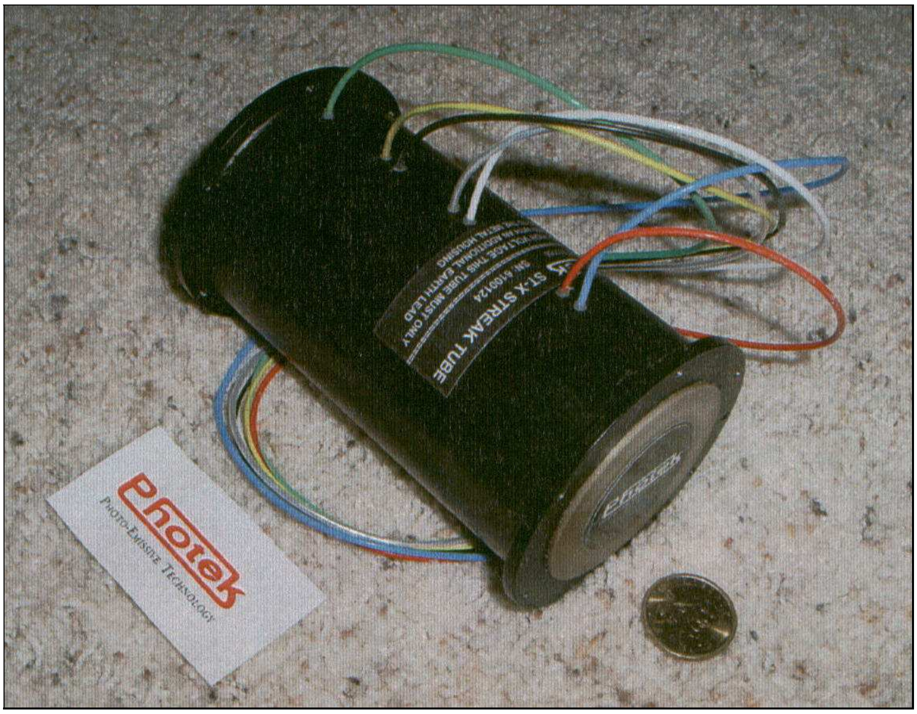
Even this modification is inadequate for some applications, and the CEA designed a novel streak tube with quadrupole focus elements, and even higher electric field close to the photocathode. This tube, Photonis P820PSU has only 15mm photocathode, so again struggles to meet the demands of experiments like LMJ in France. (Reference 11)
More recently, Photek in collaboration with Sydor and LLE, have developed a more radical re-design of the RCA style tube for even higher throughput using higher extraction field, and a novel second slot to improve spatial and temporal resolution. The magnification is lower, increasing the working area of the photocathode to 25mm.

Photek also manufacture a scaled down version of the ST-Y tube, called ST-X, equivalent to the Photonis P900 series.




## 2.2 Framing Tubes

EEV made a large number of streak and framing tubes based on a design by Butlov in 1958. These tubes were extensively sold in cameras made by DRS Hadland Ltd in their Imacon 500 series cameras. The original type was designated P856, but later versions of the tube incorporated an accelerator mesh close to the photocathode to improve time resolution. These were designated P855 for framing cameras such as the Hadland Imacon 675. The photocathode allowed an 8mm



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square input image. Magnification is approximately 2:1, so in a framing mode, two rows of four images about 16 mm square can be produced on a screen of about 75/80 mm diameter.
The EEV P855 used in the Imacon 675 cameras used 3 pairs of deflector plates. The first two pairs, with an aperture between them formed a method of shuttering the image and were known as 'shutter tubes'. For an elegant explanation of this technique see 'New wide screen gateable image intensifier for ultra-high speed photography' (Reference 17).

This "shutter tube" was quite difficult to set-up, and it was particularly difficult to adjust exposure time without altering the frame rate. A new framing camera – the Ultranac –made by IMCO, a subsidiary of NAC Inc of Japan was launched in 1985/6. The tube used 3 meshes close to the photocathode to switch the tube on for desired exposure time, and off during the time taken to deflect the next image to a new position on the phosphor screen. The centre mesh was used to switch the electron beam on or off with about 100 volts bias, while the outer mesh maintains the electron lens in optimum focus condition.
This new camera could reach 20 million frames a second, and exposure time could be adjusted independently of frame rate.

Typical mesh transmission of 50-60% means that overall transmission is of the order of 15%. This is a significant loss of sensitivity compared to the deflector plate lock of the older cameras. It is probably no worse than the optical losses in high-speed cameras using beam splitters of various kinds.

The Photochron2, made by Photek is similar to the Ultranac tube , but with only two meshes which maintains resolution, and improves transmission to about 30%.It easily replaces old tubes in Ultranac cameras, and could in principal be used to upgrade/repair Hadland streak and framing cameras.



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## 2.3 Photochron 5

After Professor Bradley became ill in 1980, this group remained at Imperial College till 1985, when several of them including Professor W Sibbett moved to St Andrews University. Various new designs were made in small quantity, through EMI made a type 9898 Photochron 3 in significant quantities. (Reference 13).

These ideas lead to Photek developing an all-metal-ceramic version of Photochron 5 for the DRS Hadland Ltd FS-300 Camera. Performance of less than 400fs was demonstrated in single shot mode (Reference 14) This tube had an internal MCP, and was designed for synchroscan operation upto 500MHz

Another version of this tube with lower magnification was developed for Optronis GmbH (Reference 15) Both tubes are highly customised to suit the camera manufacturers, and are not available to the world at large, except through Optronis GmbH. (A generic Photochron 5 is commercially available to scientific users). The tube is capable of sub-picosecond time resolution, and can be operated in synchroscan to 200 MHz and beyond. www.optronis.com

**Summary of Photek Streak Tubes**

| Type | Photochron 2 | ST-HDR | Photochron 5 | ST-X | ST-Y |
|---|---|---|---|---|---|
| **Availability** | Current | Current | Current | Current | Current |
| **Other Equivalents** | EEV P8307<br>EEV P855<br>Ultranac | P 510 | None | Photonis P930 | ITT F4157 |
| **Cathode Size** | 8 x 9 mm maximum | 35x4 | 8 mm Slit | 20 x 3 | 35 x 5 |
| **Synchroscan** | 88 MHz | ? | 200 MHz plus | Limited | Limited |
| **Time Resolution** | ~ 3 ps | 7 ps | 400fs | 10 ps | 20 ps |
| **Magnification** | ~ 2 | - | 2 - 4 | 0.7 – 1.5 | 0.7 – 1.5 |
| **Framing Option** | Double Grid X-Y Deflectors | No | X-Y Deflectors | No | No |
| **Overall Length** | 321.5 mm | 250 mm | 322 mm | 147 mm | 250 mm |

Photek have also made very large framing tubes with 80 mm photocathodes for high-speed imaging. Ref. 16.



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## REFERENCES

1. Dr C B Johnson, Applied Optics, Vol. 19 (20) pp 3491, 1980
2. Dr Hull & N J Freeman, J Phys E: Sci Instrum Vol. 13 pp 685-690 1980
3. P G May & W Sibbett, Appl Phys, Letts 43 (7) pp 624-626 1983
4. M C Adams, W Sibbett & D J Bradley Electron Optical Picosecond Streak Camera Operating at 140 MHz. Advances in E & EP 42 1979 pp 265-273
5. W Sibbett, W E Sleat & W Krause pp 171 – 174, Proc ESA Workshop on Space Laser
6. D J Bradley, et al. Optical Communications May 1975
7. P R Bird, D J Bradley, A G Roddie, W Sibbett, Picosecond Chronography at X-ray Wavelengths, Proc. 11th congress on High Speed Photography
8. Mori & Watanabe, Jap J. of Applied Physics, See pages 666 to 672, 1976
9. Dr C Lai, Design and Development of a New Streak Tube, Report UCAR-10159, LLNL
10. P.A. Jaanimagi,A.Mens & J.C.Rebuffi SPIE 2549 (1995)
11. C.Cholet, D Gontier, C.Zuber&P.Brunel,SPIE Vol 7126 pp1-12
12. I G Haig, Rev. Sci. Inst., pp 141-143 1981
13. W Sibbett, et al, Rev Sci. Inst., pp 53 758-761 1982
14. D Bowley, J.Beeley, M Pittak, 22nd International High Speed Photography, SPIE Vol 2869, pp 76-81 1996
15. J.R.Howorth, Ian Phillips & Mikhail Monastryski, IHSPP Conference Beaune, 2002
16. CC Lai, 'Electron optics design & performance of a new large format two frame framing tube', IHSPP Conference Beaune 2002
17. Boris Dashevsky & Alexander Surovegin (SPIE Vol 1243 pp 65-72 1990).
18. J Howorth, G Smith et al, Recent advances in framing tubes for high speed photography, ICHSIP30 2012



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