ELECTRON OPTICS OF ST-X, ST-Y SERIES OF STREAK & FRAMING CAMERA TUBES

INTRODUCTION

The basic electron optics of this range of streak tubes were designed by Ching Lai at the Lawrence Livermore National Laboratory (LLNL) and used by ITT in the F4157 Series tubes. Mechanically, the Photek ST-Y tube is a form–fit socket replacement, for the ITT F4157 RCA/Burle 73435 and the Photonis P510 and P520 series tubes, whilst the ST-X tube is a form fit replacement for the smaller Photonis P920 tube.

Both the ST-X and ST-Y versions are of a metal-ceramic construction with a remotely processed photocathode. The ST-X is 60% scaled from ST-Y.

The first focus electrode can take the form of a slot or a mesh. The mesh intercepts about 40% of the photo electrons, but ensures uniform focussing across the entire area of the photocathode. It also enables one to use a stronger field at the photocathode, giving the ultimate in the time response, and dynamic range. The distance between mesh and cathode can be adjusted to increase time resolution and dynamic range in streak applications, but not if the tube is intended for use in a framing camera, as this will make the setting of the mesh voltage unduly critical for best spatial resolution.

The size of the mesh aperture can be adjusted to suit the number of frames needed in a sequence. For example, the maximum aperture with a single frame would be 35 mm with ST-Y, but an aperture of 20 mm allows four sequential images to be addressed by X-Y deflector plates.

1. OPTIMUM SPATIAL RESOLUTION (FRAMING MODE)

The graph shown in figure 1 gives an indication of how voltages can be adjusted to vary the magnification in the range 0.6 to 1.0. Both distortion and edge resolution fall away either side of the optimum magnification at 0.8. For example, distortion increases from 0.5% at 0.8 to 5% at 1.0 or 13% at 0.6. At 0.8 magnification, both distortion and edge resolution are significantly improved from the ITT design by using a curved phosphor screen. With the curved screen the resolution is limited only by the phosphor screen at all radii.

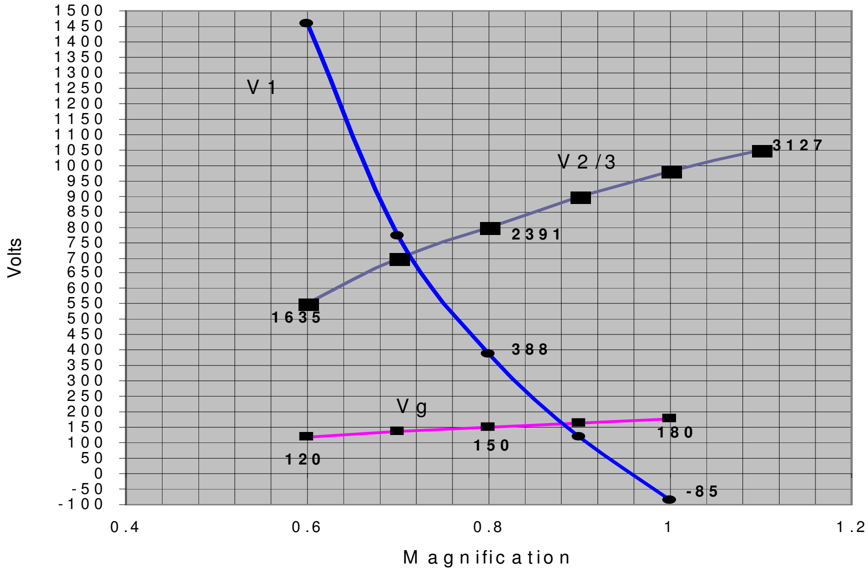

Figure 1 – Magnification

The measured spatial resolution of prototype tubes at 0.8 magnification ranges from 30-60 lp/mm, with distortion virtually impossible to detect.

The calculated time response in streak mode is 55 ps. Since the capacitance between photocathode and grid is less than 20 pF, it should be possible to gate the tube on/off very fast, with a pulse approximately 200 V.

2. STREAK MODE WITH A SLOT

Using a slit in place of a mesh ensures that all photo electrons are recorded and maximises the photon efficiency of the tube.

Because ST-Y and ST-X have an extra electrode, it is possible to increase both the slot voltage and first focus electrode to minimise the anisotropic (or cylindrical lens) effect of the slot electrode. The second focus electrode is used to compensate and bring the tube into focus.

However, as the slot voltage is increased, the tube can only be truly focussed in one axis. The table below, shows focus voltages to achieve 40 lp/mm in the time direction. In the spatial dimension, the minimum resolvable element grows, as one increases the cathode field to improve time resolution.

Focus Conditions of ST-X (Cathode at –15,000 Volts, Screen & Anode at 0V)

VOLTAGES			MAGNIFICATION				
Grid - Ug	Focus 1 – U_1	Focus 2	Time	Spatial	Resolution Spatial Micron	Working Area (mm) 18X	Time Resolution PS CTR EDGE
14,850	14,200	13,000	0.8	0.8	14	3.1	36
14,700	13,000	13,700	0.68	0.73	14	3.1	17-18
14,500	12,000	14,013	0.64	0.82	40	3.0	11-13
14,000	11,000	14,270	0.6	1.0	75	0.4	5-10
13,600	11,000	14,314	0.6	1.0	84	0.3	4-8

The magnification of the tube also changes, increasing in the spatial direction, but falling in the time direction.

There is some difference in time resolution from the centre of the tube to the extreme edge as shown in the table. Since ST-Y is exactly the same electron optically as ST-X, it will achieve exactly the same performance as indicated for ST-X, but at a higher overall voltage of approximately 23 kV.

The working area of ST-Y is 35 x 5 mm whereas ST-X is set to 18 x 3 mm.

3. STREAK MODE WITH A MESH

The voltage between cathode and first focus mesh (Ug) has to be increased to achieve fast streak mode. The extra focus electrode in the Ching Lai design enables a far wide range of options for doing this than older tube designs.

Figure 2 below shows that the ultimate time resolution is less than a picosecond in the extreme case where Ug = 5,000 V (Cathode 0 V, Screen 15,000 V).

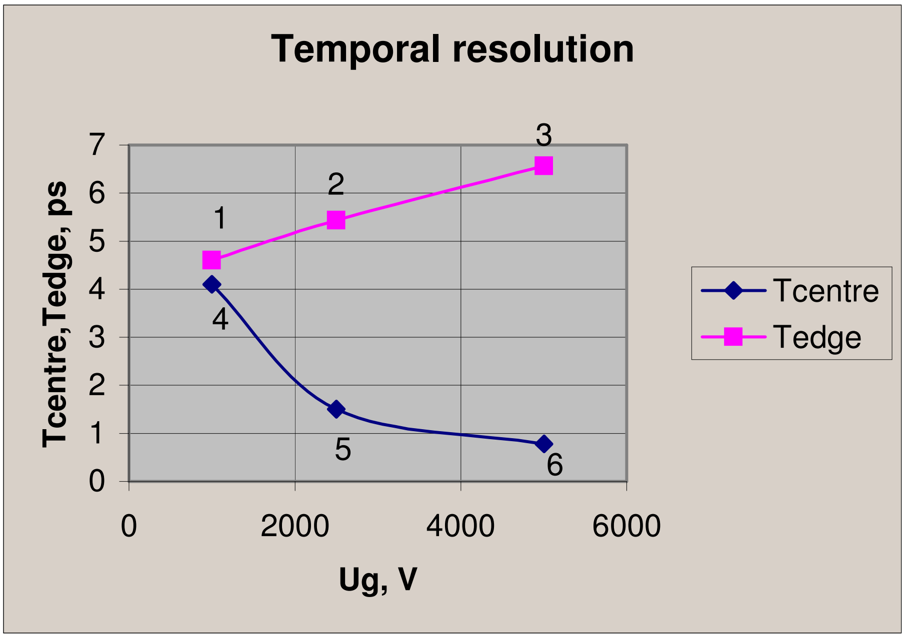

Figure 2 – The dependence of temporal resolution at the centre and at the edge (R_0=9mm) on the grid potential

1,4 – Ug = 1000	**U1 = 1641.8 V**	**U2 = 1178.3 V**
2,5 – Ug = 2500	**U1 = 4542.8 V**	**U2 = 647.9 V**
3,6 – Ug = 5000	**U1 = 10913.4 V**	**U2 = 202.5 V**

However Figures 3 and 4 show that distortion and edge resolution are also severely degraded.

The consequence of this is that the time resolution also falls away at the edge.

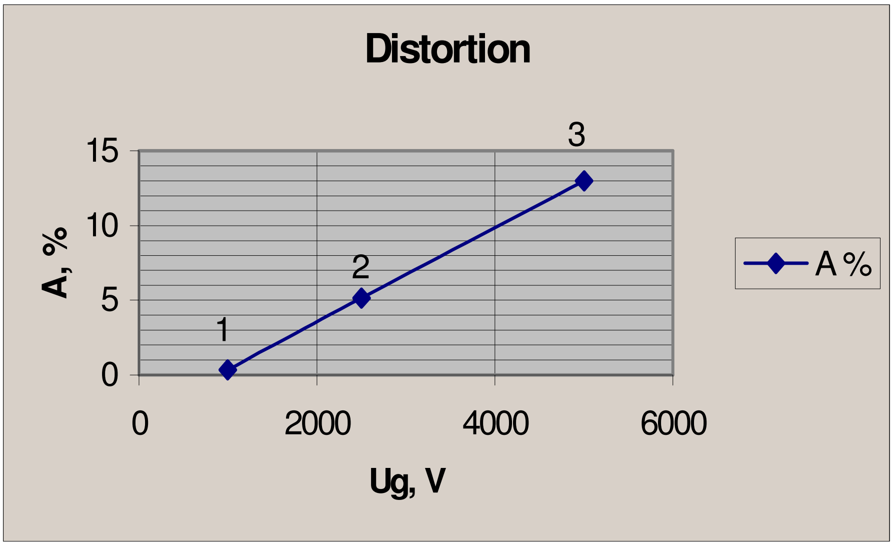

Figure 3 - The dependence of distortion at the edge (R_0=9mm) on the grid potential

1 – Ug = 1000	**U1 = 1641.8 V**	**U2 = 1178.3 V**
2 – Ug = 2500	**U1 = 4542.8 V**	**U2 = 647.9 V**
3 – Ug = 5000	**U1 = 10913.4 V**	**U2 = 202.5V**

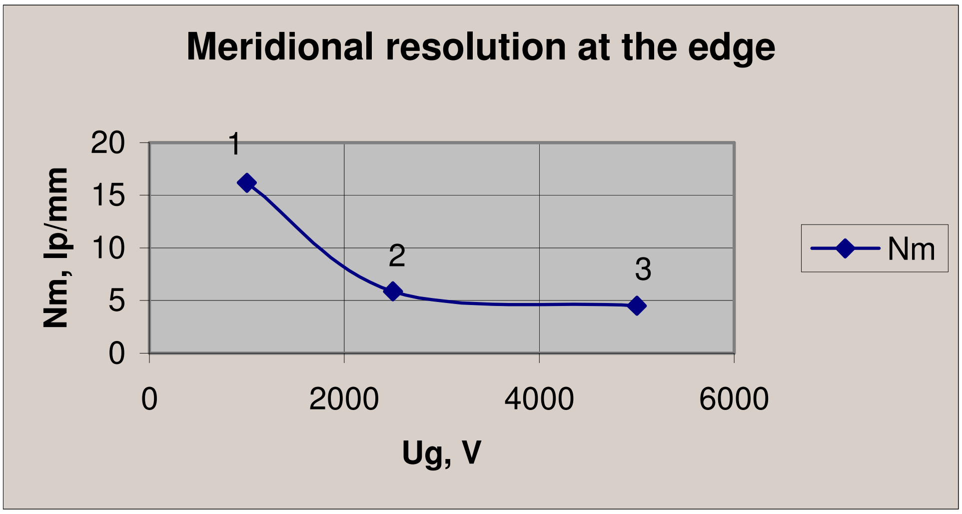

Figure 4 - The dependence of spatial resolution at the edge (R_0=9mm) on the grid potential

1 – Ug = 1000	**U1 = 1641.8 V**	**U2 = 1178.3 V**
2 – Ug = 2500	**U1 = 4542.8 V**	**U2 = 647.9 V**
3 – Ug = 5000	**U1 = 10913.4 V**	**U2 = 202.5 V**

In another words, the working area is severely reduced as the tube is re-focussed for better time resolution.

Figure 5 shows how magnification also increases as Ug is increased.

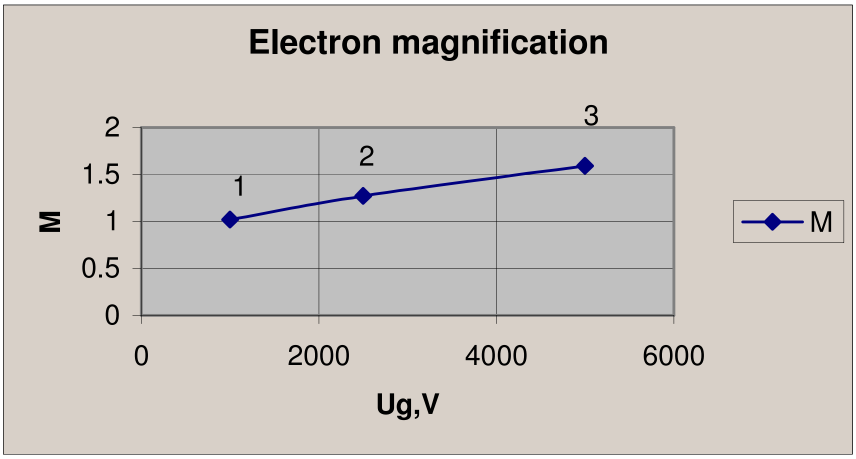

Figure 5 - The dependence of electron magnification at the centre on the grid potential

1 – Ug = 1000	**U1 = 1641.8 V**	**U2 = 1178.3 V**
2 – Ug = 2500	**U1 = 4542.8 V**	**U2 = 647.9 V**
3 – Ug = 5000	**U1 = 10913.4 V**	**U2 = 202.5 V**

It should be noted that these calculations all relate to a planoconcave input window – that is, flat on the outside and curved on the inside. The optical path distance is therefore greater on edge of the working area than in the centre. This corresponds to 0.7 ps at 4 mm radius and 1.5 ps at 6 mm radius.

The dynamic range is limited by Child's Law since the maximum current is proportional to $V^{1.5}$ divided by d^2, where d is the gap between photocathode and mesh. Optimum performance is then achieved at Ug = 1000, with a smaller gap between cathode and mesh (1.6 mm)

The time resolution, centre to edge becomes better than 2 ps, with a magnification of 1, negligible distortion and optimum resolution

The dynamic range of such a tube is approximately twice that of the slot version despite the loss of photoelectrons in the mesh.

In principal, time resolution can be improved into the sub-picosecond range on axis by increasing Ug to 2500 Volts, if off axis performance can be sacrificed.

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