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Development of X-ray streak camera electronics at AWRE

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The paper reviews a number of X-ray streak cameras developed at AWRE. These cameras are used to provide temporal and one-dimensional spatial or spectral information on X-rays emitted from laser produced plasmas. Two of these cameras have been designed to be combined with other diagnostic instrumentation; one with a Wolter X-ray microscope (×22 magnification) and the other with a Bragg diffraction crystal spectrometer. This latter instrument provides a few eV spectral resolution and ~15 ps temporal resolution; a typical experimental application at the AWRE HELEN laser facility will be described. The paper describes the circuitry of the bipolar avalanche transistor ramp generator used to drive the streak plates of the cameras. Improvements to this include: (a) increasing the fastest streak rate to ~10 ps mm^{-1} by a distributed capacitance network across each of the bipolar stacks of transistors, and (b) reducing the trigger jitter to approximately ±10 ps by the use of a new mix of transistors in the stack and a Raytheon RS 3500 avalanche transistor. Additional improvements have now been added. These include a 'half-scan' user facility to aid initial camera timing and direct switching to select the sweep rate of the camera.

1. Introduction

AWRE supports a research programme to investigate the physics of laser produced plasmas to improve the understanding of the parameters of weapon design codes. A high power pulsed Nd: YAG laser is employed in this programme together with a wide variety of diagnostic instrumentation to provide spectrally, temporally and spatially resolved data. One such instrument, the X-ray streak camera is described in this paper. Table 1 details the specification of the AWRE HELEN laser and lists the proposed upgrade to be considered for the 1986 programme.

1.1. *Camera developments*

A series of X-ray streak cameras, six to-date, have been developed by AWRE for temporal, spectral and limited spatial investigation of X-radiation as described above. These instruments are used in the following study areas:—

(a) Fast electron production and hard X-radiation.
(b) Target pre-heat.
(c) Target heating and debris motion.
(d) Time resolved spectroscopy.
(e) Hydro-dynamics and opacity.
(f) X-ray backlighting characterisation.

The first prototype camera was constructed using an open ended glass image tube with electron optics of similar design to tubes which were commercially available in the UK. Later versions, shown in figure 1, used a tube fabricated in metal and PTFE to improve the ruggedness of the design.

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Characteristics of AWRE Laser—HELEN	
Nd YAG glass laser	Nominal 1TW
Two beams	20 cm diameter
West beam	90 J at 1·06 μm (0·53 μm mid 85)
East beam	60 J at 0·53 μm
Pulse length	120 ps—800 ps
Proposed Upgrade (Mid 1986*)—HELEX*	
Increase power level	×4
Two beams for target heating	30 cm 1·06/0·53 μm
Independent oscillators	Delay variation 0–10 n/s
Pulse length	100 ps—1 ns
Third independent backlighter beam	20 cm 1·06/0·53 μm

TABLE 1. Present and proposed specification of the AWRE facility

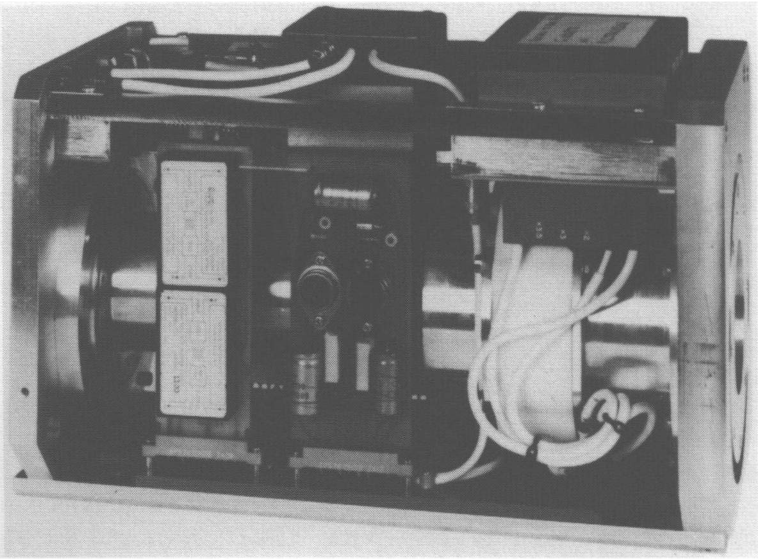


FIGURE 1.

1.2. *X-ray streak camera operation*

The operation of the camera can be demonstrated by reference to figure 2 which shows a sectional view of the prototype camera arranged to streak a pinhole image of an X-ray event. A slit is placed in front of the X-ray sensitive cathode which is normally gold on a carbon, plastic or beryllium backing or, where a higher sensitivity is required, the gold is replaced by caesium iodide. Photoelectrons from the slit area are accelerated, by the 10–15 kV/cm electrostatic field between the cathode and grid, and focussed through the earthed anode onto the output phosphor. The electron beam is streaked in a direction normal to the slit and thus produces a record of the time history of the event and its spatial variation in one dimension.

The streak is produced by a push-pull deflection voltage applied to the deflector plates. The voltage required is approx ±1 kV in order to streak the image over the 4·5 cm output screen.

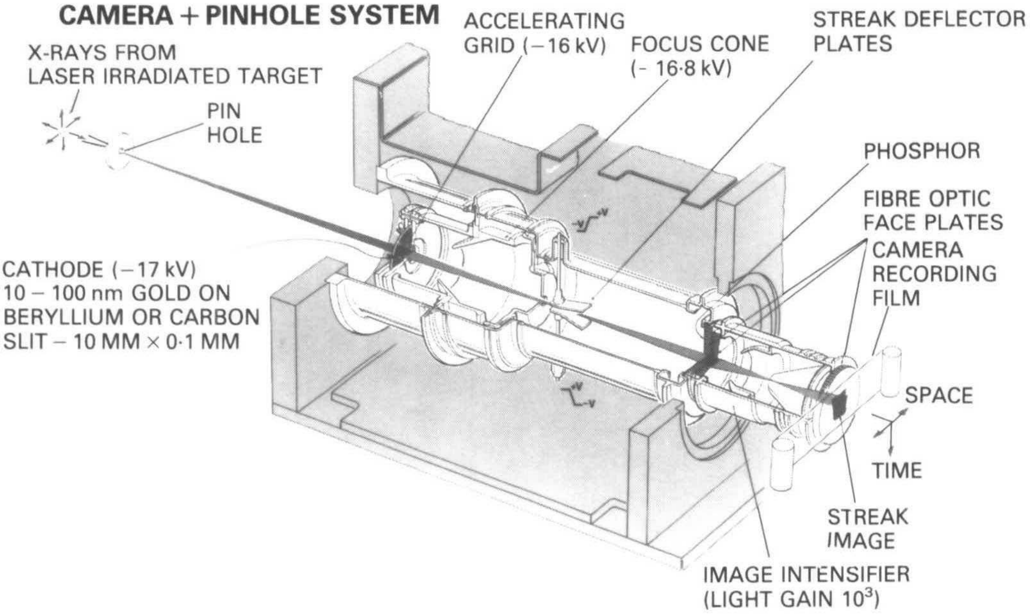


FIGURE 2.

The phosphor, of the image tube, P20/P11 converts the photoelectrons to photons which are transmitted via a fibre optic plate to an intensifier. This final stage consists of an inverting triode channel plate intensifier, which is gated on for some 200 μsecs. The gain achieved is approximately ×1000 and the photon output produced at this phosphor is then recorded on film.

The performance of the prototype is given below in table 2. It can be seen from this that the linearity, particularly at the slower scan rate, was unsatisfactory and the main section of the paper will describe the work done to improve this figure and provide additional facilities.

1.3. *Specialist camera development*

Two of the streak cameras produced have been developed to be combined with other diagnostic instrumentation. One of these will be used in conjunction with a Wolter X-ray microscope (magnification ×22). Using this technique, continuous spatial imaging of an 'event' is possible with very high temporal (~10 ps) and spatial (~ few μm) resolution.

The second combined instrument employs a streak camera coupled to a Bragg diffraction crystal spectrometer. Here, the output of the crystal spectrograph is

Time resolution	10–20 ps
Spectral range	100 eV–30 keV
Dynamic range	A few hundred
Spatial resolution	~100 μm
Linearity	at 70 ps/mm + 12%
	at 300 ps/mm + 40%
	− 14%
Jitter ±100 ps	

TABLE 2. Prototype X-ray camera performance

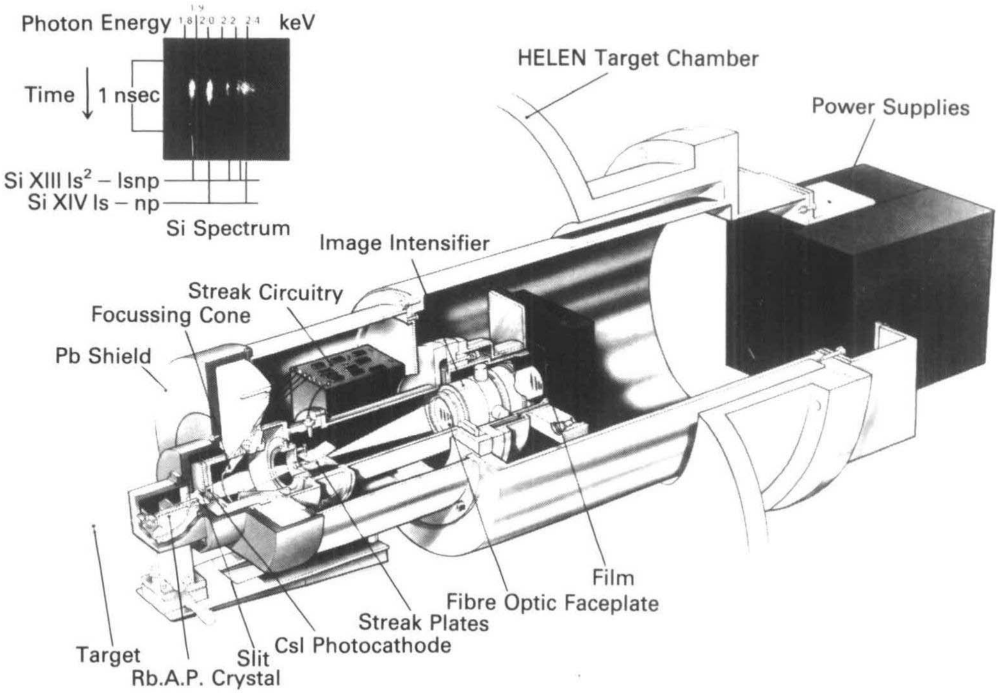


FIGURE 3.

dispersed according to the X-ray energy across the slit of the streak camera which is then streaked to provide both temporally and spectrally resolved information.

1.4. *Streaked X-ray crystal spectrograph spectral range* (1·5 keV–5·5 keV)

The second of these specialist cameras, the streaked X-ray crystal spectrograph, see figure 3, produced a number of special requirements for the electronics of the streak circuit. In order to produce the high sensitivity required the camera was designed in re-entrant form with the crystal spectrometer only 10 cm from the target. In the initial design, the ramp generator used was mounted close to the sweep plates which are less than 30 cm from the target. It was therefore both inaccessible and prone to interference.

The need to modify the camera to take the circuit out of the chamber and the requirements described earlier led us to the re-design of the electronics and this is described in the next section of this paper.

2. Electronic development

The aim of the new design of streak circuit was to incorporate the following improvements:—

(a) Better linearity.
(b) Reduced trigger jitter.
(c) Improved drive capability.
(d) Direct switching of the sweep rate.
(e) Increased max sweep speed.
(f) Half scan provision for ease of timing.

The performance of this unit, when combined with the streak plates, will determine the speed, linearity and timing jitter of the camera. The generator is required to produce a bi-polar ramp voltage of ±2 kV to sweep the electrons across the output phosphor of the image tube. A pair of avalanche transistor stacks (×10 each) act as a very high speed switch providing a step waveform output. This is then applied to the sweep plates via a series RLC resonant circuit which, with the plate capacitance etc, determines the rate of scan. The circuit of the generator is shown in figure 4. A theoretical description of the working of this type of generator is available in a recent LLNL paper. (Thomas 1984.)

The changes required to this circuit for each of the improvements will now be discussed in detail.

2.1. *Improved linearity*

The use of a cosine wave output with approximately X2 overscan should allow a linearity of close on 10% to be achieved. Such a result was available from the prototype on the fastest range, (figure 5a) but on the slower ranges the performance was worse. An investigation of the performance of the slower ranges showed that a reaction between the 'firing' of the two stacks caused 'kinks' in one or other of the bi-polar ramps. An initial improvement was made by the addition of a ground plane to the board which helped to eliminate the cross-talk and reduce RF interference.

The main improvement, though, was produced by the provision of two separate trigger pulses, one to each stack. To avoid increased jitter these trigger pulses were produced from a single source using a collector and emitter load in the RS 3500 circuit.

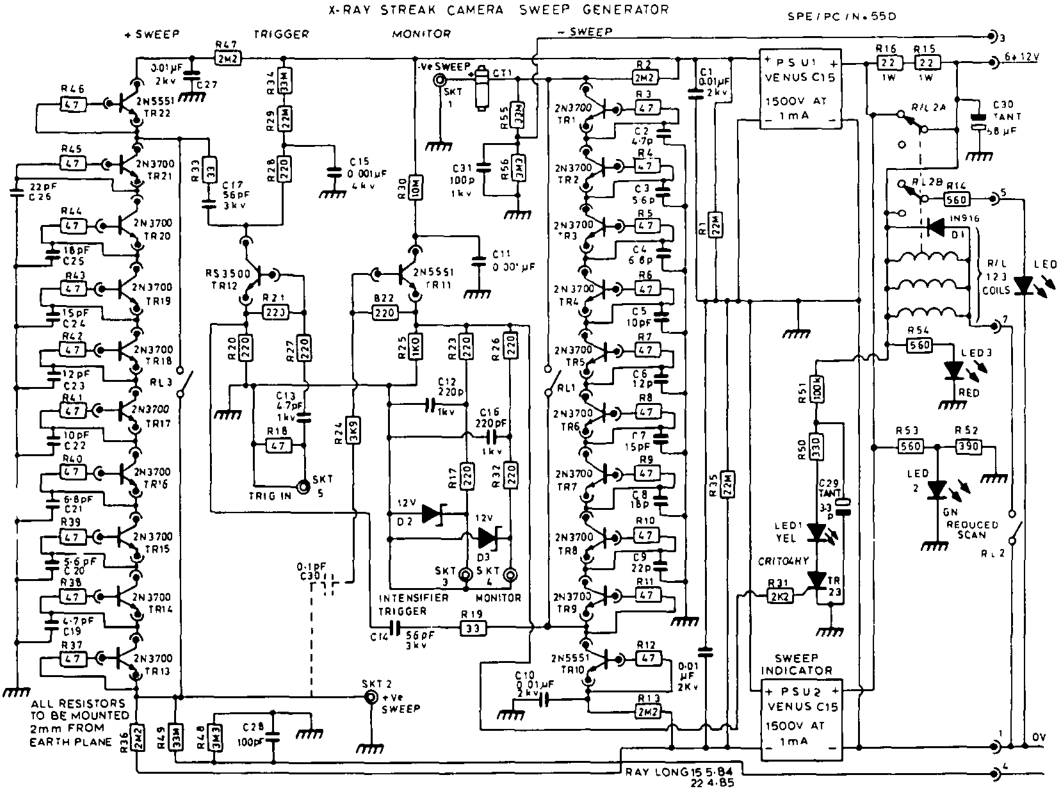
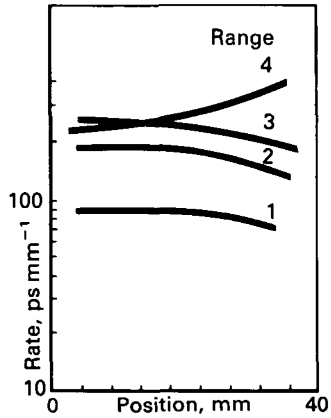


FIGURE 4.

Prototype Board

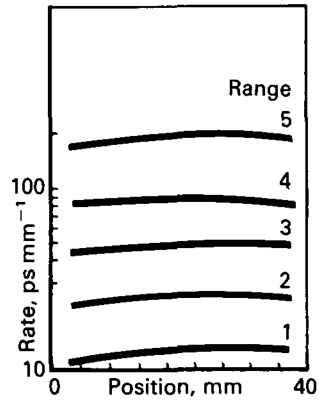
Range 1· 70 ps/mm	Linearity	12%
2·190 ps/mm		14%
3·230 ps/mm		13%
4·270 ps/mm		−14%
(centre value)		+40%



5(a)

Final Board

Range 1· 10 ps/mm	Linearity	10%
2· 25 ps/mm		10%
3· 50 ps/mm		6%
4· 80 ps/mm		5%
5·180 ps/mm		6%



5(b)

FIGURE 5.

The result of these modifications is seen in figure 5b, showing the considerable improvement in the linearity of the circuit output particularly for the slow ranges. The test procedures for the speed and linearity measurements were carried out by two methods.

The initial adjustment and optimisation of the ramp generator output was made using a 4 GHz travelling wave oscilloscope using both linear and differentiating probes.

The final confirmation of these figures was achieved by installing the generator in a Hadland 675 streak camera and using a laser and etalon system working in the 1·06 μm wavelength to provide known temporally spaced pulses. The standard Mullard 5040 intensifier was replaced by a more linear proximity focussed intensifier the ITT F4113.

More recently a new calibration technique has been devised allowing the X-ray cameras to be directly calibrated, i.e. without having to use a pulsed X-ray source. The demountable X-ray sensitive cathode is replaced by a cathode which is sensitive to ultra violet radiation (e.g. 100 Å Aluminium).

Calibrations are performed using 266 nm radiation from the two stage second harmonic generation of a 1·06 μm Nd^{3+} YAG pulse. Using this laser calibration facility, with its high pulse repetition rate, a camera can be re-calibrated in approximately 1 hour. (Perkins 1984.)

2.2. *Jitter improvements*

The variation of the time delay between receipt of the trigger pulse and start of the sweep (jitter) has been reduced from >± 100 ps to approximately ±10 ps. This reduction of jitter was brought about by the use of a new transistor by Raytheon, the RS 3500, designed specifically for avalanche operation. The availability of this avalanche transistor has now alleviated the need for selection of the trigger transistor. In addition the use of one higher voltage transistor as the first element in the stack ensures reliable cascade operation of the complete stack.

Finally, the provision of the distributed capacitor network ensures an approximately equal energy source available to each transistor and so reduces any avalanche uncertainty.

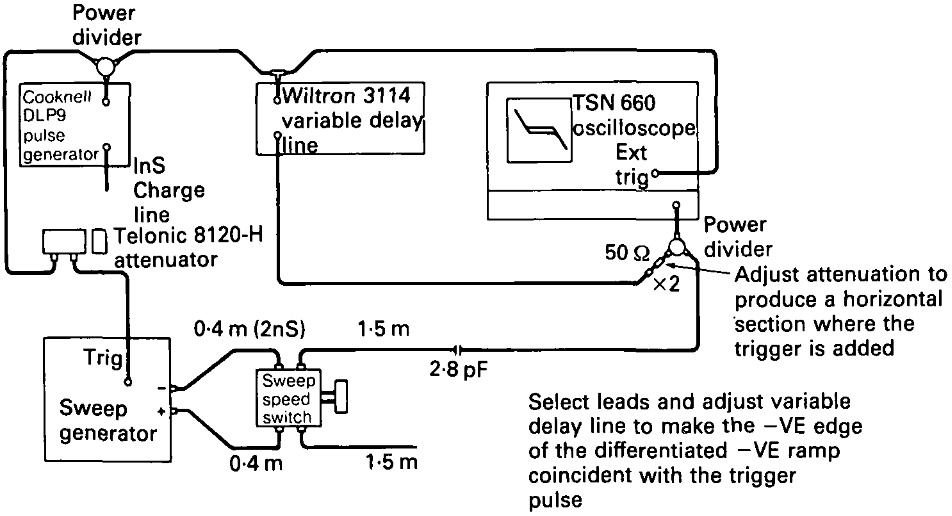
The measurement of jitter of this low value creates certain problems. A technique using the 4 GHz oscilloscope was devised allowing the circuit jitter to be distinguished from that of the oscilloscope itself. (figure 6).

The ramp output and the trigger pulse are summed in such a way as to provide a horizontal section in the total waveform. The jitter of the ramp output can be estimated from the vertical movement of this flat section. The sensitivity of this technique was calibrated by adding known delay times in the ramp signal. Use of the laser calibration facility and use in the diagnostic programme confirm that the figure quoted ±10 ps is not very far in error.

2.3. *Improved drive capabilities*

The prototype of the streaked X-ray crystal spectrometer was built with the sweep circuit mounted close to the deflection plates. This means that the circuit is within approximately 30 cm of the target in the re-entrant mounting. Initial tests of this system gave problems associated with the target radiation. It was therefore decided to drive the plates from outside the chamber also giving the additional advantage of greater ease of access.

Jitter measurement



Adjust attenuation to produce a horizontal section where the trigger is added

Select leads and adjust variable delay line to make the −VE edge of the differentiated −VE ramp coincident with the trigger pulse

FIGURE 6.

Two important changes in the sweep system therefore were required, firstly to be able to drive in excess of a metre of co-ax cable and secondly to provide screening for the cables passing into the chamber to feed the plates.

The provision of the distributed network of capacitors across the stacks, i.e. a low inductance capacitor between each collector and the ground plane increased the circuit ability to drive 50 Ω co-axial cable to well over the metre required and maintain the maximum sweep speed. The link chosen was a semi-rigid cable giving the very good screening against RF interference required. In addition such a cable retains its position and so provides an output independent of the overall layout variations.

2.4. *Direct switching of sweep rate (10–20–40–80–160–320) PS/mm*

Until recently range switching had been achieved by the use of plug in modules. This approach caused accessibility problems and the danger of the loss of pre-calibrated 'plug ins' for each camera. Switching of the rate of the sweep is now produced by using a modified multi-bank rotary switch (figure 7).

Considerable care has been found necessary in the screening of the sections of this unit. The first section is mainly used to reduce any very high frequency ripple superimposed on the ramp. The second is used to set the selected sweep rate.

In this circuit no isolation and separate bias are applied and so it is necessary to adjust the overshoot value chosen to ensure the most linear section is on screen.

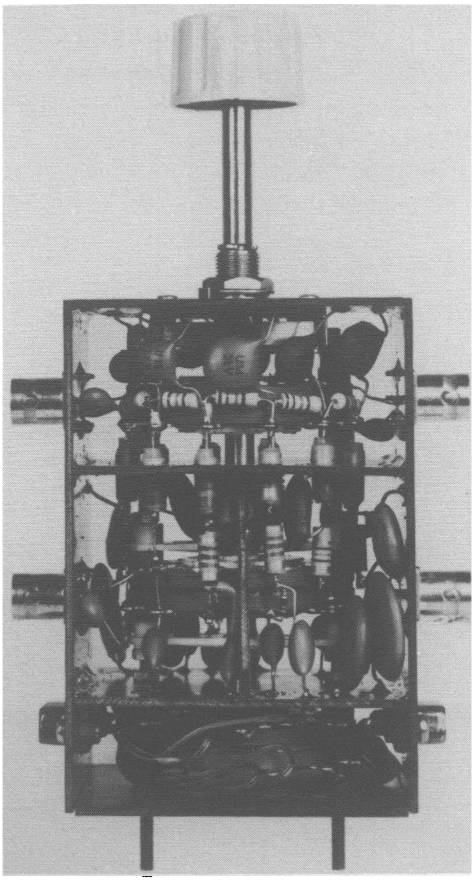


FIGURE 7.

2.5. *Increase of max rate to* 10 *ps/mm*

The use of the distributed capacitance network described earlier has allowed the maximum rate to be increased approximately five fold.

2.6. *Provision of half scan for ease of timing*

The trigger delay systems associated with the streak camera must be adjusted so that the image is timed to arrive during the 'on screen period' of the scan. The use of a cosine wave drive requires a large section of the scan to be off screen to avoid severe non-linearity. For timing purposes only, the scan is reduced so that all the scan is now 'on screen'. This allows the operator to adjust the trigger delay for use in full scan mode.

The half scan is achieved by reducing the EHT value and shorting out a number of the avalanche transistors in each stack by high voltage reed relays. Figure 8 shows the overall layout of the generator with the modified circuitry and dense ground plane.

3. Applications

There are numerous applications for these cameras within the HELEN programme particularly for use in the study of the physics of hydrodynamic instability and opacity.

Current experiments, involving classified targets at AWRE involve the use of 'snapshot' backlighting techniques to 'freeze' short time frames within the event. The work done to characterise these backlighters, of an extended and point source nature, involve the use of K, L and M shell emitting materials such as Al, Ti, Y, Pd, Ag, Ho, Gd, Yb, Ta, Bi, Au.

A number of diagnostic instruments are required in this work, particularly the streaked X-ray spectrometer described earlier, which records both the temporal history and intensity of the X-ray emission lines or bands, versus time. In addition an integrating mini-crystal spectrometer is used to measure the integrated values of intensity versus wavelengths. A Kirkpatrick-Baez X-ray microscope is used to measure

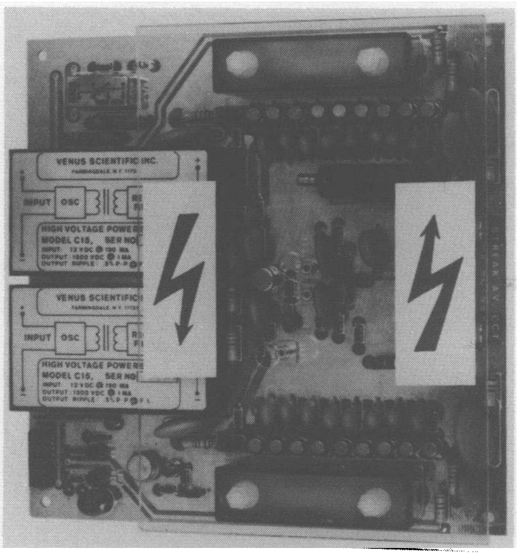
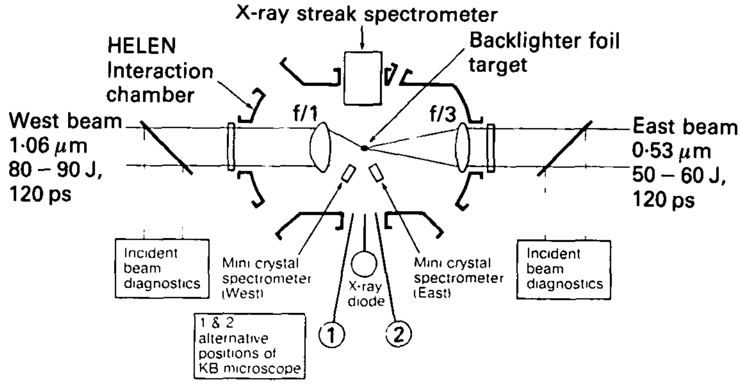


FIGURE 8.



Either East or West beams fired, usually alternately

Spectrometer—crystals RbAP, TlAP, PET
coverage 1·5 – 5·5 keV
resolution ~20 ps

FIGURE 9.

brightness uniformity and lastly a number of broad-band response X-ray diodes are used for intensity versus time measurements.

The experimental arrangement, as shown in figure 9 is used to characterise the backlighters using the materials listed above. The properties of each of the backlighters to be studied and their duration, spectral content and conversion efficiency, i.e. photon output/laser joule input are shown in figures 10 to 12.

The initial work with Aluminium produced backlighters lasting in the region of 0·3–0·8 ns. Other materials were tried, figure 11 shows the results obtain for instance with Ytterbium, giving a much shorter duration X-ray pulse i.e. in the region of 150 ps (FWHM) with a 120 ps laser pulse.

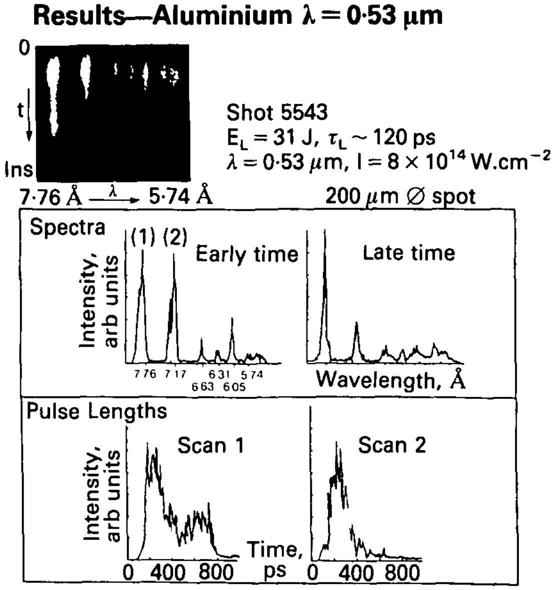

Results—Aluminium λ = 0·53 μm

FIGURE 10.

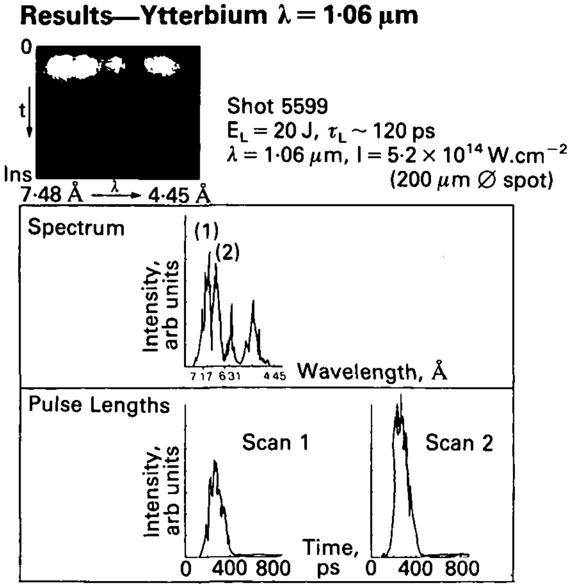
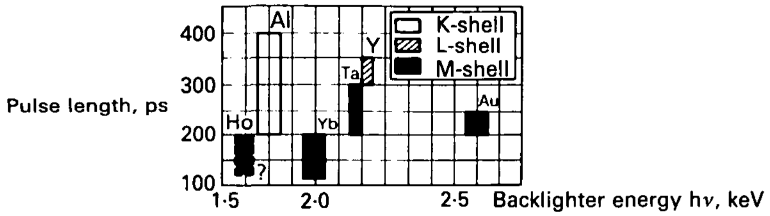


FIGURE 11.

Summary of backlighter pulse length data

Laser:
East beam 50 – 60 J, 0·53 μm, 120 ps } 200 – 700 μm ∅ spot sizes
West beam 50 – 60 J, 1·06 μm, 120 ps } I ~ 10^{13} – 10^{14} W.cm^{-2}



Notes
1) Measurements done at both wavelengths for all materials except Yttrium
2) Note that Holmium data is suspect and measurement needs to be repeated
3) 'Pulse length' indicates approximate spread between shorter and longer-lived spectral features

FIGURE 12.

A summary of the results obtained for a number of possible backlighter materials with high emission in the 1·5–2·6 keV energy range is listed in figure 12.

4. Conclusions

The electronic improvements described in this paper have increased the versatility and ease of operation of the X-ray cameras designed at AWRE for the HELEN programme. In particular the improved linearity > (factor 2), reduction of jitter (X10) and drive over relatively long distances have widened the scope of their use.

REFERENCES

PERKINS, D. A. 1984 *AWRE Report* SPE N 48/84.

THOMAS, S. W. 1984 *16th International Congress on High Speed Photography and Photons, Strasbourg. August* 27–31 1984. UCRL 90491 PREPRINT.