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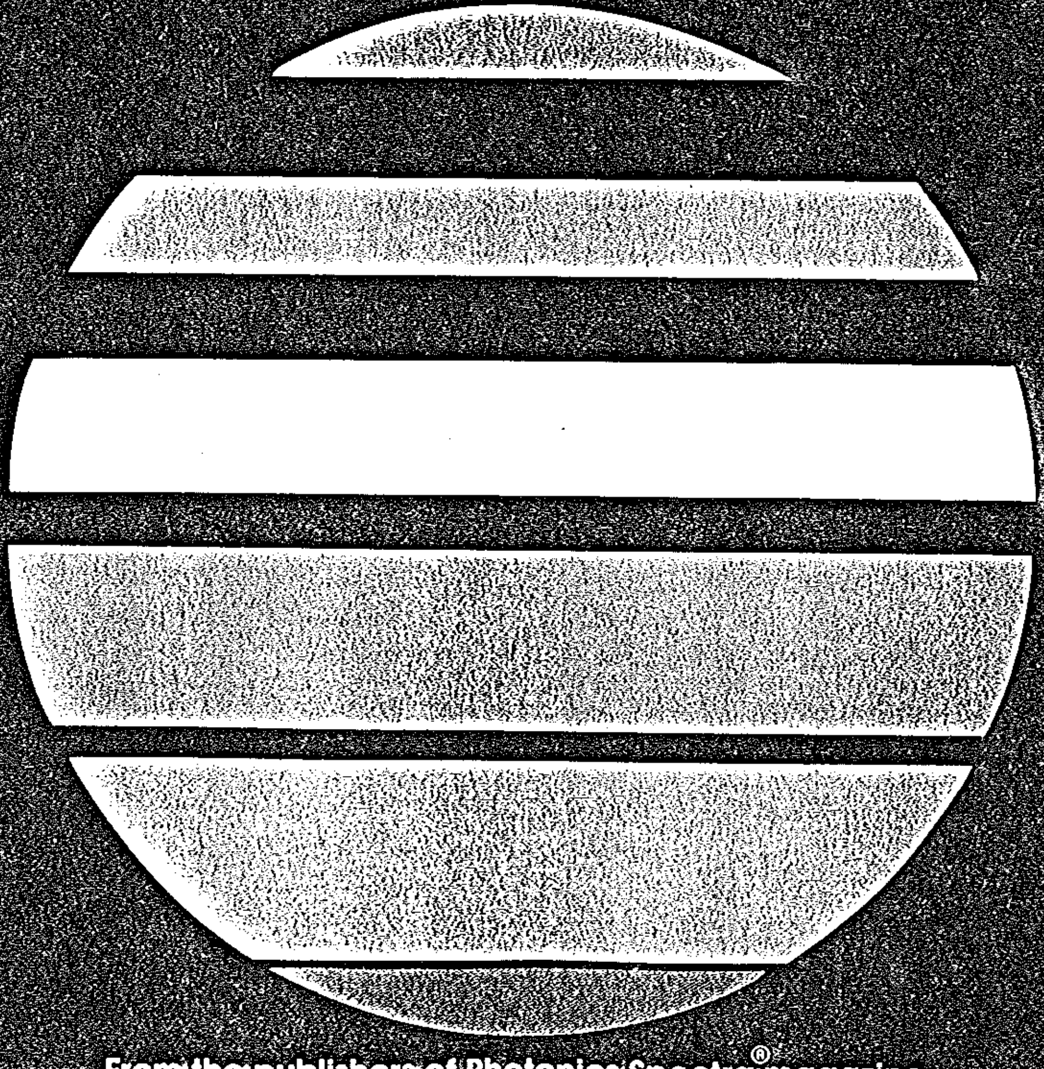
In This Book:
- Graphs, Charts, Schematics
- Characteristics and Parameters Tables
- Conversion Tables
- Design Articles



From the publishers of Photonics Spectra® magazine

Calibrating a Picosecond Streak Camera

In combination with a picosecond mode-locked laser, a streak camera can temporally resolve high-speed events. This capability has helped open up new fields of research for physicists, biologists and chemists studying the intricacies of the molecular world. Most of the basic processes occur on a picosecond time scale, so the development of streak camera technology is intimately related to the progress of picosecond and subpicosecond laser techniques. Table 1 lists the typical pulse durations achieved to date.

General operation

A streak camera spectroscopic system consists of a streak tube (Fig. 1), imaging optics, fast sweeping electrodes and video display/computer equipment. Light incident onto the photocathode produces an emission of electrons proportional to the light intensity. These electrons are accelerated by a high-voltage mesh into the streak tube, and are electrostatically swept at a known rate over a known distance, thus converting temporal information into spatial information. Electrons emitted at different times are deflected to different positions on a microchannel plate that produces electron multiplication through secondary emission. These secondary electrons impinge upon a phosphor screen, forming a streak image that is viewed by a filmback or by an electronic video readout system.

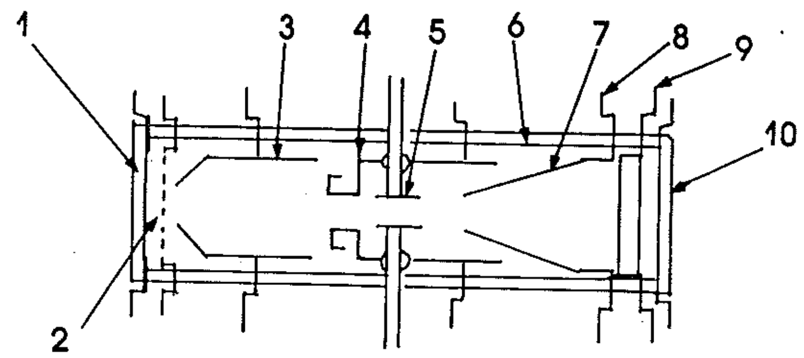


Figure 1.
Cross-section of a streak-camera tube. (1) Photocathode: (2) Mesh electrode: (3) Focusing electrode: (4) Anode: (5) Deflecting plate: (6) Wall anode: (7) Cone electrode: (8) MCP input electrode: (9) MCP output electrode: (10) fluorescent screen.

Dynamic range

The dynamic range of a streak camera is commonly defined as the input intensity at which the streak camera output pulse width is broadened by no more than 20%, using the pulse duration of lower intensity pulses (t_0) as a reference.[1] The ratio of the highest to the lowest incident light intensity for which this condition is satisfied is the linear dynamic range. Often, the video readout system limits the dynamic range by saturating before the camera, and thus a proper video recorder choice must be made to be able to utilize the full dynamic range of the camera. Typical dynamic range of streak cameras not limited by a readout system is 1000:1. Factors which limit the dynamic range are microleasing effects and space charge saturation near the photocathode. These effects cause temporal broadening of the focused beam when the current density inside the tube is large.

Calibration in time and intensity

All streak cameras at present require time and intensity axis calibration in order to display a kinetic intensity profile versus time of an event, as measured with a camera-video system. We describe such a calibration technique below.

Calibrating the time axis and linearity of a camera system in the streak mode requires an optical single pulse that has a duration (FWHM) that is less than the resolution of the camera and a wavelength within the spectral response of the unit. For this technique we use a single pulse extracted from the output train of a mode-locked laser. The pulse passes through a pair of mirrors (etalon) of transmission coefficient T coated for the wavelength of the pulse employed. Typically a transmission coefficient of 10 percent will yield the best results. The laser's pulse duration in space is much less than the etalon spacing.

Figure 2 shows a schematic diagram of the calibration system.[2] By passing the pulse through an etalon of known time spacing (d), a series of exponentially decaying intensity pulses will emerge. The calibrating pulses produced in this manner are a train separated in time ($\Delta t = 2d/c$, where c is the velocity of light). The intensity profile of the emerging train is a decaying exponential with each subse-

TABLE 1.
MODE-LOCKED LASERS

Laser	Wavelength (nm)	Mode-Locking Dye	Typical Laser Pulse Duration (psec)
Ruby	694.5	DDI in (methanol)	10-30
Nd:YAG	1064	9860, 9740 in (dichloroethane)	30
Nd:glass (silicate)	1060	9860 in (dichloroethane)	8-10
Nd:glass (phosphate)	1054	9860 in (dichloroethane)	6-7
		5 in (dichloroethane)	3-4
Rh6G	570-610	Synch pump	2-6
Rh6G	610	DODCI	0.5-0.03

quent peak reduced by $(1\text{-}T)^2$. For each round trip of the pulse between the mirrors, a light pulse (K) of intensity $I_K = I_O(1\text{-}T)^{2K}$ is produced, where K = 0, 1, 2...n. Since I_K/I_{K+1} equals $1/(1\text{-}T)^2$ equals constant, the envelope formed by the peaks of the pulses follows a single exponential decay in time as $I = I_O \exp(-t/\Delta t \ 1n\ (1\text{-}T)^2)$, where the time between peaks is t + K Δt. The peaks are used to calibrate the time axis.

This technique, with appropriate etalon transmission, may also be used to measure transient dynamic range, but is typically too noisy and may disguise the minimum measurable signal, thereby limiting the dynamic range measurements. The sweep rate per channel $\Delta t/\Delta X$ versus the average channel number (X) is used to calibrate the time base and intensity variations of the camera where X is the number of channels between peaks and Δt is fixed for a given etalon mirror spacing.

Using this calibration technique, we can generate curves representing sweep rate ($X = At$) and sweep speed linearity. The streak speed in picoseconds/channel for each scale can be determined from their sweep rate curve.

The intensity spatial profile as a function of distance (I(x)) along the phosphor screen is usually measured with a video system. In order to obtain the intensity as a function of time (I(t)) from that profile, one must take into account the streak rate for each channel. This rate is nonlinear, and it is intuitively clear that the I(x) the video system measures is not the true I(t).

For example, let us assume that the rate at one channel is larger than at a later channel; that is, the voltage ramp is such that the deflected electron beam excites the phosphor at the first channel longer than at the second channel to which it is deflected later in time. Furthermore, let us assume that the intensity of light is equal at both times. Clearly, while in reality the intensities are equal, the video system will read more intensity at the first channel because it collected the deflected electrons longer. Therefore, it is obvious that when the streak rate is nonlinear, one must take into account the differing rates to get the true I(t) from I(x).

The streak rate is taken into account by setting $I(t)dt = I(x)dx$, or:

$$I(t) = I(x)\,\frac{dx}{dt}$$

This means that I at a certain point on the x axis is multiplied by an infinitesimal amount dx and that this must be equal to I at the corresponding point on the t axis times an infinitesimal amount dt. Since I(x)dx is the total intensity measured in the immediate vicinity of x, and I(t)dt is the total intensity measured in the immediate vicinity of t, this simply requires that the total intensity measured at x equal the total intensity measured for the corresponding time. The equation above tells us that by multiplying the I(x), measured at each channel by the video system, by the $\Delta x/\Delta t$ of that channel, x, we can obtain the intensity as a function of time.

Now that I(t) has been obtained one has to convert the x axis into a time axis. This is done by noting:

$$t = \frac{dt}{dx}\,dx$$

In effect, this is doing the integral

$$t = (dt/dx)dx$$

numerically, which is necessitated by the fact that we have values at discrete channels and do not have a continuous curve. Because of the nonlinear streak rate, the distance between equal times will vary. However, since we now know the time to which each point on the x axis corresponds, and we know the value of I(t) at that point, it is easy to regraph the ordered pairs (t, I(t)) so distance between equal times is equal.

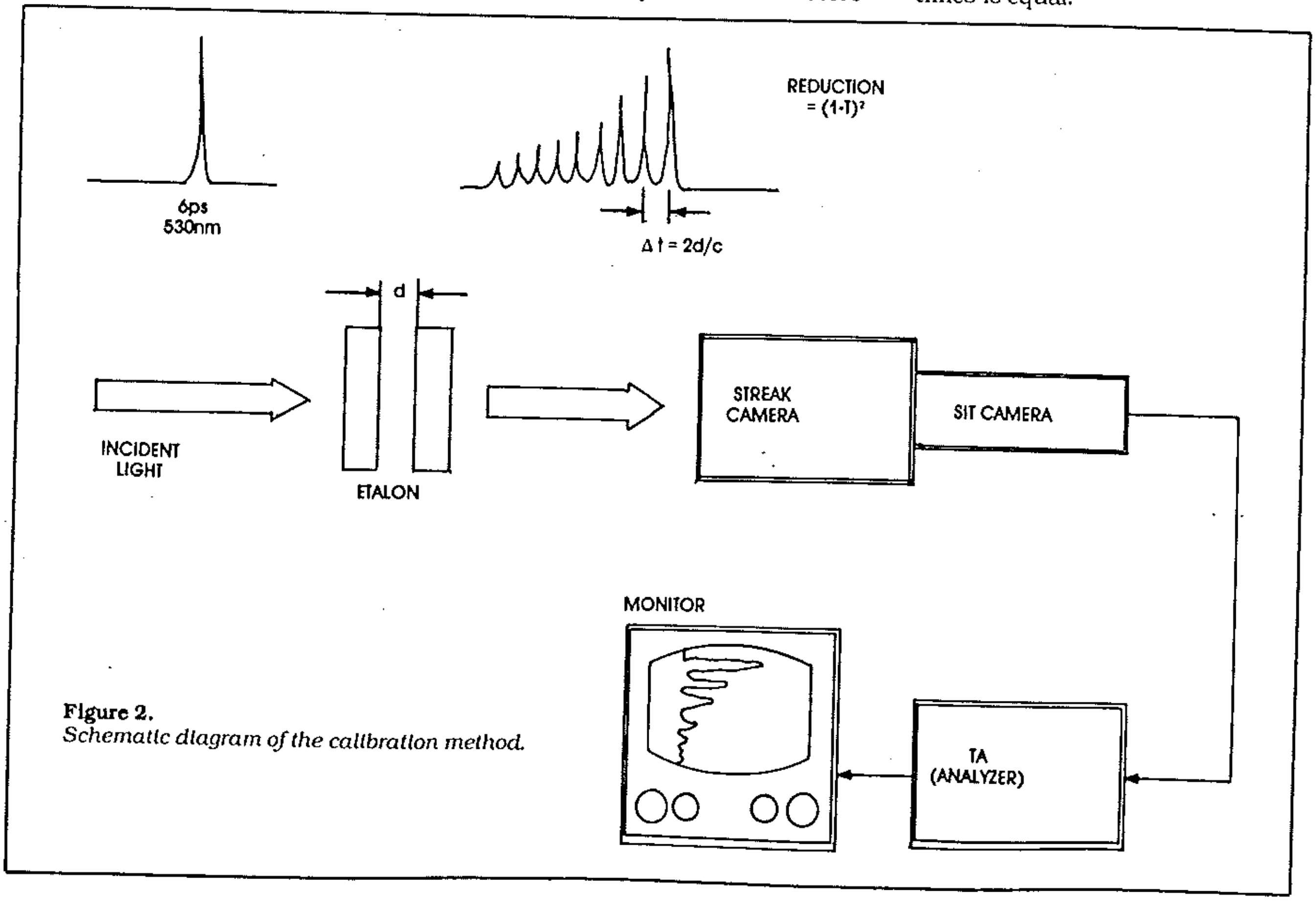


Figure 2.
Schematic diagram of the calibration method.

Streak cameras exhibit trigger jitter and trigger delay. Trigger jitter is the difference, from shot to shot, in the time between the arrival of the trigger signal and the beginning of the actual deflection sweep. Typically, jitter ranges from a psec to tens of nsec, depending on the streak camera model, manufacturer and trigger circuitry scheme. Jitter and fluctuations in sweep speed are two problems that constantly haunt the streak camera user.

In order to reduce the fluctuations in sweep and jitter, some systems employ a light-activated silicon switch.[3] These switches, which are silicon transmission lines that exhibit quasi-metallic photoconductivity when excited by intense-light picosecond pulses, have the advantage that their intrinsic switching speeds are limited primarily by the exciting optical pulse width. When used to directly trigger a streak camera, a high-voltage bias is applied to the switch, which, when opened upon excitation by that part of the laser beam sent to it, provides the deflection voltage for the streak camera. The silicon switch's pulse-width-limited risetime results in a relatively stable streak speed and nearly negligible jitter (1.7psec).

In most commercial systems, the deflecting voltage is triggered by a low-voltage pulse produced outside the streak camera. In order to synchronize the arrival of the light signal with the beginning of the deflection sweep, a portion of the laser pulse is split off to a pin diode to produce the trigger pulse. The pulse to be investigated is sent along a delay path so that it arrives at the camera when streaking begins. Trigger delay is the amount of elapsed time between the production of a trigger signal and the beginning of the deflection sweep. Streaking begins 10 to 100nsec after triggering, depending on the sweep rate, and the trigger delay time varies for different sweep settings. Light takes approximately 3.3nsec to travel 1 meter in air. In addition to the optical delay path, an electronic delay is necessary as a means of making incremental changes in the delay time. This fine tuning is necessary to compensate for jitter, as well as to provide the change in delay time needed when changing streak speeds.

Table 2 lists some of the commercially available picosecond streak cameras with various characteristics.

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References

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3. Knox, W. and G. Mourou (1981). *OPT. COMM.* 37,203.

Table 2.
Comparison of Picosecond Streak Cameras

MANUFACTURER*		HAMAMATSU		HADLAND		CORDIN	THOMPSON
MODEL		C979	C1370	675/II (with 50/40)	675/II (with 50/40)	179-LLL	TSN 504-04
Time Base Configuration		Fast Plug-In	Ultrafast	Standard	Ultrafast Plug-In	Individual Plug-Ins	Plug-In
Sweep Range Full Scale		Variable 1, 2, 5, 10nsec	Variable 0.38, 0.5, 1.2nsec	Variable 44 steps 1.5 to 500nsec	Fixed 0.5nsec	Fixed 1.3, 4, 13nsec	Variable 1, 2, 5, 10, 20nsec
Maximum Time Resolution for S-20 Photocathode at 530nm		10psec	2psec	4psec	2psec	10psec	5psec
Maximum Streak Velocity		67psec/mm	25psec/mm	30psec/mm	10psec/mm	33psec/mm	25psec/mm
Streak Image Output Format		15mm Dia.	15mm Dia.	15 x 50mm	15 x 50mm	40 mm Dia.	25 x 40mm
Time Window (at Maximum Streak Velocity)		1nsec	375psec	1.5nsec	500psec	1.3nsec	1nsec
Electronic Trigger Characteristics	Minimum Delay	11nsec	11nsec	12nsec	30nsec	16nsec	15nsec
	Jitter	±50psec	±50psec	±25psec	±500psec	±100psec	≤300psec
	Electrical Pulse Voltage	2-10V (50 ohm)	2-10V (50 ohm)	10V (50 ohm)	10V (50 ohm)	30-50V (50 ohm)	50V (50 ohm)
Direct Optical Input Trigger Characteristics	Minimum Delay	—	—	1.5nsec	—	1.7nsec	—
	Jitter	—	—	±25psec	—	>100psec	—
	Optical Pulse Energy	—	—	10μJ	—	1-10μJ	—
Spatial Resolution		7 lp/mm	25 lp/mm	7 lp/mm	7 lp/mm	7 lp/mm	12 lp/mm
Photocathode Format		4.2mm Dia.	9mm Dia.	7.5mm Dia.	7.5mm Dia.	13mm Dia.	35mm Dia.
Photocathode		S-1, S-20 Multialkali (UV glass)	S-20 Multialkali (UV glass)	S-1 S-20 S-20UV	S-1 S-20 S-20UV	S-1 S-20	S-20 S-20UV
Image Intensifier**		Built In	Built In	External	External	External	Built In

* Each manufacturer makes a variety of different model streak cameras, plug-ins and accessories. For the sake of brevity, each manufacturer is represented by no more than two units. The parameters displayed in the table were obtained from information supplied by the manufacturers or compiled from available datasheets. Since there are no standard definitions used to define the various parameters, the authors are not responsible for, or knowledgable of, the testing techniques used by the other manufacturers in obtaining the values used in this table. Equal numbers may not represent an equal comparison in all cases.

** For the image intensifier, "Built In" indicates that the intensifier is built into the streak tube.