PICOSECOND STREAK CAMERAS:

STEP-BY-STEP CALIBRATION

by N.H. Schiller, A. Dagen and R.R. Alfano

The streak camera, a device that converts time information into spatial information, has become an important tool for measurement of the dynamic behavior of luminous events.[1,2] Basically it works like this: Photons striking the photocathode of the camera's streak tube produce an emission of electrons in proportion to the intensity of the incident light. An accelerating electrode then thrusts the electrons into the streak tube, where they are electrostatically swept at a known rate over a known distance. The electrons strike a microchannel plate capable of producing electron multiplication through secondary emission. Secondary electrons released at different times in relation to the incident photons impinge upon a phosphor screen, forming a streak image. An electronic video readout system views the streak luminous output formed on the phosphor screen, and the information is interpreted as time versus intensity.

All streak cameras at present require routine 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, in a sequel to our earlier article in this journal cited as Reference 1.[3,4]

A step-by-step method

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 of 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 1 shows a schematic diagram of the calibration system.[4] 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 ($\Delta\tau = 2d/c$, where c is the velocity of light). In this technique, we are taking advantage of the fact that the speed of light in air is a constant: 1mm in 3.33 picoseconds. Therefore, if a single pulse were passed through two partially reflective parallel mirrors (etalon) of known spacing, say 1cm, the round trip or spacing between two successive reflected pulses would be equal to twice the mirror spacing ($\Delta\tau = 2d/c$); i.e., round trip time for the 2cm would be 66.7psec.

The intensity profile of the emerging train is a decaying exponential with each subsequent 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 $I = I_o \exp(-t/\Delta\tau \ 1n\ (1\text{-}T)^2)$, where the time between peaks is $t = K\Delta\tau$. 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 $\Delta\tau/\Delta X$ versus the average channel number (X) is used to calibrate the time base and intensity variations of the camera where ΔX is the number of channels between peaks and $\Delta\tau$ is fixed for a given etalon mirror spacing. Figure

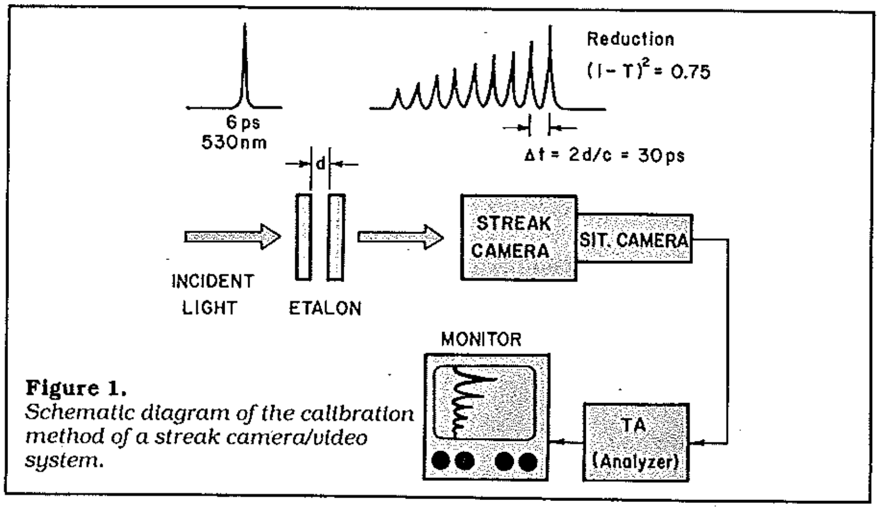

Figure 1.
Schematic diagram of the calibration method of a streak camera/video system.

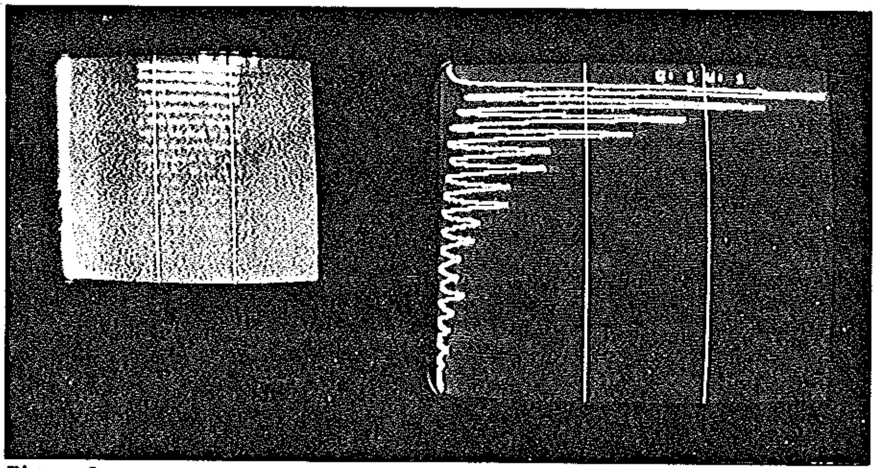

Figure 2.
Still-frame video of the streak image and graphic representation of the intensity profile of a 6psec pulse at 530nm passing through a 30psec etalon.

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No	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
Line Number	X_1	X_2	$\frac{X_1+X_2}{2}$	$\Delta X = X_2 - X_1$	$\frac{\Delta\tau}{\Delta X}$ = psec/ch	Sample Channel Number	$\frac{\Delta\tau}{\Delta X}$	$\frac{\Delta\tau}{\Delta X} \times 10$	Running Sum Column 8	Relative Time (%)
1	62	85	$\frac{62+85}{2} = 73.5$	85-62=23	$\frac{50}{23} = 2.17$	10	2.6	26	26	5.3
2		110	$\frac{85+110}{2} = 97.5$	110-85=25	$\frac{50}{25} = 2$	20	2.55	25.5	51.5	10.5
3		136	$\frac{110+136}{2} = 123$	136-110=26	$\frac{50}{26} = 1.92$	30	2.5	25.0	76.5	15.6
4		etc.	etc.	etc.	etc.	40	etc.	etc.	etc.	etc.
5	163	193				50				

Figure 3.
Example of a streak camera calibration data reduction sheet.

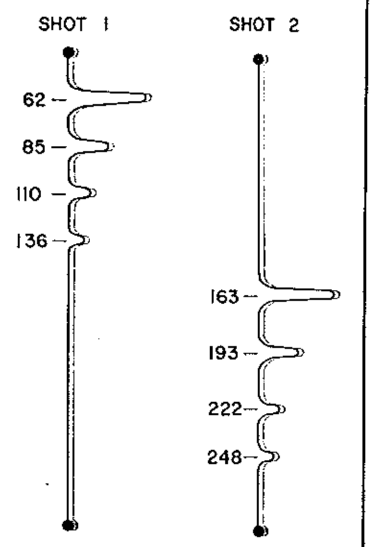

Figure 4.
Schematic representation of two laser shots as displayed on a video readout system.

2 shows a typical video picture and digitized output of a time-segmented intensity profile.[4,5]

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

Figure 3 shows a data reduction sheet to guide the user through the data analysis and reduction technique used to plot each calibration curve. The following is an explanation of what each column represents.

The following illustration should aid in plotting the curve representing sweep rate — that is, time/channel (psec/ch) vs. TA channel number (CH) — for a system. In order to gather the data necessary to plot the calibration curve, a series of measurements must be taken. The resulting data are recorded in the appropriate columns of the data reduction sheet for two laser shots shown schematically in Figure 4.

- Column 1 (X_1) represents channel number of first peak.
- Column 2 (X_2) represents channel number of each succeeding peak.
- Column 3$[(X_1 + X_2)/2]$ represents channel number *midway* between two succeeding peaks. Add channel numbers of two succeeding peaks and divide by 2. Examples for shot number 1 are shown in Figure 3.
- Column 4 ($\Delta X = X_2 - X_1$) represents the number of channels between two succeeding pulses. Subtract channel number of peak in column 2 from channel number of previous peak to determine the number of channels between the two peaks. See column 4 in Figure 3.
- Column 5 ($\Delta\tau/\Delta X$) is the value of picoseconds per channel. Light travels 1cm in 33.3 picoseconds. Therefore, if two partially reflective mirrors were paralleled to each other and spaced 1cm apart, the round trip time would be 66.7psec. If a 50psec etalon spacing were used to obtain the above data, this value (50psec) would be divided by ΔX (column 4) to obtain the column 5 value. See this column in Figure 3.

Figure 5 shows a plot of the data from columns 3 and 5, TA channel versus time/channel. A typical calibration curve is displayed in Figure 6. It takes about ten laser shots to form a calibration curve. Such curves are used to calibrate both the time axis and intensity variations on each sweep scale.

Sweep speed linearity

The following explanation should aid in plotting the curve representing relative time (T) versus TA channel number (ch). Data for columns 6-10 of the sheets are obtained from Figure 6.

- Column 6 (ch) represents channel to be sampled on the Figure 6 curve. Value of $\Delta\tau/\Delta X$ at that channel will be chosen every 10 channels and recorded in column 7.
- Column 7 ($\Delta\tau/\Delta X$): look at the time/channel vs. TA channel curve, locate channel number 10 and record in this column the value plotted on the curve. Do this for each of the sample channels up to 255.
- Column 8$[(\Delta\tau/\Delta X) \times 10]$: multiply the value of column 7 times 10.
- Column 9: sum sequence values from column 8 to previous values as illustrated in Figure 3 and record in column 9. On line number 1, use value from column 8; on line number 2, sum line number 1 from column 9 and line number 2 from column 8; on line number 3, sum line number 2 from column 9 and line number 3 from column 8, etc., until the final line is the sum of all 25 lines. The value obtained in column 9, line 26 is the value of full scale deflection (for this sweep range) from TA channel number 1 to channel number 256 — say, for this example, 490psec full scale for 1nsec time scale. This value is an important

number and should be noted for each range. Use this value to obtain percentage difference in column 10.

- Column 10 (%): divide each value in column 9 by the value of full scale deflection. Multiply results by 100 and record in column 10. (Figure 3.)

Use the data from column 6 and column 10 to plot relative time (%) vs. TA channel (ch). This curve represents sweep linearity for each sweep range. Figure 7 shows a typical 1nsec range over 500psec.

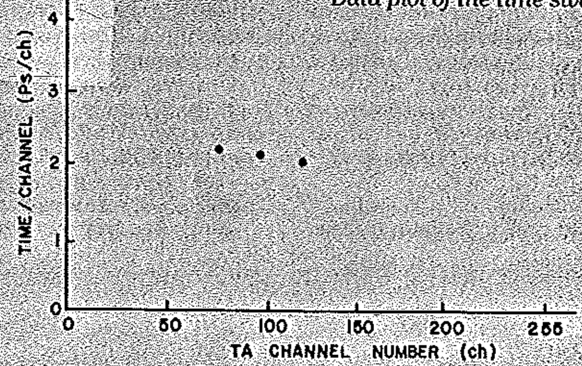

Figure 5.
Data plot of the time sweep calibration.

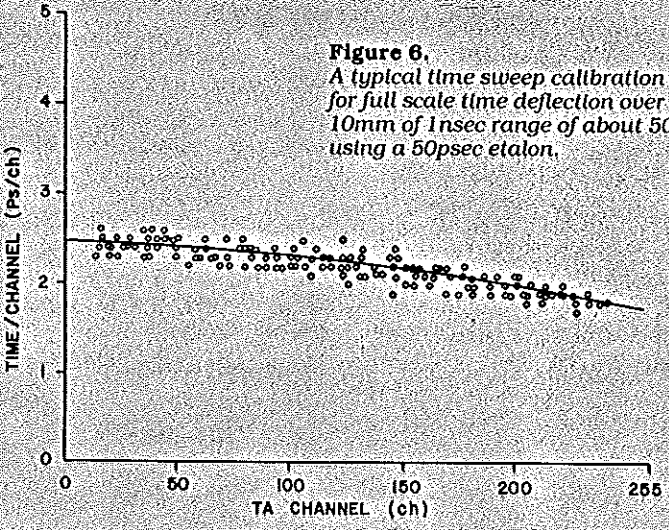

Figure 6.
A typical time sweep calibration curve for full scale time deflection over 10mm of 1nsec range of about 500psec using a 50psec etalon.

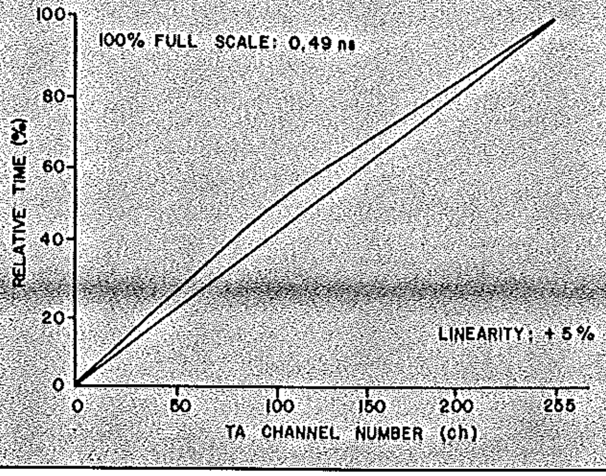

Figure 7.
A typical curve representing sweep linearity on the 1nsec range of about 500psec.

Obtaining intensity

After the camera has been triggered, video systems such as a temporal analyzer measure the intensity spatial profile as a function of distance along the phosphor screen.

Scientists are usually interested in the intensity (I) as a function of time. To obtain I(t) from I(x), one must take into account the streak rate for each channel, which was calculated in the previous section. Since this rate is nonlinear, 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 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 account of the differing rates to get 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. This is the standard mathematical way of converting a function of one variable, such as x, into a function of another, such as t. The equation above tells us that by multiplying the I(x), measured at each channel by the video system, by the $\Delta x/\Delta \tau$ of that channel, x, we can obtain the intensity as a function of time.

Now that we have obtained I(t), or the ordinate of our graph for each unit of time, we must convert each point on the abscissa to the corresponding time. This is done noting:

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

In effect, this is doing the integral $t = \int(dt/dx)dx$ numerically, which is necessitated by the fact that we have values at discrete channels and do not have a continuous curve. By using the second equation, one finds the time to which each point on the x axis corresponds. 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.

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