Time Calibration Techniques

INTRODUCTION

This article describes a collection of measurements wherein pulsed light sources are used to measure baseline timing calibration of ultrafast optical detectors.

When studying optical phenomena which occur at fast timescales, it is important to understand the timing response of the detector and detector system. Poor detector performance can limit the experiment's capabilities, or lead to mis-understandings in the acquired data. Having a set of calibrations on-file is often necessary to achieving scientific-grade results.

Sydor Technologies faces this problem in a similar manner when inspecting our photomultiplier tubes, image intensifiers, and streak cameras to ensure they meet stated performance. We have developed a set of pulsed light sources for quality control, and encourage our customers to utilize these products as well, to meet the continuing challenges encountered when using time-resolved instrumentation.

Below, we describe how these products are used for three different measurements relating to the time response of our detectors, including:

- Recording the time resolution of PMTs in analog and photon-counting mode
- Measuring the gating response of an image intensifier
- Using a precise pulse train (optical comb) to calibrate a streaked image

1. INSTRUMENT RESPONSE FUNCTION

Ultrafast, micro-channel plate photomultiplier tubes (PMTs) and photodiodes are capable of resolving optical pulses down to one-hundred picoseconds or less. In order to accurately model fast dynamic events recorded with these detectors, their instrument response function must first be measured. Sydor and Photek use the Laser Pulse Generator (LPG) when verifying the tube response with the specification.

Analog Response

The LPG's laser pulse is 40 ps, shorter than the expected detector response time for most PMTs and photodiodes. Sending this short pulse at the detector under test and measuring electrical output signal produces a dataset which is broader than the optical pulse input. This dataset reflects the instrument's intrinsic response, and is known as the instrument response function (IRF). The IRF is accurately measured using the short pulse width of the LPG, and is valuable in modeling experimental data recorded from the PMTs.

One example of this is seen in Figure 1, where the LPG-405 pulsed laser is used to measure the single pixel analog output of a multi-anode PMT. The average of 50 oscilloscope traces shows the full-width at half-max (FWHM) of the transient signal as approximately 430 ps.

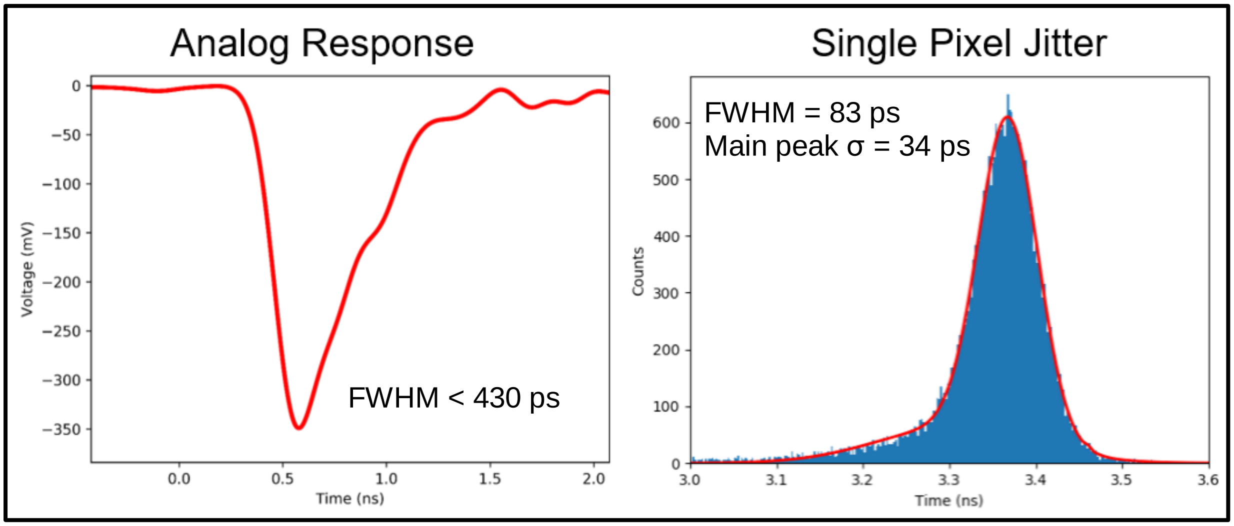

Figure 1: (Left) Average of 50 pulses measured on a 5 GHz oscilloscope, using an LPG-405 pulsed laser. (Right) Histogram of 5,000 single-photon pulse arrival times measured with an attenuated LPG-405.

Photon Counting Response

Many photon-counting experiments measure the time difference between the laser pulse's generation and single photon detection at the PMT, such as time-correlated single photon counting (TCSPC).

In photon-counting mode, the electronic jitter in the PMT will dominate the IRF. To measure this, a time-to-analog converter (TAC) is set to 'start' counting when the laser fires, and 'stop' counting when the photon pulse is registered at the tube output. This essentially measures the amount of time for photoelectrons to travel through both the tube and readout electronics, effectively known as the electron transit time. There will be small variations in the transit time, known as the transit time jitter. By repeating the above start-and-stop sequence thousands of times, and plotting the arrival times on a histogram, the statistics of the transit time are observed. The width of this histogram is the transit time jitter.

An example of this behavior is measured as the single pixel jitter in a multi-anode PMT, as seen in the left-hand portion of Figure 1. The transit time was measured using attenuated output of the LPG-405, with the triggered-output going to the 'start' of the TAC, and the pixel's electronic signal providing the 'stop' signal. The horizontal axis shows the histogram to be centered around 3.35 ns, which is the average transit time. The FWHM of this histogram is the transit time jitter, and is 83 ps. The data is fit to a modified Gaussian, as shown in red, and this curve could be used to help fit models to experimental TCSPC data.

2. GATING MEASUREMENT

Gated photocathodes are often used in PMTs as fast optical shutters, or in image intensifiers for time-resolved fluorescence experiments (e.g., FLIM). A gate module is used to provide a time-varying voltage to the photocathode, and can turn the detector either ‘on’ or ‘off’ for a period of time, also called the gate window.

The combined (gate module plus detector) system performance is characterized using a pulsed light source. The pulsed light source should have a time duration that is much shorter than the gate window, so the pulse can be ‘walked’ through the gate pulse as described below.

A typical setup for such a characterization is shown in Figure 2. The delay generator synchronizes the laser, gate module/controller, and CCD timing. At the start of the characterization, the delay generator sets the laser pulse to arrive before the gate pulse begins, and so no signal is recorded in the detector. In the next repetition of this cycle, the delay generator adjusts when the laser pulse is sent, so that the pulse arrives just near the gate pulse turning on. Subsequent cycles have the laser arrive fully within the gate window, and the delay is walked until the laser arrives within the trailing edge of the gate pulse.

For each datapoint within the measurement, the intensity of the signal arriving at the digitizer is recorded, as seen in the right-hand dataset of Figure 2. When all data points are combined into a series, a true representation of the gate window for a given device and gate module combination is produced.

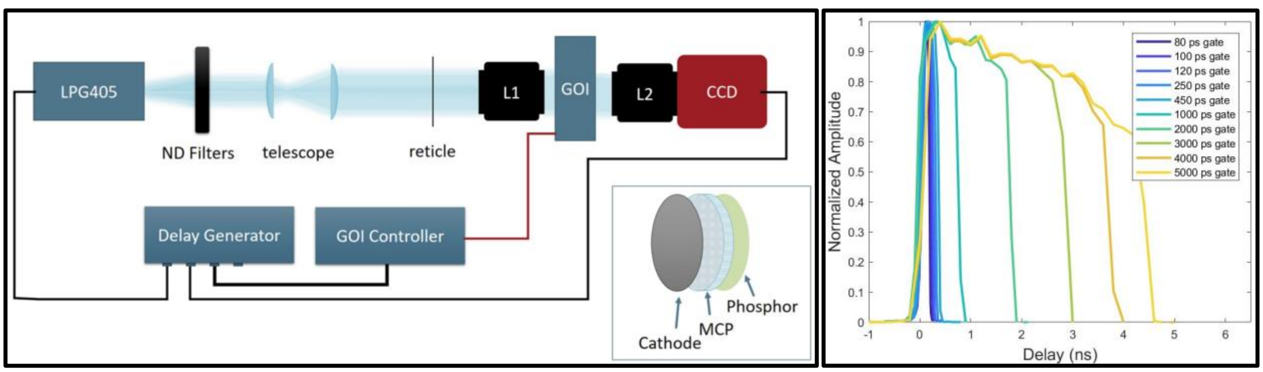

Figure 2: (Left) Schematic for a gating characterization measurement of a gated optical imager (GOI). (Right) Data acquired with an LPG-405 being sent to Sydor’s Picosecond Gated Optical Imager (ps-GOI).

The gating measurement for image intensifiers also gives users a sense of how the gate pulse propagates across the active area of the device, as seen in Figure 3. This result shows an LPG-405 laser pulse being stepped through a 4 ns gate window generated by a Photek Gate Module Unit on a Photek 18 mm Image Intensifier (MCP118). Each step represents an extra 200 ps delay on the laser pulse.

In measuring the 4 ns gate window, we see that part of the intensity modulation is due to the pulse propagating in the ‘on’ state first from the outer edge, leaving portions of the center inactive. By the 10th image in the series, the intensifier is fully turned on as seen by the uniformly illuminated circles. At the trailing edge of the gate pulse, the inverse effect is seen as the outer edges first turn ‘off’, an effect known as irising.

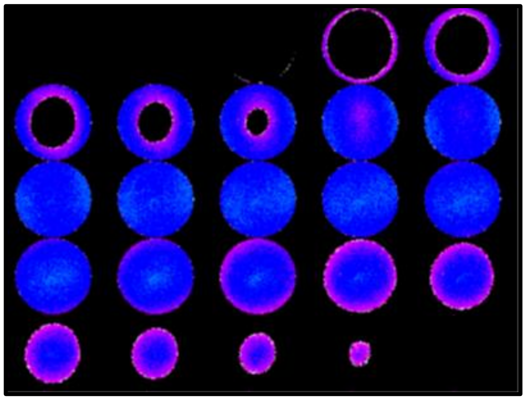

Figure 3: Effect of irising as seen in an MCP118 with a 4 ns gate window. Each step represents 200 ps delay of the laser.

3. TIME DOMAIN REFERENCE

At the heart of a streak camera is the streak tube, which uses electron optics to deflect an electron beam across a phosphor. The electron beam is created by photons impinging a one-dimensional photocathode, enabling time-varying optical signals to be recorded and digitized. The final image is a mixture of a spatial component (vertical direction in Figure 4) and time component (horizontal direction). This type of data set is known as a streaked image, and the dataset in Figure 4 shows how time-varying interferometer fringes can be recorded using streak tube technology.

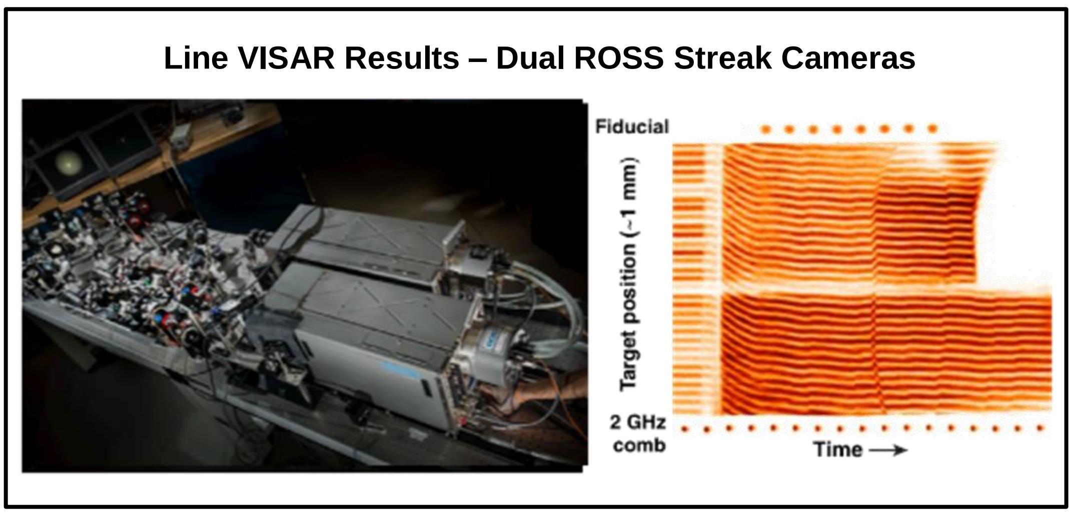

Figure 4: (Left) Streak camera benchtop setup for VISAR. (Right) Streaked image showing interferometer fringes, a facility fiducial (top), and a built-in comb reference (bottom).

In order to quantitatively use the streaked image, a time calibration must be established. This is because the deflection of the electron beam relies on a time-varying voltage, or ramp, which contains inherent nonlinearities. Accounting for these nonlinearities is key to fully leveraging a streaked image for data analysis.

Time calibration is done by sending a series of optical pulses (optical comb) onto the photocathode. Particularly in a ROSS camera, the comb can be input to the photocathode concurrent with the experiment-based input, as seen in Figure 4. The comb appears as a series of dots along the time axis, reminiscent of a ruler.

If the pulse train (or optical comb) has enough precision, then a highly reliable calibration can be performed. Sydor comb generators are built with premier VCSEL sources and internal oscillators, and are frequency stabilized to 1 part-per-million. This enables robust mathematical fitting of the fiducial, and establishes a reference time-base with which to analyze the data portion of the streaked image.

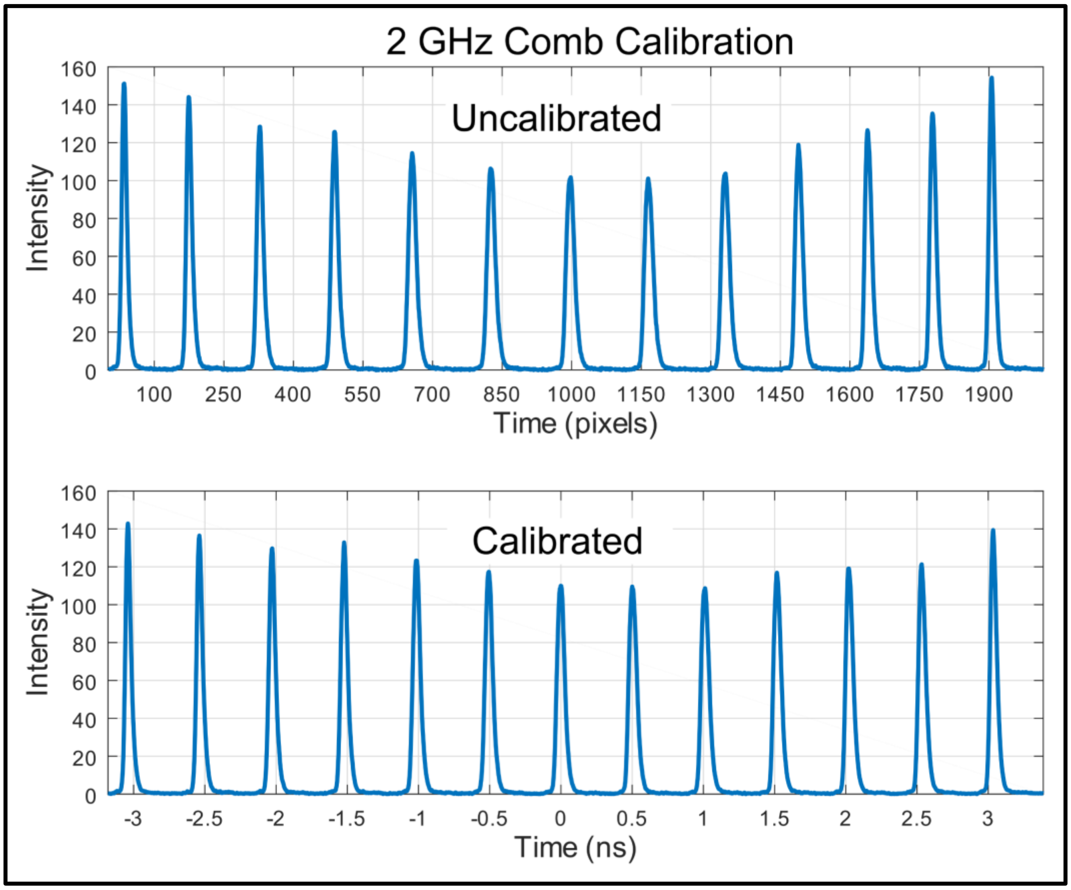

Figure 5: 2 GHz comb shown in an uncalibrated (top) and calibrated (bottom) lineout from a system data test at the factory.

The Sydor Comb Generator is supplied with two frequencies, determined in collaboration with the customer, based on their camera's configured sweep windows. For very long sweep windows (>1 µs), a Fiberized Laser Pulser (FLP) is used with a delay generator to generate pulse trains from single shot to 10 MHz. This light source is also used during streak camera quality inspection, in providing verification of the jitter and delay-to-center parameters.

Sydor's Comb Generators and Fiberized Laser Pulsers are available as standalone light sources which are compatible with streak cameras from any manufacturer. A reliable pulsed light source is an essential tool in absolute calibration of a streaked dataset, and the Sydor Comb Generator assures certainty for dynamic events down to picosecond timescales.

SUMMARY

Pulsed light sources are used to measure the time characteristics of several detector types. Calibration of the temporal response is an important step in data acquisition at ultrafast timescales and with fast detectors, such as streak cameras and photomultiplier tubes. Our light source instrumentation is used for the three types of time response detailed above, and their characteristics are summarized in the table below.

Email our applications team today to see how a light source can verify your data collection and instrumentation.

Product Family	**Fiberized Laser Pulser**	**Fiberized Laser Pulse Generator**	**Laser Pulse Generator**	**Comb Generator**
Central λ (nm)	680	350, 405, 650	350, 405, 650	680
Pulse width	5 ns	40 ps	40 ps	~ 10-15% duty cycle
Pulse Rep. Range	Up to 10 MHz	0 - 300	0 - 300	Dual Range - choices from 10 MHz to 10 GHz
Pulse Rep. Unit	External	KHz	KHz	GHz
Optical Output	Fiber	Fiber	Free Space	Fiber
Datasheet	FLP	LPG	LPG	Comb
Measurement Use				
Instrument Response Function	✓	✓	✓	
Gating Measurement	✓	✓	✓	
Timing Reference for Streaked Images	✓			✓ ✓