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# Compact optical technique for streak camera calibration

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## I. INTRODUCTION

The National Ignition Facility (NIF) is under construction at the Lawrence Livermore National Laboratory (LLNL) for the U.S. Department of Energy Stockpile Stewardship Program. Optical streak cameras are an integral part of the experimental diagnostics instrumentation. To accurately reduce data from the streak cameras a temporal calibration is required. This article describes a technique for generating trains of precisely timed short-duration optical pulses[1] (optical comb generators) that are suitable for temporal calibrations.

These optical comb generators (Figure 1) are used with the LLNL optical streak cameras. They are small, portable light sources that produce a series of temporally short, uniformly spaced, optical pulses. Comb generators have been produced with 0.1, 0.5, 1, 3, 6, and 10-GHz pulse trains of 780-nm wavelength light with individual pulse durations of ~25-ps FWHM. Signal output is via a fiber-optic connector. Signal is transported from comb generator to streak camera through multi-mode, graded-index optical fibers.

**Figure 1.** Comb generator unit.

At the NIF, ultra-fast streak-cameras are used by the Laser Fusion Program experimentalists to record fast transient optical signals. Their temporal resolution is unmatched by any other transient recorder. Their ability to spatially discriminate an image along the input slit allows them to function as a one-dimensional image recorder, time-resolved spectrometer, or multichannel transient recorder. Depending on the choice of photocathode, they can be made sensitive to photon energies from 1.1 eV to 30 keV and beyond.

Comb generators perform two important functions for LLNL streak-camera users. First, comb generators are used as a precision time-mark generator for calibrating streak camera sweep rates. Accuracy is achieved by averaging many streak camera images of comb generator signals. Time-base calibrations with portable comb generators are easily done in both the calibration laboratory and *in situ*. Second, comb signals are applied to a streak camera just before and at shot time to verify that the streak camera sweep unit is functioning properly. A comb signal applied at shot time does not have the statistical quality of the multiple recordings used to calibrate a streak camera time base. However, it does allow the user to verify that the correct sweep card is installed and that it is functioning within about 1.5% of its expected speed[2].

The principle component in the comb generator is a custom packaged Vertical Cavity Surface Emitting Laser (VCSEL), Figure 2. The laser is modulated either directly by a crystal controlled sine wave oscillator or by an impulse generator that is supplied by the oscillator, Figure 3. A pulse bias is added to the sine wave or impulse input to bring the VCSEL to lasing for the time interval that the optical comb train is required. The pulse bias can be used to adjust the intensity of the optical pulse train. An example of a 3 GHz comb streak is shown in Figure 4(a).

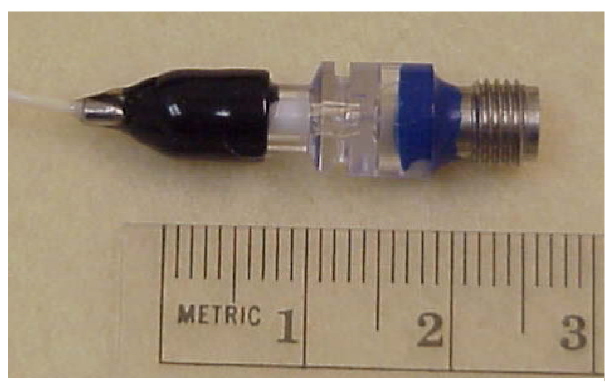


**Figure 2.** 10 GHz VCSEL as packaged by Emcore. Characteristics: SMA input, fiber output, 780 nm wavelength, power output from fiber 3+ mW.

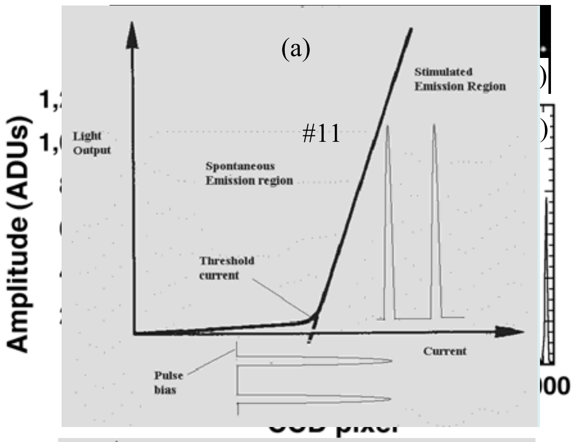


**Figure 4.** 3 GHz comb signal recorded by a LLNL streak camera. (a) Raw image; (b) temporal profile.

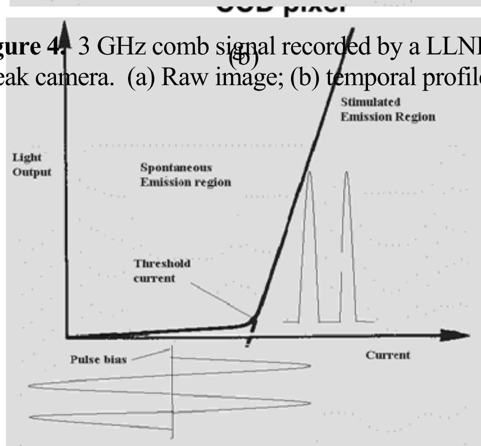


**Figure 3.** VCSEL response curves for Sine Wave (a) and Impulse (b) drives currents with pulse bias.

## II. CALIBRATION PRECISION

The stability of the periodicity of the VCSEL laser output is determined by the crystal controlled oscillators that have frequency stability of 1 part in $10^5$. This frequency stability in conjunction with the short pulse durations (~25 ps FWHM) give the pulses precise timing and simplify finding the apex of the pulses. Examples of the pulse profile and the pulse width are shown in Figures 4(b) and 5. An automated IDL software tool determines the dwell time (Figure 6) at each temporal pixel in the following manner. For a set of ten comb images, the pulse positions are determined, the dwell time per pixel between peaks calculated, and the set of dwell times smoothed to give the final calibration curve.

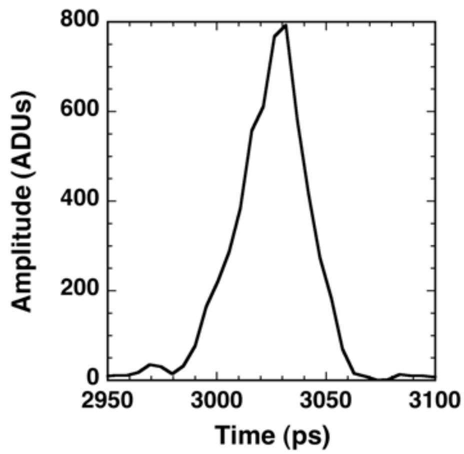


**Figure 5.** Expanded temporal profile of pulse #11 in Figure 4 (a). Pulse is 25 ps FWHM.

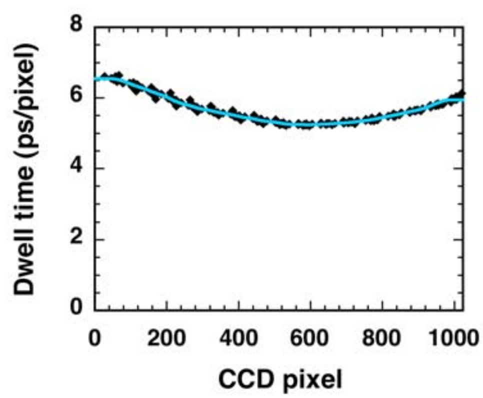


**Figure 6.** Dwell-time curve. Streak camera timebase calibration is presented as the time the streak camera signal dwells at each time pixel.

## III. OPTICAL COMB GENERATOR DESIGN

The basic design for these comb generators is over 15 years old and dates back to Nelson[3] of EG&G Energy Measurements. A block diagram of the design is shown in Figure 7, and the following is a description of each of the blocks.

*Crystal Controlled Oscillator*: Depending on the frequency of the system being built, this module may be a crystal controlled oscillator, crystal controlled

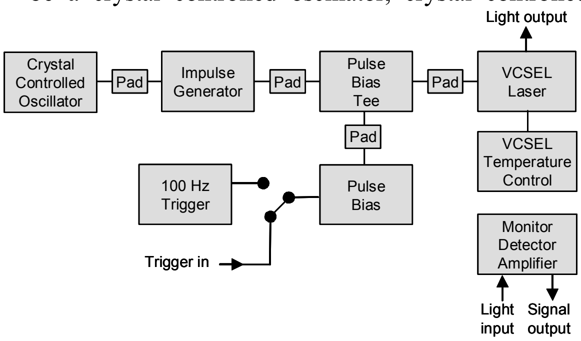


**Figure 7.** Simplified optical comb generator system.

oscillator w/multipliers, or a phase locked oscillator, with a crystal controlled reference. Power output levels may be 0 dbm to over +21 dbm depending on the brand/model used.

*Impulse Generator*: This frequency-specific device is supplied with an input rating of either 0 dbm, +10 dbm, or +20 dbm. The value of the Pad at the input of the Impulse Generator is selected to reduce the signal from the oscillator to an appropriate value (usually ±2 db of input rating of the Impulse Generator) and to produce the optimum shaped comb pulses. The Pad at the output of the Impulse Generator is required by the manufacturer to ensure a near 50 ohm load and also is selected in value for best-shaped comb pulses. Typical final value of this Pad is between 1 and 3 db.

*Pulse Bias Tee*: The Pulse Bias Tee is a broadband device that serves to combine the continuous stream of comb pulses or sine wave signal with a gate bias signal. The purpose of the Pad at the bottom of the Pulse Bias Tee is to reduce the amplitude of intrusive comb pulses or sine wave signal that otherwise could negatively affect the Pulse Bias circuitry. A typical value for this pad is 6 db.

*VCSEL Laser*: The VCSEL laser is mounted on an aluminum block that is thermally controlled. This is done to assure that there is minimal change in the lasing threshold due to ambient temperature changes. The laser, pad, aluminum block and connecting coaxial copper cable are all insulated and covered. A thermistor (for the temperature controller) and a Centigrade temperature sensor (for laser temperature readout) are also mounted on the aluminum block. The Pad at the input of the laser (usually a value of 1 db) serves to ensure that the laser is seen as a 50 ohm load.

*VCSEL Temp. Control*: This circuitry drives the thermo-electric cooler. The temperature is set at about +23 degrees Centigrade.

*Pulse Bias*: The pulse bias consists of circuits needed to generate a flat-top bias signal to drive the Bias Tee. A screwdriver adjust potentiometer sets the amplitude, normally set between 2 to 4 volts. Another screwdriver adjust potentiometer is used to adjust the gate width. This is normally set between 0.5 and 5 microseconds depending on experimental requirements.

*Trig in:* The Trig In connection allows for external triggering with a TTL signal that is able to drive 50 ohms.

*100 Hz Trigger*: This is a multivibrator that supplies a continuous internal trigger. It is selected when the Mode switch is set for CONT. A screwdriver adjust potentiometer is used to adjust the frequency (usually set about 100 Hz).

*Monitor Detector Amplifier*: If light output is connected to light input (using an optical fiber), the optical signal will be detected and can be observed by connecting an oscilloscope to the signal output connector (50 ohms).

The monitor has been added to the comb unit as an aid to setting the amplitude of the optical pulse train and as a timing aid for synchronizing the pulse train with the event to be recorded. It consists of a two stage amplifier with Hamamatsu MSM photodiode detector and has an impulse response time of 90 ps FWHM. The sensitivity is ~70 mV per mW, at 780 nm, into a 50 ohm system.

## IV. COMPONENTS

When the LLNL requirement for additional comb generators arose it was found that the original critical components were either no longer available or were available only in large quantities. With the exception of the diode laser, we were able to find several manufacturers who were willing to work with us and who eventually supplied us with substitute components.

The crystal-controlled oscillators are available, in small quantities, from Micro Lambda. The pulse bias tee (modified) is available from MCE Inmet, and the impulse generators, with or without amplifiers, are available from Herotek. We were unable to find any off-the-shelf laser that worked to our satisfaction.

As many of the S-20 streak camera photocathodes roll off in sensitivity beyond 800 nm, the laser wavelength can not be greater than 800 nm. In addition the laser needs to be modulated up to 3 GHz or higher and have a peak power of 2 mW or higher. For circuit design reasons we wanted the lasing threshold current to be less than 50 ma and the drive voltage to be positive. After testing most of the laser diodes on the market the 780 nm VCSEL laser from Thor Labs showed the greatest promise. However, the peak power output of 1.4 mW was marginal and the TO can housing the VCSEL die was frequency limiting above 2 GHz. These limitations were overcome with the cooperation of AXT and Emcore. AXT manufactures the die used in the Thor Labs 780 nm VCSEL and Emcore has been developing a 10 GHz, 850 nm VCSEL package for the communication industry. AXT was willing to sell us their 780 nm VCSEL dies and Emcore was willing to select the best dies and package them using our specifications

We gave Emcore the following specifications on a best-effort basis: a) SMA electrical input, b) 6 GHz modulation; c) optical fiber output, 62.5 micron graded index; d) positive drive voltage; e) dies selected for max power; f) 780 nm output.

Subsequent to the purchase of the AXT dies, Emcore found that VCSEL dies that they had developed for another program, also satisfied our power, wavelength and frequency requirements with the addition of a lower lasing thresholds (2 to 3 ma). We are currently using both dies. The laser package produced from this collaboration is shown above in Figure 1.

The package produces 3+ mW out of the fiber at 780 nm wavelength, modulates up to 10 GHz, takes a positive drive voltage, and has a lasing threshold of ~3 ma. Peak powers up to 6mW have been achieved for several microseconds, with elevated pulse biasing.

## V. VCSEL CURRENT DRIVE

The choice of drive for the VCSEL is dependent on the limitation that may be put on the width of the pulses in the pulse train. The sine wave drive shown in Figure 3 (a), produces the same rate precision as the impulse drive, Figure 3 (b), but with wider pulses. The short-duration spike from the impulse generator will produce shorter pulses. Pulse durations of 18 ps FWHM have been measured at 3 GHz modulation using the impulse drive and 35 ps FWHM with the sine wave drive, also at 3 GHz modulation. At lower modulation rates the sine wave drive will produce wider pulses. The additional cost of the impulse generators is about 1500 dollars.

The 3 ma threshold current of the VCSEL has made them much easier to drive than the 60 ma threshold of the original Ortel lasers. They require less power to operate than the Ortel and produce higher light output for the same impulse drive voltage. The improved operating efficiency, high modulation frequency and smaller size opens the possibility of incorporating the comb generators as an integral part of the streak camera.

## VI. SUMMARY

We have been able to reproduce an older technology that had been lost due to component unavailability. Many improvements have been made which allow the modern units to service a much larger need. We plan to make additional improvements over the next few years which include the addition of multiple frequency generators, which will allow one unit to cover a wide temporal range. We also plan to make the unit fully controllable via an RS232 input.


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