

# Range Finding Using Pulse Lasers

## Application Note

### Introduction

“Time-of-flight” (TOF) measurement by using pulsed lasers has entered a great variety of applications. It can be found in the consumer and industrial field (e.g. for range finding, scanning applications, speed measurement) and as well in the automotive field (e.g. for Adaptive Cruise Control ACC, Pre Crash Sensing). Although the measurement principle is the same for these applications, some differences are existing e.g. in

- the distance range to be measured (some meters for pre crash sensing, from several tens of meters up to some 100 meters for ACC)
- the beam angle for scanning (small narrow beam for distance measurement or ACC)
- the scanning frequency

This article describes the principle of the TOF measurement and gives some proposals for using OSRAM pulse laser diodes.

### Principle

The basic principle is shown in Figure 1. The pulse laser emits a short light pulse which starts the time measurement in the receiver. As soon as the pulse reflected from the object reaches the photo detector the time measurement is stopped. The elapsed time  $t_p$  between start and stop pulse is used to compute the distance to the reflector.

In principle the distance which can be measured, depends on several parameters:

- laser peak power
- beam divergence
- optics
- characteristics of medium transmitted (air, rain, fog)
- reflectivity of the object
- sensitivity of the detector.

While object and medium characteristics are normally given by the application conditions, a selection can be made in the choice of emitters (wavelength, driving conditions, beam properties) and the detectors used

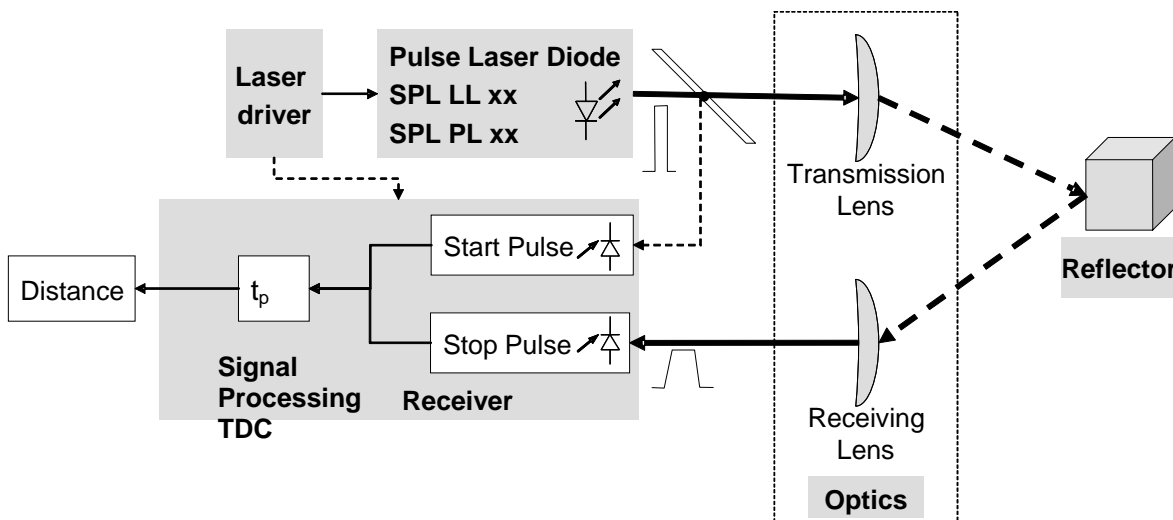


Figure 1: Basic Principle of Time-of-Flight Measurement.

(type, sensitivity, bandwidth). The range which can be sensed will increase with higher peak power and higher signal-to-noise ratio. The accuracy of TOF measurement depends on the pulse characteristics of the laser like pulse shape (width, rise and fall time), detector bandwidth and the signal processing. The measurement accuracy increases with smaller pulse length, faster rise and fall time and higher bandwidth of the detector.

A pulsed time-of-flight laser range finder typically consists of a laser pulse transmitter, the necessary optics, two receiver channels and a time-to-digital converter (TDC), as shown in figure 1. The laser pulse transmitter emits a short optical pulse (typically 2 to 50 ns) to an optically visible target and the transmission event is defined either optically, by detecting a fraction of the pulse, or electrically, from the drive signal of the laser diode. The start pulse is then processed in a receiver channel, which generates a logic-level start pulse for a TDC. In the same way the optical pulse reflected from the target and collected by the photo detector of the stop receiver channel is processed and a logic-level stop pulse is generated for the TDC. The TDC uses its time base to convert the time interval to a digital word which represents the distance from the target [1].

## Devices

As shown in Figure 1, the following key components are needed besides some signal processing circuitry: laser emitters, photo detectors and optics.

### Transmitter:

The transmitter consists of a pulsed laser diode and the driver electronics.

OSRAM is providing two types of pulsed laser diodes suited for TOF systems:

- **'Pulse Lasers' (SPL PLxx)** which contain a laser chip mounted on a lead frame inside a radial plastic package.



- **'Smart Lasers' (SPL LLxx)** which incorporate some current driving capabilities. This enables the generation of short optical pulses down to several ns FWHM in a straightforward way.

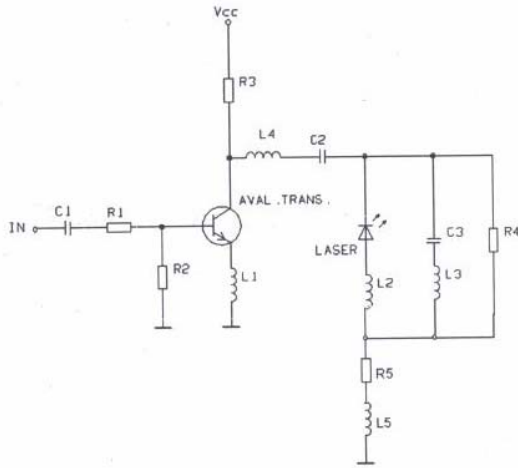


The lasing wavelengths are 850 and 905nm, respectively. Please refer to data sheets and application notes available on the OSRAM OS web site [2].

'Pulse Laser' SPL PLxx:

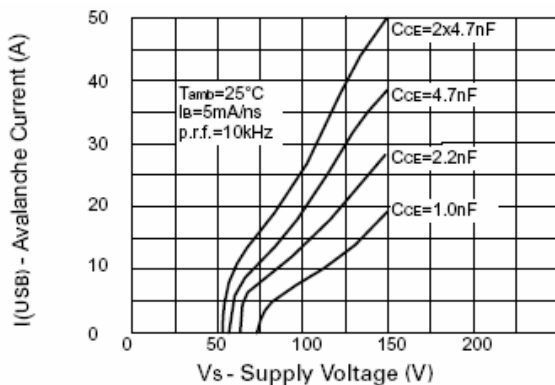
To operate the SPL PLxx type laser diodes a high (several 10 Amps) and narrow (several nanoseconds) current pulse has to be transmitted to the laser diode.

The pulsed laser driver consist of a capacitor with capacitance C and a switch which discharges the charge of the capacitors to the laser. The charging of the capacitor is done between two laser pulses. As switch a MOSFET or an avalanche transistor can be used. Figure 2 shows a schematic pulser circuit using an avalanche transistor as switch.



**Figure 2:** Schematic pulse laser driver circuit with a capacitor C2 for storing the electrical energy and an avalanche transistor as switch [6].

OEM driver boards using power MOSFETs as switch are offered by the companies Directed Energy Inc. [3], EO-Devices Inc. [4] and Dr. Heller Elektronik KG [5]. A supplier of specially manufactured avalanche transistors is the company Zetex [6]. Figure 3 shows the avalanche current against supply voltage for the Zetex ZTX413 avalanche transistor.



**Figure 3:** Avalanche current against supply voltage for the ZTX413 avalanche transistor.

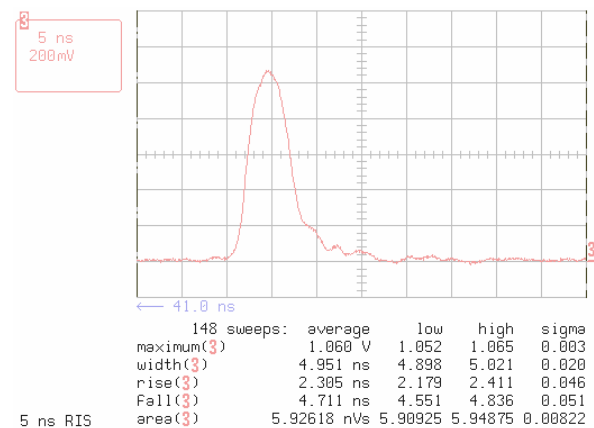
A simple approximation for the value of the storage capacitance C is:

$$C \times U = I_p \times t_p$$

Increasing the value of C increases both the width of the current pulse  $t_p$  and the peak amplitude of the current  $I_p$ . By increasing the operating voltage the amplitude of the current pulse increases (and in practice, at the same time the width of the current pulse decreases slightly, because the on state resistance of the transistor decreases) [7], [8]. Please note that it is very important to minimize the inductance of the circuit. Therefore low loss RF capacitors (ceramic chip capacitors) have to be used. Current carrying conductors have to keep to the bare minimum. Also the leads of the laser diode have to be cut as short as possible. Note that each inch of length adds approximately 20 nH of inductance. This means that a di/dt of 20A/10ns generates a transient Ldi/dt voltage of 40 V per inch of wire length. The real effect will be a significant increase in rise time [9].

Figure 4 shows the detector signal of a SPL PL85 pulse laser (850 nm) driven by a fast MOSFET laser pulser from Dr. Heller Elektronik KG.

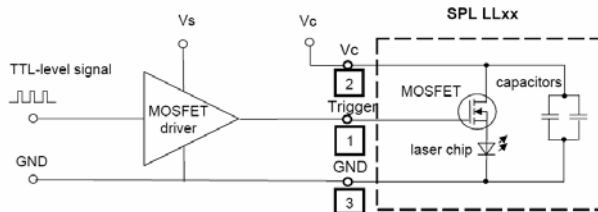
For more details about operating the 'Pulse Laser' SPL PLxx see reference [10].



**Figure 4:** PIN photo diode signal of SPL PL85 driven by a fast MOSFET laser pulser (Dr. Heller Elektronik KG). Peak power is 17 W, pulse width is 5 ns (FWHM) and rise/fall times are 2.3 and 4.7 ns respectively.

## 'Smart Lasers' SPL LL xx:

In the 'Smart Lasers' the capacitors and MOSFET switch are integrated in a hybrid package. For operating the laser only a MOSFET driver IC is needed for charging the gate of the MOSFET. The laser peak power can be adjusted by the value of charge voltage and/or gate voltage.

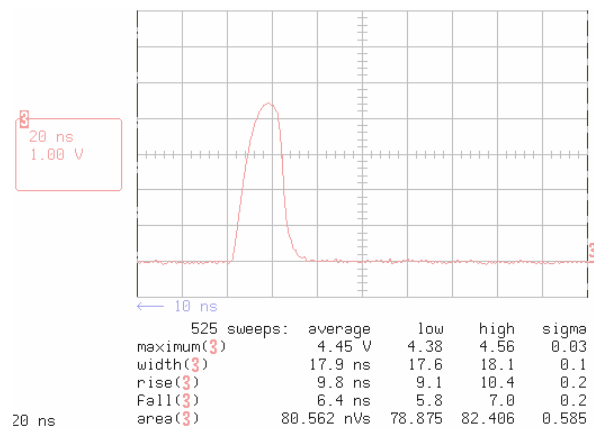
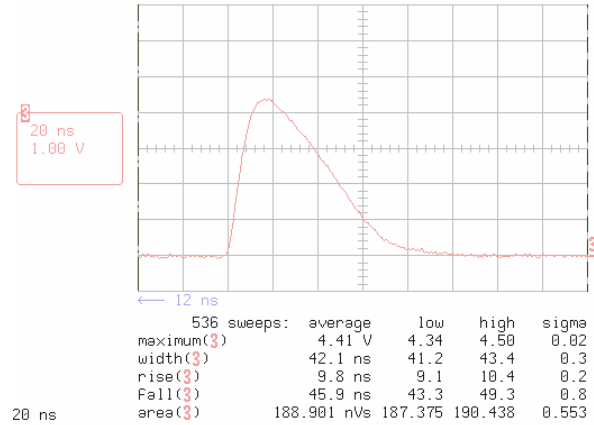


**Figure 5:** Schematic of SPL LLxx with MOSFET driver.

The maximum laser pulse width is determined by the internal capacitors to 40 ns. By switching off the MOSFET before the capacitors are discharged completely a minimum pulse width of 15 ns can be achieved while maintaining the maximum peak power as can be seen in figure 5.

Recommended MOSFET driver ICs are the Elantec EL7041C [11] and the Micrel MIC4452 [12]. Because the gate charging currents exceed peak values of several amps, proper connection of driver with MOSFET is essential.

More details concerning the operation of the 'Smart Laser' can be found in [13].



**Figure 6:** PIN photo diode signal of SPL LL90\_3 at 70 W peak power. Top: capacitors are discharged completely (gate pulse width >100 ns) resulting in a FWHM pulse width of 42 ns. Bottom: pulse width is reduced to 22 ns by switching off the FET after 22 ns.

## Receiver:

Silicon PIN diodes or silicon APDs (avalanche photo diode) can be used as photo detectors. The APD has the advantage of high signal-to-noise-ratio (SNR) but needs high bias voltage (>300 V). For PIN diodes the bias is low (<40V) but much lower sensitivity compared to APDs requires electrical amplification. Regarding the bandwidth i.e. speed of the detector there are suited detectors of both types. APDs are preferred for long and PIN diodes for short distance range finding.

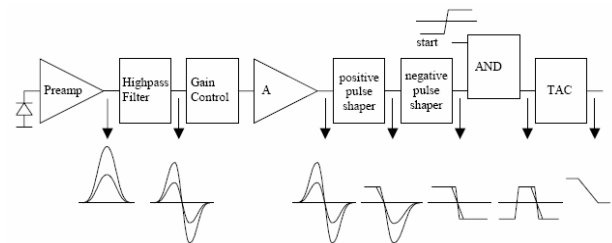
The width of the laser pulse and the bandwidth of the receiver channel should be matched to one another ( $f_{max}=0.35/t_r$ ). If the laser pulse is too narrow, the receiver channel is not able to react to it with full amplitude and the sensitivity of the channel is reduced. If the bandwidth of the channel wider than the bandwidth corresponding to the rise time of the laser pulse, the amplifier will produce excess noise and the measurement precision will deteriorate [14].

To increase the SNR an optical band-pass filter should be used in front of the detector to block ambient or disturbing light. Note that the spectral width of the pulse laser diodes is about 4 nm and the temperature induced shift of peak wavelength is 0.3 nm/K.

The amplitude of the received stop signal varies over a wide range depending on the measurement distance and the reflectivity and angle of the target. The dynamic range of the signal depends on the application, and may be 1:1000 or even more. As the length of the laser beam is much longer than the accuracy usually needed (2 metres vs. a few 10 centimetres), a specific point in the pulse has to be defined, and consequently a logic-level pulse for the TDC has to be produced. The timing event should not change when the level of the signal varies, as it will directly affect the measurement result. The function of the receiver is to produce accurately timed logic-level pulses from optical input pulses of varying amplitude.

The timing event can be generated either from the edge of the pulse which is allowed to saturate in the receiver channel or by linear signal processing, in which gain control structures are usually needed, due to the wide dynamics of the input signal and the limited dynamic range of the receiver channel. The simplest way of defining the timing point is the former one, a leading edge discrimination technique in which a comparator with a constant threshold voltage is used to trigger the leading edge of the received pulse. The drawback of the

technique is that if the amplitude of the pulse changes, the timing point also changes and generates a timing error. Thus the timing error represents the change that takes place in the timing event when the amplitude of the pulse varies. In high-pass timing discrimination the timing point is generated from a unipolar input pulse using a high-pass filter. The zero-crossing point of the bipolar output signal defines the timing point, which is insensitive to variation in the amplitude of the input signal as long as the signal is processed in a strictly linear manner, i.e. the pulse is not distorted in the receiver. Thus the discrimination will not have the same timing error as leading edge discrimination [1].



**Figure 7:** Building blocks and signals of the receiver channel using high-pass timing discrimination [1].

#### Optics:

The beam emitted by the laser diode is highly divergent. The beam angle is 25° x 11° deg FWHM in vertical and horizontal direction respectively. Therefore the laser beam has to be imaged by some optics to the distance of interest. The common way is to use a single aspheric lens.

A lateral and/or angular resolution can be achieved by:

- using several laser diodes or a laser diode array,
- a lateral distribution of the laser light by light wave guides,
- using a rotating polygon mirror.

With multiple emitter and detector channels operated in sweep mode one can detect (beside the distance) the lateral dimension

and position of the object. These data can be used to calculate

- the impact,
- the angle and
- the position at the car

of the anticipated crash.

Also the power density is increased by the number of emitters, i.e. the laser beam is imaged on a smaller area. Higher power density increases SNR and/or range. The same applies to the rotating mirror version. By using light guides the optical power can be distributed across the scene without increasing power density.

Both the transmitter and receiver have their own imaging optics. For a multiple channel system each emitter channel is assigned to the corresponding detector channel. This also increases SNR and/range.

## Operating Parameters

Typical laser pulses for TOF systems have peak powers of several 10 W and pulse widths ranging from several ns to several 10 ns. Because light travels 0.3 m within 1 ns, a very narrow laser pulses with fast rise and fall time are essential for measuring short distances as it is the case in the pre-crash application.

Beside the laser pulse shape also the bandwidth of the detector and the timing resolution determine the ranging resolution of the system.

Usually the laser pulses are emitted in bursts (packages of multiple pulses) with repetition frequencies of several kHz within the burst. By using bursts several detector pulses can be averaged for calculating the distance value. The time interval between the bursts is in the range of several 10 ms.

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[11] Data sheet EL7104C:  
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[12] Data sheet MIC4452:  
<http://www.elantec.com/pages/pdf/d47104.pdf>

[13] Application note: Operating the pulsed laser diode SPL LLxx :  
<http://www.osram.convergy.de/uploa>

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[14] A. Kilpelä, R. Pennala, J. Kostamovaara, Precise pulsed time-of-flight laser range finder for industrial distance measurements, Review of Scientific Instruments Vol 72(4) pp. 2197-2202, April 2001

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