OSRAM
Opto Semiconductors

Time-of-flight (ToF) measurement using pulse lasers

Application Note

Valid for:
Pulse laser diodes from OSRAM Opto Semiconductors

Abstract

OSRAM Opto Semiconductors offers pulse laser diodes that are well suited for automotive and industry applications.

This application note provides a guideline for the proper use of OSRAM Opto Semiconductors pulse laser diodes and describes their technical details as well as their operation.

Further information:
For more detailed technical information such as optical and electrical simulation models and the latest product update visit www.osram.com/os or contact your local sales office to get technical assistance during the design-in phase.

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A. Time-of-flight measurement

“Time-of-flight” (ToF) measurement by using pulsed lasers is used in 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 also in the automotive field (e.g. for Adaptive Cruise Control ACC, Pre-Crash Sensing, Autonomous Emergency Breaking AEB). Although the measurement principle is the same for these applications, some differences exist e.g. in:

- the distance range to be measured (a few meters for pre-crash sensing, from tens to hundreds of meters for ACC).
- the beam angle for scanning (small narrow beam for distance measurement or ACC).
- the scanning frequency.

This application note describes the principle of ToF measurements and offers some proposals for using OSRAM Opto Semiconductors pulse laser diodes.

Light-based distance measurement

There are various ways of measuring distance optically using a pulse laser as an emitter and a photodetector as receiver.

Direct ToF. With direct ToF (Figure 1), the distance to a target is calculated by measuring the time in which a pulsed light passes from the light source to reach a target and return to the sensor.

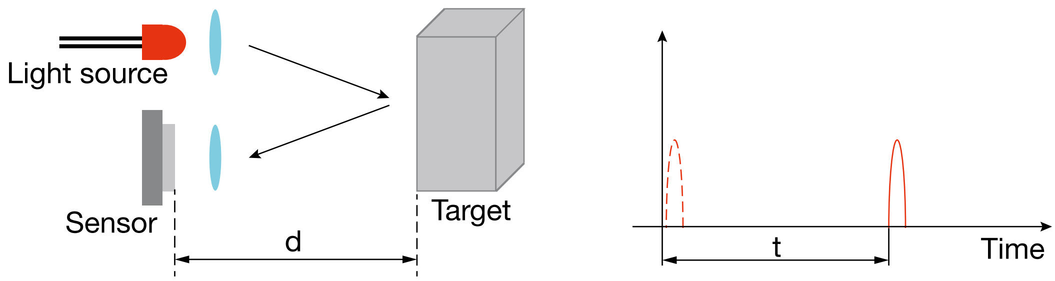
$$d = \frac{c \cdot t}{2} \qquad (1)$$

, where c is the light velocity and t the time the light takes for the distance to and from the target.

Pulsed ToF has the advantage of producing high laser peak power which enables long-range distance measurement, but also have low average optical power which is important for systems that need to adhere to optical safety requirements.

With this method the distance measurement range is wide, but to read out pulsed light at high speeds the circuit design and configuration is highly complex.

Figure 1: Direct ToF method measuring the time delay of the signal received



Indirect ToF. With indirect ToF (Figure 2), the distance to a target is calculated by measuring the phase difference between the signal emitted and received. This method is more suitable for short distance measurement in the tens of meters range. For long distances the calculated result would be ambiguous due to the periodicity of the emitter signal.

$$d = \frac{c \cdot \varphi}{4 \cdot \pi \cdot f} \qquad (2)$$

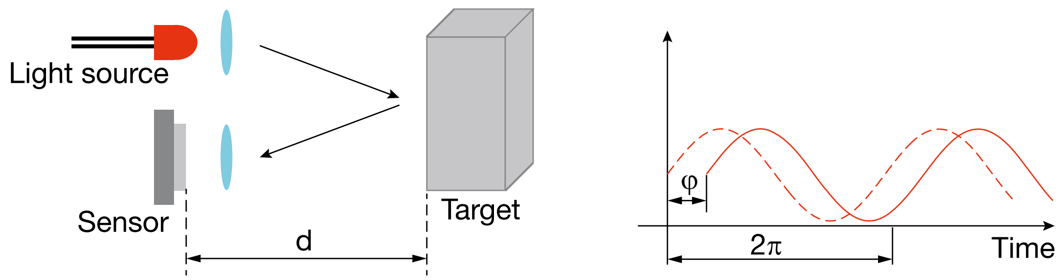
, where c is the light velocity, φ the measured phase shift of the received signal and f the modulation frequency used.

Given the speed of light (c) and the modulation frequency (f), ambiguity will happen at distances (d) that are a multiple of

$$d = \frac{c}{2 \cdot f} \quad .$$

To reduce the impact of this effect, multiple frequencies can be used to increase the sensing range, which makes the evaluation circuit even more complex.

Figure 2: Indirect ToF method measuring the phase shift of the signal received



Triangulation. This method calculates the distance to the target by detecting the position to which the light is reflected from the target. Triangulation offers very high resolution in short distance measurement (mm — µm range), but is not suitable for mid or long range, if the emitter and detector are placed close together.

Various dimensions of ToF distance measurement

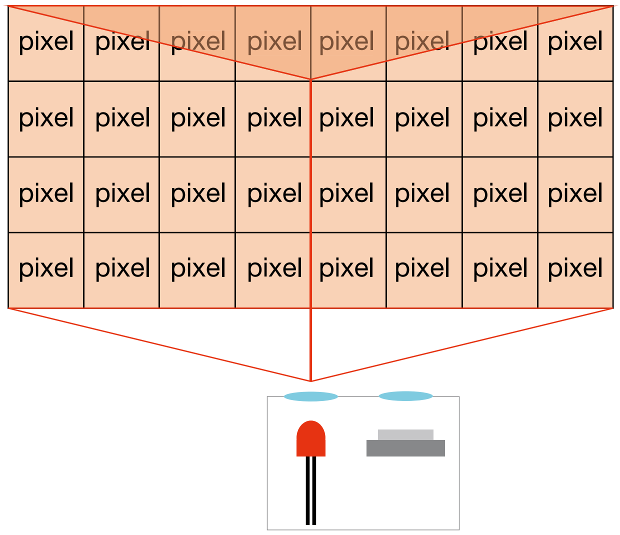
Various ToF systems are used on the market and various wordings are used to describe the systems. Range finder systems often incorporate just one single point distance measurement (1D).

Lidar (Light detecting and ranging) systems focus on generating a 3D point cloud, which means that they match a corresponding x/y coordinate to each distance measured. Such systems can provide similar information as a stereo camera system or a radar sensor and can be used as input for a sensor fusion system for e.g. autonomous driving cars.

For Lidar, two different main systems are used to get a 3D point cloud.

3D Flash. With a 3D Flash Lidar (Figure 3) the pulsed laser beam is emitted to the whole solid angle of interest at one shot. To obtain a certain resolution of the point cloud, an n x m array of the photosensitive detector (e.g. arrays of photodiodes or CMOS ToF chip) is required.

Figure 3: Basic principle of 3D flash Lidar with simultaneous illumination of the target FoV by the laser and its conversion to a certain resolution by an n x m array on the receiver side, e.g. a CMOS ToF camera chip

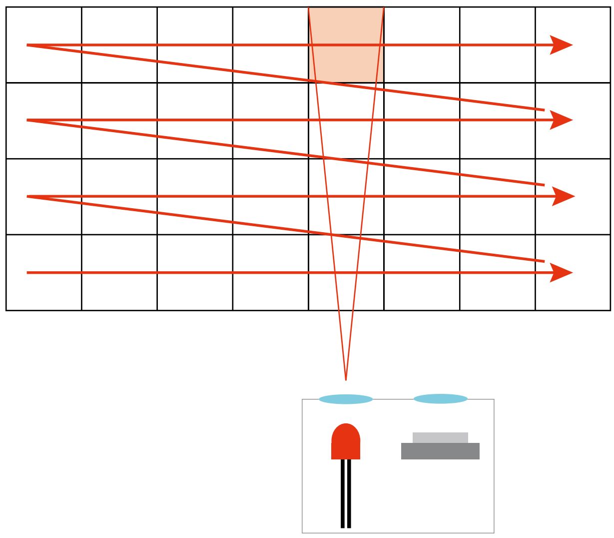


Scanning Lidar. A scanning Lidar system (Figure 4) consists of a focused pulsed laser beam which is directed to a certain small solid angle by either a mechanical rotating mirror or a MEMS (micro electro-mechanical system) mirror.

As the high power pulsed laser beam is controlled so as to be only emitted into a small solid angle, the reachable distance with the optical power used can be much larger compared to 3D Flash systems.

Usually the mirrors used (mechanically rotating or MEMS) allow scanning in only one direction. The resolution in this direction is achieved with the pulse repetition frequency of the laser and the scanning frequency of the mirror. To obtain a certain resolution in the other direction, n x 1 arrays of fast PiN photodiodes or avalanche photodiodes are used.

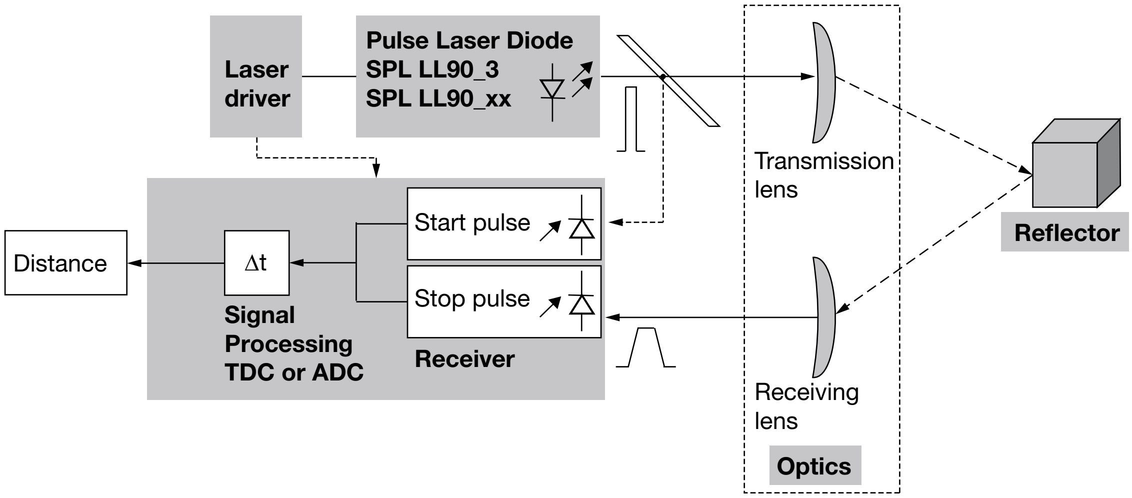
Figure 4: Basic principle of a scanning Lidar system with a focused laser beam directed to a small solid angle and a photodiode that receives the signal from this direction



Principle of a direct ToF

The basic principle is shown in Figure 5. 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 the start and stop pulse is used to compute the distance to the reflector.

Figure 5: Basic principle of 1D direct Time-of-Flight measurement



The measurable distance mainly depends on several parameters:

- Laser peak power
- Beam divergence
- Secondary 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 and beam properties) and the detectors used (type, sensitivity and bandwidth). The range which can be sensed will increase with higher laser peak power, higher combined sensitivity of the TIA (transimpedance amplifier) and detector and higher signal-to-noise ratio. The resolution of the ToF distance measurement depends on the rise time of the laser, the detector bandwidth and the signal processing, but also the performance of the electronics such as the minimum reachable resolution of the TDC (time-to-digital converter).

The distance measurement accuracy increases with smaller pulse lengths, faster rise and fall times and higher bandwidths of the detector.

A decreasing pulse width enables one to increase the peak optical output power with regards to eye safety constraints.

A pulsed laser based 1D ToF system typically consists of a laser pulse transmitter, the necessary optics, two receiver channels and a TDC or a high-speed ADC (Analog-to-Digital Converter), as shown in Figure 5. 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] A high-speed ADC based system could have a performance advantage compared to a TDC based system. As an ADC digitizes the return signal and not only measures the time, sophisticated signal processing of the return signal can be performed.

B. Key components

As shown in Figure 5, the following key components are required besides some signal processing circuitry:

- Transmitter (laser emitter)
- Receiver (photo detector)
- Optics

Transmitter

The transmitter consists of a pulsed laser diode and the driver electronics. OSRAM Opto Semiconductors provides two types of pulsed laser diodes suitable for TOF systems:

1. “Pulse lasers” (SPL PL90 and SPL PL90_3) which contain a laser chip mounted on a lead frame inside a radial plastic package (Figure 6).

Figure 6: Pulse laser SPL PL90_3

2. “Smart lasers” (SPL LL90_3) which incorporate some current driving capabilities (Figure 7). This enables the generation of short optical pulses down to several ns FWHM in a straightforward manner.

Figure 7: Smart laser SPL LL90_3

The lasing wavelength λ_{peak} is 905 nm, respectively. Please refer to data sheets and application notes available on the OSRAM Opto Semiconductors web site.

Electronic driver circuit.

“Pulse laser” SPL PL90 / SPL PL90_3. To operate the SPL PL90 / SPL PL90_3 type laser diodes a high (several 10 A) and narrow (several nanoseconds) current pulse must be transmitted to the laser diode.

The pulsed laser driver consists 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 performed between two laser pulses. A MOSFET, an avalanche transistor or a GaN FET can be used as a switch.

To obtain short optical pulses, the gate of the switch (e.g. MOSFET or GaN FET) must be charged very quickly. In order to obtain the required gate-source threshold voltage, the specific gate capacitance must be charged within the range of a few nanoseconds. For very short optical pulses, the GaN FET technology has advantages compared to a MOSFET due to the lower gate capacitance, which enables faster switching and therefore a shorter pulse width. Moreover, a lower on resistance $R_{DS\ on}$ offers lower conductance losses and enables more efficient system designs.

To reach a certain optical peak power within a very short time, a minimum current slope is required. The formula below describes the induced voltage of parasitic inductances in the circuit, which hinder the increase of the laser current. So the current slope can be increased by either decreasing the parasitic inductances in the circuit or by increasing the supply voltage. The supply voltage is limited due to technical generation reasons, by safety reasons and by the switch used. GaN FETs are capable of handling higher voltages.

$$u_L(t) = L \cdot \frac{di_L(t)}{dt}$$

Enhancement Mode GaN (eGAN) FETs are offered e.g. by the company EPC Corp. https://epc-co.com/epc/

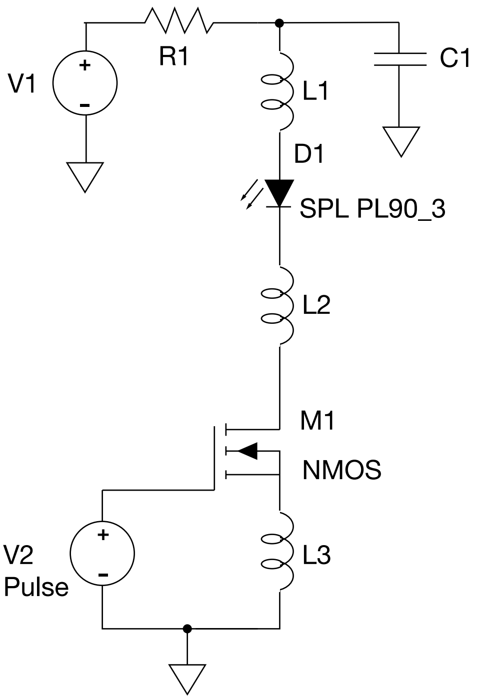
To ensure the capability of reaching high currents within a few nanoseconds delay, a FET must fully turn on extremely quickly.

Figure 8 shows a simplified schematic of a pulser circuit using an n-channel MOSFET as a low-side switch. The capacitor C1 provides the necessary charge for the high peak current, which is charged between 2 laser pulses via a DCDC-converter, in the schematic simplified as source V1. Parasitic inductances (simplified L1, L2, L3) due to PCB circuit design should be kept as small as possible. The gate of the MOSFET is controlled by a pulsed voltage source V2, which is normally a high-speed gate driver for MOSFET/GAN FETs.

Gate drivers for eGaN FETs are offered e.g. by Texas Instruments Inc. For example the LMG1020 features a single, low-side gate driver targeted at driving enhancement mode GaN FETs. http://www.ti.com/power-management/gan/fet-drivers/overview.html

LMG1020 has been optimized for high-speed applications due to its low-inductance waver chip scale package (WCSP).

Figure 8: Schematic pulse laser driver circuit with a capacitor C1 for storing the electrical energy and a MOSFET as a switch



OEM driver boards using power MOSFETs as a switch are offered by the companies Directed Energy Inc. [3], EO-Devices Inc. [4] and Dr. Heller Elektronik KG. [5] The company Diodes Inc. [6] is a supplier of specially manufactured avalanche transistors.

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

$$C \cdot U = I_p \cdot t_p$$

Increasing the value of C increases both the width of the current pulse t_p and the peak amplitude of the pulse current I_p. By increasing the operating voltage U 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) must be used. The capacitor used must allow the maximum supply voltage in order to provide the charge required to sustain the current and should have a minimum inductive path and low ESR (equivalent series resistance).

Current carrying conductors must be kept as low as possible. In addition, the leads of the laser diode must be cut as short as possible to avoid parasitic inductances and series resistance. Note that each inch of length adds approximately 20 nH of inductance.

This means that a di / dt of 20 A / 10 ns generates a transient L*di / dt voltage of 40 V per inch of wire length. The real effect will be a significant increase in rise time. [9]

Figure 9 shows the measured power of a SPL PL90_3 pulse laser driven by the PCO-7110 model 100-7 from Directed Energy Inc. The optical peak power is 70 W at 250 V operating voltage of the driver board (see Figure 10).

Figure 9: PIN photo diode signal of SPL PL90_3 driven by the PCO-7110 board model 100-7 from Directed Energy Inc. Peak power is 70 W, pulse width is 15 ns (FWHM) and rise/fall times are 6 and 12 ns respectively

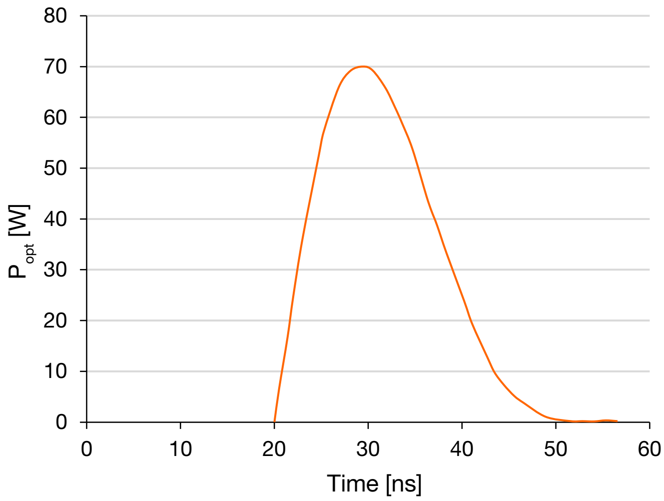
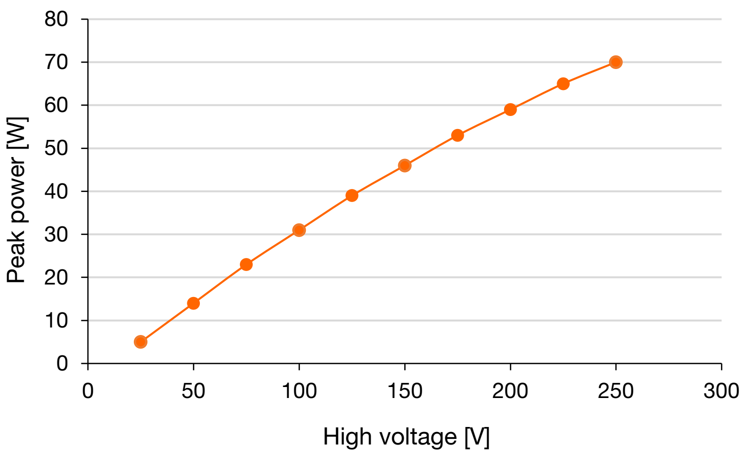


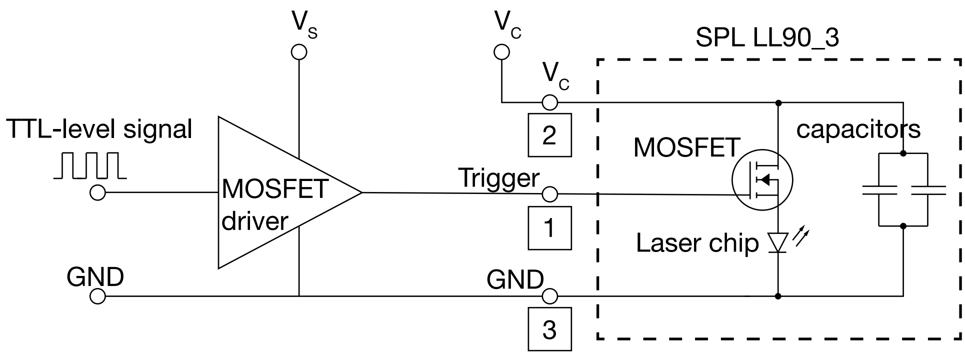
Figure 10: Peak power vs. pulser voltage for SPL PL90_3 with pulser PCO-7110 model 100-7 from Directed Energy Inc.



For more details about operating the “Pulse laser” SPL PL90xx please refer to the application note “Operating the pulsed laser diode SPL LLxx”.

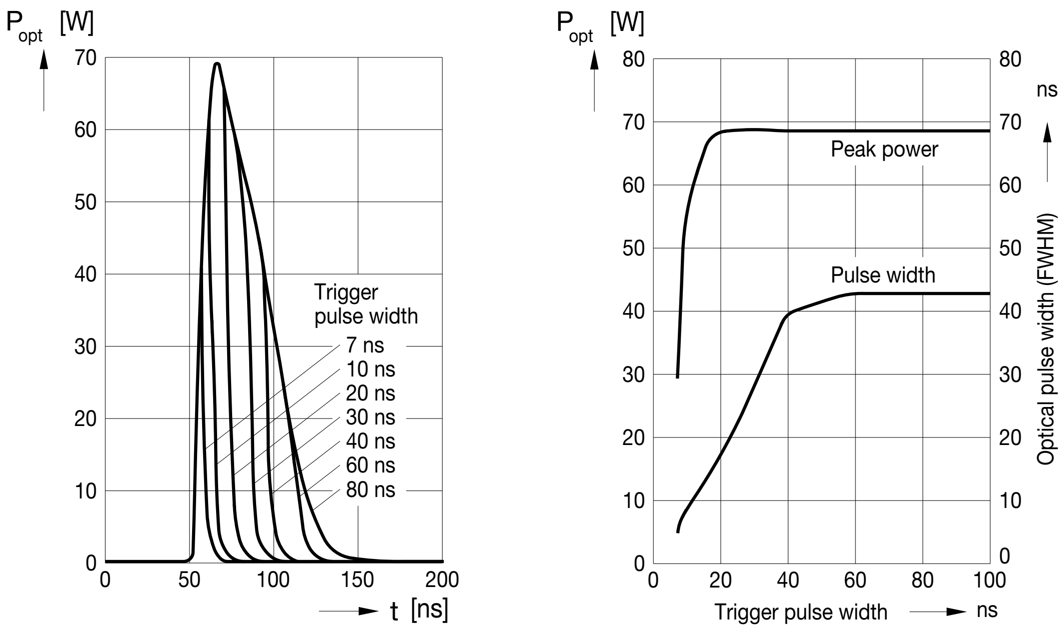
“Smart lasers” SPL LL90_3. In the ‘Smart Lasers’ the capacitors and MOSFET switch are integrated in a hybrid package. To operate the laser only a MOSFET driver IC is required for charging the gate of the MOSFET. The laser peak power can be adjusted by the value of charge voltage and/or gate voltage.

Figure 11: Schematic of SPL LL90_3 with MOSFET gate driver



The maximum laser pulse width is determined by the internal capacitors (two 47 nF in parallel) to 40 ns. By switching off the MOSFET before the capacitors are completely discharged a minimum pulse width of 15 ns can be achieved while maintaining the maximum peak power as can be seen in Figure 12. This can be achieved by adjusting the pulse width of the MOSFET trigger (gate) signal.

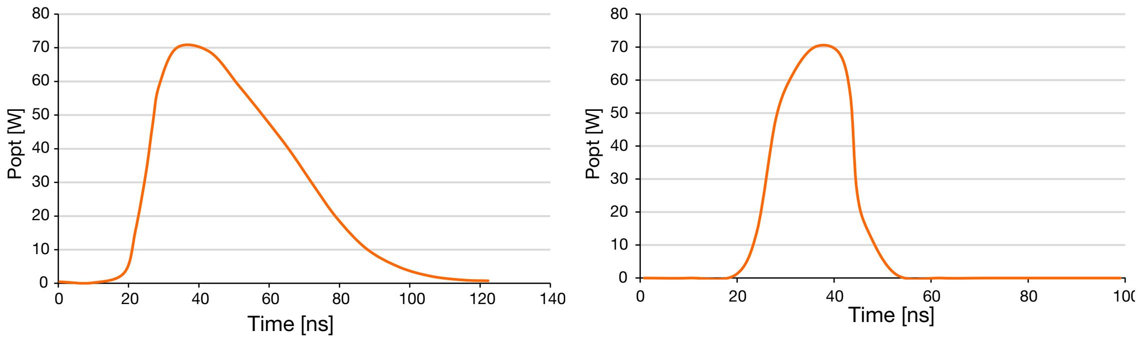
Figure 12: Optical pulse form for various trigger pulse widths of SPL LL90_3 (left) and variation of optical pulse width (FWHM) and peak power with trigger pulse width (right). Operating conditions are 15 V gate voltage, 18.5 V charge voltage and 1 kHz PRF, using the MOSFET driver Renesas EL7104C



The MOSFET driver ICs recommended are the Renesas EL7104C [10], the Micrel MIC4452 [11] or the Fairchild FAN3224T. Since the gate charging currents exceed peak values by several amperes, proper connection of the driver with MOSFET is essential.

More details concerning the operation of the "Smart Laser" can be found in the respective application note from OSRAM Opto Semiconductors "Operating the pulsed laser diode SPL LL90_3".

Figure 13: PIN photo diode signal of SPL LL90_3 at 70 W peak power. Left: Capacitors are completely discharged (gate pulse width > 100 ns) resulting in a FWHM pulse width of 42 ns. Right: Pulse width is reduced to typically 22 ns by switching off the FET after 22 ns



Receiver

For sensing the diffracted optical power and converting it into an electric signal, typically silicon PIN diodes or silicon APDs (avalanche photo diode) can be used as photo detectors, which produce a low current in proportion to the return signal. A very low-noise transimpedance amplifier (TIA) is required to optimize the range of the system because the amplitude of the return signal decreases in proportion to the square of the distance.

Important parameters are:

- Sensing wavelength: should match the wavelength transmitted, a bandpass filter matched to the transmitted wavelength in front of the receiving element can enhance the SNR by blocking ambient light noise.
- Responsivity (A/W): The current sensed depending on the received optical power measured.
- Dark current: the lower the dark current the higher the SNR for the system.
- Rise time: with increased slope of the laser optical pulse, the achievable resolution rises, as do also the fast rise times on the receiver side including the electronic circuit so it is important to be able to catch the pulsed signals.
- Dynamic range: dynamic range from a black target far away to a shiny target nearby.

The APD has the advantage of a high signal-to-noise-ratio (SNR) but needs high bias voltage (> 300 V). For PIN diodes the bias is low (< 40 V) but also has much lower sensitivity compared to APDs which require electrical amplification.

The width of the laser pulse and the bandwidth of the receiver channel should be matched to one another (f_{max} = 0.35/tr). If the laser pulse width is too small, 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 receiver channel is wider than the bandwidth corresponding to the rise time of the laser pulse, the amplifier produces excess noise and the measurement precision deteriorates. [12]

To increase the SNR an optical band-pass filter should be used upstream 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 signal received 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 pulse is much longer than the accuracy usually required (two meters vs. a few tens of centimeters), a specific point in the pulse must be defined, and consequently a logic-level pulse for the TDC must be produced. The timing point for the stop signal should not change when the level of the signal varies, as this would 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 point 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 required 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 pulse received. The disadvantage 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 does not have the same timing error as leading edge discrimination. [1]

Figure 14: Building blocks and signals of the receiver channel using high-pass timing discrimination [1]

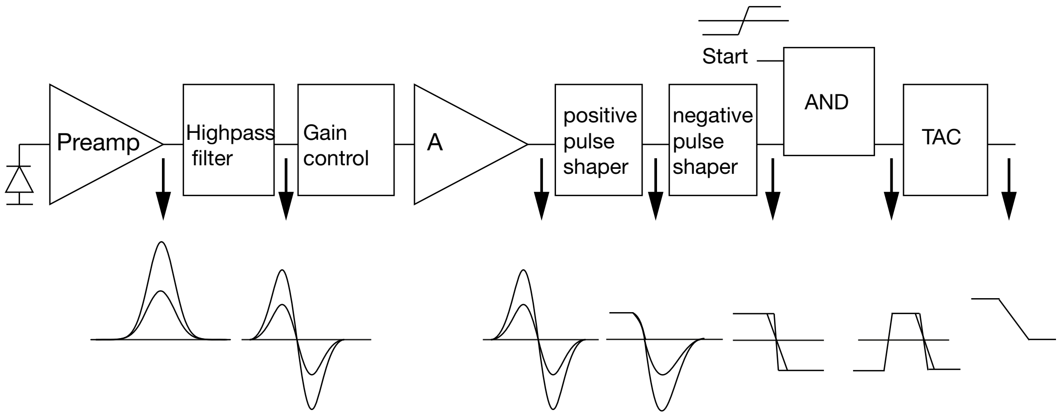
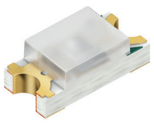
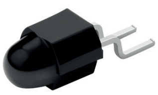
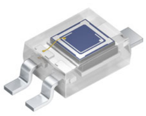
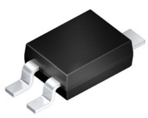


Table 1 shows a series of recommend PiN photodiodes with compact size and fast rise and fall times.

Table 1: Series of OSRAM Opto Semiconductors photo detectors with compact size and fast rise/fall time which is suitable for high-speed ToF measurement

Part number	Picture	Spectrum range	Half angle	Rise/fall time
SFH 2701		400 ~ 1100 nm	± 60 °	2 ns
SFH 203FA		750 ~ 1100 nm	± 20 °	5 ns
SFH 2500FA		750 ~ 1100 nm	± 15 °	5 ns
SFH 2400		400 ~ 1100 nm	± 60 °	5 ns
SFH 2400 FA		750 ~ 1100 nm	± 60 °	5 ns

Optics

Eye safety. The laser eye safety standard IEC 60825 is an important design consideration for a laser system. It is highly recommended that you familiarize yourself with this standard before starting the design.

Optics. The beam emitted by the laser diode is highly divergent. The beam angle is 25° x 11° FWHM in the vertical and horizontal direction respectively. Therefore, the laser beam must be imaged by some optics to the distance of interest.

At a high level, the optic design must fulfill the following requirements:

- The field of view overlap between the transmit path and the receive path must be as large as possible.
- The optics design needs to maximize the power transmitted to the target before it is reflected back to the sensor.
- The receiving optics must maximize the power received by the photodiode.
- The optics may include filtering ambient light to reduce the background noise seen by the system.

To further improve the light collecting capability and enhance SNR, an anti-reflective coating for 905 nm and a bandpass filter around 905 nm to block ambient light is recommended.

The smaller the resulting spot size of the laser beam is, the more sharply the outlines of the target object can be detected and the more defined is the distance information.

Coming from a point-to-point distance measurement, a lateral and/or angular resolution can be achieved by:

- using several laser diodes or a laser diode array which emit to the same solid angle.
- a lateral distribution of the laser light by light wave guides in combination with a detector array.
- using a rotating polygon or MEMS (micro electro-mechanical system) mirror.

The power density is also increased by the number of emitters if several emitters are focused on the same point, 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/or range.

Example system consideration. A simplified, theoretical example system consideration is performed in this chapter for a 1D direct ToF measurement with the single-junction pulse laser SPL PL90 together with the fast PiN photodiode SFH 2400 FA for an example distance of 5 m.

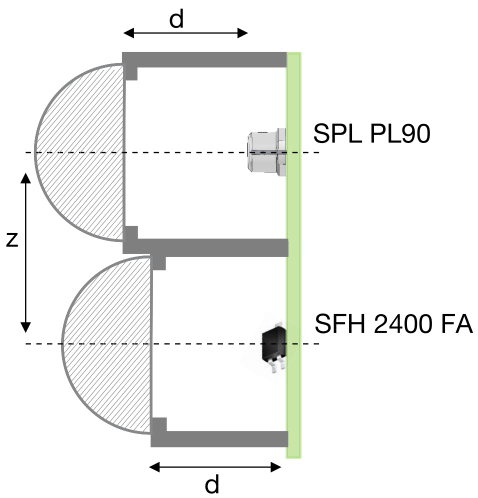
One target application might be industrial autonomous vehicles.

Figure 15 shows the principle setup of an example optical system using plano-convex lenses both for collimating the laser beam of SPL PL90 and focusing the reflected signal to the photodiode SFH 2400 FA.

Both plano-convex lenses have a distance to the laser/photodiode of 25 mm. The distance of the 2 optical center axis is z, which is larger than the lens diameter due to the mechanical setup.

Off-the-shelf lenses and mechanical lens holders are available e.g. at Thorlabs https://www.thorlabs.com or Lightpath Technologies http://www.lightpath.com.

Figure 15: Principle optic system setup for pulse laser SPL PL90 and receiver photodiode SFH 2400 FA



The following considerations do not take into account the astigmatism of the pulse laser diode.

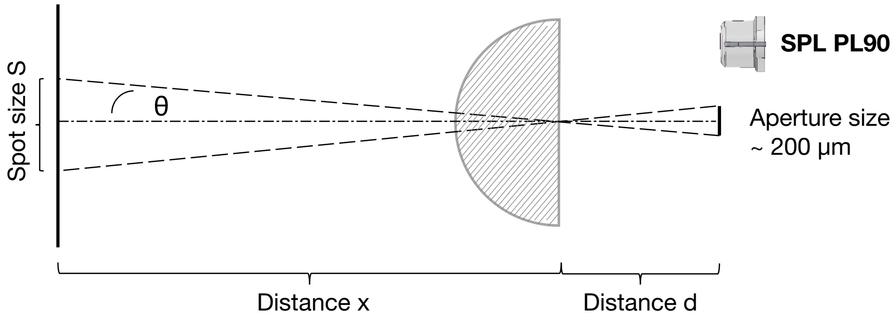
The pulse laser diode SPL PL90 is a single-junction device and has an aperture size in nearfield of ~ 200 µm x 2 µm (parallel x perpendicular to pn-junction).

For a first rough estimation we assume the laser to act as a point source for the direction perpendicular to the pn-junction due to the small aperture size in this direction, so the beam in fast axis can be collimated at a certain distance. In order to be able to collect all the light in the fast axis, the lens size and the distance of the laser to the lens play a major role.

For the direction parallel to pn-junction a minimum reachable spotsize in a certain distance results due to a certain aperture size of ~ 200 µm.

Figure 16 shows the minimum reachable spot size S at a certain distance x, by assuming a distance d of the laser aperture to the collimation lens.

Figure 16: Minimum possible spot size resulting in direction parallel to pn-junction due to aperture size of ~ 200 µm of the pulse laser SPL PL90



For very rough calculation we use the following formula to estimate the resulting spot size for this direction:

$$\frac{200\ \mu m}{S} = \frac{d}{x}$$

For our example with a distance of x = 5m and an example distance of laser to collimating lens of d = 25 mm it results in a minimum spotsize of S = 40 mm.

The resulting spot creates an angle of:

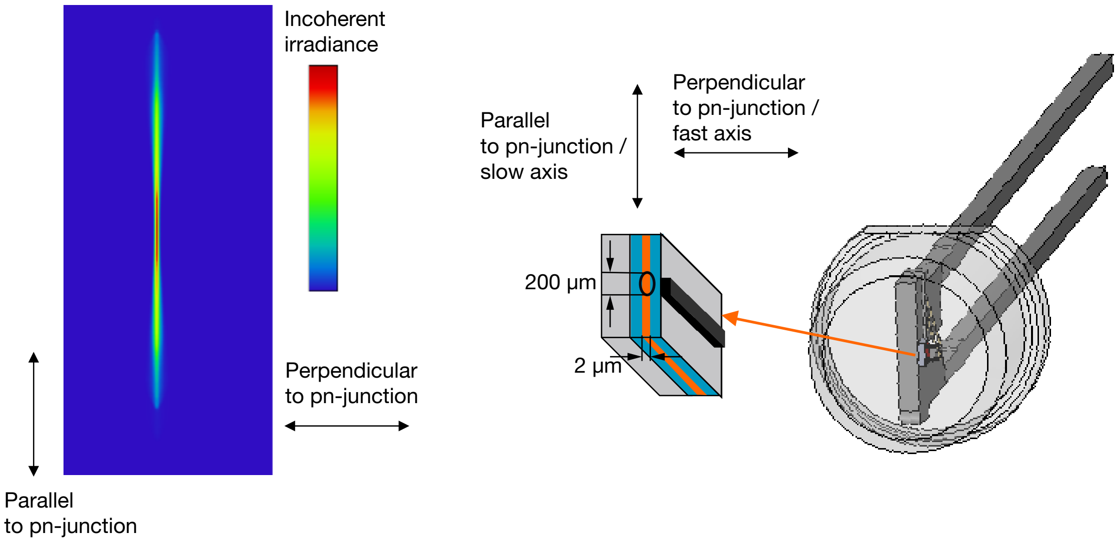
$$\tan\theta = \frac{S}{2 \cdot x}$$

In our example for the distance x = 5 m and a spotsize of S = 40 mm, a spot angle of θ ~ ± 0.23° is generated.

Figure 17 shows quantitatively the resulting spot shape at 5 m with a height of the spot of roughly S = 40 mm if the laser is twisted, so the pn-junction is in the vertical direction. The right part of the figure shows the orientation of the laser diode, the laser die inside the package and so the aperture of the laser in this example.

For more detailed spot size calculation we recommend that you perform an optical simulation. Rayfiles of the pulse laser diodes are available for download. [2]

Figure 17: Resulting spot shape of SPL PL90 at 5 m distance, mainly dominated by the aperture size parallel to pn-junction. SPL PL90 is twisted, so pn-junction is in the vertical direction. The right part of the figure shows the orientation of the laser diode, showing the laser die and the aperture orientation



On the receiving element side it must be ensured that the photodiode can collect as much of the light reflected back as possible.

Using the die size of the SFH 2400 FA of 1 mm x 1 mm, an active region of ~ 1 mm results for first estimation.

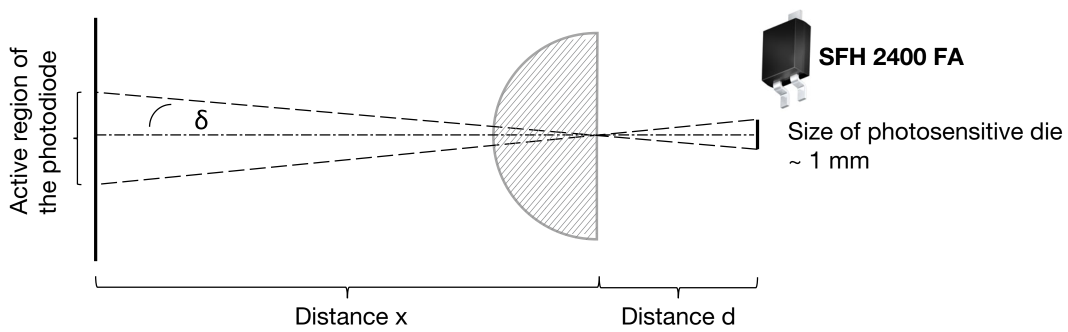
The resulting active region of the photodiode creates an angle of (Figure 18):

$$\tan\delta = \frac{1\ \text{mm}}{2 \cdot d}$$

In our example a receiving angle of δ ~ ± 1.15° results for the distance of the photodiode to the focusing lens of d = 25 mm.

As the resulting angle of the receiving element is δ ~ ± 1.15° and much larger than the resulting angle of the laser spot θ ~ ± 0.23°, it is ensured that the receiving element can collect as much of the reflected light as possible.

Figure 18: Resulting angle of the receiving element for the SFH 2400 FA



The minimum distance that can be sensed is strongly related to the geometrical setup of the pulse laser towards the photodiode and the system FoV of both the sender and receiver part.

Figure 19 shows the 2 beams of the sending unit (pulse laser plus collimating lens) and the receiving unit (photodiode plus focussing lens) overlapping at a certain distance d_{min} (case 2, right side of the picture). At this distance the signal of the laser diode can theoretically be fully received and detected by the photodiode, assuming all other conditions such as sufficient SNR etc. are fulfilled. The case 1 (at the center of the picture) shows the distance where no overlapping of the 2 FoV exists, so no reflected signal can be sensed by the photodiode.

Figure 20 shows the geometrical constellation of sending and receiving units, with the distance x between the center lines of the sending and receiving unit and distance d_{min} at which the FoV of both units fully overlap.

$$d_{min} = \frac{z}{\tan\delta - \tan\theta}$$

In the case of our example, assuming a distance z between laser and photodiode of 30 mm and using the resulting angles of the sending ($\theta = 0.23°$) and receiving ($\delta = 1.15°$) unit which are shown in the above calculation, a minimum distance of d ~ 1.9 m would result in a full overlap of both active areas. This can be optimized with a smaller distance z and smaller secondary lenses.

Figure 19: Simple schematic to show the minimum distance that can be sensed with the resulting beam of the laser sending unit and the sensitive area of the receiving unit with the photodiode

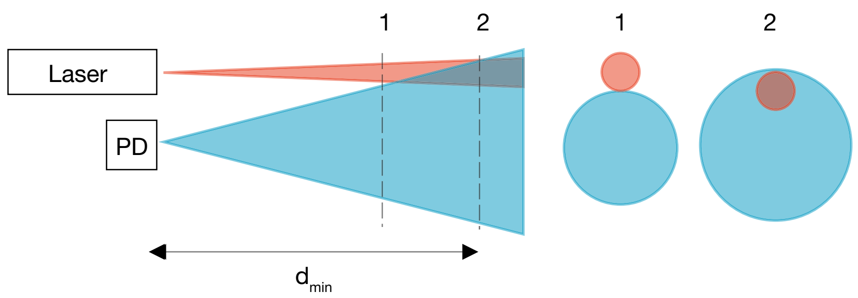
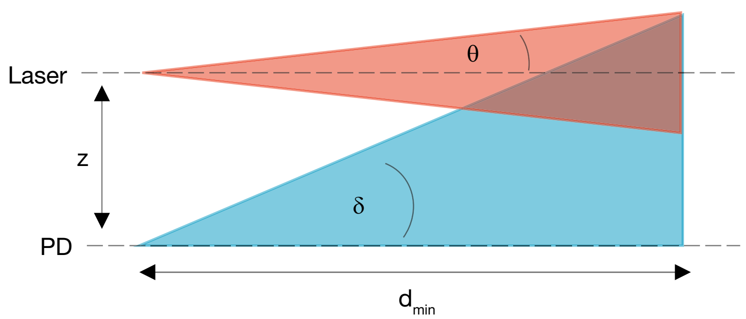


Figure 20: Geometrical constellation with minimum distance d_{min} at which the sender and receiving unit FoVs fully overlap



To do a very rough estimation of the resulting photocurrent of the SFH 2400 FA, we can use the assumptions below for simplification.

The optical efficiency of the sending and receiving unit is 100 %, so there are no optical losses on the lenses. The pulse laser SPL PL90 emits a laser pulse with 25 W optical peak power. The resulting laser spot can be collimated and completely hits the target at 5 m. The target surface has ideal reflexion behavior and reflects the 25 W back completely. We assume that the total optical power can be concentrated on one point at the target, which is not the case due to the aperture size of the laser (Figure 17). The target surface acts as a Lambertian emitter and generates a back-reflected signal with radiant intensity in the main axis of

$$I_e = \frac{Phi_e}{\pi} = \frac{25\ \text{W}}{\pi} = 7.96\ \text{W/sr}$$

The irradiance at the photodiode can be calculated by

$$E_e = \frac{I_e}{d^2} = \frac{7.96\ \text{W/sr}}{(5\text{m})^2} = 0.32\ \text{W/m}^2 = 32\ \mu\text{W/cm}^2$$

Using the resulting irradiance at the photodiode and using the data sheet curve of photocurrent I_p as the function of irradiance E_e for the SFH 2400 FA, we get a photocurrent of I_p ~ 200 nA which must be processed by the following electronics. As the SFH 2400 FA reaches its maximum of the spectral sensitivity curve close to the wavelength of the emitted light of the pulse laser, we do not use a correction factor here.

Similar considerations as above can be done for a scanning Lidar system assuming all the transmitted light hits the target.

With a flash Lidar system assuming a Lambertian emitter in the sending unit, the optical power on the target object relates to ~ $1/d^2$, which results in a relation for the signal at the photodiode of ~ $1/d^4$ with reference to the optical power emitted from the laser diode.

This example consideration should give a first rough starting point for the system design and is targeted to show basic considerations of their interaction.

As this approach only shows a part of the system design with rough estimations, we recommend that you evaluate the whole system based on simulations and testing on prototype status.

OSRAM Opto Semiconductors cannot be held liable for the completeness of the recommendations. The customer must perform his own tests to verify the design.

The larger the optical size of the receiving lens, the more of the reflected signal can be sensed, but on the other hand by increasing this size, the reachable distance between the sending and receiving unit increases, which increases the minimum distance to an object that can be sensed.

Operating Parameters

Typical laser pulses for ToF systems have peak powers of several tens of watts and pulse widths ranging from several ns to several tens of ns. Since light travels 0.3 m within 1 ns, very narrow laser pulses with fast rise and fall times are essential for measuring short distances as is the case in the pre-crash application.

Beside the laser pulse shape the bandwidth of the detector and the timing resolution also 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 tens of ms.

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