# OPTICAL RADIATION SAFETY INFORMATION
Application Note

## General

Direct viewing the intensive optical radiation from the **laser diode (LD)** may cause damage to the eye. The potential optical hazard depends on the nature of the (invisible) optical radiation that may become accessible. Primarily in this wavelength region almost instantaneous thermal retinal damage of the eye is the hazard:

- Radiation of wavelength less than approximately 1.4  m penetrates the ocular media and is absorbed significantly in the retina.
- No protection of the eye is given by aversion reactions (blink reflex).
- The small point-type diverging beam sources produce an unresolved (diffraction limited) point retinal image due to the accommodation capabilities of the eye: the irradiance (radiant flux density) at the exposed cornea will be focussed to one point at the retina and there it will be increased by a factor of about $10^5$.
- Additional optics between the source and the eye may extend the hazard due to increased power collection of the extended entrance aperture.

The desire to operate optical measurement systems over long distances reliably, enhances the use of high radiance optical sources like the SPL PL and LL-type lasers. Depending on the driving conditions of the emitter, the optical power levels required to obtain an acceptable level of system performance sometimes may even exceed the **Maximum Permissible Exposure (MPE)** limits of the eye.
In these cases precautions must be provided with mounting, service and maintenance. An unintentional viewer can not realize the hazard and therefore has to be protected.

## Laser safety standard

For description of the actual hazard a safety classification system is standardized based upon biologically/physiologically determined MPE- values and class-related safety philosophy. IEC 60825-1 is the most common international standard. According to IEC 60825-1:1993+A2:2001 laser products are designated with classes for each of which **Accessible Emission Limits (AEL)** are specified. Generally, this standard has actually not to be applied to single components, since the classification depends on the use and driving conditions:
"...However, laser products which are sold to other manufacturers for use as components of any system for subsequent sale are not subject to IEC 60825-1, since the final product will itself be subject to this standard..."
Therefore, device manufacturers may only support by informing generally about the derived device-specific requirements and the safety-related physical characteristics and limitations of the laser diodes within the scope of the data sheets.

Considered for SPL-laser diodes the driving conditions (current, pulse width, duty cycle) possibly can cause classification into any of the following classes:

**Class 1:** Laser products which are safe under reasonably foreseeable conditions either inherently or by virtue of their engineering design.

**Class 1M:** Laser products which are eye safe without optical instruments but potentially hazardous when viewed using optical instruments such as eye loupes. The AEL values for Class 1 and Class 1M are the same but the measurement criteria differ.

**Class 3R:** Laser products which are unsafe for the eye but the risk is much lower than for Class 3B. (They are exceeding the MPE, but the radiation output power is limited to 5x the AEL of Class 1)

**Class 3B:** Direct intrabeam viewing of these lasers is always hazardous.

Only Class 1 (and 1M) is furthest free from restrictions: instead of an explanatory label on the product the same classification information can be declared in the customer instruction.

The applicable AELs have to be determined taking into account wavelength, source size and the emission duration of the sources.

Due to the small dimension of the source the retinal image appears at an angle not larger than the limiting angular subtense $_{min}$ when measured at a minimum distance of *r* = 100 mm. Therefore the lasers of the SPL-series have to be considered as diverging-point-type sources.

Intentional viewing is usually not inherent in the design or function of infrared sources. Therefore the applicable time base *T* amounts to 100 s.
Since the emission of the laser diodes under use conditions is modulated, the three requirements for repetitively pulsed sources of IEC 60825-1, § 8.4 f) must be considered, depending on the actually applied pulse regime.

The AEL must be determined by using the most restrictive of these requirements:

i) The exposure from any single pulse within a pulse train shall not exceed the AEL for a single pulse.
ii) The average power for a pulse train of emission duration *T* (applicable time base) shall not exceed the power corresponding to the $AEL_{AV}$...for a single pulse of emission duration *T*.
iii) The average pulse energy from pulses within a pulse train shall not exceed the AEL for a single pulse multiplied by the correction factor $C_5$. If pulses of variable amplitude are used, the assessment is made for pulses of each amplitude separately, and for the whole train of pulses.

$$AELtrain = AEL_{SP} \times C_5$$

where:

AELtrain is the AEL for any single pulse in the pulse train;

$AEL_{SP}$ is the AEL for a single pulse;

$C_5 = N^{-0.25}$

N is the Number of pulses in the pulse train during...$T_2$ (=10 s)

If multiple pulses appear within the period of...18 µs...they are counted as a single pulse to determine N and the energies of the individual pulses are added to be compared to the AEL of...18 µs...provided that all pulse durations are greater than $10^{-9}$ s.

## Application to the SPL-laser diodes

Determination of the applicable AEL

In order to determine the specific applicable limits, following data have to be provided:
duration of a single pulse: $t_p$ [s]
pulse repetition rate: f [Hz] and
duty cycle d (= f x $t_p$) if f > 55 kHz

For the wavelengths of concern the above requirement i) need not to be considered in detail, since it is contained in requirement iii) (more restrictive). The remaining two requirements for pulsed sources can be separated as follows:
if f > 55 kHz requirement (ii) is most restrictive
if f < 55 kHz requirement (iii) is most restrictive
ii) At high repetition rates above 55 kHz the emission is considered as a continuous wave (CW) source with a power level equal

to the average power emitted by the transmitter:
The average power for a pulse train within the applicable time base T amounts to (see also Fig. 1 for $T$ = 100 s):

$AEL_{AV}$ at 850 nm peak-wavelength
Class 1/1M: 0.78 mW
Class 3R: 3.9 mW

$AEL_{AV}$ at 905 nm peak-wavelength
Class 1/1M: 1 mW
Class 3R: 5 mW

In order to determine the AEL for one single pulse of the train, this values have to be divided by the duty cycle d:

$$AEL_{SP}ii = AEL_{AV} / d.$$

iii) If the repetition rate is smaller than 55 kHz, requirement (iii) has to be verified:

The applicable $AEL_{SP}$ for various single pulse durations $t_p$ are shown in Fig. 1.
These $AEL_{SP}$ are valid for one single pulse and have to be reduced by the following factor:

$$AEL_{SP}iii = AEL_{SP} \times (10 \times f)^{-0,25}$$

As long as pulses of the same amplitude are used, just the number of these pulses within 10 s have to be determined for the calculation of $C_5$ - even if the pulses are not temporally uniformly distributed. However, if multiple pulses (e.g. bursts) occur within the time frame of 18 µs, they have to share the applicable energy-limit, $AEL_{18}$, for 18 µs-pulses, reduced by $C_5$ - which is now determined by the number $N_{18}$ of such 18 µs-pulses within 10 s.
In order to determine the single pulse-limit, the following $AEL_{18}$ have to be multiplied by $N_{18}^{-0,25}$ (=$C_5$) and the result has to be divided by the number of pulses which are grouped within 18 µs. (The division with the single pulse duration leads to the applicable limit in W.)
$AEL_{18}$ at 850 nm peak-wavelength
Class 1/1M: $4 \times 10^{-7}$ J
Class 3R: $2 \times 10^{-6}$ J

$AEL_{18}$ at 905 nm Peak-wavelength
Class 1/1M: $5.14 \times 10^{-7}$ J
Class 3R: $2.57 \times 10^{-6}$ J

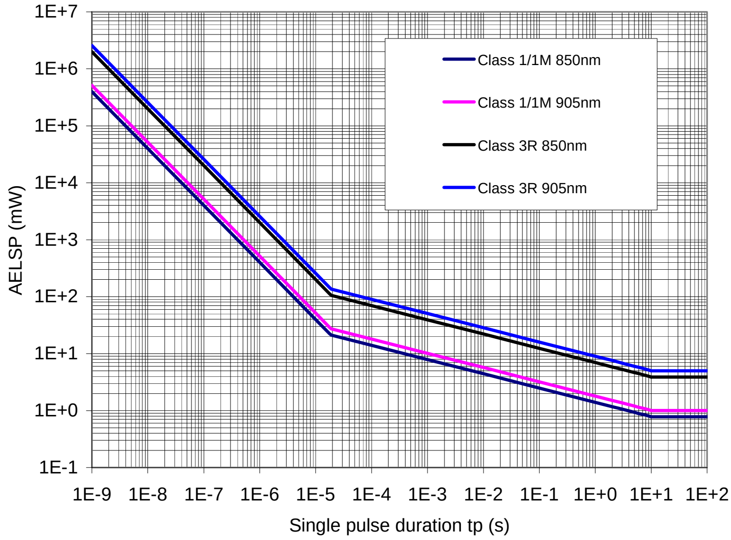



*Fig 1: $AEL_{SP}$ for single pulses according to IEC 60825-1, Tab. 1 and Tab. 3*

<u>Consideration of the measurement procedures</u>

The AEL have to be compared with the actual emitted radiation power, measured under different specific conditions:
In order to classify the diode into Class 1 and 3R the radiation power has to be measured with an aperture of 7 mm diameter in a source distance of 14 mm. For classification into Class 1M, the measurement distance would amount to 100 mm. The power measured with these procedures must not exceed the respective AEL. The corresponding allowable total emitted power of the device depends on the fraction that passes through the measurement aperture.
Also the impact of the applicable measurement condition can be checked by calculations:
the cross-sectional area of the laser beam at the measurement distance which contains 63% of the total emitted power has to be

determined (e.g. from the actual divergence):

$$A_{63} = \frac{r^2 \pi \tan\alpha \tan\beta}{2{,}9} \qquad [mm^2],$$

where: r: measurement distance [mm],
and : half angles [°] of the divergence, 2,9: conversion factor (for a Gaussian beam) to calculate the area that contains 63% of the total power
the intercepted fraction of the measurement aperture can now be calculated as:

$$\eta = 1 - e^{-(\frac{38{,}5}{A_{63}})}$$

the maximum allowable total emitted power of the laser amounts to:

$$P_{AEL} = \frac{AEL}{\eta}$$

These values may be compared with the corresponding values of the data sheets and may help to decide if actions are necessary or not.
In the case that no additional optics are used, the divergences of the laser diodes may be taken from the data sheets. However, due to the rather close measurement distance for classifications into Classes 1 and 3R, nearly the whole amount of emitted power will be captured by the measurement aperture – and has to be compared with the corresponding AEL. Therefore, this transformation is useful especially for the classifications into Class 1M.
The resulting most restrictive $AEL_{SP}$ of the above pulse requirements simply has to be multiplied by the following factor:

| Divergence of the LD | Increasing factor for the Class 1M AEL | |
|---|---|---|
| 11 x 25 deg | 6 | SPL PL-series |
| 14 x 30 deg | 9 | SPL LL-series |

Although they have the same AEL (see Fig. 1), the resulting allowable total emitted powers for Classes 1 and 1M are quite different. In the present case, the allowable total power in Class 1M even exceeds those of Class 3R. In such cases, the product has to be assigned to the lower Class (i.e. there is no Class 3R available and after Class 1M follows immediately Class 3B).
Note: the above transformation factors and conclusions are valid for the unchanged spatial emission characteristics (according to the data sheets) of the laser diodes only.

Safe viewing distance

Sometimes the rather low limits will not satisfy the required system performance and a classification above Class 1M will be necessary. Depending on the actual mounting and set up constellation the hazard for an unintentional viewer should be checked and minimized also in these cases. Due to the beam divergence the irradiance strongly decreases with the distance from the source ("inverse square law"). The minimum safe viewing distance (or NOHD: Nominal Ocular Hazard Distance) represents that range at which under ideal conditions the irradiance (or the radiant exposure) fall below the appropriate MPE. If the limits of Class 1M are exceeded, the following formula may be used to determine the applicable NOHD:

$$NOHD_{LD} = \sqrt{\frac{P}{\pi \cdot \sin\alpha \cdot \sin\beta \cdot MPE}}$$

where:
P = total emitted radiation (pulse) power
and = (half)angles of beam divergence (parallel and perpendicular) in deg.
MPE = the applicable most restrictive (pulse) MPE according to the above mentioned pulse requirements – determined in the same way

Note: The MPE (in $W/m^2$) may be determined also from Fig. 1: by dividing the Class 1/1M AEL (in mW) with 3.9 x $10^{-2}$ (represents the size of the measurement aperture).

Note: if it is reasonably foreseeable that viewing aids (such as binoculars, telescopes etc.) will be used within the laser range, it is necessary to extend the NOHD to account for the increase in radiation entering the eye (see examples in Annex A of IEC 60825-1).

<u>Extended sources</u>

As mentioned, the above calculations consider the (bare) laser diodes as so called point sources (worst case). For specific applications, the laser may be covered by windows, optics or lenses which include somewhat scattering material (diffusers). If the resulting source subtends an angle of more than 1,5 mrad in a viewers eye (i.e. diameter containing 63% of total power: >150 µm from a viewing distance of 100 mm), the source can be considered to be (intermediate) extended. In these cases the applicable AEL can be increased by a factor $C_6$ (= /1,5, where: the angular subtense of the source in mrad) and also the applicable measurement distance r for classes 1 and 3R increases by the following formula:

$$r = 100\sqrt{\frac{\alpha + 0,46}{\alpha}}$$

The particular angular subtense has to be determined in detail. However, both effects lead to considerable relaxation.

**Remark**
Generally, classifications shall be made under each and every reasonable foreseeable single fault consideration. This includes also component or software failures.
In order to ensure the classified conditions, adequate reliability of the electronic driving circuits and a redundant prevention of increased emission under fault conditions should be established.

**Annex: Manufacturing requirements and Labeling (according to IEC 60825-1)**

Each <u>Class 1</u> laser product shall have affixed an explanatory label (Fig. 2) bearing the words:

CLASS 1 LASER PRODUCT

Each <u>Class 1M</u> laser product shall have affixed an explanatory label (Fig. 2) bearing the words:

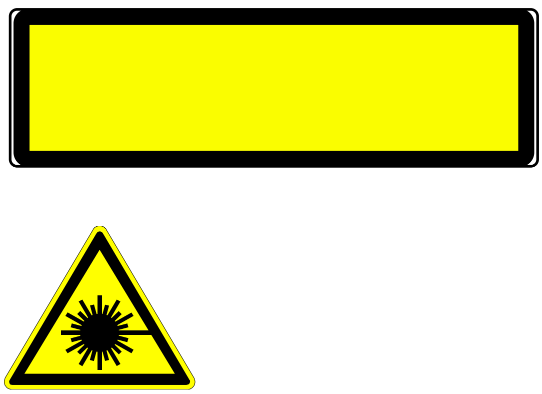
INVISIBLE LASER RADIATION
DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS (MAGNIFIERS)
CLASS 1M LASER PRODUCT
P = X mW; $t_P$ = XX s, =XXX nm; IEC 60825-1:1993+A2:2001

Where: P : maximum output of laser radiation, $t_P$: the pulse duration (if appropriate) and : the emitted wavelength(s).

**Instead of the above labels, at the discretion of the manufacturer, the same statements may be included in the information for the user.**

Each <u>Class 3B</u> laser product shall have affixed a warning label (Fig. 3) and an explanatory label (Fig. 2) bearing the words:
INVISIBLE LASER RADIATION
AVOID EXPOSURE TO BEAM
CLASS 3B LASER PRODUCT
P = X mW; $t_P$ = XX s, =XXX nm; IEC 60825-1:1993+A2:2001

Fig. 2 and 3: explanatory and warning label:



The following table (D2 of IEC 60825-1) contains a summary of manufacturer's requirements:

| **Requirements Subclause** | **Classification** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Class 1** | **Class 1M** | **Class 2** | **Class 2M** | **Class 3R** | **Class 3B** | **Class 4** |
| Description of hazard class 8.2 | Safe under reasonably foreseeable conditions | As for Class 1 except may be hazardous if user employs optics | Low power; eye protection normally afforded by aversion responses | As for Class 2 except may be more hazardous if user employs optics | Direct intrabeam viewing may be hazardous | Direct intrabeam viewing normally hazardous | High power; diffuse reflections may be hazardous |
| Safety interlock in protective housing 4.2 & 4.3 | Designed to prevent removal of the panel until accessible emission values are below that for Class 3R | | | | Designed to prevent removal of the panel until accessible emission values are below that for Class 3B | | |
| Remote control 4.4 | Not required | | | | | Permits easy addition of external interlock in laser installation | |
| Key control 4.5 | Not required | | | | | Laser inoperative when key is removed | |
| Emission warning device 4.6 | Not required | | | | Gives audible or visible warning when laser is switched on or if capacitor bank of pulsed laser is being charged. For Class 3R only applies if invisible radiation is emitted | | |
| Attenuator 4.7 | Not required | | | | | Gives means besides the On/Off switch to temporarily block beam | |
| Location controls 4.8 | Not required | | | | Controls so located that there is no danger of exposure to AEL above Classes 1 or 2 when adjustments are made | | |
| Viewing optics 4.9 | Emission from all viewing systems must be below Class 1M AEL as applicable | | | | | | |
| Class label 5.1 to 5.6 | Required wording | | Figures 2 and 3 and required wording | | | | |
| Aperture label 5.7 | Not required | | | | Specified wording required | | |
| Service entry label 5.9.1 | Required as appropriate to the class of accessible radiation | | | | | | |
| Override interlock label 5.9.2 | Required under certain conditions as appropriate to the class of laser used | | | | | | |
| Wavelength range label 5.10 & 5.11 | Required for certain wavelength ranges | | | | | | |
| User information 6.1 | Operation manuals must contain instructions for safe use. Additional requirements apply for Class 1M and Class 2M | | | | | | |
| Purchasing and service information 6.2 | Promotion brochures must specify product classification; service manuals must contain safety information | | | | | | |

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