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Eye safety of IREDs used in lamp applications

Application Note

Valid for:
IR LEDs (IREDs) from OSRAM Opto Semiconductors

Abstract

This application note describes the possible hazards of infrared LEDs (IREDs) used for lamp applications with respect to the IEC-62471 standard and how to classify IREDs according to different risk groups.

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A. General information

As the radiated optical power of light emitting diodes (LEDs) has increased in recent years, the issue of eye safety has received an ever-increasing amount of attention. Within this context there has been much discussion about the right safety standard — either the laser standard IEC-60825 [2] or the lamp safety standard IEC-62471 [1] — to apply to the classification of LEDs. Before mid 2006 all LED applications were covered by the IEC-60825. Today most of the LED applications are covered by the lamp standard. Other than lasers, lamps are only generally defined in this standard as sources made to produce optical radiation. Lamp devices may also contain optical components such as lenses or reflectors. Examples are lensed LEDs or reflector type lamps which may include lens covers as well. The status quo is, that for different applications of LEDs, such as data transmission or irradiation of objects, different standards have to be used:

- Data transmission → IEC-60825
- Lamp applications → IEC-62471

Both safety standards do not cover general exposure scenarios and are not legally binding. However, the presented methods and limit calculations are used as a basis in regional guidelines, e.g. in the European Directive 2006/25/EC [3], which describes “the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation)”.

Within this application note a general survey of the different hazards of IR-A radiation (780 — 1400 nm) and the basics of calculating the exposure limits are described. The different risk groups for lamp classification are introduced, and three example calculations are presented to show how to do the calculations.

This application note focuses on the IR-A range. Further photochemical hazards, e.g. by ultraviolet or blue radiation, are not considered. Only the main issues of the standard are explained and simplifications are made. The application note gives guidance to classify applications that use IR emitting components regarding eye safety.

OSRAM Opto Semiconductors gives assistance to the best of its knowledge, but does not guarantee that every hazard of any application is described by the information given in this text.

The eye safety classification of the final product, using IREDs, is the responsibility of the manufacturer.

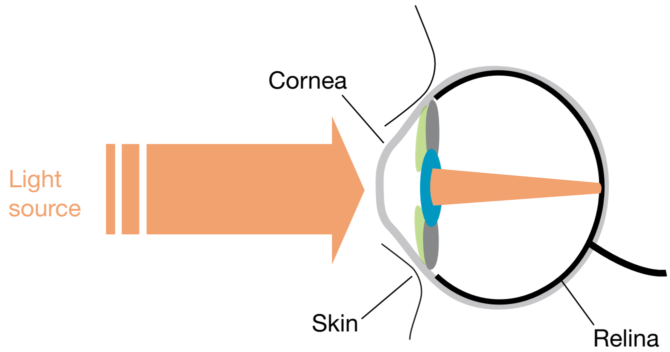
In case you need help with the radiation safety certification of your application according to the latest available standards, please contact test houses that are accredited for offering such a consulting service.

Hazard exposure limits

When irradiating the human body with intense infrared light over a defined period of time, different tissues (such as skin or retina, see Figure 1) are affected in different ways. That is why three distinct exposure limits are given in the IEC-62471 standard for IR-A radiation:

1. Infrared radiation hazard exposure limits for the eye (cornea)
2. Thermal hazard exposure limit for skin ($t < 10$ s)
3. Retinal thermal hazard exposure limit

Figure 1: Cross section of the human eye under irradiation



Damage by IR-A radiation is caused primarily by the overheating of the irradiated tissue, resulting in the destruction of cells. This can cause, for example, a permanent vision handicap. The irradiation limits of skin and cornea can be calculated in a quite simple way.

Exposure limits for the cornea

The maximum allowed irradiance E_{IR} ($E_{e,max}$) of the cornea for different time scales of exposure is defined as given below:

For exposure times t ≤ 1000 s the limit is depending on the exposure time itself

$$E_{IR} = \sum_{\lambda = 780}^{3000} E_\lambda \cdot \Delta\lambda \leq 18000 \cdot t^{-(0,75)} \; [W \cdot m^{-2}] \qquad (1)$$

For exposure times t > 1000 s a fixed value is used:

$$E_{IR} = \sum_{\lambda = 780}^{3000} E_\lambda \cdot \Delta\lambda \leq 100 \; [W \cdot m^{-2}] \qquad (2)$$

, where E_λ is the spectral irradiance in W/m²/nm, Δλ given in nm and t in seconds.[1]

For cold environments, the limit for t > 1000 s is increased to 400 W/m^2 at 0 °C and 300 W/m^2 at 10 °C.

The irradiance E_e can be calculated from the radiant intensity I_e and distance d (in the far field) using the inverse square law

$$E_e = \frac{I_e}{d^2} \qquad (3)$$

Example calculation for SFH 4770S . using data sheet values, distance source to eye d = 0.1 m, t > 1000 s, $I_{F\ max,\ DC}$= 1.5 A, $I_{e,typ}$ (1.5A) = 560 mW/sr, T_a = 25 °C:

1. Note that the term on the right side of equation (1) has the appropriate unit to satisfy E_{IR} in W/m^2. The same applies for the terms in the following equations. This is the same notation as used in IEC 62471.

The limit calculation for t > 1000 s is done by equation (2):

Exposure limit (EL) is 100 W/m².

For actual exposure values the irradiance E_e according equation (3) is 0.56 W sr/(0.1 m)² = 56 W/m², which is below the limit.

Exposure limits for skin

A similar equation can be used for the irradiance skin limit:

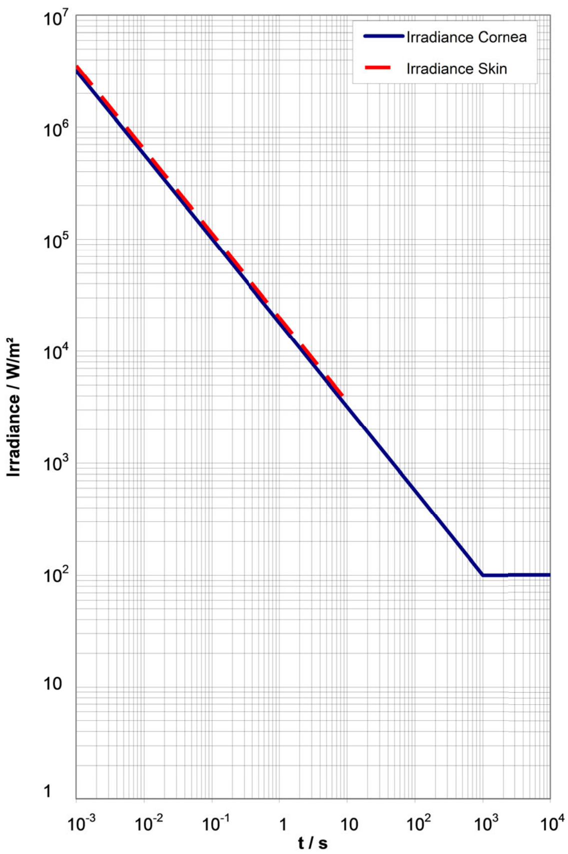
$$E_H = \sum_{\lambda = 380}^{3000} E_\lambda \cdot \Delta\lambda \leq 20000 \cdot t^{-(0,75)} \quad [W \cdot m^{-2}] \tag{4}$$

, where E_λ is the spectral irradiance in W/m²/nm, Δλ given in nm and t in seconds.

For exposure times of more than ten seconds, acute pain occurs before the skin can be damaged. In Figure 2 the respective limit curves are shown. The shorter the light pulse, the higher the possible irradiance can be.

The diagram indicates that for skin the maximum irradiance limit is slightly higher than for the cornea. Therefore, the cornea limit can be taken for worst case considerations.

Figure 2: Irradance exposure limits as a function of time



Exposure limits for the retina

When determining the limits of the retina, the pupil diameter, source size of the emitter and the emitted wavelength are important parameters.

For IR-A light the visual stimulus of the eye is very low. That means that the aversion response, which normally protects the eye from excessive continuous irradiation (for times greater than 0.25 s), does not work. As there is no trigger of the iris contraction, we have to calculate with the full 7 mm pupil diameter that collects the light.

The apparent light source is focused by the cornea and the lens onto the retina, and defines the irradiated area which is thermally stressed. Therefore, the angular subtense α of the light source is correlated with the focus area. Due to physical limitations and movements of the eye, an effective $\alpha_{min,eff}$ is defined as a lower limit (as a function of exposure time). The upper limit α_{max} is always 0.1 radians (no spot-size variation on the retina considered for extended sources, see Table 1). Calculation of angular subtense α at a viewing distance d for a mean source extension Z:

$$\alpha = \frac{Z}{d} \tag{5}$$

with $$Z = \frac{(l + w)}{2} \tag{6}$$ [2]

, where l is the length and w the width of the active area of the light source.

For radiance measurements (see appendix) the min/max limits of the acceptance angle γ_{FOV} have to be used as shown in Table 1.

Table 1: Limits of the angular subtense α and measurement field of view γ_{FOV} for the different time ranges

Time range	$\alpha_{min,eff}$, $\gamma_{FOV,min}$	$\alpha_{max,eff}$, $\gamma_{FOV,max}$
t ≤ 0.25 s	0.0017 rad	0.1 rad
0.25 s < t < 10 s	$0{,}0017 \cdot \sqrt{\frac{t}{0{,}25}}$ rad	0.1 rad
t ≥ 10 s	0.011 rad	0.1 rad

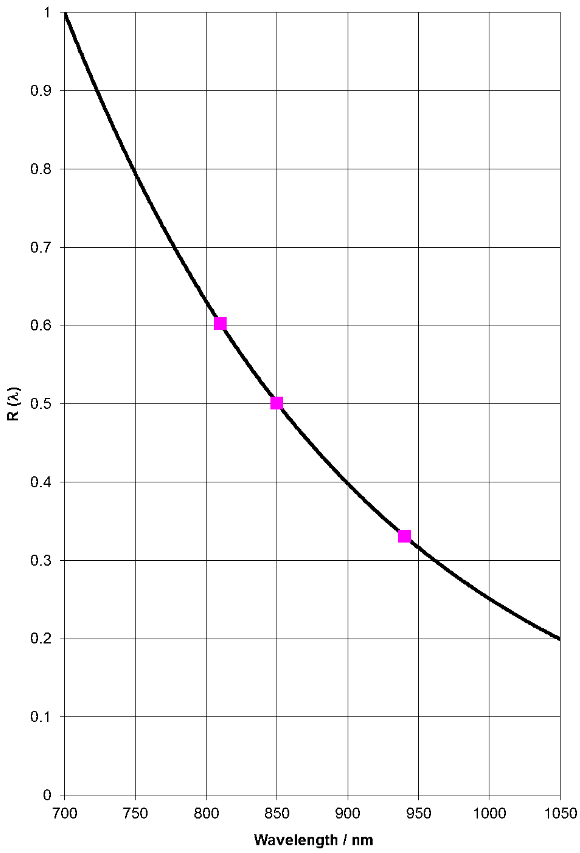
The thermal stress is dependent on the wavelength as well. The so-called burn hazard weighting function is defined as:

$$R(\lambda) = 10^{\left[\frac{(700-\lambda)}{500}\right]} \tag{7}$$

2. For an estimation of the virtual apparent source please have a look at the Law of Conservation of the Radiance (IEC 62471-2) in the appendix.

, with the wavelength λ in nm from 700 — 1050 nm is shown in Figure 3. The hazard decays with increasing wavelength.

Figure 3: Burn hazard weighting function R(λ)



Putting everything together the retinal thermal hazard exposure limit (EL) for the burn hazard weighted radiance L_R for exposure times below 10 s, which is also valid for the visible spectral region, is defined as:

λ = 380 — 1400 nm (t = 10 µs ...10 s)

$$L_R = \sum_{\lambda = 380}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \leq \frac{50000}{\alpha \cdot t^{0,25}} \quad [W \cdot m^{-2} \cdot sr^{-1}] \tag{8}$$

L_λ is the spectral radiance in W/m²/nm/sr, use numerical value of α in rad and t in seconds.

For longer exposure times we have to distinguish between the visible range (strong visual stimulus of the human eye) and the near infrared range (weak visual stimulus).

The near infrared burn hazard weighted radiance L_{IR} (for weak visual stimulus) is limited to

λ = 780 — 1400 (t > 10 s)

$$L_{IR} = \sum_{\lambda = 780}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \leq \frac{6000}{\alpha} \quad [W \cdot m^{-2} \cdot sr^{-1}] \quad (t > 10s) \tag{9}$$

L_λ is the spectral radiance in W/m^2/nm/sr, use numerical value of α in rad and t in seconds.

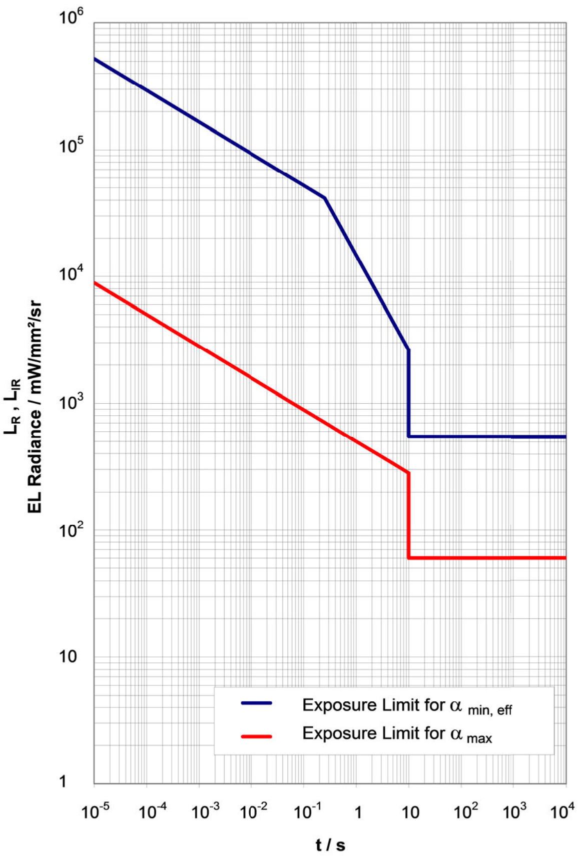
In good approximation one can use:

$$L_{IR} \approx I_e \cdot \frac{R(\lambda)}{((l + w)/2)^2} \qquad (10)$$

to calculate the radiance L_{IR} from data sheet values.

The calculated radiance exposure limits (for the possible extreme angular subtenses α as a function of the exposure time are shown in Figure 4. The description of a measurement method to obtain the radiance of the emitted radiation can be found in the appendix.

Figure 4: Exposure limits (EL) over irradiation time t



Example values for SYNIOS® SFH 4770S (850 nm):

$I_{F\,max,\,DC}$ = 1.5 A, $I_{e,typ}$ (1.5 A) = 560 mW/sr, die size 1 x 1 mm², distance d = 200 mm, t = 100 s, T_a = 25 °C using data sheet values:

Table 2: Example values for the SFH 4770S

	SFH 4770S	
Die size l x w [mm^2]	1 x 1	data sheet
$\alpha < \alpha_{min\ eff}$ [rad]	0.005	acc. (5)
$\alpha_{min\ eff}$ ($t \geq 10$ s) [rad]	0.011	acc. Table 1
λ [nm]	850	data sheet
R(λ)	~ 0.5	acc. (7)
L_{IR} [$mW/mm^2/sr$]	~ 280[1]	acc. (9)
L_{IR} [$mW/mm^2/sr$]	280[2]	acc. (10)
Exposure limit for L_{IR} [$mW/mm^2/sr$]	545.5	acc. (9)

[1] calculated from real spectral data

[2] calculated using $L_{IR} \approx I_e \cdot R(\lambda)/((l+w)/2)^2 = 560\ mW/sr \cdot 0.50/1\ mm^2 = 280\ mW/mm^2/sr$

For simplification and as a worst case scenario the total Ie of the part is assumed to be direct radiation from the die.

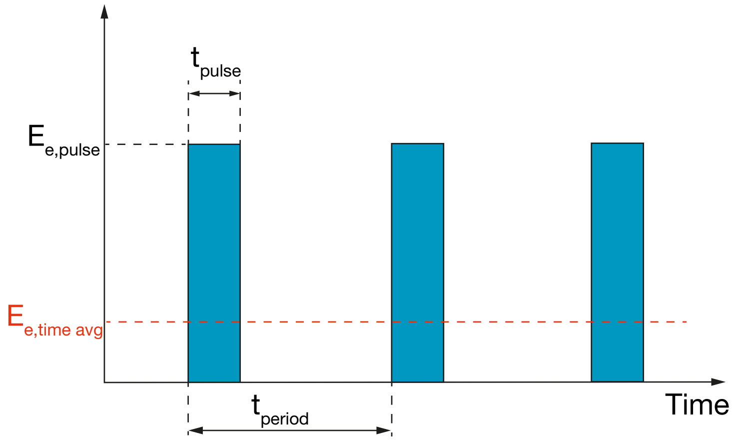
B. Pulsed lamps

For repetitively pulsed lamps the weighted radiant exposure ($t_{avg,max} = 0.25$ s) shall be compared with the continuous wave exposure limits (EL) by using the time averaged values (see Figure 5) of the pulsed emission as long as E_e of the single pulse does not exceed any limit on its own.

$$E_{e,\ time,avg} = E_{e,\ pulse} \cdot D = E_{e,\ pulse} \cdot \frac{t_{pulse}}{t_{period}} \qquad (11)$$

, whereby D is the duty cycle.

Figure 5: Schematic of time averaged E_e



Lamp risk groups

According to IEC-62471-1 [1] the hazard values are reported at a fixed distance d = 200 mm. The emission limits for the risk groups are defined as (α given in rad):

- **Exempt group (no hazard)**
  $L_R \leq 28000/\alpha$ [W/m²/sr] within 10 s, acc. (8)
  L_{IR} (low vis stimulus) $\leq 6000/\alpha$ [W/m²/sr] within 1000 s — for retina
  $E_{IR} \leq 100$ [W/m²] within 1000 s — for cornea
- **Risk Group 1 (low risk)**
  $L_R \leq 28000/\alpha$ [W/m²/sr] within 10 s
  L_{IR} (low vis stimulus) $\leq 6000/\alpha$ [W/m²/sr] within 100 s
  $E_{IR} \leq 570$ [W/m²] within 100 s
- **Risk Group 2 (moderate risk)**
  $L_R \leq 71000/\alpha$ [W/m²/sr] within 0.25 s
  L_{IR} (low vis stimulus) $\leq 6000/\alpha$ [W/m²/sr] within 10 s
  $E_{IR} \leq 3200$ [W/m²] within 10 s
- **Risk Group 3 (high risk)**
  One of the limits of Risk Group 2 is exceeded.

The labeling of the classified IR products is described in the second part of the safety standard IEC-62471-2 [4] as follows:

Table 3: Labeling of the classified IR products according to IEC-62471-2 [4]

Hazard	Exempt risk group	Risk Group 1	Risk Group 2	Risk Group 3
Cornea/lens infrared hazard 780 —3000 nm	Not required	NOTICE IR emitted from this product	CAUTION IR emitted from this product	WARNING IR emitted from this product
Retinal thermal hazard, weak visual stimulus 780 — 1400 nm	Not required	WARNING IR emitted from this product	WARNING IR emitted from this product	WARNING IR emitted from this product

Example 1 (SYNIOS®)

Array of 10 x SFH 4770S (SYNIOS® package), DC operation at I_F = 1 A for irradiation purpose. Die size = 1x1 mm², 850 nm, t > 1000 s, $I_{e,typ}(T_a$ = 25 °C) = 370 mW/sr, minimum distance to user r > 0.5 m in application.

Lamp classification (d = 0.2 m).

- Cornea hazard

Emission limit (EL) calculation. Assuming ideal overlap of radiation characteristics of 10 x SFH 4770S (worst case).

=> total I_e = 3.7 W/sr

Based on (3):

$\mathbf{E_e}$ = I_e/d^2 = 3.7 W/sr /(0.2 m)²

= **92.5 W/m²**

< $\mathbf{E_{IR}}$ = 100 W/m² (EL).

Note: E_e depends on the number of IREDs. Exposure limit would be reached when using 11 SFH 4770S @ I_F = 1 A with ideal overlap.

- Retinal Hazard

Calculation of the emission limit (EL). The angular subtense α is calculated according to (5) and (6):

α = Z/d = 1 mm/200 mm = 0.005 rad, with Z = (l+w)/2 = (1 mm + 1 mm)/2 = 1 mm

According to Table 1 with t = 1000 s

=> α_{eff} = 0.011 rad.

Based on (9) the Emission limit (EL) for the radiance is

$\mathbf{L_{IR}}$ = 6000 / α_{eff} = **545.5 mW/mm²/sr**

Calculation of actual value L_{IR} based on example data:

$R(\lambda = 850\ nm) = 0.50$ (Figure 3)

$\mathbf{L_{IR}} = I_e \cdot R(\lambda) / ((l+w)/2)^2$ acc. (10)
$= 370\ mW/sr \cdot 0.50/(1\ mm)^2$
= 185 mW/mm²/sr
<< 545.5 mW/mm²/sr (EL)

Summary: Limits of L_{IR} and E_{IR} are not exceeded within 1000 s.
=> Exempt group (no risk)

Actual exposure scenario in example 1 with distance r > 0.5 m:
$E_e = I_e/d^2 = 3.7\ W/sr / (0.5\ m)^2$
= 14.8 W/m²

Example 2 (OSLON® Black):

Arrangement of 5 x SFH 4715AS (OSLON Black® package), DC operation at $I_F = 1$ A for irradiation purpose. Die size for one OSLON Black (1 x 1) mm², 850 nm, t > 1000 s, $I_{e,typ}$ ($T_a = 25$ °C) = 780 mW/sr @ $I_F = 1$ A, min. distance to user r > 1 m in application.

Lamp classification (d = 0.2 m).

- Cornea hazard

Emission limit (EL) calculation: Assuming ideal overlap of radiation characteristics of 5 x SFH 4715AS (worst case).
=> total $I_e = 3.9$ W/sr

Based on (3)

$\mathbf{E_e} = I_e/d^2 = 3.9\ W/sr / (0.2\ m)^2$
= 97.5 W/m²
< $\mathbf{E_{IR}}$ **= 100 W/m²** (EL).

Note: E_e depends on the number of IREDs, limit would be exceeded when using more than 5 SFH 4715AS @ $I_F = 1$ A with ideal overlap.

- Retinal hazard

Calculation of the emission limit (EL): The angular subtense α is calculated according to (5) and (6) for the SFH 4715AS package. Using l_{LED} x w_{LED} = 1.3 mm x 1.3 mm (example from appendix).

$\alpha = Z/d = 1.3\ mm/200\ mm = 0.0065$ rad, with $Z = (l+w)/2 = (1.3\ mm + 1.3\ mm)/2 = 1.3\ mm$
=> $\alpha_{eff} = 0.011$ rad (t = 1000 s) (according to Table 1)

Based on (9) the emission limit (EL) for the radiance is:
$\mathbf{L_{IR}} = 6000 / \alpha_{eff} =$ **545.5 mW/mm²/sr**

Calculation of actual value L_{IR} based on example data:

R(λ=850 nm) = 0.50 (Figure 3)

$\mathbf{L_{IR}} = I_e \cdot R(\lambda) / ((l+w)/2)^2$ according to (10)
= 780 mW/sr · 0.50 / (1.3 mm + 1.3 mm/2)²
= **230 mW/mm²/sr**
<< 545.5 mW/mm²/sr (EL)

Summary: Limits of L_{IR} and E_{IR} are not exceeded within 1000 s.
=> Exempt group (no risk)

Actual exposure scenario in example 2 with distance r > 1 m:
$E_e = I_e / d^2$ = 3.9 W/sr / (1 m)²
= **3.9 W/m²**

Example 3 (Power TOPLED®)

Array of 20 x SFH 4240 (Power TOPLED® package), pulsed operation at $I_{F,\ pulse}$ = 0.6 A, t_p = 100 µs, dutycycle D = 0.1 for irradiation purpose, minimum distance to user r > 0.5 m in application. Die size: (0.3 x 0.3) mm², 940 nm, t > 1000 s. From data sheet: $I_{e,max}(T_a$ = 25°C, I_F = 0.6 A) = 32 mW/sr · 5[3] = 160 mW/sr

Lamp classification (d= 0.2 m).

- Cornea Hazard

Assuming an ideal overlap of radiation characteristics of the twenty SFH 4240 (worst case).
=> I_e total = 20 x 160 mW/sr = 3.2 W/sr

Based on (3)

$\mathbf{E_e} = I_e / d^2 \cdot D$ = 3.2 W/sr/(0.2 m)² · 0 .1
= **8 W/m²**
<< $\mathbf{E_{IR}}$ = 100 W/m² (EL).

Note: E_e depends on the number of IREDs, limit would be reached when using 250 SFH 4240 under the given conditions.

- Retinal Hazard

The angular subtense α is calculated according to (5) and (6) for the chip in the Power TOPLED® package:

α(d = 200 mm) = 0.3 mm / 200 mm = 0.0015 rad
=> α_{eff} (t_p = 100 µs) = 0.0017 rad (according to Table 1)
=> α_{eff} (t_p = 1000 s) = 0.011 rad (according to Table 1)

3. Factor 5 from data sheet diagram I_e/I_e (100 mA).

Emission limit calculation for the burn hazard weighted radiance L_R according to (8):

E_L for L_R = 50000 / [α_{eff} · (100 · $10^{-6})^{0.25}$]
(Single Pulse) = 2.94 · 10^5 mW/mm²/sr

Emission limit calculation for the burn hazard weighted radiance L_{IR} (low visible stimulus) according to (9):

E_L for L_{IR} = 6000 / α_{eff}
= 545.5 mW/mm²/sr

Calculation of actual value L_R and L_{IR} based on example data:

R(λ = 940 nm) = 0.33
L_{IR} (t = 100 µs) = I_e· R(λ)/Z² acc. (10)
(Single Pulse) = 160 mW/sr · 0.33/(0.3 mm)²
= **586.7 mW/mm²/sr**
<< 2.94 · 105 mW/mm²/sr (EL)

L_{IR} (t = 1000 s) = I_e · R(λ)/Z² · D
=160 mW/sr · 0.33 / (0.3 mm)² · 0.1
= **58.7 mW/mm²/sr**
<< 545.5 mW/mm²/sr (EL)

Summary: Limits of L_{IR} and E_{IR} are not exceeded within 1000 s.
=> Exempt group (no risk)

Actual exposure scenario in example 3 with distance r > 0.5 m:
E_e = I_e / d² · D = 3.2 W/sr/(0.5 m)² · 0.1
= **1.28 W/m²**

C. Glossary

- α: Angular subtense [rad]
- EL: Exposure limit (for exposure time t > 0.01 ms — 8 h) Exposure level which is expected to cause no damage to eye or skin.
- E_e = dΦ/dA: Irradiance [W/m^2] (weak visual stimulus for L_v < 10 cd/m^2)
- L_λ: Spectral radiance [W/m^2/nm/sr]
- L_R: Burn hazard weighted radiance [W/m^2/nm/sr]
- L_{IR}: Near infrared radiance [W/m^2/nm/sr]
- L_V: Luminance [cd/m^2]

- $H = \int_{\Delta t} (E \cdot dt)$: Radiant exposure [J/m^2]
- Φ: Optical power [W]

D. References

[1] IEC 62471:2006 / CIE S 009 / E:2002, Photobiological safety of lamps and lamp systems.

[2] IEC 60825-1:2007, Safety of laser products — Part1: Equipment classification and requirement.

[3] Directive 2006/25/EC, Official Journal ofthe European Union, 27.04.2006.

[4] IEC/TR 62471-2 Ed. 1.0, Photobiological safety of lamps and lamp systems — Part 2: Guidance on manufacturing requirements relating to non-laser optical radiation safety, 08/2009.

Further information:

[5] “LED-Strahlung: Mögliche fotobiologische Gefährdungen und Sicherheitsvorschriften, Teil 1“, Werner Horak, Strahlenschutzpraxis 03/2008, pp. 56-63.

[6] “LED-Strahlung: Mögliche fotobiologische Gefährdungen und Sicherheitsvorschriften, Teil 2“, Werner Horak, Strahlenschutzpraxis 04/2008, pp. 40-46.

E. Appendix

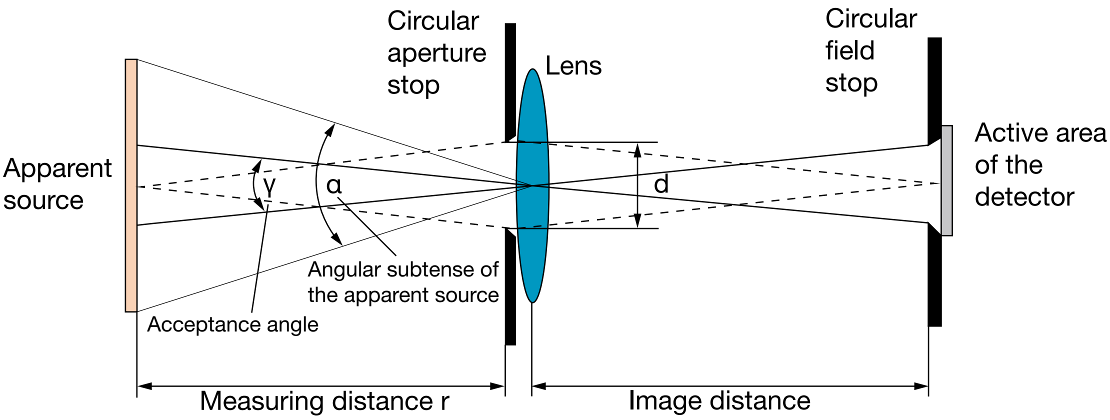
Measurement of radiance

A possible setup to measure the radiance L is shown in Figure 6. The radiant power Φ, that passes through a defined aperture stop at a defined distance r is measured with a detector at the image distance (the field stop aperture in front of the detector defines the acceptance angle γ_{FOV}). The diameter d of the aperture (with a minimum size of 7 mm) defines the solid collection angle Ω (sr) and the measurement area A_{FOV}.

The radiance can be calculated as follows:

$$L = \frac{\Phi}{\Omega \cdot A_{FOV}} \qquad [W/m^2/(sr)]$$

Figure 6: Typical setup to measure the radiance of a light source



F. Law of conservation of the radiance

The ratio of the real chip area A_{Chip} and the projected area A_{LED} equals to the related radiant intensities of the original I_{Chip} and the modified I_{LED}. [4]

$$\frac{A_{Chip}}{A_{LED}} = \frac{I_{Chip}}{I_{LED}}$$

This formula can be used as a first approximation for corrections or the determination of the apparent source size. If you need a more accurate result then you need to do a measurement.

Example 4:

SFH 4715AS with die size: (1 x 1) mm², I_{LED} = 780 mW/sr and Φ_{Chip} = 1340 mW from data sheet.

$A_{Chip} = L_{Chip} \times W_{Chip}$ =1 mm x 1 mm = 1 mm^2

$I_{Chip} = \Phi_e$ Chip / π = 427 mW/sr (as the chip of SFH 4715AS is a Lambertian radiator)

$A_{LED} = A_{Chip} \times I_{LED}/I_{Chip}$ = 1 mm^2 x 780 mW/sr / 427 mW/sr = 1.8 mm^2

$A_{LED} = (L_{LED})^2$ (square geometry)

$$L_{LED} = \sqrt{A_{LED}} = \sqrt{1.8\ \text{mm}^2} = 1.3\ \text{mm}$$

Don't forget: LED Light for you is your place to be whenever you are looking for information or worldwide partners for your LED Lighting project.

www.ledlightforyou.com

ABOUT OSRAM OPTO SEMICONDUCTORS

OSRAM, Munich, Germany is one of the two leading light manufacturers in the world. Its subsidiary, OSRAM Opto Semiconductors GmbH in Regensburg (Germany), offers its customers solutions based on semiconductor technology for lighting, sensor and visualization applications. OSRAM Opto Semiconductors has production sites in Regensburg (Germany), Penang (Malaysia) and Wuxi (China). Its headquarters for North America is in Sunnyvale (USA), and for Asia in Hong Kong. OSRAM Opto Semiconductors also has sales offices throughout the world. For more information go to www.osram-os.com.

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