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TECHNICAL REPORT

colour inside

Fibre optic active components and devices – Test and measurement procedures – Part 7: Calculation methodology of laser safety class for optical transceivers and transmitters

IEC TR 62150-7:2024-09(en)

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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FIBRE OPTIC ACTIVE COMPONENTS AND DEVICES – TEST AND MEASUREMENT PROCEDURES –

Part 7: Calculation methodology of laser safety class for optical transceivers and transmitters

FOREWORD

IEC TR 62150-7 has been prepared by subcommittee 86C: Fibre optic active components and devices, of IEC technical committee 86: Fibre optics. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
86C/1934/DTR	86C/1940/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62150 series, published under the general title *Fibre optic active components and devices – Test and measurement procedures*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

Laser safety criteria calculations for optical transceivers and transmitters are defined in IEC 60825-1. However, the calculation methodology in IEC 60825-1 is complicated and covers a wide range of laser products. This document provides simple calculation guidelines that are tailored to transceiver and transmitter products for fibre optic telecommunication systems.

The intent of this document is to resolve possible confusion on how to handle the specifications in IEC 60825-2, which define safety criteria for Optical Fibre Communication Systems (OFCSs). In IEC 60825-1 the safety categories are called "Class n", but in IEC 60825-2 they are called "Hazard level n". As single units that are not connected to an OFCS, optical transceivers and transmitters are components, for which the specifications of IEC 60825-1 are applicable, that is the safety categories "Class n". However, when optical transceivers and transmitters are integrated in (i.e. connected to) an Optical Fibre Communication System, the specifications of IEC 60825-2 apply, which uses the safety categories "Hazard level n". Hence, when the power levels in an OFCS are examined, the "Hazard level n" categories of IEC 60825-2 apply. For the same number n, the power limits of "Hazard level n" are usually lower than the power limits of "Class n". The fact that the power limits for "Class n" and "Hazard level n" are sometimes different causes considerable confusion in the industry. This document therefore also includes Hazard level calculations, which are provided in informative Annex A.

FIBRE OPTIC ACTIVE COMPONENTS AND DEVICES – TEST AND MEASUREMENT PROCEDURES –

Part 7: Calculation methodology of laser safety class for optical transceivers and transmitters

1 Scope

This part of IEC TR 62150, which is a technical report, provides simple calculation guidelines for the laser safety class of optical transceivers and transmitters, whose baseline standard is IEC 60825-1. The calculation methodology for Class 1 and Class 1M safety levels is the main scope of this document, because most of optical transceivers and transmitters are specified for these classifications. The calculations and classifications in this document follow IEC 60825-1, which specifically advises that laser safety classifications be based on tests that consider any reasonably foreseeable single-fault condition in the application of a transceiver or transmitter. More information can be found in IEC 60825-1:2014, 5.1.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60825-1:2014, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 60825-2, *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCSs)*

NOTE IEC 60825-2:2021 refers to IEC 60825-1:2014 as a normative reference.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60825-1 and IEC 60825-2 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

4 Calculation methodology

4.1 General

Optical transceivers and transmitters are categorized as optical components, for which the laser safety specifications are defined in IEC 60825-1. However, when the power levels in an optical fibre communication system (OFCS) are considered, into which the transceivers or transmitters are integrated, the safety specifications for OFCSs apply, which are defined in IEC 60825-2. Both standards are important for transceiver and transmitter laser safety specifications, depending on the application.

4.2 Wavelength

In IEC 60825-1 and IEC 60825-2, laser wavelengths are categorized into several ranges, as shown in Table 1, for which important parameters, such as the measurement conditions, the Accessible Emission Limits (AELs) for Class 1 and Class 1M, and the coefficients C_4, C_6 and C_7, are defined differently. The wavelength dependence of these parameters reflects the fact that the effects causing physical damage are wavelength dependent.

Table 1 – Laser wavelength categorization for each specific parameter

<table>
<tr><th>Wavelength range
nm</th><th>Condition 1, 2, 3</th><th>AEL for Class 1 / 1M</th><th>AEL for Class 1 / 1M (extended)</th><th>C_4</th><th>C_6</th><th>C_7</th></tr>
<tr><td>700 to 1 050</td><td rowspan="4">✓</td><td rowspan="4">✓</td><td>✓</td><td>✓</td><td rowspan="4">✓</td><td rowspan="2">✓</td></tr>
<tr><td>1 050 to 1 150</td><td rowspan="3">✓</td><td rowspan="3">✓</td></tr>
<tr><td>1 150 to 1 200</td><td>✓</td></tr>
<tr><td>1 200 to 1 400</td><td>✓</td></tr>
<tr><td>1 400 to 4 000</td><td>✓</td><td>✓</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Reference document</td><td>IEC 60825-2:2021 Table 4

IEC 60825-1:2014 Table 10</td><td>IEC 60825-1:2014 Table 3</td><td>IEC 60825-1:2014 Table 4</td><td colspan="3">IEC 60825-1:2014 Table 9</td></tr>
</table>

When considering optical transceivers for fibre optic telecommunication systems, three wavelength ranges are of utmost importance. These wavelength ranges are shown in Table 2. In this document, a case study for these three wavelength ranges is provided to simplify laser class calculations.

Table 2 – Wavelength ranges for fibre optic telecommunication systems

Wavelength range nm	Optical modulation format	Fibre
700 to 1 050	Intensity modulation (on-off keying)	Multimode fibre (MMF)
1 200 to 1 400	Intensity modulation (on-off keying) Coherent modulation (phase-shift keying)	Single-mode fibre (SMF)
1 400 to 4 000	Intensity modulation (on-off keying) Coherent modulation (phase-shift keying)	Single-mode fibre (SMF)

4.3 Time base

In IEC 60825-1 and IEC 60825-2, the time base of exposure is one of the principal parameters for laser class calculations, as shown in IEC 60825-1:2014, Table 3 and Table 4. In the case of optical transceivers and transmitters for fibre optic communication systems, the power of on-off-keyed optical signals varies randomly with time but at relatively high speed, whereas the power of phase-shift-keyed signals, which are often used in coherent transmission systems, is quasi-continuous. In this document, a time base of more than 100 s is assumed for Table 3 and Table 4 in IEC 60825-1:2014 to simplify the calculations, considering actual laser product emission duration.

4.4 Hazard for eye and skin

In case of calculating laser safety specifications, the hazards for eye and skin are both considered to satisfy the laser safety conditions.

4.5 Class categories

IEC 60825-1 specifies eight levels of safety categories for laser products, which are Class 1 and 1M, Class 1C, Class 2 and 2M, Class 3R, Class 3B, and Class 4. For fibre optic transceivers and transmitters, Class 1 and 1M are of primary concern in the industry. Therefore, the criteria of only these two levels and their calculation methodology are reviewed in this document.

"Class 1" limits the optical power to less than or equal to Class 1 power criteria for Condition 1 and Condition 3 (these conditions are described in more detail in 4.6). "Class 1M" limits the optical power to greater than the Class 1 power and less than the Class 3B power for Condition 1, and less than or equal to the Class 1 power for Condition 3. The requirements are summarized in Table 3, which shows that the "Class 1 power" is automatically prescribed by the minimum of the Class1 power limits under Condition 1 and Condition 3, whereas the "Class 1M power" is the minimum of the Class 3B power limit under Condition 1 and the Class 1 power limit under Condition 3.

Table 3 – Class 1 and Class 1M power criteria

	Condition 1	Condition 2	Condition 3
Class 1 power	Power ≤ Class 1	-	Power ≤ Class 1
Class 1M power	Class 1 < power < Class 3B	-	Power ≤ Class 1

4.6 Measurement conditions 1, 2, and 3

Three combinations of measurement aperture stop and distance from source to aperture for evaluation are specified in IEC 60825-1 and IEC 60825-2. Figure 1 shows a graphic illustration of the measurement setup.

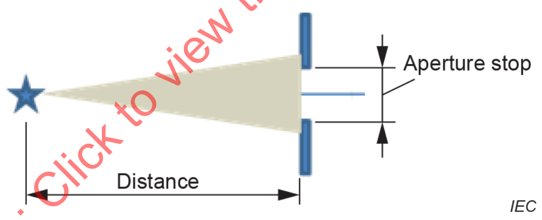

Figure 1 – Graphic illustration of distance to source and aperture stop

Three conditions are described in Table 4:

- Condition 1 applies to collimated beams, where the use of a telescope or binoculars can increase the hazard;
- Condition 2 applies to divergent beams, where the use of eye loupes or high power magnifiers can increase the hazard;
- Condition 3 applies to naked eye viewing or viewing with low power magnifiers.

More information on these measurement conditions can be found in IEC 60825-1:2014, 5.4.1, and in IEC 60825-2:2021, 4.7.1.

In IEC 60825-1, only Condition 1 and Condition 3 are considered. In IEC 60825-2, all three conditions are examined. Two wavelength ranges are specified for these three conditions, as listed in Table 4.

Table 4 – Measurement aperture diameters and distances for evaluation

	Condition 1		Condition 2		Condition 3	
Wavelength range nm	**Aperture stop** mm	**Distance** mm	**Aperture stop** mm	**Distance** mm	**Aperture stop** mm	**Distance** mm
400 to 1 400	50	2 000	3,5	35	7	100
1 400 to 4 000	24,5 (time > 10 s)	2 000	3,5	14	3,5 (time > 10 s)	100

Assuming that the total output power of the laser source is P_i and the power passing through a circular aperture is P_o, then the collecting efficiency η (with $0 < \eta < 1$) is defined as $\eta = P_o/P_i$. As can be seen from Figure 1, the power P_o passing through the specified aperture usually is less than the source output power P_i, so that the ratio η is a number less than 1. The maximal allowable laser power P_{imax} is the power P_i at which P_o is equal to a specified power limit P_{AEL}, which is referred to as the Accessible Emission Limit (AEL). Hence, P_{imax} is given by Formula (1).

$$P_{imax} = P_{AEL} / \eta \tag{1}$$

For each column of Table 4 (defined by the combination of condition and wavelength range), η is calculated assuming a light beam with Gaussian divergence. The diameter d_{63} of a divergent beam that contains 63 % of the total power at a distance r from the apparent point source (e.g. an optical fibre end) is used to calculate η.

In the case of MMFs, the numerical aperture θ_{NA} of a point source is defined as the sine of one-half the divergence angle of an emergent laser beam, ϕ, of the output beam, as measured at the 5 %-off-peak-irradiance points. This relationship is described by Formula (2).

$$\phi / 2 = \text{asin}\,(\theta_{NA}) \tag{2}$$

For a Gaussian beam, the beam diameter d_{63} is given by Formula (3).

$$d_{63} = \frac{2r}{1{,}7} \tan\left[\text{asin}\left(\theta_{NA}\right)\right] \approx \frac{2r}{1{,}7}\theta_{NA} \tag{3}$$

The denominator 1,7 is the ratio of the beam diameter d_{95} that corresponds to the 5 %-off-peak-irradiance point to d_{63}, i.e. $d_{95}/d_{63} = 1{,}7$.

The parameter η is the collecting efficiency of a Gaussian beam passing through the aperture. Its value is calculated from Formula (4).

$$\eta = 1 - \exp\,[-(d / d_{63})^2\,] \tag{4}$$

where

d is the diameter of the aperture stop.

For MMFs, θ_{NA} = 0,18 can be assumed. For each of the three conditions, the resulting values of $1/\eta$ can then be calculated from Formulae (3) and (4), using the corresponding values for d from Table 4. The results are summarized in Table 5. Please note that these values are for MMFs under the assumption that θ_{NA} is 0,18. The NA of MMFs can vary between 0,2 and 0,29, depending on the design. However, a value of 0,18 is used in these exemplary calculations to harmonize with IEC 60825-1. For practical applications, it is advisable to use the actual NA of the particular MMF used in the transceiver or transmitter.

Table 5 – Values of $1/\eta$ under Conditions 1, 2 and 3 for MMFs

Wavelength nm	Condition 1	Condition 2	Condition 3
400 to 1 400	72,25	5,00	9,66
1 400 to 4 000	299,34	1,33	37,11

It follows from Table 5 and Formula (1) that Condition 2 yields the lowest values for P_{imax}, compared with Condition 1 and Condition 3.

In the case of SMFs, d_{63} is calculated from Formula (5).

$$d_{63} = 2r\sqrt{2}\,\lambda/(\pi\omega_0) \tag{5}$$

where

λ is the wavelength, expressed in nm;

ω_0 is the beam spot size of the fibre, expressed in nm.

With this result, η can be calculated as shown in Formula (6).

$$\eta = 1-\exp\left[-\left(\frac{d}{d_{63}}\right)^2\right] = 1-\exp\left[-\left(\frac{\pi\omega_0}{2\sqrt{2}\,\lambda}\frac{d}{r}\right)^2\right] \tag{6}$$

Table 6 summarizes the values of d/r for SMFs calculated for the three conditions. It is seen from this table that the largest values of d/r are obtained for Condition 2. Since $1/\eta$ decreases monotonically with increasing d/r, it follows from Formula (1) that Condition 2 yields the smallest values for P_{imax}, compared with Conditions 1 and 3.

Table 6 – Values of d/r under Conditions 1, 2 and 3 for SMFs

Wavelength nm	Condition 1	Condition 2	Condition 3
400 to 1 400	0,025	0,1	0,07
1 400 to 4 000	0,012 3	0,25	0,035

It is assumed in this document that the outgoing beam has a circular Gaussian profile, but for some optical transceivers, it is more appropriate to assume an elliptical two-axes Gaussian profile for the outgoing beam. However, neither IEC 60825-1:2014 nor IEC 60825-2:2021 specify a calculation methodology for such a beam profile.

4.7 Correction factors

In MMF applications, the correction factor C_6 is applied, which is defined by the angular subtense α of the apparent source. In SMF applications, C_6 = 1. In MMF applications, the fibre core diameter (e.g. 50 µm, 62,5 µm, or 80 µm) is considered as the diameter of the apparent source, d_s, so that α is given by Formula (7).

$$a = d_s / r \quad (7)$$

A laser source is considered an extended source when the angular subtense α of the output beam is greater than α_{min} = 1,5 mrad. Most laser sources have an angular subtense of less than 1,5 mrad and thus appear as a "point source" when viewed from within the beam. Indeed, a circular laser beam cannot be collimated to a divergence of less than 1,5 mrad if it is emitted by an extended source. Hence, a laser source with a beam divergence of 1,5 mrad or less cannot be treated as an extended source. For point sources, α is set to α_{min} = 1,5 mrad and C_6 = 1. For extended sources, where α is greater than 1,5 mrad, the AEL is increased by a factor of α / α_{min} (which is the correction factor C_6), due to the spreading effect of the light source. The correction factor C_6 is calculated from Formula (8).

$$C_6 = \begin{cases} 1 & , \quad \alpha \le \alpha_{min} \\ \dfrac{\alpha}{\alpha_{min}} & , \alpha_{min} \le \alpha \le \alpha_{max} \\ \dfrac{\alpha_{max}}{\alpha_{min}} & , \quad \alpha \ge \alpha_{max} \end{cases} \quad (8)$$

where

α_{min} = 1,5 mrad;

α_{max} = 100 mrad.

Table 7 summarizes the values of C_6 calculated for the three measurement conditions and the three fibre core diameters. This table also lists the values of the parameter T_2, which is called "time break point" and defined as shown in Formula (9).

$$T_2 = \begin{cases} 10\ \text{s} & , \quad \alpha \le \alpha_{min} \\ 10 \times 10^{\left(\alpha - \alpha_{min}\right)/98.5}\ \text{s} & , \alpha_{min} \le \alpha \le \alpha_{max} \\ 100\ \text{s} & , \quad \alpha \ge \alpha_{max} \end{cases} \quad (9)$$

where

α_{min} = 1,5 mrad;

α_{max} = 100 mrad.

Hence, the value of T_2 depends on measurement conditions and fibre core diameter. The damage caused by laser irradiation is most severe when the exposure time is longer than T_2. For MMFs, T_2 is 10 s when $\alpha \le$ 1,5 mrad but increases beyond 10 s when α > 1,5 mrad. For the purpose of this document, it is assumed that the exposure time is always greater than T_2.

Table 7 – Values of C_6 and T_2 for an extended light source

Fibre core diameter µm	Distance *r* mm	*α* mrad	C_6	T_2 s
50	14	3,57	2,38	10,5
50	35	1,43	1	10
50	100	0,5	1	10
50	2 000	0,025	1	10
62,5	14	4,46	2,98	10,72
62,5	35	1,79	1,19	10,07
62,5	100	0,63	1	10
62,5	2 000	0,031	1	10
80	14	5,71	3,81	11,04
80	35	2,29	1,52	10,19
80	100	0,8	1	10
80	2 000	0,04	1	10

Two additional correction factors, C_4 and C_7, are used in the evaluation of the Accessible Emission Limits (AELs). Their values are wavelength dependent, as shown in Table 8.

Table 8 – Values of the correction factors C_4 and C_7

Parameter	Wavelength range nm
$C_4 = 10^{0,002\ (l\ –\ 700)}$	700 to 1 050
$C_4 = 5$	1 050 to 1 400
$C_7 = 1$	700 to 1 150
$C_7 = 10^{0,018\ (l\ –\ 1\ 150)}$	1 150 to 1 200
$C_7 = 8 + 10^{0,04\ (l\ –\ 1\ 250)}$	1 200 to 1 400

4.8 Class 1 and Class 1M power calculations

The Accessible Emission Limits (AEL) for Class 1, Class 1M, and Class 3B are specified in IEC 60825-1:2014, Table 3, Table 4, and Table 8. Table 9 provides a summary of the AEL values.

Table 9 – Accessible Emission Limits (AEL)

Wavelength nm	AEL (Class 1) W	AEL (Class 3B) W
700 to 1 050	$7 \times 10^{-4} \times C_4 \times C_6 \times T_2^{-0.25}$ (for $C_6 > 1$) $3{,}9 \times 10^{-4} \times C_4 \times C_7$ (for $C_6 = 1$)	0,5
1 050 to 1 400	$3{,}9 \times 10^{-4} \times C_4 \times C_7$	0,5
1 400 to 4 000	$1{,}0 \times 10^{-2}$	0,5

5 Example of calculations

5.1 Class 1 power for MMF applications between 700 nm and 1 050 nm wavelength

In 5.1, the AELs for MMF with 50 µm, 62,5 µm and 80 µm core diameter are calculated. As shown in Table 4, the distances for Condition 3 and Condition 1 are 100 mm and 2 000 mm, respectiviely. From Table 7 it is found that $C_6 = 1$ and $T_2 = 10$ s for any combination of the three fibre core diameters (50 µm, 62,5 µm and 80 µm) and two distances (100 mm and 2 000 mm). Therefore, the optical power P_{AEL} at the AEL is given by Formula (10).

$$P_{\mathrm{AEL}} = 3,9 \times 10^{-4} \times C_4 \times C_7 \qquad (10)$$

After substituting C_4 and C_7 from Table 8, Formula (10) becomes Formula (11).

$$P_{\mathrm{AEL}} = 0,39 \times 10^{0,002\,(l - 700)} \qquad (11)$$

where

λ is the wavelength, expressed in nm;

P_{AEL} is the AEL, expressed in mW.

Formula (11) is valid for MMFs with 50 µm, 62,5 µm, and 80 µm core diameter.

As shown in Table 5, $1/\eta = 9,66$ for Condition 3. Using this value, the Class 1 power limit is calculated to be $P_{\mathrm{imax}} = 3,76 \times 10^{0,002\,(l - 700)}$ (in mW) for MMFs with 50 µm, 62,5 µm, and 80 µm core diameter.

At a wavelength of 850 nm, for example, the Class 1 power limit is $P_{\mathrm{imax}} = 7,50$ mW for 50 µm, 62,5 µm, and 80 µm core diameter. The power limits for other wavelengths are plotted in Figure 2.

The Class 1M power is defined by the restrictions "Class 1 < Power < Class 3B for Condition 1" and "Power < Class 1 for Condition 3". The values for $1/\eta$ in Table 5 are 72,25 for Condition 1 and 9,66 for Condition 3. Therefore, the maximal power for Class 1M is defined by the AEL power for Class 1 under Condition 3, which is the same maximal power as for Class 1.

Since the power limits for Class 1 and Class 1M are the same, it is not necessary to define the category of Class 1M in the laser safety regulations for fibre optic telecommunication systems.

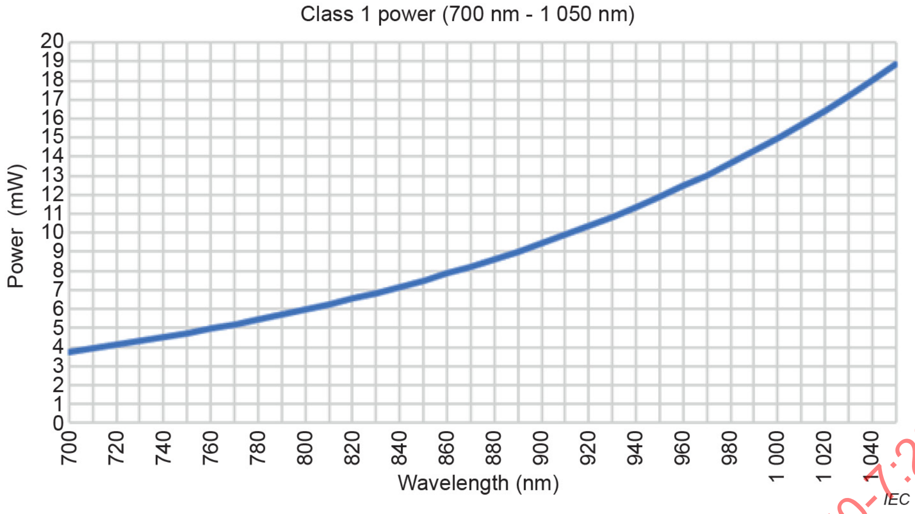

Figure 2 – Class 1 power P_{imax} for MMF applications

5.2 Class 1 power for SMF applications between 1 200 nm and 1 400 nm wavelength

For wavelengths between 1 200 nm and 1 400 nm, C_4 = 5 and C_7 = [8 + 10 $^{0,04\ (l\ -\ 1\ 250)}$] in Table 8. Substituting these values into Formula (10) yields Formula (12), where P_{AEL} is expressed in mW.

$$P_{AEL} = 1{,}95 \times [\ 8 + 10^{0{,}04\ (l\ -\ 1\ 250)}\ ] \qquad (12)$$

Also, as shown in Table 6, d/r = 0,07 for Condition 3, so that η can be calculated as shown in Formula (13).

$$\eta = 1 - \exp\left[-\left(\frac{\pi\,\omega_0}{2\sqrt{2}\,\lambda}\,0{,}07\right)^2\right] \qquad (13)$$

Therefore, the maximal power for Class 1 is given by P_{imax} = 1,95 × [8 + 10 $^{0,04\ (l\ -\ 1\ 250)}$]/η (in mW).

Figure 3 shows the power limit versus wavelength for the example ω_0 = 11 µm.

As discussed in 5.1, the maximal power for Class 1M is the same as the maximal power for Class 1. Thus, it is not necessary to define the category of Class 1M in the laser safety regulations for fibre optic telecommunication systems.

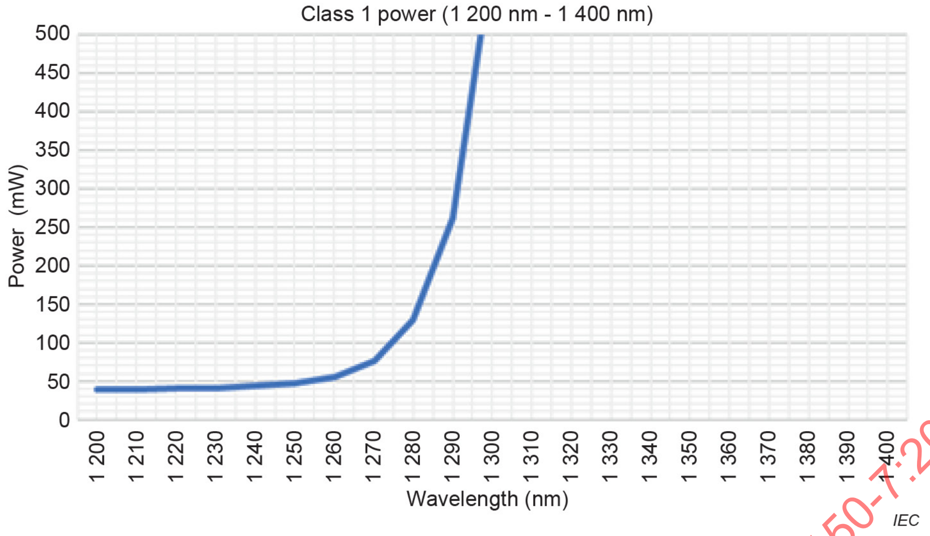

Figure 3 – Class 1 power P_{imax} for SMF applications (1 200 nm < λ < 1 400 nm)

5.3 Class 1 power for SMF applications between 1 400 nm and 1 650 nm wavelength

The AEL of the Class 1 category is 10 mW. The value of η is calculated from Formula (14), using d/r = 0,035 from Table 6 for Condition 3 and wavelengths between 1 400 nm and 1 650 nm.

$$\eta = 1 - \exp\left[-\left(\frac{\pi\omega_0}{2\sqrt{2}\,\lambda}0{,}035\right)^2\right] \tag{14}$$

The maximal power for Class 1 is therefore given by P_{imax} = 10/η (in mW). Figure 4 shows the power limit versus wavelength for the example ω_0 = 11 µm.

As discussed in 5.1, the maximal power for Class 1M is the same as the maximal power for Class 1. Thus, it is not necessary to define the category of Class 1M in the laser safety regulations for fibre optic telecommunication systems.

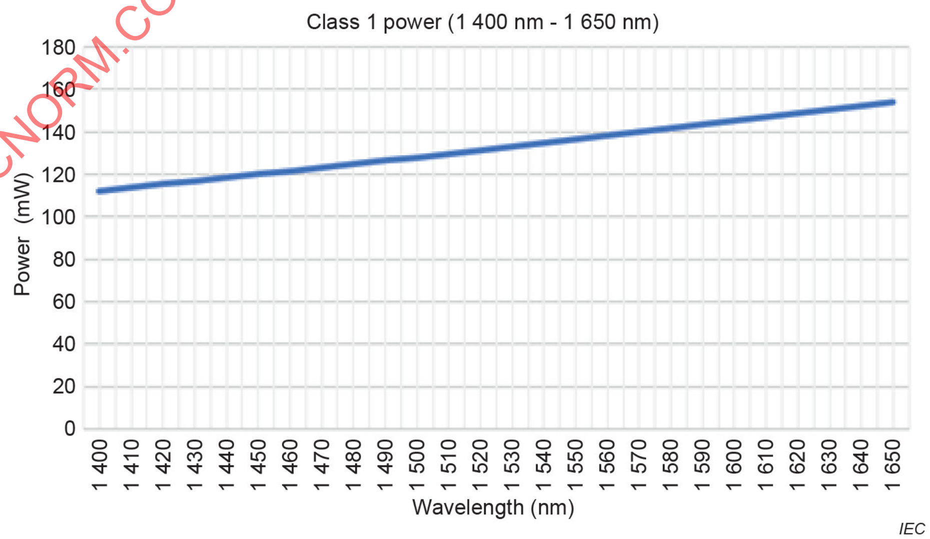

Figure 4 – Class 1 power P_{imax} for SMF applications (1 400 nm < λ < 1 650 nm)

6 Specific interface applications

6.1 Applications with wavelength-division multiplexing (WDM)

WDM interfaces operating in the 1 300 nm wavelength band are often used in intra-data-centre links for transmission distances between 500 m and 40 km, whereas long-haul and data-centre-interconnect (DCI) links often use dense-WDM (DWDM) interfaces operating in the 1 550 nm wavelength band. This section describes the calculation method for both WDM transmission bands.

Denoting the WDM wavelengths as λ_1, λ_2, ..., λ_n, it is considered that the power of all wavelengths is weighted. Ordinarily, the same output power for each λ_i is specified. Assuming that the dependency of η on λ is negligibly small, the maximal allowable power P_X for each wavelength λ_i is given by Formula (15).

$$P_X = P_{AEL,\,\lambda i} \;/\; \eta \tag{15}$$

The efficiency for each λ_i (i.e. the ratio of effective power for $P_{AEL,\,\lambda i}$) is evaluated as shown in Formula (16).

$$P_X \times \eta \;/\; P_{AEL,\,\lambda 1} \tag{16}$$

The allowed power P_X is calculated so that the total efficiency is 1, as expressed in Formula (17).

$$P_X \times \eta \left(\frac{1}{P_{AEL,\lambda 1}} + \frac{1}{P_{AEL,\lambda 2}} + \ldots + \frac{1}{P_{AEL,\lambda n}} \right) = 1 \tag{17}$$

Solving Formula (17) for P_X yields Formula (18).

$$P_X = \frac{1}{\eta} \frac{1}{\left(\frac{1}{P_{AEL,\lambda 1}} + \frac{1}{P_{AEL,\lambda 2}} + \ldots + \frac{1}{P_{AEL,\lambda n}} \right)} \tag{18}$$

6.2 Fibre array applications

According to IEC 60825-2, in the case of a general breakage of a fibre array, numerous experiments have verified that the law of energy addition is not applicable, so that the most severe optical power limit in the array can be specified as a single fibre output.

In the case of cleaved fibre ends, the fibre array is considered to be an extended source, consisting of many light sources. The overall allowable optical power P_{AEL} is calculated by modifying the power of the point source using the C_6 and T_2 correction factors (to find the minimum value of angular subtense averaged in 2-axis direction). Then, the allowable P_{AEL} per fibre is calculated by dividing the overall allowable optical power P_{AEL} by the number of fibres in the array. If the number of fibres in the array is N, the allowable optical power per fibre is calculated for all combinations n = 1, 2, ..., N, and the smallest power among them is the maximal allowable optical power of the fibre array.

The general calculation method is as follows. Assuming that the mode field diameter (MFD) is d, the fibre array pitch is p, the number of fibres is N, and the distance from the light source to the object is r, then the vertical and horizontal angular subtenses, α_v and α_h, are given by Formulae (19) and (20).

$$\alpha_v = d / r \tag{19}$$

$$\alpha_h = [(N-1) \times p + d] / r \tag{20}$$

The parameters C_6 and T_2 are calculated separately for α_v and α_h and can then be averaged.

In the case of SMF, the total maximal power is given by Formula (21).

$$P_{AEL} = 3{,}9 \times 10^{-4} \times C_4 \times C_7 \times C_6 \times T_2^{-0.25} \tag{21}$$

Therefore, the power limit per fibre is given by Formula (22).

$$P_{AEL\_f} = P_{AEL} / N \tag{22}$$

All combinations of N are examined and the minimal value of P_{AEL_f} is the power limit per fibre array.

The calculations presented in 6.2 apply to a one-dimensional optical fibre array. In the case of multi-core fibres, for example, it is important to consider an extended light source in two dimensions. In such a case, the calculations are performed under the most stringent conditions, where the average angular subtense of the two orthogonal axes becomes smallest for any given fibre combination.

Annex A
(informative)

Hazard level calculations

A.1 General

When optical transceivers and transmitters are integrated in an optical fibre communication system (OFCS), the laser safety categories are defined and specified in IEC 60825-2, which classifies them as "Hazard levels". Hazard level 1 and Hazard level 1M are often examined in the fibre optic industry. The Hazard level specifications are similar to the Class1 and Class 1M criteria, but with some important differences. It is important to note that these criteria are transmission system safety criteria and not component safety criteria.

The differences between the criteria for the Class and Hazard level categories depend on the measurement conditions. Table A.1 lists the criteria to meet Hazard level 1 and Hazard level 1M safety requirements.

Table A.1 – Power limits for Hazard levels 1 and 1M

Hazard level	Condition 1	Condition 2	Condition 3
1	Power ≤ Class 1 limit	Power ≤ Class 1 limit	Power ≤ Class 1 limit
1M	Class 1 limit < power < Class 3B limit	Power ≤ Class 3B limit	Power ≤ Class 1 limit

As can be seen from Table 5 and Table 6, the value of $1/\eta$ is smaller for Condition 2 than for Condition 1 and Condition 3. Therefore, the Hazard level power limits are determined by the limits of Condition 2. In the case of SMF in Table 6, $1/\eta$ is minimal when d/r is maximal.

Another important point to remember is that the values of C_6 and T_2 are different for MMFs with 50 µm, 62,5 µm and 80 µm core diameter.

Calculations for the power limits of the Hazard levels are made with reference to Clause 5.

A.2 Example of calculations

A.2.1 MMF applications at wavelengths between 700 nm and 1 050 nm

The related parameters for Class 1 and Hazard level 1 calculations are summarized in Table A.2. The AEL is calculated from the equations shown in Formula (A.1).

$$P_{AEL} = 7 \times 10^{-4} \times C_4 \times C_6 \times T_2^{-0,25} \text{ (for } C_6 > 1)$$

$$P_{AEL} = 3,9 \times 10^{-4} \times C_4 \times C_7 \text{ (for } C_6 = 1) \qquad \text{(A.1)}$$

$$C_4 = 10^{0,002\,(l - 700)}$$

Table A.2 – Related parameters for MMF applications

Category	Core µm	C_6	T_2	$T_2^{-0,25}$	AEL mW	$1/\eta$	Condition	Power limit mW
Class 1	50	1	10	0,562	0,393 4 C_4	9,66	3	3,76 C_4
	62,5	1	10	0.562	0,393 4 C_4	9,66	3	3,76 C_4
	80	1	10	0,562	0,393 4 C_4	9,66	3	3,76 C_4
Hazard level 1	50	1	10	0,562	0,393 4 C_4	5,00	2	1,97 C_4
	62,5	1,19	10,07	0.561	0,467 3 C_4	5,00	2	2,34 C_4
	80	1,52	10,19	0,560	0,595 8 C_4	5,00	2	2,98 C_4

The AEL values for Class 1/1M and for Hazard levels 1 and 1M are summarized in Table A.3. As described in 5.2, Class 1 and Class 1M have the same power limits. In the case of Hazard level 1M, the power limit of Class 3B is 0,5 W, and the maximal power limits of Condition 1 and Condition 2 are more than 2,5 W. Therefore, Hazard level 1M is determined by the power limit of Class 1 under Condition 3.

Table A.3 – AEL values for Classes 1 and 1M and Hazard levels 1 and 1M

Category	Core µm	AEL mW	$1/\eta$	Condition	Power limit mW
Class 1 / Class 1M	50	0,393 4 C_4	9,66	3	3,80 C_4
	62,5	0,393 4 C_4	9,66	3	3,80 C_4
	80	0,393 4 C_4	9,66	3	3,80 C_4
Hazard level 1	50	0,393 4 C_4	5,0	2	1,97 C_4
	62,5	0,467 3 C_4	5,0	2	2,34 C_4
	80	0,595 8 C_4	5,0	2	2,98 C_4
Hazard level 1M	50	0,393 4 C_4	9,66	3	3,80 C_4
	62,5	0,393 4 C_4	9,66	3	3,80 C_4
	80	0,393 4 C_4	9,66	3	3,80 C_4

Table A.5 in IEC 60825-1:2014 specifies the Maximum Permissible Exposure (MPE) to human skin, which is 2 000 × C_4 (Wm^{-2}). Considering an aperture area of $\pi \times (7/2)^2 = 38{,}47\ mm^2$, the skin MPE is given by $76{,}9 \times 10^{0{,}002\,(l\,-\,700)}$ (in mW). The skin MPE is always larger than the Class 1 and Hazard level 1 power limits listed in Table A.3. Therefore, the maximal Class 1 and Hazard level 1 power is derived from AEL calculations.

For reference, the power limits for Class1 and Hazard level 1 are shown in Figure A.1. The power limits for Hazard level 1M are not shown in this graph, because they are the same as for Class 1.