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AMENDMENT 1

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Amendment 1

Safety of laser products –

Part 2:
Safety of optical fibre communication systems

Amendement 1

Sécurité des appareils à laser –

Partie 2:
Sécurité des systèmes de télécommunication par fibres optiques

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FOREWORD

This amendment has been prepared by IEC technical committee 76: Optical radiation safety and laser equipment.

The text of this amendment is based on the following documents:

FDIS	Report on voting
76/162/FDIS	76/169/RVD

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

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Add the titles of the following two new annexes D and E as follows:

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Add, after annex C, the new annex D as follows:

Annex D
(informative)

Application notes for the safe use of optical fibre communication systems

D.1 Introduction

This annex provides guidance on the application of IEC 60825-2 to specific practical situations. This annex applies to optical fibre communication systems (OFCS) where optical power is normally confined in a fibre and may be accessible at a great distance from the optical source. It does not apply to optical fibre systems primarily designed to transmit optical power for applications such as material processing or medical treatment.

It is an informative annex to assist OFCS operators in applying the requirements of IEC 60825-1 and IEC 60825-2 to their specific application. It does not contain any manufacturer or installer requirements.

D.2 Definitions

For the purpose of this annex D, the following definitions apply:

D.2.1
accessible location
a location anywhere in an optical fibre communications system where optical radiation might become accessible in reasonably foreseeable circumstances

D.2.2
FITs:
an indicator of reliability defined as the number of failures per 10^9 h

D.2.3
HITs
the number of hazard incidents per 10^9 h

D.3 Areas of application

D.3.1 Typical optical fibre installations

a) Locations with controlled access (see 3.13):

cable ducts;

street cabinets;

manholes;

dedicated and delimited areas of network operator distribution centres;

test rooms in cable ships.

b) Locations with restricted access (see 3.14):

secured areas within industrial premises not open to the public;

secured areas within business/commercial premises not open to the public (for example telephone PABX rooms, computer system rooms, etc.);

general areas within switching centres;

delimited areas not open to the public on trains, ships or other vehicles;

overhead fibre optic cables and cable drops to a building;

optical test sets.

c) Locations with unrestricted access (see 3.15):

domestic premises;

industrial commercial or business premises;

public areas on trains, ships or other vehicles;

open public areas such as parks, streets, etc.

Distributed fibre networks may pass through unrestricted public areas (for example in the home), restricted areas within industrial premises, as well as controlled areas such as cables ducts or street cabinets.

OFCS Local Area Networks (LANs) may be deployed entirely within restricted business premises.

Fibre systems may be entirely in unrestricted domestic premises such as hi-fi interconnections.

Infra-red (IR) wireless LANS are outside the scope of this annex.

D.3.2 Typical hardware components

a) Fibre cables: single/multiple/ribbon construction;
single/multimode;
carrying single/multiple wavelengths;
uni/bidirectional, fibre;
communications/power feeding.

b) Optical sources: LEDs, communications lasers, pump lasers, optical amplifiers, bulk/distributed, continuous/low/high-frequency emission.

c) Connectors: permanent/semi-permanent, single/multiple.

d) Power splitters, wavelength de/multiplexers, attenuators.

e) Enclosures and protective housings.

f) Fibre distribution frames.

D.3.3 Typical conditions

a) Installation.

b) Operation.

c) Maintenance.

d) Servicing.

e) Fault.

f) Measurement (including optical time domain reflectometry – OTDR).

D.4 Optical fibre power system limits

Mean power fibre limits for the laser classes are presented below at various wavelengths in the optical fibre. For most typical systems with duty cycles of between 10 % to 100 %, the peak power can be allowed to increase as the duty cycle decreases. However, for duty cycles of ≤ 50 %, it is most straightforward to limit the peak powers to twice these mean power limits, although IEC 60825-1 can be used for a more sophisticated analysis in order to identify any increase in peak powers permissible for these types of systems.

D.5 Hazard level evaluation examples

NOTE – For optical sources, enclosures and protective housings already classified according to IEC 60825-1 by the manufacturer, the hazard level according to IEC 60825-2 may be different from the classification according to IEC 60825-1. The reasons for these differences are:

– IEC 60825-2 has a hazard level $k \times$ 3A for restricted and controlled access situations;

– operator uses automatic power reduction (APR) for determination of the hazard level;

– results from fault analysis in IEC 60825-2 may be different from single fault analysis in IEC 60825-1.

D.5.1 Multiple wavelengths over the same fibre

When more than one wavelength is used on the same fibre, such as on a wavelength division multiplex system (WDM), then the hazard level depends on both the power levels and whether the wavelengths are additive. For skin exposure to wavelengths usually used in optical fibre communication systems, the hazards are always additive. For most fibre systems, 1 400 nm is the point at which addition conditions change:

a) if two wavelengths are both below 1 400 nm they add, i.e. the combined hazard is higher;

b) if two wavelengths are both above 1 400 nm they add, i.e. the combined hazard is higher;

c) if one is above 1 400 nm, and one below, then retinal hazards do not add, i.e. the combined hazard does not increase.

It is necessary to calculate separately for skin and retinal hazards. To calculate the combined hazard level in a multi-wavelength system, it is necessary to calculate the system power at each wavelength as a proportion of the AEL for that class at that wavelength (for example 25 %, 60 %, etc. up to 100 %), and add together. If the totalled proportion exceeds 1 (100 %), then the hazard level exceeds that class.

Multi-wavelength example

An optical transmission system using multimode fibre of 50 micrometres core diameter and a numerical aperture 0,2 ± 0,02 carries six optical signals: at wavelengths of 840 nm, 870 nm, 1 290 nm, 1 300 nm, 1 310 nm and 1 320 nm. Each of these signals has a maximum time-averaged power of –8 dBm (0,16 mW). Determine the location hazard level at the transmitter site.

In the absence of any other information concerning the transmitter emission duration when a connector is removed, assume that no shut-down system operates, and classify on the basis of the power levels accessible at the transmitter connector (removing the connector is a reasonably foreseeable event).

Assess on the basis of:

100 s emission duration (see 9.3 e) of IEC 60825-1), and

a minimum viewing distance of 100 mm (see 8.2 c) of IEC 60825-1).

Table 5 of IEC 60825-1 indicates that the effects of all wavelengths are additive. The evaluation must therefore be made on the basis of the ratio of the accessible emission at each wavelength to the AEL for the laser class at that wavelength (see 9.3b) of IEC 60825-1).

Note, however, that the AELs are constant in the wavelength range 1 200 nm to 1 400 nm; hence, the four signals in the vicinity of 1 300 nm may be considered as a single signal with a power level equal to the sum of powers in those signals.

First compare the emission levels with the AEL for class 1:

$$\mathrm{AEL}_{840\ \mathrm{nm\ or}\ 870\ \mathrm{nm}} = 7 \times 10^{-4} t^{0,75} C_4 C_6\ \mathrm{J}$$

$$= 7 \times 10^{-4} t^{-0,25} C_4 C_6\ \mathrm{W}$$

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

and for a point source, $C_6 = 1$

$$\mathrm{AEL}_{1\ 300\ \mathrm{nm}} = 3,5 \times 10^{-3} t^{0,75} C_6 C_7\ \mathrm{J} = 3,5 \times 10^{-3}\ t^{-0,25}\ C_6 C_7\ \mathrm{W}$$

where $C_7 = 8$

hence $\mathrm{AEL}_{840\ \mathrm{nm}}$ = 0,42 mW

$\mathrm{AEL}_{870\ \mathrm{nm}}$ = 0,49 mW

$\mathrm{AEL}_{1\ 300\ \mathrm{nm}}$ = 8,9 mW

Using the expression for the diameter of the beam from an optical fibre (equation (1) in A.6 of IEC 60825-1), the diameter at the 63 % (1/e) points for the smallest NA fibre (worst case) is:

$$d_{63} = \frac{2r\ \mathrm{NA}}{1{,}7} = \frac{2 \times 100 \times 0{,}18}{1{,}7} = 21{,}2\ \mathrm{mm}$$

The fraction of the beam that would pass through the 50 mm aperture specified in the measurement conditions is therefore (using equation (3) of example A.6 of IEC 60825-1):

$$\eta = 1 - \exp(-[d_a/d_{63}]^2) = 0{,}99$$

Thus, in this case, all of the fibre power would be collected by the 50 mm aperture, and no correction is needed.

Summing the ratios of the power at each wavelength to the corresponding AEL yields:

$$\sum \left[\frac{(\mathrm{Power})}{\mathrm{AEL}}\right] = \frac{0{,}16}{0{,}42} + \frac{0{,}16}{0{,}49} + \frac{4 \times 0{,}16}{8{,}9} = 0{,}78$$

This ratio is less than 1; thus, the accessible emission is within class 1 limits and a location hazard level 1 applies.

D.5.2 Bi-directional (full duplex) transmission

There is no additive effect from each separate direction of transmission, as each broken fibre cable end represents a separate hazard if the fibre breaks. The hazard level is determined by the transmission direction with the higher power.

D.5.3 Automatic power reduction

Automatic power reduction is an available option for optical fibre communications systems in order to classify an end to end OFCS at a lower hazard level than the laser/LED power of that system would otherwise permit. This is important when the hazard level of the internal optical transmitters of a system may put a limitation on where that system may be deployed. See annex B.

Following the indications of this standard, assessment of the hazard level shall take place at the time of reasonably foreseeable human access to radiation (for example after a fibre break) unless measurement at a later time would result in a larger exposure (see 4.4.1). This could be almost instantaneously after an unprotected fibre splice, after approximately 1 s after a fibre connector disconnect, or after several hours as in the time it takes for a ship to pull up a broken cable from the bottom of the ocean.

Automatic power reduction <u>should not</u> take the place of good work practices and proper servicing and maintenance. Also, the reliability of the APR mechanism shall be taken into account when assessing the hazard level.

Automatic power reduction cannot be regarded as a universally protective measure because after a fibre break, it is common practice to use an optical test set (usually an optical time domain reflectometer, OTDR) to determine the location of the break. This instrument launches laser power down the fibre under test. Therefore, even if the normal telecommunications transmitter is shut down or removed, the diagnostic tools may impart laser power at a later time.

These OTDRs typically operate at class 1, so no potential hazard is present. However, higher power may require class 3A or class 3B OTDRs to detect the break. Also, OTDR signals may be amplified to a higher class if sent through an optically amplified system.

It is also important that the laser safety professionals of the OFCS operator consider the hazard level under which it is desirable to work. Hazard level 3A or *k* × 3A is often cited because workers would be trained not to use any optical (collimating) instruments that would increase the hazard and typically they would have no need to examine the fibre at a close range. Hazard level 3B is acceptable in controlled environments with proper labelling and connector conditions.

This subclause will examine APR under several circumstances:

– on a readily accessible fibre in a splice tray;
– at a fibre optic connector;
– on a fibre not readily accessible in a submerged/buried cable;
– in restricted and unrestricted environments;
– ribbon cables.

For these tables, the following upper limit powers are calculated for the typical wavelengths using worst case singlemode fibre (see clause D.4):

1 300 nm:	hazard level 1	= 8,85 mW
	hazard level 3A	= 24 mW
	hazard level *k* × 3A	= 83 mW
	hazard level 3B	= 500 mW
1 550 nm:	hazard level 1	= 10 mW
	hazard level 3A	= 50 mW
	hazard level *k* × 3A	= 54 mW
	hazard level 3B	= 500 mW

D.5.3.1 Fibre in a splice tray

As powers increase in an OFCS, it is important that splicing operations on potentially energized fibres of hazard level 3B or greater powers take into consideration the safety of the operator, and a fully enclosed splicing system should be employed. If splicing is not to take place in a protective enclosure, automatic power reduction is an option for reducing the hazard level and therefore the exposure. Because accessibility to the cut fibre is immediate, power reduction should also be immediate. Table D.2 outlines some timing requirements at typical wavelengths.

D.5.3.2 Connectorized systems

Another area where access to energized fibre is reasonably foreseeable, is when an energized system has one or several of its fibres disconnected at an optical connector. A possible and likely assumption that could be made is that human accessibility to the energized fibre would not occur until 1 s after the disconnection. As a result, the power reduction durations specified in table D.2 would be increased by 1 s for this application.

However, another alternative that would result in a safer hazard classification for the transmission equipment itself would be the use of shuttered connectors. These connectors, provided that they meet the reliability characteristics outlined in clause D.6 of this annex, could be a mechanical solution that could be implemented at any connector point along the OFCS. Such a solution would be desirable for controlling exposures from unmated connectors. These shutters should operate within the time restrictions of the previous paragraph. (It should be noted that shutters may not be practical or desirable for controlling hazard level 4 and some higher 3B conditions. In these situations, APR may be the only solution.)

D.5.3.3 Submerged/buried cable for undersea systems

Certain undersea systems have the potential to carry substantial optical power levels. Typically, damage to fibre cable is incurred on the submerged portion, not on the buried land portion. Because the fibre cable is submerged, an appropriate shipping vessel is necessary to retrieve the cable and repair it, which may take hours or days to accomplish. As automatic power reduction may not be appropriate or practical for these systems, rigorous administrative controls, including manual laser shutdown procedures, may need to be employed. This will ensure that proper working conditions are maintained below hazard level 4 as specified in this standard.

Manual shutdown of the system under repair/maintenance/service conditions is currently the practice for many operators because of the hazardous electrical power associated with the submerged cable. This electrical power is used to power the undersea repeaters along the route. In the future, for repeaterless systems, this electrical power may no longer be a part of the cable. However, the work practice to de-energize fibre before extraction must be continued and maintained because of the hazards of the associated laser power.

D.5.3.4 APR for restricted and unrestricted environments

An OFCS that reaches into restricted and unrestricted environments typically contains laser or LED powers in the safer class 1 or class 3A hazard level ranges. Therefore, automatic power reduction methods are less likely to be required for hazard level control. See annex B for other requirements. However, OFCS designers shall be aware of the restrictions in annex B regarding restricted and unrestricted environments, and incorporate APR into any system that has the potential to expose humans to laser or LED power of class 3B (class 3A for unrestricted) and above in these respective environments. Appropriate reliability precautions shall be taken when designing this power down system.

D.5.3.5 APR for ribbon cables

Use of ribbon cables can place the OFCS in a more restrictive hazard level. A careful hazard assessment, as explained in D.5.5, should take place, and appropriate APR, shuttering and splicing considerations should be evaluated and implemented with respect to the potentially increased hazard level and the environment of the OFCS.

D.5.4 Multiple fibres

The hazard from bundles of broken (i.e. not cleaved) fibre within a broken fibre cable does not increase beyond that of the worst case fibre within that cable. This has been shown by a considerable number of measurements on broken fibre ends, consideration of reflection and scattering at fibre ends, and random alignment and movement of fibre ends.

These measurements and considerations have also been shown to apply to broken ribbon fibre, but not to ribbon fibre cleaved as a unit (see D.5.5).

D.5.5 Ribbon cable

Ribbon fibre ends cleaved as a unit will exhibit a higher hazard level than that of a single fibre. An example would be eight fibres within a ribbon, each carrying a power level just within class 3A. Individually, they are of a relatively safe class 3A hazard level, but cleaved as an unseparated unit the hazard level becomes class 3B, thus presenting a genuine eye risk. This results from the small centre-centre separation distances of typical ribbon fibre of 150 µm to 250 µm. The low angular separation of several equally spaced fibres leads to a cumulative effect. At the measurement distance of 100 mm, the α of one singlemode fibre is $<<\alpha_{min}$ for cw emission (for $t > 10$ s, $\alpha_{min} = 11$ mrad, (see 9.3 d) of IEC 60825-1).

The angular subtense of the ribbon in its plane will depend on the number of fibres and their separation (for example an eight fibre ribbon with fibres spaced at 200 microns will subtend 14 mrad at 100 mm). If this subtense does not exceed α_{min}, the ribbon is considered as a point source. If the angular subtense in the ribbon plane is greater than α_{min}, then the ribbon may need to be treated as an extended source. Any angular dimension that is more than α_{max} or less than 1,5 mrad should be limited to α_{max} or 1,5 mrad respectively before determining the mean.

The total power permitted in the ribbon fibre is then the appropriate (point source or extended source) AEL and, in general, this would be divided equally between all fibres in the ribbon. IEC 60825-1 can be used for a more sophisticated analysis in order to identify any increase in peak powers permissible for ribbon cable arrays.

Ribbon fibre example calculation

<u>Example of calculation</u>:

The ribbon consists of eight equally spaced singlemode fibres. What is the maximum allowed class 1 cw output power per fibre for a wavelength of a) 1 300 nm, and b) 1 500 nm?

Solution for a)

The AEL value determines the summed emission for all eight fibres. The 8,85 mW has to be divided by the number of emitters, which leads to a maximum allowed power of 1,1 mW per fibre.

Solution for b):

At 1 550 nm the hazard for the cornea dominates. Consequently, there is no correction factor C6. The maximum power per fibre is simply the corresponding AEL for one source, divided by the number of fibres, i.e. 10 mW/8 = 1,25 mW.

Ribbon fibre issues

The additive property of the radiation hazard from ribbon fibre sources, therefore, means that the hazard level of a location can depend on the choice of cable type. As it may be impractical to be forced to switch off essential systems if they are designed for live maintenance, a solution will probably be required for reducing the hazard if ribbon fibres are to be used in fibre networks.

The solution may not be too difficult. As broken ribbon fibres do not present a problem, it is only the cleaving and splicing operations that require consideration. Separated ribbon, being no different to normal fibre, also does not present a problem.

If access to unseparated cleaved fibre end can be assuredly prevented, then, as the hazard level relates to ACCESSIBLE emission limits, the hazard level may be prevented from increasing. Any method would have to prevent access under reasonably foreseeable circumstances (i.e. not just an instruction "not to look"!). A possibility might be to use a cleaving tool that stayed attached to the cleaved fibre end until it was inserted into a ribbon splicer that likewise prevented access during the whole operation.

Once ribbon fibre is used in the network, it will be difficult to control what type of system is put onto it.

D.5.6 Power diminution due to power splitters and fibre losses

This may be taken into account, for example at the customer side of a distribution network, the hazard level after some length of fibre may be lower than at the distribution point.

Figure D.1 shows the layout of a typical passive optical network (PON).

D.5.7 General considerations and examples

a) The assessment of hazard levels shall always consider worst case conditions, including reasonably foreseeable fault conditions (see 4.4.2). Consequently, it may be necessary to include multiple fault conditions, the probability of which shall be judged by the responsible organization.

NOTE –Whereas IEC 60825-1 refers to single fault conditions, it may be reasonably foreseeable that more than one fault will combine to cause a dangerous situation.

b) Service conditions often result in higher hazard levels (see clause 5). These shall be considered by the responsible organization and persons. Examples are: the introduction of high power or amplified OTDR pulses into an operating fibre network; failure or overriding of the APR (see 4.3 j)); the system restart pulse.

c) Changing of components, system parameters or of the network structure may result in changed hazard levels. Examples are: replacement of conventional bundled fibre cables by ribbon cables (this may be beyond the direct supervision of the network manager); change of the modulation scheme; change in transmitter circuit pack power or wavelength; addition/change of optical amplifiers, etc.

D.6 Fault analysis

Fault analysis is essential for systems where the optical output is dependent on the integrity of other components and the performance of the circuit design. For hazard levels 1 and 3A systems, the probability of exceeding the class 3A accessible emission limits (under reasonably foreseeable circumstances) should not exceed 500 FITs. It is recommended that the manufacturer or operator should carry out a fault analysis.

Explanation and guidance

Fault analysis

The purpose of fault analysis is to identify failures in the optical control circuits that could have significant consequences affecting the safety classification. The lasers used in hazard level 3A systems may have the capability of emitting power levels in excess of the maximum hazard level 3A AEL limit. However, under normal operation, they operate within the hazard level 3A limit. A fault in a component in the laser drive circuit may increase the power emitted by the laser such that it exceeds the maximum permitted for its assigned classification. Thus, a hazard level 3A system may become hazard level 3B under fault conditions.

Fault probability levels

No system is 100 % fail-safe since there is always a non-zero probability that failures will occur. To quantify the risk of exposure to hazardous radiation, all laser drive circuits should be subject to fault analysis using recognized techniques. Fault analysis carried out on laser drive circuit designs demonstrate that a figure of less than 500 FITs is achievable. On the basis of this figure and the estimated amount of time an engineer works on live fibres throughout his working life, the incident rate for the risk of injury to the eye is less than five HITs. (For example in the UK, the Health and Safety Executive considers an occupational risk of less than 5,43 HITs for accidents to be trivial.)