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BSI Standards Publication

Fibre optic communication system design guides

Part 11: Multimode launch conditions

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

Part 11: Multimode launch conditions

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This publication contains an attached file titled, “Supplemental Data for Section 8”, in the form of an Excel Spreadsheet. This file is intended to be used as a complement and does not form an integral part of the standard.

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The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86C/1004/DTR	86C/1038/RVC

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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INTRODUCTION

At the meeting of IEC TC86 and its subcommittees and working groups at Cape Town in 2005, there were numerous discussions regarding the accuracy of attenuation measurements on multimode fibres, cables, passive components and installed cabling. Liaisons had also been received from ISO/IEC JTC SC25 WG3 that reported on the development of ISO/IEC14763-3 for testing fibre optic cabling in premises cabling. This standard used a mode power distribution template in an attempt to control the launch conditions to improve measurement accuracy and reduce uncertainty when testing the attenuation of multimode fibre optic cabling.

It was decided to set up a “Multimode Launch Co-ordinating Group” referred to as MMLCG. This would be set up directly reporting to TC86 and include representatives from interested persons in Subcommittees 86A, 86B and 86C as well as ISO/IEC JTC1 SC25 WG3. The scope of this group was defined as:

“To coordinate the harmonization of the variety of multimode modal launch conditions that exist within the documents being prepared and published by the subcommittees of TC86 for the purpose of attenuation and return loss measurements.”

The intent of this technical report is to keep available the key technical aspects issued by the MMLCG.

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FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

Part 11: Multimode launch conditions

1 Scope

This technical report is intended to show the background of encircled flux for the characterisation of multimode launch conditions. This includes the selection of the encircled flux and the definition of the encircled flux requirements in conjunction with the implied variation in attenuation measurements.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61280-1-4:2009, *Fibre optic communication subsystem test procedures – Part 1-4: General communication subsystems – Light source encircled flux measurement method*

IEC 61280-4-1:2009, *Fibre optic communication subsystem test procedures – Part 4-1: Installed cable plant – Multimode attenuation measurement*

IEC 62614:2010, *Fibre optics – Launch condition requirements for measuring multimode attenuation*

IEC 61745, *End-face image analysis procedure for the calibration of optical fibre geometry test sets*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
coupled power ratio
CPR
difference, expressed in dB, between the power exiting a multimode fibre and the power exiting a single-mode fibre concatenated to the same multimode fibre with the same launching conditions

NOTE TO ENTRY: See also Annex A.

[SOURCE: IEC 62614:2010]

3.2
differential mode attenuation
DMA
variation in attenuation among the propagating modes of a multimode optical fibre

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3.3
encircled flux
EF
fraction of the radial-weighted cumulative near field power to the total radial-weighted output power as a function of radial distance from the optical centre of the core

[SOURCE: IEC 61280-1-4:2009]

3.4
mode power distribution
MPD
relative mode power in each of the mode groups of a multimode fibre, often shown graphically

3.5
overfilled launch
OFL
controlled launch where all modes of the fibre are ideally excited with the same optical power

3.6
relative power distribution
RPD
metric used to determine launch conditions in terms that are relative to a light source's overall launched power

4 Background

When launched into multimode fibre, LED and laser sources used in measuring link attenuation may exhibit varying modal power distributions. These differing modal power distributions, combined with the differential mode attenuation (DMA) inherent in most multimode components, commonly cause measurement variations when measuring the attenuation. For example, attenuation measurement variations can occur when two similar light sources or different launch cords are used. For many legacy networking technology applications, the measurement uncertainty due to variation in launch conditions was not a large concern. The application requirements simply were not that demanding. Therefore, most standards that specified launch conditions for attenuation measurements did so with an understanding of the measurement uncertainty effect. As the technology has evolved, system requirements for attenuation have become more stringent. In turn, this has led to requirements for lower loss optical components, particularly fibre optic connectors and especially "reference grade terminations," to be used on test cords, which should have a loss per connection of less than 0,1dB. Demanding application and component requirements are driving the need for more accurate and reproducible multimode attenuation measurements among a variety of field and factory test instruments.

Attenuation measurement experiments using different field test instruments that meet existing launch prescriptions (i.e. those defined by coupled power ratio (CPR) and mandrel wraps) have shown variations induced by their differing launch conditions, which are significant relative to the more stringent power budgets of applications running at 1 Gb per s or higher. To reduce this variation in measurements, this technical report reviews some launch condition options and recommendations for test instrument suppliers, component manufacturers and installers.

5 Metrics for multimode launch conditions

5.1 General

The objective of the Multimode Launch Co-ordinating Group was to define limits on the near-field of the source so the source induced variation of measured attenuation is within 10 % of the attenuation obtained when using the ideal source, which has to be defined. In other

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words, to define quantitative requirements (a metric) based on near-field measurements so that the variation in attenuation values associated with these limits is known.

5.2 Coupled power ratio (CPR)

The measurement of the coupled power ratio is the first characterisation of the launch condition. It has been commonly used. This is the measurement of the ratio of the total power from a multimode fibre to the power measured when a single mode fibre is coupled to the multimode fibre.

Annex B provides details on CPR evaluation.

It has been demonstrated by mathematical analysis of the CPR characteristic that the CPR cannot be used to regulate the source power distribution at large radii.

5.3 Mode power distribution / relative power distribution (MPD/RPD)

Limits on mode power distribution were tentatively introduced to improve the CPR metric.

The mode power distribution metric (MPD) was defined based on the measurement of near field intensity $I(x)$.

The mode transfer function is first defined by

$$I(r) = \int_{\delta(r)}^{\Delta} \mathrm{MTF}(\delta)\,d\delta \quad \text{and} \quad \delta(r) = \Delta\left(\frac{r}{a}\right)^{\alpha} \qquad (1)$$

where

a is the fibre radius

α is the profile factor

Δ is the relative index difference

The mode power distribution (MPD) is then calculated

$$\mathrm{MPD}(m') = \mathrm{MTF}(m')\,m' \quad \text{and} \quad m' = \frac{m}{M} = \left(\frac{\delta}{\Delta}\right)\hat{}\left(\frac{2+\alpha}{2\alpha}\right) \qquad (2)$$

where

M is the total number of modes

m is the discrete mode group number

Limits on the MPD function were defined but it has not been possible to associate these limits to a variation of the attenuation.

The RPD is very similar to Formula (1), but is written out as an integration in relative mode value, m', or m''.

$$\mathrm{RPD}(m'') = \int_{m''}^{1} \mathrm{MTF}(m')\,dm' \qquad (3)$$

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5.4 Encircled flux (EF)

The encircled flux function $EF(r)$ is defined from the near field measurement of the light coming from the end of the test cord

$$EF(r) = \frac{\int_0^r xI(x)dx}{\int_0^R xI(x)dx} \tag{4}$$

where

$I(x)$ is the near field intensity.

The function is then compared to the radial bound requirements that were defined with the aim of maintaining uncertainties attached to launch conditions below 10 %.

The encircled flux target is defined in IEC 62614:2010.

The encircled flux limits around this target are defined for installed fibre optic cabling in IEC 61280-4-1:2009. Currently, the same limits have also been applied for testing connectors, although it is recognised that tighter limits may be desirable as encircled flux measurement capability improves, in order to maintain a 10 % variation in insertion loss for lower loss components such as individual connectors.

The requirements for the measurement and the process details are defined by IEC 61280-1-4:2009. The calibration procedure is given in IEC 61745.

Clause 7 details theory and assumption for the radial bound requirements.

6 Uncertainties

6.1 General

Any measurement should be associated with the appropriate evaluation of the uncertainties. ISO/IEC Guide 98-3, also known as the GUM (Guide to the expression of uncertainty in measurement), provides all necessary information for this evaluation.

This part of the technical report provides a simplified analysis of the link attenuation measurement using the three cords method (See IEC 61280-4-1:2009, Annex C).

6.2 Measurement model and uncertainties

The measured value of the attenuation is determined from two power level measurements P_1 and P_2. The attenuation, L, is given by the following formula

$$L = 10\log_{10}\left(P_1 / P_2\right) \text{ (dB)} \tag{5}$$

The measurement uncertainty of insertion loss, L, can be calculated from the contribution of each contributing element using the standard formula for accumulation of the uncertainties

$$u(L) = \sqrt{u_{\text{setup}}^2 + u_{\text{ref}}^2 + u_{\text{rand}}^2} \tag{6}$$

where

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u_{setup} is the uncertainty due to the setup (source, environment …) (see 6.3)
u_{ref} is the uncertainty of the power meter (see 6.4)
u_{rand} is the uncertainty due to the fibre manipulation and to launch conditions (see 6.5)

6.3 Uncertainty due to the setup

The following uncertainties may come from the setup

a) uncertainty due to the source power instability (e.g. the variation of the output power versus time and environment)

b) uncertainty due to the insertion loss stability of the source connector versus time and environment

c) reaction of the source to the variations of back-reflections

Uncertainty values should be available from the source documentation.

6.4 Uncertainty due to the power meter

The uncertainties related to the power meter are mostly

a) non-linearity of the power meter

b) display resolution

c) all random uncertainties associated with the power level measurement

Uncertainty values should be available from the power meter documentation.

Note that the absolute uncertainty of the power meter does not impact the measurement. This is because the insertion loss is equal to the ratio between two power levels, P_1 and P_2, measured using the same power meter shown in Formula (5).

The absolute calibration error of the power meter is expressed by a correction factor, Cf, which should be used to correct the read value

$$P_i = Cf \times Pread_i \tag{7}$$

Therefore, it is clear that the correction factor has no effect on the insertion loss formula.

$$L = 10\log_{10}\left(Cf \times Pread_1 / Cf \times Pread_2\right) = 10\log_{10}\left(Pread_1 / Pread_2\right) \text{ (dB)} \tag{8}$$

For the same reason, the wavelength dependence of the power meter does not impact the measurement.

6.5 Random uncertainties

6.5.1 Uncertainty due to fibre manipulation

Fibre manipulations generate some random variations of the connector's loss.

The amplitude of such variations can be estimated using more than 10 repeated measurements of the reference power, $P_{1,\text{k}}$, associated with repeated connection and disconnection of the substitution cord. Then the estimation of the uncertainty, u_{manip}, is provided by the following calculation process.

First, calculate the arithmetic mean of the power $\overline{P}$:

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$$\overline{P} = \frac{1}{n}\sum_{k=1}^{n} P_{\mathrm{k}} \tag{9}$$

Then calculate the experimental standard deviation:

$$s_{typeA} = \left[\frac{1}{m-1}\sum_{i=1}^{m}\left(y_i - y_{mean}\right)^2\right]^{1/2} \tag{10}$$

where

$\overline{P}$ is the arithmetic mean of the reference power;

P_{k} are the measurements of the reference power;

n is the number of measurements.

The uncertainty, u_{manip}, is the experimental standard deviation of the mean:

$$\sigma_{typeA} = \frac{s_r}{\sqrt{n}} \tag{11}$$

6.5.2 Uncertainties due to launch conditions

The encircled flux limits defined by IEC 62614:2010 were intended to constrain loss variation, relative to the loss measured by a source exactly on the target launch, to be no greater than the larger of ± 10 % (on a dB basis) or the threshold value (see IEC 62614:2010, 5.6)

For example, a threshold value of 0,08 dB means that the loss variation is usually expected to be within ± 10 % for losses equal to or greater than 0,8 dB, and within 0,08 dB for losses less than 0,8 dB.

Figure 1 provides uncertainty values to be used for a given measured loss (having different wavelengths and fibres). This is a graphic representation of IEC 62614:2010, Table 5.

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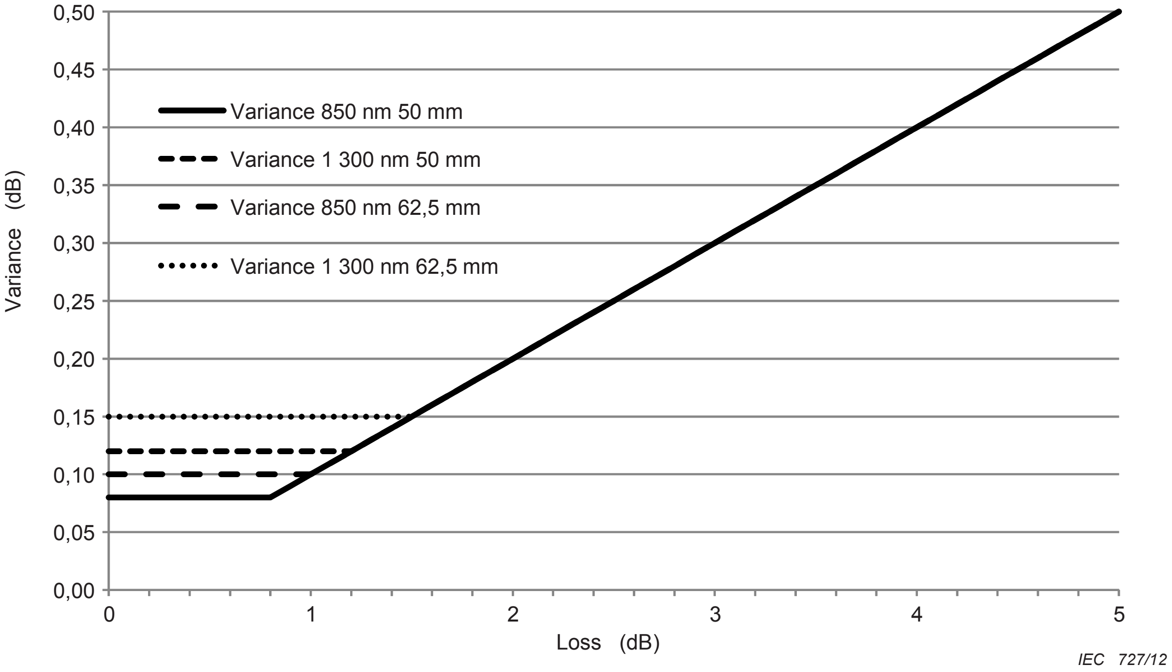

Figure 1 – Uncertainties due to the launch conditions for a given loss

NOTE In the insertion loss model, the uncertainties come from a limited number of connectors. The number of connectors is too small to allow the validity of the central limit theorem, therefore the distribution of the uncertainty should be considered as rectangular.

6.6 Example of uncertainty accumulation

Table 1 provides a typical presentation of the results.

Table 1 – Uncertainties accumulation

Uncertainty components			
Light source stability	0,03	dB	K=2
Light source connector stability	0,03	dB	maximum
Other light source instability	0,005	dB	maximum
Power meter linearity	0,04	dB	K=2
Power meter resolution	0,001	dB	maximum
Uncertainty of manipulation	0,08	dB	K=1
Uncertainty attached to LC	0,2	dB	2 dB attenuation

Source	**Units**	**Distribution**	**Value** U **or** a	**Divisor**	u_i	$(u_i,c_i)^2$
Light source stability	dB	Normal	$6,932 \times 10^{-03}$	2,0000	$3,466 \times 10^{-03}$	$1,20 \times 10^{-05}$
Light source connector stability	dB	Rectangular	$6,932 \times 10^{-03}$	1,7321	$4,002 \times 10^{-03}$	$1,60 \times 10^{-05}$
Other light source instability	dB	Rectangular	$1,152 \times 10^{-03}$	1,7321	$6,651 \times 10^{-04}$	$4,42 \times 10^{-07}$
	Sum					$2,85 \times 10^{-05}$

Source	Units	Distribution	Value U or a	Divisor	u_i	$(u_i,c_i)^2$
Power meter linearity	dB	Normal	$9,253 \times 10^{-03}$	2,0000	$4,626 \times 10^{-03}$	$2,14 \times 10^{-05}$
Power meter resolution	dB	Rectangular	$2,303 \times 10^{-04}$	1,7321	$1,330 \times 10^{-04}$	$1,77 \times 10^{-08}$
	Sum					$2,14 \times 10^{-05}$

Source	Units	Distribution	Value U or a	Divisor	u_i	$(u_i,c_i)^2$
Uncertainty of the manipulation	dB	Normal	$1,859 \times 10^{-02}$	1,0000	$1,859 \times 10^{-02}$	$3,46 \times 10^{-04}$
Uncertainty attached to LC	dB	Rectangular	$4,713 \times 10^{-02}$	1,7321	$2,721 \times 10^{-02}$	$7,40 \times 10^{-04}$
	Sum					$1,09 \times 10^{-03}$

Combined standard uncertainty, $u(L)$	$3,37 \times 10^{-02}$
Expanded uncertainty, $U=ku(L)$, with k=2	$6,74 \times 10^{-02}$
Expanded uncertainty expressed in dB	0,28

NOTE The accumulation of uncertainties is the accumulation of the linear values, so the values in the “Value” column of the table are converted from the “dB” values provided at the top of the table.

7 Encircled flux envelope – theory and assumptions

7.1 Mode field eigenfunctions

The optical field intensity of multimode optical fibre is comprised of a number of discrete individual modes which depend in detail on the refractive index profile and wavelength. For the purposes of this standard, the infinite parabola model assumption for the refractive index profile is used. This results in mode fields that have been variously reported [4, 5][1] as Laguerre-Gauss polynomials in circular coordinates, (r,θ) or Hermite-Gauss polynomials in rectilinear coordinates (x,y) [6, 7].

NOTE Real fibres are neither exactly parabolic nor circular. However, the simplified theory has been found to yield reasonable results on limiting the effects of launching cord near field variations to variance in measured attenuation.

The infinite parabola model is defined as

$$n^2(r) = n_{co}^2\left(1 - 2\Delta R^2\right) \tag{12}$$

where

$$\Delta = \frac{n_{co}^2 - n_{SiO_2}^2}{2n_{co}^2} \quad R = \frac{r}{a}$$

n_{co}^2 is the refractive index at the core centre

$n_{SiO_2}^2$ is the refractive index of the cladding

a is the core edge (μm)

r is the radius (μm)

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[1] Figures in square brackets refer to the Bibliography.

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The parameters, V and ξ, which are combinations of these parameters along with wavelength, λ, are used in the calculations

$$V = kan_{co}(2\Delta)^{1/2} \quad \xi = \frac{\sqrt{V}}{a} \tag{13}$$

where

$k = 2\pi / \lambda$

λ is in the same units as a.

The modes combine into mode groups that are indexed by g. The individual modes are indexed either (l,n) for Laguerre-Gauss or (p,q) for Hermite-Gauss. The total number of mode groups, n_g, is V/2.

The Laguerre-Gauss mode fields are given as

$$\psi_{l,n}(r,\theta) = (r\xi)^l L\left(n,l,(r\varepsilon)^2\right)\exp\left[-(r\xi)^2/2\right]\Phi(\theta) \tag{14}$$

where

$L()$ is the Laguerre polynomial

$\Phi(\theta)$ is either $\sin(l\theta)$ or $\cos(l\theta)$

The mode field is scaled for unit power $\int_0^{2\pi}\int_0^{\infty} r\left(\psi(r,\theta)\right)^2 dr\, d\theta = 1$. The mode group number, g, is given by $g = 2n + l + 1$. For l>0, there are two modes for each l,n permutation.

The Hermite-Gauss mode fields are given as

$$\psi_{p,q}(x,y) = h_p(x\xi)h_q(y\xi)\exp\left\{-\left[(x\xi)^2 + (y\xi)^2\right]/2\right\} \tag{15}$$

where

$h_x()$ is the Hermite polynomial,

the mode group, g, is given by $g = p + q + 1$,

and the mode is scaled for unit power $\int_{-\infty}^{\infty} h_x(x\xi)^2 \exp\left(-(x\xi)^2\right)dx = 1$.

It is assumed that the modes within a mode group exchange power within a few metres of propagation, which results in equal power for all the modes within a group. In addition, it is assumed that all modes act as uncorrelated sources. This allows a reduction of the number of terms to the number of mode groups, each defined as the sum of squares of the mode field eigenfunctions within the group.

NOTE Depending on the coherence of the source, these simplifying assumptions are not valid. However, the simplified theory has been found to yield reasonable results on limiting the effects of launching cord near field variations to variance in measured attenuation.

The mode group eigenfunctions (MGE) are given as

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$$\Psi_g^2(r) = \frac{1}{g} \sum_{l,n:g=2n+l+1} \int_0^{2\pi} \psi_{l,n}^2(r,\theta) d\theta = \frac{1}{g} \sum_{p,q:p+q+1=g} \int_{x^2+y^2 \le r^2} \psi_{p,q}^2(x,y) dxdy \tag{16}$$

The near field is a linear combination, or weighted total, of the MGEs. That is

$$I(r) = \sum_g w_g \Psi_g(r) \tag{17}$$

If the near field is normalized to unit total power, then the sum of the weights is one, and the encircled flux is

$$EF(r) = \sum_g w_g \int_0^r x \Psi_g^2(x) dx \tag{18}$$

For an ideal OFL launch, the weights are proportional to the mode group number.

7.2 Connections, attenuation and the encircled flux template

At connections of two optical fibres, the mode fields of the input optical fibre combine with the mode fields of the receiving optical fibre so the power is exchanged. Power that is not exchanged is lost and results in attenuation.

The exchange of power can be expressed as a mode coupling matrix, C, that maps the input mode group weights to the mode group weights in the receiving optical fibre as

$$\vec{w}_{OUT} = C\vec{w}_{IN} \tag{19}$$

where

the mode group weights are now expressed in vector format.

Subclause 7.4 has more information on the calculation of the coupling matrices.

The output power is the sum of the output weights. The attenuation is -10log$_{10}$ of the output power divided by the input power. When the input power is normalized to one, the attenuation is seen to be related simply to the vector product of the column sum of the C matrix with the input weight vector as

$$P_{\mathrm{OUT}} = \vec{1}^T C \vec{w}_{\mathrm{IN}} \tag{20}$$

where

$\vec{1}^T$ is the transpose of a vector of ones.

As the input weights are varied, the output power and attenuation will change depending on the characteristics of the coupling matrix.

For a concatenation of connections, the coupling matrix is determined for each connection. These are then multiplied together in series to yield a combined coupling matrix.

The target near field is expressed as a target set of input weights that yields the target encircled flux and a target output power for each of a number of assumed concatenations of

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lateral offset connections. Each such concatenation results in a different coupling matrix and a different output power response to alternative weights.

The objective to limit the variation in attenuation to within ±10 % of the target attenuation leads to output power limits for each assumed concatenation. These limits lead to an ability to determine whether a set of alternative weights will meet the requirement for all concatenations. This could be done by inserting the alternative weights into Formula (8) for each concatenation and comparing the results to the defined limits. This would, however, entail a determination of weights for a given near field, which is non-trivial.

An alternative based on linear programming leads to the encircled flux template. The combination of the assumed coupling matrices and output power limits form a system of linear constraints. Any set of weights (summing to one) will also yield an encircled flux curve using Formula (7), which is also a linear combination. For each of a finite number of radial values, the encircled flux is either maximized or minimized with respect to the alternative weights and the constraint set. These extrema, plotted versus radius, form the encircled flux template.

The constraint set is augmented by also posing constraints that the alternative weights must each be within ±75 % of the target weights. These additional constraints guard against the possibility of some very peculiar input near fields that could have adverse effects on concatenations that are not covered by the assumptions. This last constraint set is called the shape constraint.

The constraints used involve both a two connection concatenation and a five connection concatenation. For each, four common lateral offsets of 2 μm, 3 μm, 4 μm and 5 μm are applied to yield a total of eight power constraints.

By varying the constraints in the investigative phase the following observations are made:

- As the number of concatenations or lateral offset magnitude is increased, the encircled flux limits at lower radial values get tighter.
- Adding small offsets with fewer concatenations tightens the encircled flux limits at the upper radial values.
- The target weights and target encircled flux are substantially overfilling compared to the steady state near field associated with any of the concatenations.

7.3 Target weights

The target weights for 50 μm optical fibre at 850 nm have been studied most extensively.

They evolved from a concatenation experiment in which the near fields seemed to stabilize. Following this, the following main observations were made:

- The results were very close to the upper limit of the 10 Gb per s Ethernet limit for transmitters, which means that using it would be conservative; i.e. if the cabling ‘passed’ when tested using this metric then it would be certain to support 10Gb per s Ethernet.
- The results were very close to an OFL followed by an 18 mm to 20 mm mandrel with five turns. This is close to what had been defined in some standards as the requirement for testing in premises cabling.

The DMA function from a 20 mm mandrel with five turns and lit with an OFL was determined by fitting the measurement data to the Laguerre-Gauss model and comparing the weights from the OFL to the weights from OFL plus mandrel. This allowed an identification of the form of the DMA function, which was then adjusted slightly to obtain a better agreement with the original target. This was done to generate a target near field with the tails intact. The tails had been truncated in the original data.

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This was effected before the coupling matrix calculations were revisited. The creation of coupling matrices allowed a different way to define weights that

- is based on a theoretical concatenation of offsets lit with OFL
- is in good agreement with the weights derived empirically
- allows a determination and comparison with steady-state weights
- allows a calculation of a physically possible encircled flux curve that corresponds with the outside of the range of expected transmitters.

NOTE Steady state weights depend on the coupling matrix and are such that the output weights are proportional to the input weights.

Figure 2 shows the comparison.

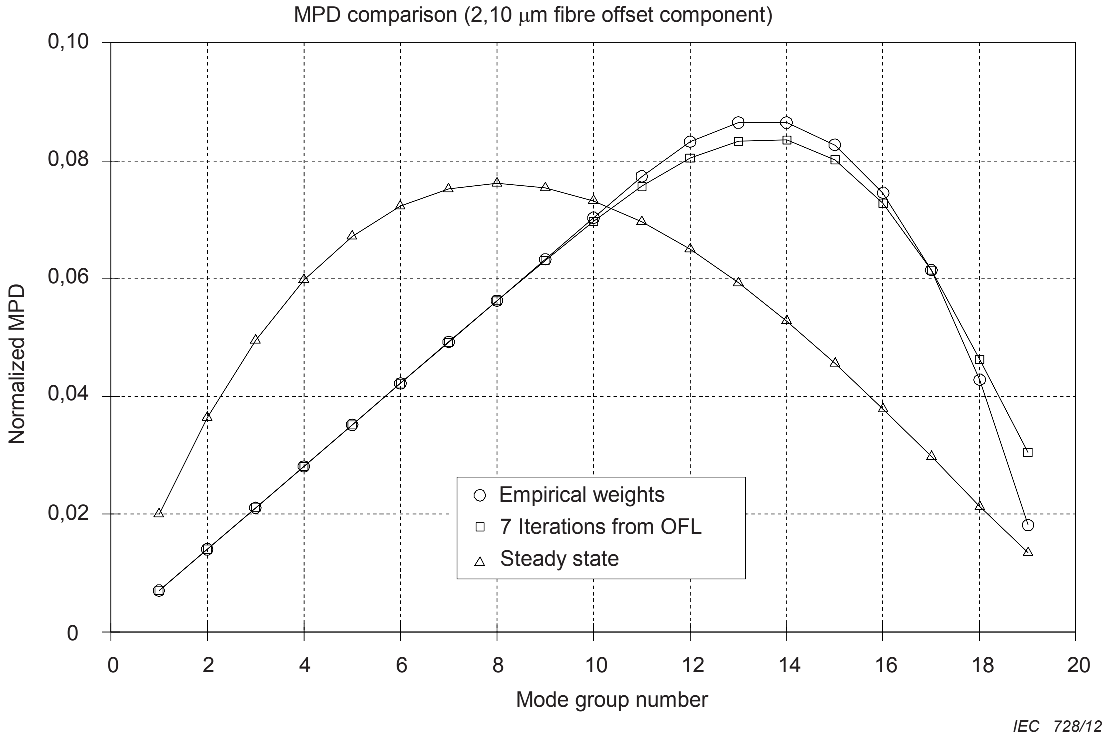

Figure 2 – Comparison of target weights

A first concatenation-based target was defined with a concatenation of seven offset connections of 2,1 µm lit with OFL. After study and consideration of the resultant encircled flux curves, it was decided to further adjust the target to a slightly more filled state by a definition based on a concatenation of seven offset connections of 2,0 µm lit with OFL.

Some of the other features of the 50 µm optical fibre, 850 nm target are as follows

- Several LEDs have been observed to result in a passing encircled flux with no mandrel or other conditioning. They are naturally underfilling, but not too underfilling. This also gives an indication that the target launch tends to simulate the output of these devices.
- The theoretical coupled power ratio with a 6 µm single-mode optical fibre is 21,5 dB.
- The incremental attenuation induced by adding connections at different points in the link is a strong function of link location when OFL is used as the source. With the target launch, this dependence is much reduced. This means that if the target launch were used for single connectors, the attenuation values would be applicable to the incremental attenuation of links into which they are placed – more or less independently of placement.

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- Variance in the measured connector attenuation due to lateral offset variations can be essentially eliminated by using a substantially underfilled source such as VCSELs. The launch can be so restricted that the light does not have any power in the attenuating region. This type of launch would fail to discriminate between different levels of offset that are of interest. The target launch does allow discrimination between such offsets.

These last two points are illustrated in Figure 3 and Figure 4.

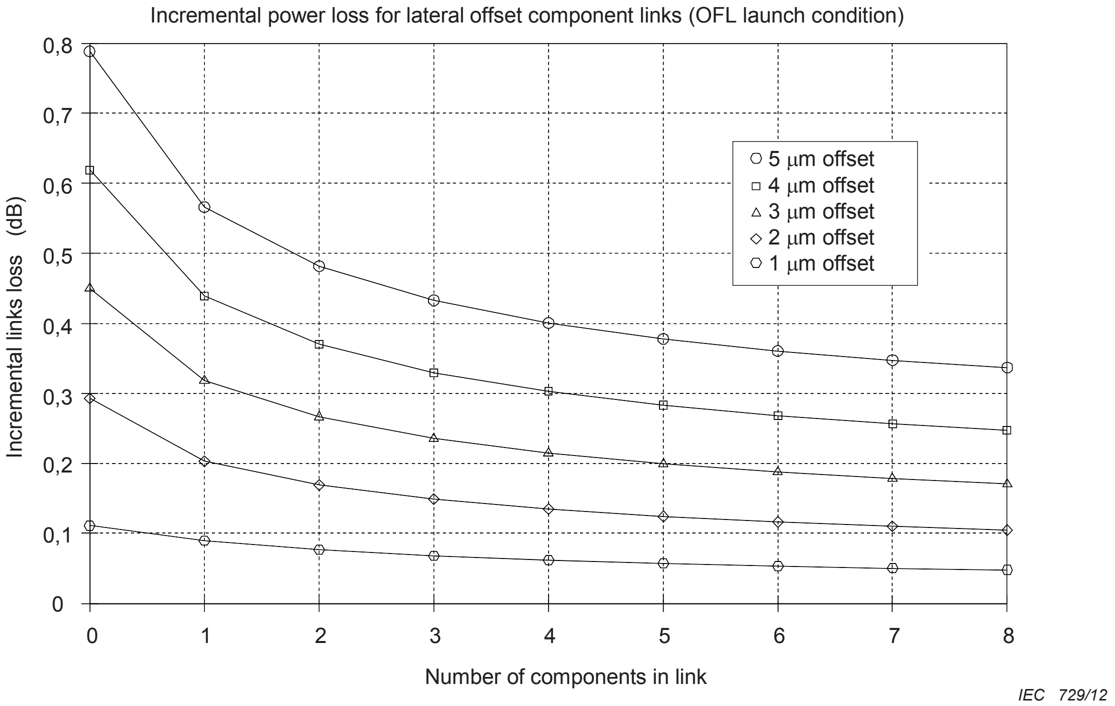

Figure 3 – Incremental loss using OFL launch

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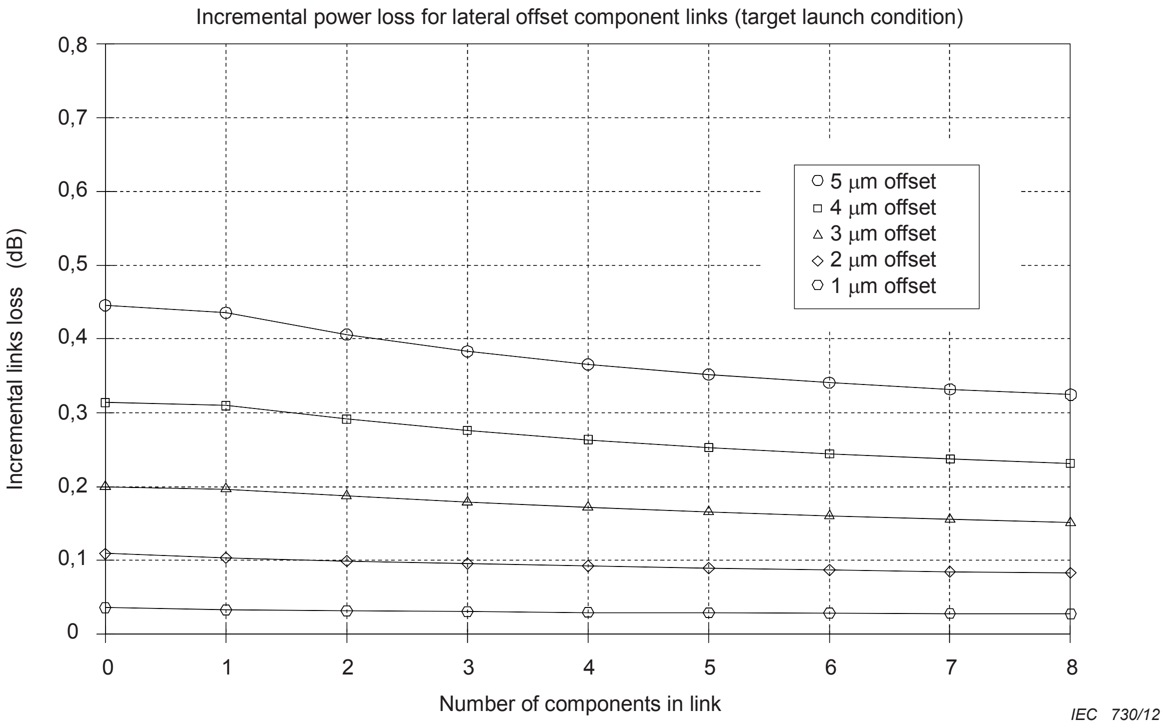

Figure 4 – Incremental loss using target launch

The target weights for 50 µm optical fibre at 1 300 nm are derived from the coupling matrix for seven concatenations of 2,0 µm lateral offsets. One difference is that the number of modes and mode groups is smaller at 1 300 nm, so the coupling matrix dimension and composition is different.

The target weights for 62,5 µm optical fibre at both 850 nm and 1 300 nm are based on a concatenation of four 2,34 µm lateral offsets lit with OFL. This results from a determination of weights which produced encircled flux curves that match experimental results of a measurement of a nominal 62,5 µm optical fibre that was lit with OFL and with a five turn 20 mm mandrel applied.

7.4 Coupling matrix calculations

This describes the coupling matrix calculations in terms of the Hermite-Gauss mode field eigenfunctions that are defined in 7.1. The calculations are essentially overlap integrals of each transmitted mode field with each receiving mode field. The transmitting modes are designated with r and s to distinguish them from the receiving modes which are designated with p and q. The lateral offset is designated with the variable, d.

For each combination of all possible values of the mode indices, calculate the overlap integrals

$$\delta_{p,q,r,s}(d) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \psi_{p,q}(x,y)\psi_{r,s}(x-d,y)dydx \tag{21}$$

The separability of the x and y parts of the Hermite-Gauss formulation allows the integration to be done for the y components independently from the x components.

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The rows of the coupling matrix correspond to the receiving mode groups and are labelled with i. The columns of the coupling matrix correspond to the transmitting optical fibre mode groups and are labelled with j. The elements, $c_{i,j}$, are given as sums of squares of the $\delta_{p,q,r,s}$ values. The p, q indices resulting in receiving mode group i are summed into the rows and the r, s indices resulting in transmitted mode group j are summed into the columns:

$$c_{i,j} = \frac{1}{j} \sum_{p,q:p+q+1=i} \quad \sum_{r,s:r+s+1=j} \delta^2_{p,q,r,s} \tag{22}$$

The parameters describing the two optical fibres may be different, which can result in different eigenmodes and numbers of mode groups for the transmitting and receiving optical fibres.

For the coupling matrices used in the definition of the target weights and in the loss limit constraints, the core radius parameter, a (see Formula (1)), is 25 µm for 50 µm core optical fibre and 31,25 µm for 62,5 µm core optical fibre. The delta parameters used are 0,01 and 0,019 for the two optical fibre sizes, respectively. The value used for the refractive index of silica is 1,452 498 2.

8 Wavelength bias correction to EF targets/limits with spectrally broad sources

8.1 General

Experimental results indicating a bias between 850 and 1 300 nm measurements were demonstrated. As a result, there was a request to re-evaluate the encircled flux (EF) targets to remove the bias. The experiments, however, are typically done with LEDs.

The conclusion was that if one hit the EF target using LEDs, one would obtain attenuation values larger than if one used a monochromatic source. The effect seen was larger, as a percentage, for lower attenuation conditions than for higher attenuation conditions. However, the increase was not seen in the values calculated for 1 300 nm. For 62,5 µm fibre, the opposite relationship emerged. The combined effect would produce biases. This section provides the approach and results for a bias correction to the EF target/limits with spectrally broad sources.

8.2 Modified spectrum assumptions

The Hermite-Gauss assumptions and fibre parameters documented in Clause 7 are used.

Since the calculations can be done for only one discrete wavelength at a time, it has been assumed that the spectrum is comprised of 19 individual wavelengths. The spectrum, $S(\lambda)$, is assumed to follow the raised cosine with parameter, W (FWHM), as

$$S(\lambda) = \cos^2\left(\left(\frac{\pi}{2}\right)\frac{(\lambda - \lambda_0)}{W}\right) \tag{23}$$

The stopping points are at λ-λ_0 = ± 0,9 W. The spectral power values are normalized so the sum is one before application to the other aspects of modal power.

For 850 nm sources, the width is 50 µm FWHM. For 1 300 nm sources, the width is 120 nm FWHM. These widths correspond to approximately the midpoint of the current allowed ranges.

The launch for each wavelength is initiated with an ideal theoretical OFL that is subsequently filtered by application of multiple offset connections. A common set of connections is used for

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each wavelength, but the effects vary from wavelength to wavelength because the number of mode groups and mode field shapes change with wavelength.

The launches are adjusted by changing the number of offset connections and the magnitude of the offsets that are used. For all cases, common offset magnitudes are used for all connections used in a given launch. This allows the calculation of a single mode group coupling matrix for a given offset magnitude at each wavelength. Combining these in a number of concatenations is therefore simplified and yields a set of nineteen mode group weights for a given launch.

The mode group coupling matrices are done with overlap integrals of the offset mode fields. These integrals are done with Gaussian quadrature and have been independently verified.

Similarly, the DMA function of the conditions evaluated for attenuation is done for each discrete wavelength. The dot product of the mode group weight and the DMA for a given wavelength yields the output power for the wavelength. The spectrally weighted sum of output powers yields the total output power which is evaluated for attenuation.

Application of the mode group weights to the encircled flux functions, which also vary with wavelength, yields an encircled flux for each wavelength. The spectrally weighted sum of these EF functions yields the overall EF results

8.3 Determining the EF targets

When the launching weights for each wavelength are applied to a concatenation representing “cabling,” there is an output power for each wavelength. The spectrally weighted total output power is used to compute the attenuation of the cabling.

A range of launch conditions were evaluated for proximity to the EF targets. From one to twenty concatenations of from 0,5 μm to 4,5 μm, in increments of 0,01 μm, were checked. For the “cabling,” one, two or five concatenations of 1 μm to 5 μm were evaluated for the resulting attenuation. The variance to target is reported as a percent of target attenuation. This allows calculation of the average percent variance of all the one, two or five connection sets.

The launch that best matches the target for each condition is reported in Table 2 for 50 µm multimode fibre at 850 nm and 1 300 nm. Additional matrices are in the referenced Microsoft Excel file labelled “Supplemental Data for Section 8” including 62,5 µm multimode fibre.

Table 2 – Percent variation for best fit against target to derive adjustment for encircled flux for 50 μm MMF

	850 nm		1 300 nm	
Link_ concatenation	**Monochromatic target attenuation** (dB)	**Best fit: 1 concatenation** (% diff)	**850 LED target attenuation** (dB)	**Best fit: 1_2** (% diff)
1_1	0,036 0	3,52	0,037 3	-14,69
2_1	0,069 6	2,34	0,071 2	-12,15
5_1	0,162 6	0,34	0,163 1	-8,84
1_2	0,110 7	1,16	0,112 0	-0,01
2_2	0,216 1	-0,49	0,215 1	-0,93
5_2	0,508 0	-1,77	0,499 0	-2,24
1_3	0,203 7	-0,91	0,201 9	3,73
2_3	0,404 4	-1,75	0,397 3	1,41
5_3	0,950 4	-1,9	0,932 4	-0,5
1_4	0,320 1	-1,77	0,314 5	1,53

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	850 nm		1 300 nm	
Link_ concatenation	**Monochromatic target attenuation** (dB)	**Best fit: 1 concatenation** (% diff)	**850 LED target attenuation** (dB)	**Best fit: 1_2** (% diff)
2_4	0,635 1	-2,02	0,622 2	-0,04
5_4	1,474 5	-1,52	1,452 1	-1,01
1_5	0,454 6	-2,11	0,445 0	0,6
2_5	0,896 1	-1,9	0,879 1	-0,49
5_5	2,059 7	-1,07	2,037 6	-0,97

For 850 nm, the target is the current monochromatic target. For 1 300 nm, the target is the output of the 850 nm target that is selected. The best fit target launch was based on various criteria. For 850 nm, the outcome of adding the dB difference to target is calculated. These form the target attenuation for 1 300 nm. In Tables 3 and 4, the adjusted calculated target for both 850 nm and 1 300 nm of 50 µm multimode fibre is shown.

Table 3 – Encircled flux adjustment at 850 nm for 50 µm multimode fibre

Encircled flux	10	15	20	22
Monochromatic (target)	0,325 2	0,640 0	0,909 7	0,970 6
1 concatenation (adjustment)	0,335 0	0,655 0	0,919 3	0,975 1

Table 4 – Encircled flux adjustment at 1 300 nm for 50 µm multimode fibre

Encircled flux	10	15	20	22
850 LED (target)	0,329 9	0,647 7	0,9162	0,972 7
1_2 (adjustment)	0,336 6	0,656 7	0,9186	0,972 8

The selected launches produce a balanced set of differences to target for all cases.

8.4 Determining the EF limits

Two approaches to finding the EF limits using the exhaustive search approach can be used. These are distinguished by the risk emphasis.

a) If a launch passes all the attenuation variance requirements, enlarge the EF limits to include it.

b) If a launch fails any attenuation variance requirement, shrink the EF limits to exclude it.

Approach a) is essentially the rule that yielded the current monochromatic limits, since the infinite 19 dimensional space can be explored using a simplex algorithm for each candidate control radius. The approach can yield some “unphysical” results though, so the space was further reduced by using the “shape constraint”.

One difference of the simplex versus the exhaustive search algorithm used for broad spectrums is that the exhaustive search does not actually explore the whole of the huge

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space that could be possible. For example, random offset connections or mandrels of various bend radius and wraps could be envisioned.

A solution for the limits based on simplex could be used. This is done by making a simultaneous solution to all the mode group weights for all wavelengths: Minimize or maximize the spectrally weighted EF while staying within the spectrally weighted output power limits (and maintain some shape factor constraint). However, this would not provide a final answer that reflects the fact that there should be a certain correlation of the mode group weights at one wavelength to the others.

Approach a) is essentially to minimize the producer risk (instrument maker being the producer). If a launch is not ruled out by attenuation, it is allowed in EF. There are, in the end, launches that pass the resultant EF that fail attenuation at some conditions.

Approach b) is essentially to minimize the customer risk (test lab being the customer). If a launch is ruled out by attenuation, it is not allowed in EF. In the end, the EF limits generated by this rule will fail many launches for which the attenuation passes all limits.

Both approaches were tried. Approach b) yielded limits that seemed impractically narrow. Even approach a) yielded limits that are tighter than the current limit width. For both cases, a third pass, to check the results, was made. This is described in the next section.

Table 5 displays the resulting encircled flux limits for 50 µm multimode fibre at 850 nm and 1 300 nm. Recall that the tolerance thresholds vary by wavelength and fibre size as shown in Table E.1 of IEC 61280-4-1:2009.

Table 5 – Calculated encircled flux limits for 50 µm multimode fibre at 850 nm and 1 300 nm

	850 nm			1 300 nm		
EF radius	**EF (min)**	**EF (target)**	**EF (max)**	**EF (min)**	**EF (target)**	**EF (max)**
10	0,323 2	0,335	0,361 2	0,322 6	0,336 6	0,360 8
15	0,637 7	0,655	0,684 1	0,636 5	0,656 7	0,683 4
20	0,910 5	0,919 3	0,928 1	0,908 5	0,918 6	0,929 2
22	0,969 1	0,975 1	0,991 1	0,966 4	0,972 8	0,979 3

For the case of 50 µm fibre at 850 nm, the “rounding rules” were used to enlarge the attenuation variance limits in order to get wider EF limits. This results in some maximum per cent deviations from target near ±10,5 %.

8.5 Validating the EF limits

In order to validate the EF limits, one must determine launch combinations near the EF limits to assess the effect on attenuation variance. Evaluation of the monochromatic case showed that these conditions, just passing EF, yielded a significant number of cases where the design value attenuation variance was exceeded.

There are two reasons for this:

a) use of selection rule a), producer risk
b) reduction of the number of control radii to the handful currently used.

Within the range of measurement capability, defined at 22 µm for 50 µm, 850 nm, adding control radii did not significantly limit the attenuation variance. This implies that a main source of risk is using rule a).

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The approach to assessing the risks is to re-generate the whole range of launches used in finding the EF limits. For each launch, determine pass/fail on EF limits and then characterize the attenuation variance.

The attenuation variance is characterized in three ways:

- max/min deviation and per cent deviation from target
- average deviation and per cent deviation from nearly failing EF
- per cent of launches failing attenuation but passing EF

Item 2) is defined with “per cent tolerance used” (PTU). This is calculated by taking the difference between EF and EF target and normalizing to the EF limit width. Passing PTU have values of ±100 and failing EF have PTU outside that range. PTU values between 95 and 100 or between -95 and -100 define nearly failing EF.

Given all the other uncertainties and the difficulty in defining a dual frequency/magnitude metric that can easily be understood, this average of nearly failing metric seemed sensible.

The EF limits displayed in Table 5 were used for checking 50 µm multimode fibre. The number of passing EF and the fraction of these that fail some attenuation limit was 4 030 at 850 nm and 4 772 at 1 300 nm.

The limits for the maximum control radius have been manually adjusted to the width of the current limits for each wavelength and fibre size. For 50 µm at 850 nm, for example, the output of the limit finding routine produced limits of ± 0,004 whereas the limits producing the risk found in the files are expanded to ± 0,006. This manual adjustment is done because of measurement issues and an observation that the risk did not change appreciably.

The main part of these files shows the risk assessments. For 50 µm fibre at 850 nm, for example, all the conditions yield average deviation of those close to failing EF close to ±10 %.

The same risk assessment for the current targets using monochromatic assumptions on 50 µm fibre at 850 nm was completed. With few exceptions, the apparent risk is worse. It seems that either the allowed space implied by simplex is too large, or that the attenuation response to EF changes is dampened out by the using spectrally broad sources – or both.

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Annex A
(informative)

IEC international standards related to multimode launch conditions

A.1 Introduction

There are three main IEC standards that define the multimode launch conditions. See Table A1.

Table A.1 – Standards for multimode launch condition

Application	Standard	Alternative standard
Specification	IEC 62614:2010	IEC 61280-4-1:2009
Measurement	IEC 61280-1-4:2009	
Calibration	IEC 61745	

A.2 Specification

IEC 62614:2010 describes the launch condition requirements used for measuring multimode attenuation in passive components and in installed cable plants. In this standard, the fibre types that are addressed include category A1a (50 μm /125 μm) and A1b (62,5 μm /125 μm) multimode fibres, as specified in IEC 60793-2-10. The nominal test wavelengths detailed are 850 nm and 1 300 nm.

IEC 61280-4-1:2009 is applicable to the measurement of attenuation of installed fibre optic cabling using multimode fibre, typically in lengths of up to 2 000 m. This second edition includes launch condition requirements as part of measurement source characteristics. An informative annex provides simple methods to check the sources.

A.3 Measurement

IEC 61280-1-4:2009 is used to measure the encircled flux of a multimode light source. Encircled flux is a measure, as a function of radius, of the fraction of the total power radiating from a multimode optical fibre's core.

The basic approach is to collect 2D near field data using a calibrated camera, and to mathematically convert the 2D data into three normalized functions of radial distance from the fibre's optical centre. The three functions are intensity, incremental flux and encircled flux. Intensity has dimension optical power per area; incremental flux has dimension power per differential of radius; and encircled flux has dimension total optical power, all three being functions of radius.

In the second edition of IEC 61280-1-4:2009, several changes have been made to the computation procedure

- The integration methodology of the radial functions was simple summation and is now specified to use trapezoidal integration or other higher-order techniques;
- A baseline subtraction step is specified to improve immunity to DC drifts;
- The ring width parameter is explicitly specified;
- The integration limit is specified.

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A.4 Calibration

IEC 61745 defines the calibration procedure of the test set to be used for collecting the 2D near field data; and, on a more general basis, defines a standard procedure for the calibration of test sets for measuring the glass geometry of optical fibres.

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Annex B
(informative)

Coupled power ratio measurement for fibre-optic sources

B.1 Introduction

In IEC 61280-4-1:2009, the annex concerning CPR has been removed.

However, even if the characterisation of the multimode launch condition should not be used, there are still a huge number of documents using CPR.

The intent of this annex is only to maintain available the initial annex of IEC 61280-4-1:2003. It has been reformatted in order add referenced text.

B.2 Object

This annex describes the procedure for determining the launch category of a light source by measuring its coupled power ratio (CPR), as defined in B.3.

B.3 Source

The light sources shall conform to the spectral characteristics of Table 1 and modal launch conditions, unless otherwise specified in the detail specification or other reference document.

Table B.1 – Light source characteristics

Centre wavelength nm	Spectral width nm, FWHM
850 ± 30	30 to 60
1 300 ± 20	100 to 140

The light sources may contain internal lenses, pigtails and mode conditioners, provided they meet the following modal launch conditions.

B.4 Apparatus

a) The light source of B.3
b) A power meter capable of measuring relative optical power
c) Two test cords, between 1 m and 5 m long, with coatings that strip cladding light, having connectors compatible with the light source and power meter
   - Test cord 1 shall contain multimode fibre of the same nominal core diameter and numerical aperture as the fibre of the cable plant to be tested. Connectors may be single-mode grade with ferrule diameters fitted to the fibre outside diameter. (Note this may be called a ‘reference grade termination.)
   - Test cord 2 shall contain standard category B1.3 single-mode fibre for tests on 1 300 nm light sources and fibre which is single-moded at 850 nm for tests on 850 nm light sources. Suggested specifications are MFD = 9,0 μm ± 1 μm for 1 300 nm tests, and MFD = 5,0 μm ± 0,5 μm for 850 nm tests.
   - The connectors on test cords 1 and 2 shall have losses less than or equal to 0,5 dB (at 850 nm and 1 300 nm), as measured in accordance with IEC 61300-3-4. Connectors

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which inhibit Fresnel reflections (for example, physical contact (PC) finish connectors) are preferable.

B.5 Procedure

a) Measure the power coupled from the light source under test into test cord 1, the multimode cord.

b) Deploy the cord in such a way as to minimize changes in deployment which could affect the modal power distribution and avoid bend radii less than 50 mm.

c) Leaving the multimode cord still connected to the light source, connect the single-mode test cord 2 to the output of the multimode cord and measure the power out of the single-mode cord. The single-mode cable shall be deployed with a high order mode filter. Typically, a 30 mm diameter loop is sufficient for these purposes.

d) In cases where mechanical instability causes variations >0,5 dB between successive power readings, reconnect the test cords to the light source five times and repeat both readings five times, then average the results.

e) Calculate CPR as the difference in decibels (round to the nearest 0,1 dB) between the power levels out of test cords 1 and 2.

f) Locate the value of CPR in Table B.2 or Table B.3 as appropriate, selecting the line for the fibre size under consideration.

Table B.2 – Light source categorization by CPR value (850 nm wavelength, CPR values in decibels)

Fibre size	Category 1 Overfilled	Category 2	Category 3	Category 4	Category 5 Greatly underfilled
50/125	20 to 24	16 to 19,9	11 to 15,9	6 to 10,9	0 to 5,9
62,5/125	25 to 29	21 to 24,9	14 to 20,9	7 to 13,9	0 to 6,9
100/140	30 to 34	26 to 29,9	18 to 25,9	10 to 17,9	0 to 9,9

Table B.3 – Light source categorization by CPR value (1 300 nm wavelength, CPR values in decibels)

Fibre size	Category 1 Overfilled	Category 2	Category 3	Category 4	Category 5 Greatly underfilled
50/125	16 to 20	12 to 15,9	8 to 11,9	4 to 7,9	0 to 3,9
62,5/125	21 to 25	17 to 20,9	12 to 16,9	7 to 11,9	0 to 6,9
100/140	26 to 30	22 to 25,9	15 to 21,9	8 to 14,9	0 to 7,9

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Annex C
(informative)

Limits on RPD and MPD

C.1 Introduction

With the publication of ISO/IEC 14763-3:2009, the annex concerning RPD and MPD limits will be removed.

The intent of this annex is to maintain availability of the original annex found in ISO/IEC 14763-3:2000. It has been reformatted in order accommodate referenced text.

C.2 Modal transfer function

The near field radiation pattern of the output end of a patch cord attached to the source shall be measured according to the procedure defined in IEC 61280-1-4:2009.

The derivative of the near field with respect to radial position shall be calculated from Formula (1) and Formula (3).

$$MTF(\delta) = \left[\frac{\mathrm{d}I(r)}{\mathrm{d}r} \cdot \frac{1}{r^{\alpha-1}} \right] \tag{C1}$$

The resultant mode transfer function (MTF) indicates the power distribution amongst all the modes, m.

A sample MTF is shown in Figure C.1. The information is normalised to display on vertical and horizontal scales that span from 0 to 1.

This information is converted to MPD or RPD in order to establish compliance limits in a way that is meaningful to loss measurements while affording flexibility in meeting the requirements with various launch conditions.

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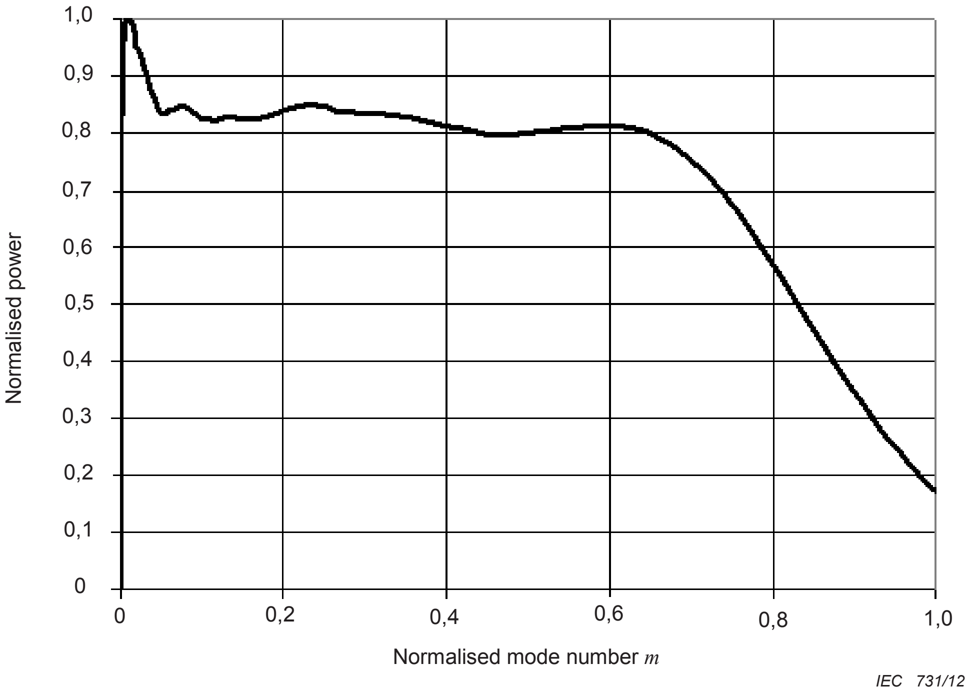

Figure C.1 – Example of a characteristic MTF

C.3 Relative power distribution (RPD)

The MTF is converted to RPD in order to establish compliance limits in a way that is meaningful to loss measurements while affording flexibility in meeting the requirements with various launch conditions. RPD provides this flexibility by defining the launch condition in terms that are relative to the source's overall launched power rather than relative to an absolute power distribution.

The RPD is determined from the MTF using the computation shown in Formula (C.2).

$$RPD(m) = \frac{\left| \int_{1}^{\mu} MTF(m) \cdot dm \right|}{\int_{0}^{1} MTF(m) \cdot dm} \tag{C.2}$$

where

RPD and MTF are both functions of mode number, *m*

μ is the lowest mode number to which the launch specification applies

The numerator is the area under the MTF curve starting from the highest mode number

The denominator is the total area under the MTF

The integration in the numerator starts at the highest mode number because the loss mechanisms in cabling and connectors are generally most sensitive to the degree of excitation of the highest order modes

Formula (C.3) defines the nominal MTF that establishes a target launch condition, T(*m*)

$$T(m) = 1 \text{ for } 0 \leq m \leq 0{,}65 \text{, and}$$

$$2{,}56 - 2{,}40m \quad \text{for } 0{,}65 \leq m \leq 1 \tag{C.3}$$

This nominal MTF was determined by fitting the distribution to data of various launch conditions to find the launch that contains the maximal mode power after attenuation of high order mode power that gives rise to transient losses.

The RPD of this target MTF is defined by Formula (C.4) as $\mathrm{P}(m)$

$$\mathrm{P}(m) = \frac{\left| \int_1^{\mu} \mathrm{T}(m) \cdot dm \right|}{\int_0^1 \mathrm{T}(m) \cdot dm} \tag{C.4}$$

where

$\mathrm{P}(m)$ for this specification is found with $\mu = 0$ to encompass all of the modes.

The tolerance allowance about $\mathrm{P}(m)$ establishes the upper and lower power limits for the launch condition. In this standard these limits are set to meet a simultaneous launch precision of ± 10 % and ± 0,2 dB.

The upper limit, Λ_{upper}, is defined in Formula (C.5).

$$\Lambda_{upper} = lesser\ of \left\{ 1 - 10^{\left[\log(1-\mathrm{P}(m)) - \tau_u/10 \right]}, (1+\alpha_u)P(m) \right\} \tag{C.5}$$

where

τ_u is the upper tolerance limit expressed in dB

α_u is the percentage upper tolerance limit expressed as a decimal

The lower limit, Λ_{lower}, is defined in Formula (C.6).

$$\Lambda_{lower} = greater\ of \left\{ 1 - 10^{\left[\log(1-\mathrm{P}(m)) - \tau_l/10 \right]}, (1+\alpha_l)P(m) \right\} \tag{C.6}$$

where

τ_l is the lower tolerance limit expressed in dB

α_l is the percentage lower tolerance limit expressed as a decimal

The specification RPD is graphed in Figure C.2. The source RPD shall lie between the curves.

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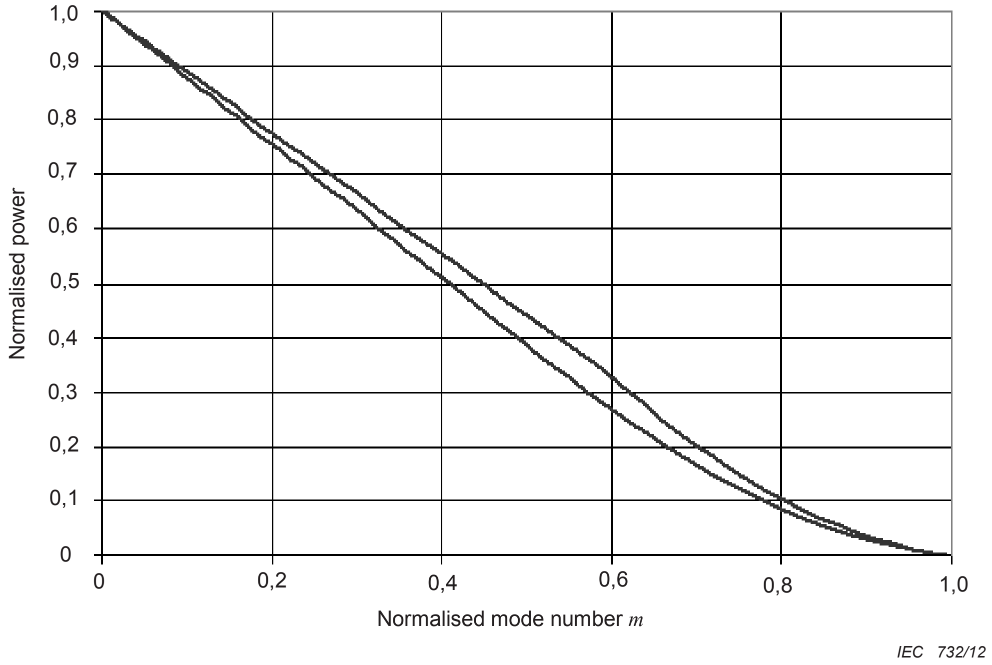

Figure C.2 – Relative power distribution (RPD) specification

C.4 MPD (modal power distribution)

C.4.1 General

The MPD is a graphical representation of the relative power in each of the mode groups within a MMF as shown in Figure C.3.

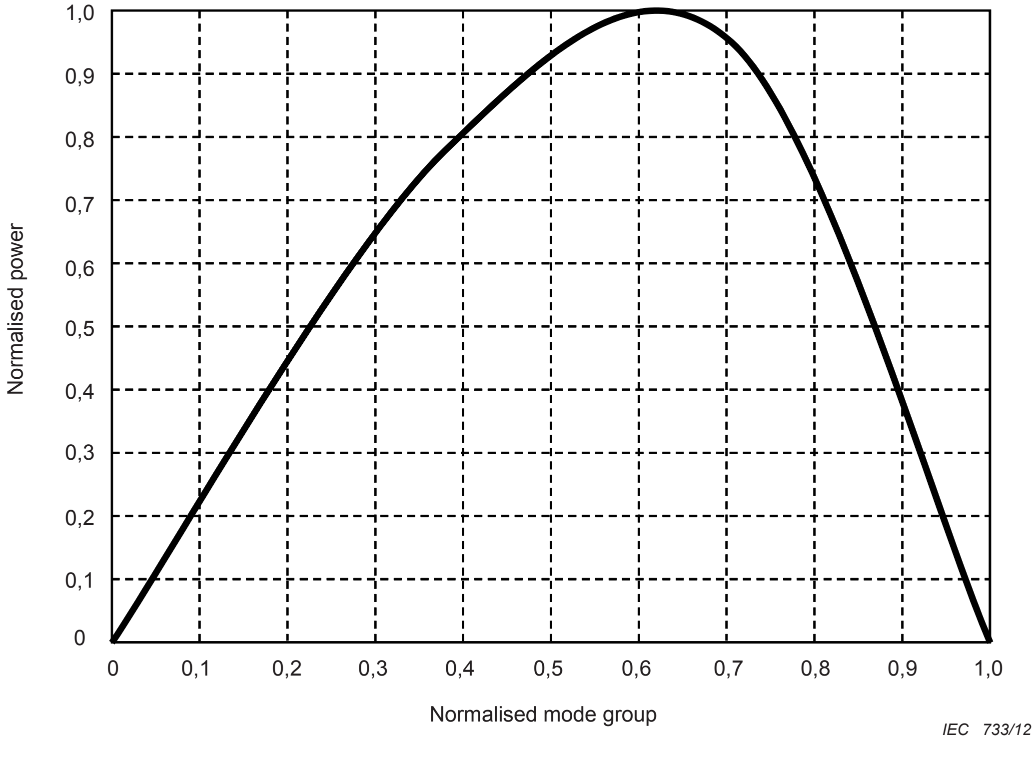

Figure C.3 – Example of a characteristic MPD

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The normalised mode group (x-axis) represents the mode group as a fraction of the highest mode group number.

For a 50/125 µm IEC A1a (as defined in IEC 60793-2-10)

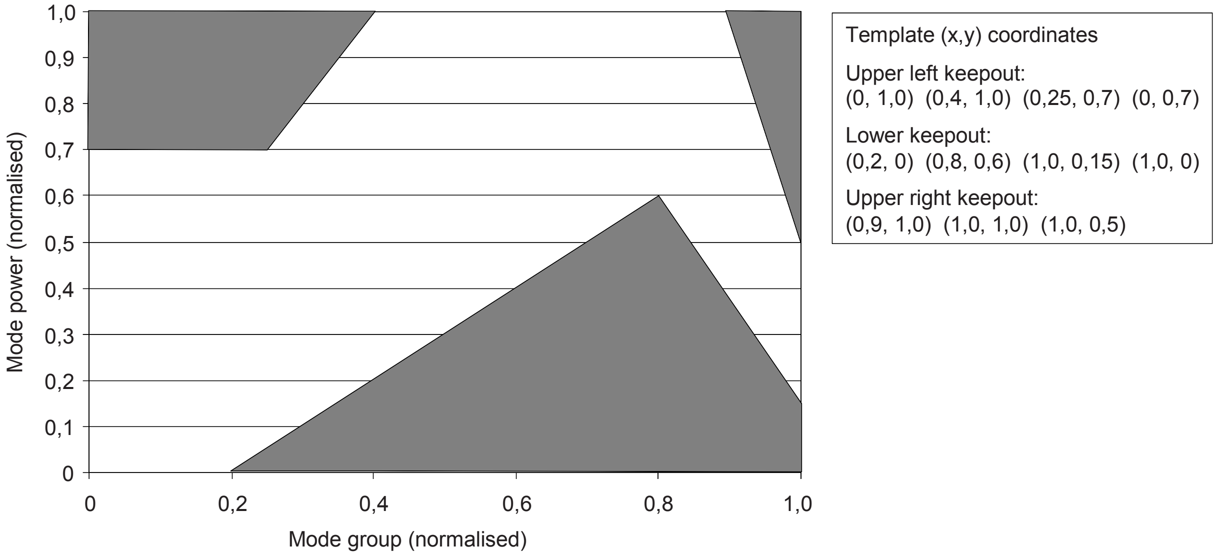
- at 850 nm there are approximately 19 mode groups – so a NMG value of 0,42 represents a mode group number of 08
- at 1 300 nm there are approximately 12 mode groups – so a NMG value of 0,42 represents a mode group number of 05

For a 62,5/125 µm A1b (as defined in IEC 60793-2-10)

- at 850 nm there are approximately 31 mode groups – so a NMG value of 0,42 represents a mode group number of 13
- at 1 300 nm there are approximately 19 mode groups – so a NMG value of 0,42 represents a mode group number of 08

C.4.2 Requirements

The MPD shall meet the requirements of Figure C.4.



Template (x,y) coordinates

Upper left keepout:
(0, 1,0) (0,4, 1,0) (0,25, 0,7) (0, 0,7)

Lower keepout:
(0,2, 0) (0,8, 0,6) (1,0, 0,15) (1,0, 0)

Upper right keepout:
(0,9, 1,0) (1,0, 1,0) (1,0, 0,5)

IEC 734/12

Figure C.4 – MPD (Modal power distribution) specification

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