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Guideline for combining different single-mode fibres types

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National foreword

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GUIDELINE FOR COMBINING DIFFERENT SINGLE-MODE FIBRES TYPES

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IEC 62000, which is a technical report, has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86:Fibre optics.

This second edition cancels and replaces the first edition (2005) and constitutes a technical revision.

The major technical changes with respect to the previous edition are considerations concerning B6 fibres.

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

Enquiry draft	Report on voting
86A/1276/DTR	86A/1283/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.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
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GUIDELINE FOR COMBINING DIFFERENT SINGLE-MODE FIBRES TYPES

1 Scope

This technical report provides guidelines concerning single-mode fibre compatibility.

A given type of single-mode fibre, for example B4, may have different implementations by suitably optimising several of the following parameters: mode field diameter (hence effective area), chromatic dispersion coefficient, slope of the chromatic dispersion curve, cable cut-off wavelength.

This guideline indicates the items that should be taken into account when planning to connect: (1) different implementations of single-mode fibres of the same type, e.g. different implementations of type B single-mode fibres, and (2) single-mode fibres of different types, e.g. B1.1 with B4. See IEC 60793-2-50 for the attributes and definitions of single-mode fibre. The attributes and definitions of fibres covered in this technical report are given in Table 1.

Table 1 – Correspondence table of various single-mode fibres

Common name	*Use (IEC 6079-2-50)*	*IEC Class*	*ITU-T Recommendation*
Dispersion unshifted single-mode fibre	Optimised for use in the 1 310 nm region but can be used in the 1 550 nm region	B1.1	G.652 A, B
Cut-off shifted single-mode fibre	Optimised for low loss in the 1 550 nm region, with cut off wavelength shifted above the 1 310 nm region	B1.2	G.654
Extended band dispersion unshifted single-mode fibre	Optimised for use in the 1 310 nm region but can be used in the O, E, S, C and L-band (i.e. throughout the 1 260 nm to 1 625 nm range).	B1.3	G.652 C, D
Dispersion shifted single-mode fibre	Optimised for single channel transmission in the 1 550 nm region. Multiple channels can only be transmitted if care is taken to avoid the effects of four wave mixing by, for example, moderating the power levels or appropriate spacing or placement of the channels	B.2	G.653
Non-zero dispersion-shifted single-mode fibre	Optimised for multiple channel transmission in the 1 550 nm region with a cut off wavelength that may be shifted above the 1 310 nm region	B4	G.655
Wideband non-zero dispersion-shifted single-mode fibre	Optimised for multiple channel transmission in the wavelength range of 1 460 to 1 625 nm with the positive value of the chromatic dispersion coefficient that is greater than some non-zero value over the same wavelength range.	B5	G.656
Bend loss optimised	Bending loss insensitive single-mode fibre suitable for use in the access networks, including inside buildings at the end of these networks. B6_a fibres are suitable to be used in the O, E, S, C and L-band (i.e. throughout the 1 260 nm to 1 625 nm range) and meet the requirements of B1.3 fibres.	B6_a	G.657.A
	Bending loss insensitive single-mode fibre suitable for use in the access networks, including inside buildings at the end of these networks.	B6_b	G.657.B

Common name	Use (IEC 6079-2-50)	IEC Class	ITU-T Recommendation
	B6_b fibres are suitable for transmission at 1 310 nm, 1 550 nm, and 1 625 nm for restricted distances that are associated with in-building transport of signals.		

This guide does not consider the connection of fibres with the same implementation from different manufacturers, which is already considered by the standardisation procedure.

2 Abbreviations

OTDR: Optical Time Domain Reflectometre

PMD: Polarization Mode Dispersion

DWDM: Dense Wavelength Division Multiplexing

NRZ: Non Return to Zero

RZ: Return to Zero

3 System issues

The different characteristics of B type fibres can be explicitly combined to optimise system performance in terms of the dispersion characteristic (global dispersion coefficients, slope) of the link. It is in fact possible to combine fibres with opposite signs of the dispersion coefficient in a given wavelength range to bring the total link dispersion to near-zero in that range. The final result will however depend on the accuracy of individual fibre dispersion measurements and the ability to match lengths.

The process of combining fibres with different dispersion coefficient characteristics can be one of the ways to make dispersion management in a transmission line (the most common one being the periodical insertion of dispersion compensating modules).

Combining fibres with different effective area is also a possible way to minimise the overall impact of non-linear effects. For instance, it is possible to place large effective area fibres in the initial section of a link, where the propagating power is relatively large. In this case, the large core reduces the associated non-linear effects. For link sections away from the source, where power levels are reduced, fibres with smaller effective area may be used, to take advantage of a possible reduction of the dispersion slope or to increase the efficiency of Raman amplification. The relative size and placement of fibres with large effective area versus fibres with smaller effective area are critical issues in system design.

Splice loss considerations (see section 4.3) should also be taken into account when fibres with different effective area or mode field diameter are combined.

4 Fibre issues

4.1 General

Most fibre characteristics are wavelength dependent: the actual operating wavelengths of the system shall therefore be taken into account when considering the following comments and suggestions.

The compatibility between the fibre specified characteristics (e.g. attenuation and dispersion) and the system operating wavelength must be considered.

4.2 Cut-off wavelength

Different fibres have been historically developed for operation in different wavelength ranges: they can therefore have different cut-off wavelengths. If the source wavelength is below the cut-off wavelength, undesirable multi-modal propagation and modal noise could occur.

It should however be considered that the cut-off wavelength is reduced after cabling and installation. The amount of the reduction depends on the refractive index profile, i.e. on the fibre type. If fibre cut-off wavelength is specified, it can be assumed that, after cabling and installation, the cut-off will be down-shifted by several tens of nanometres (depending on the fibre type). Cable cut-off wavelength is therefore specified in Standards. See IEC 60793-2-50 and IEC 60793-1-44.

These considerations should be applied when connecting different fibre types, e.g. type B4 with B1, in order to avoid multimodal operation and noise, which could affect the system performance, depending on the source wavelength. A launch from another single-mode fibre will typically serve as a mode filter which can significantly reduce or eliminate the potential for multimode transmission.

4.3 Splicing issues

The very different mode field diameter ranges, typical of the several fibre families, have an effect on splice losses when fibres of different categories are spliced together. Care must be taken to properly adjust splicing equipment and to correctly evaluate the splicing losses among different fibre families, which can show increases in comparison with conventional splice losses.

The optimal set-up parameters of fusion splicers are not the same for the different types of fibres (e.g. B1 versus B6 fibres) or combinations of different implementations of fibres.

Some B6_b fibres may cause difficulties with the core alignment systems of some fusion splicing machines because the characteristics that provide improved bend loss performance can interact with the splicer alignment field of view. Amended splice programs or specialist fusion splicing technology has eliminated this problem on many fusion splicers. An alternative and recommended approach is to use an outside diameter (OD) or cladding alignment fusion splicing program as is generally used with multimode optical fibres. Since recent advances in fibre manufacturing technology have resulted in improved fibre geometry – with fibre core concentricity errors typically less than 0,5 μm - the splice losses encountered are usually $< \sim 0,1$ dB.

Another factor that has to be taken into account when using an OTDR to measure the splice loss across fibres with different mode field diameters is that the bidirectional method is strictly required. The mismatch of mode fields can make a splice appear to have much more loss from one direction than the other. Negative loss or "gain" can also be apparent with uni-directional OTDR measurements. See IEC TR 62316 for more information.

When using an OTDR to measure the distance between splices of various sections of fibre with different mode field diameters, the apparent distance can be different than the actual distance because the group velocity for the different fibres may not be the same. For accurate length measurements, the OTDR length calibration setting must be adjusted according to the section and type of fibre that is present.

Most of the previous considerations also apply to mechanical (temporary or permanent) connections.

4.4 Combination of fibre parameters: chromatic dispersion coefficient and slope, polarization mode dispersion (PMD)

The chromatic dispersion coefficients of two fibres combine linearly on a length-weighted basis. It is possible to combine different fibres or dispersion compensation devices to achieve the desired overall system chromatic dispersion values.

When different fibre families are combined, it is recommended that the calculations for the overall chromatic dispersion be completed by using the chromatic dispersion of each section, in ps/nm, rather than considering the combination of possibly misleading descriptive parameters such as the zero-dispersion wavelength or slope. In fact, zero-dispersion wavelength and slope are not defined for some fibre families.

Sometimes the term slope compensation is found, referring to a situation where fibres with different wavelength-dependence of the chromatic dispersion coefficient are combined: the resulting dispersion vs. wavelength curve will be the linear combination (on a length weighted basis) of the two original curves.

Details on dispersion accommodation and compensation and on slope compensation can be found in IEC TR 61282-5.

For Polarization Mode Dispersion (PMD), the PMD values combine in quadrature (square root of sum of squares) rather than in the linear fashion that is appropriate for chromatic dispersion. Because PMD is a stochastic attribute, the link characteristics are defined statistically. See IEC 60794-3 for information on the calculations for concatenations of cables and IEC TR 61282-3 for information on the calculation for the combined link, including the effects of other link components such as amplifiers. See IEC TR 61282-9 for more information on PMD generalities and theory.

4.5 Non-linear effects

Non-linear effects come from the interactions of the propagating pulse with the transmission medium that make the propagation sensitive to the channel optical power. They are generated with an efficiency, which is dependent on the concentration of energy in the fibre core (therefore proportional to optical power and inversely proportional to effective area), and on the distance over which the light is propagated.

The local chromatic dispersion of the fibre also has an effect on the impairment due to nonlinear effects, depending on, for example, the channel density, bit rate, and modulation format.

See IEC TR 61282-4 for more information.

For high power DWDM systems operating at 10 Gb/s and higher, the local fibre chromatic dispersion shall be different than zero by an amount that is dependent on the details of the system. The actual values of the optimal chromatic dispersion coefficient and effective area for a given link section are a trade-off depending on the number of optical channels, the powers of the channels in the section, the bit rate, and the modulation format (NRZ versus RZ).

The global characteristic of hybrid links, obtained by the combination of different fibre families, shall be consistent with the initial link design considerations that take into account the effects of overall distortion, optical signal to noise ratio and receiver sensitivity.

5 Launch fibres, pigtails, patch-cords and jumper cables

Generally it is not necessary to adopt the same fibre type in the pigtail as the fibre to be measured or connected into a system, e.g. B1.3 fibre may well be used for pigtails and patch-cords in a network with B4 or B5 fibre, even though:

- in some situations more care may be necessary to obtain the desired patch cord / fibre interface performance;
- regardless of the fibre types that are connected, the back-reflected light from a connection point may affect system performance and should be considered in advance, see IEC TR 62316.

6 Attenuation

Different fibre types have been designed to operate preferably at specific wavelengths and in specific deployment conditions (e.g. bends): their attenuation performances can vary when used at different wavelengths. For instance: a B1.1 fibre is optimized for use in the 1 310 nm region, with some characteristics in the 1 383 nm region which are not the same as B1.3 fibres; a link obtained by combining several fibre types would have consequently a 1 383 nm attenuation performance depending on their length-weighted composition, although they belong to the same sectional specification.

7 Summary

Table 2 summarises the level of attention which should be dedicated to each issue when connecting fibre types in the first and second column. It is not intended to give guidance on the preferred combination: some of these combinations are not preferred from the fibre view point, but may be dictated by the existing link architecture and/or by system design considerations. The ranking is:

1 = low – means that the parameter should be considered properly (as suggested in the reference clause), although it is not expected to cause system related issues provided the operating wavelength(s) is compatible with the characteristics of both fibre types.

2 = medium – means that the parameter should be considered properly (as suggested in the reference clause); if all aspects of the two fibre types (with respect to the system design), with reference to the specific parameter, are taken into account, then the combination is not expected to cause system related issues, provided the operating wavelength(s) is compatible with the characteristics of both fibre types.

3 = high – means that the parameter should be considered carefully (as suggested in the reference clause); in some situations, system performances can be severely degraded by the indicated combination; users are recommended to carefully consider the characteristics of the two fibre types with respect to that parameter, taking also into account the actual operating wavelength of the system and its compatibility with both fibre types.

Table 2 – Level of attention to be dedicated to each issue when connecting fibre types

Fibre type	With fibre type	Attenuation [a]	Dispersion & dispersion slope [b]	off considerations [c]	Splice or connection loss[d]
B1.1	B1.1	1	1	1	1
	B1.2	1	2	3	3
	B1.3	2	1	1	1
	B2	1	3	1	2
	B4	1	3	3	2
	B5	1	3	3	2
	B6_a	1	1	1	1
	B6_b	2	2	1	2
B1.2	B1.2	1	1	1	1
	B1.3	1	2	3	3
	B2	1	3	3	3
	B4	1	3	3	3
	B5	1	3	3	3
	B6_a	1	2	3	3
	B6_b	1	3	3	3
B1.3	B1.3	1	1	1	1
	B2	1	3	1	2
	B4	1	3	3	2
	B5	1	3	3	2
	B6_a	1	1	1	1
	B6_b	2	2	1	2
B2	B2	1	1	1	1
	B4	1	3	3	2
	B5	1	3	3	2
	B6_a	1	3	1	2
	B6_b	1	3	1	2
B4	B4	1	2	1	2
	B5	1	2	3	2
	B6_a	1	3	3	2
	B6_b	1	3	3	2
B5	B5	1	1	1	1
	B6_a	1	3	3	2
	B6_b	1	3	3	2
B6_a	B6_a	1	1	1	1
	B6_b	1	1	1	2
B6_b	B6_b	1	1	1	2

[a] Clause 6; [b] Clause 4.3; [c] Clause 4.1; [d] Clause 4.2.

NOTE The total system performance can be degraded by some of the indicated issues (e.g. splice losses), and improved by others (e.g. dispersion compensation).

Bibliography

IEC 60793-2-50, *Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single-mode fibres*

IEC 60793-1-44, *Optical fibres – Part 1-44: Measurement methods and test procedures – Cut-off wavelength*

IEC TR 62316, *Guidance for the interpretation of OTDR backscattering traces*

IEC TR 61282-9, *Guidance on polarization mode dispersion measurements and theory*

IEC 60794-3, *Optical fibre cables – Part 3: Sectional specification – Outdoor cables*

IEC TR 61282-3, *Fibre optic communication system design guides – Part 3: Calculation of polarization mode dispersion*

IEC TR 61282-4, *Fibre optic communication system design guides – Part 4: Accommodation and utilisation of nonlinear effects.*

IEC TR 61282-5, *Fibre optic communication system design guides – Part 5: Accommodation and compensation of dispersion*

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