TECHNICAL REPORT

IEC TR 61282-7

First edition
2003-01

Fibre optic communication system design guides –

Part 7: Statistical calculation of chromatic dispersion

Guides de conception des systèmes de communications à fibres optiques –

Partie 7: Calcul statistique de la dispersion chromatique

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

Part 7: Statistical calculation of chromatic dispersion

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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IEC 61282-7, which is a technical report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

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

Enquiry draft	Report on voting
86C/429/DTR	86C/468/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 2009-12. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

Part 7: Statistical calculation of chromatic dispersion

1 Scope

This part of IEC 61282 is a guideline providing methods of representing the process statistics of the chromatic dispersion of optical fibres and related components that may be combined in a link.

Chromatic dispersion (ps/nm) is the derivative, with respect to wavelength, of the group delay (ps) induced by the spectral content of light propagating through an optical element or fibre. Chromatic dispersion is normally a function of wavelength and can be either positive (group delay increasing with wavelength) or negative (group delay decreasing with wavelength).

The presence of chromatic dispersion can induce distortions in signals leading to bit errors depending on

– source spectral width;
– source chirp;
– bit period;
– distance.

In addition, chromatic dispersion is interactive with the effects of non-linear optical effects and second order polarisation mode dispersion (PMD). The above system impairments are beyond the scope of this technical report.

When different components or fibres are combined, the chromatic dispersion of the combination is the total of the chromatic dispersion values of the individuals, on a wavelength-by-wavelength basis. A section with high chromatic dispersion will be balanced by sections with lower values. The variation in the total dispersion of links will therefore be dependent on the distributions of the products that are used in the link. This document provides methods to calculate the distribution statistics of concatenated links based on information on the distributions of different fibre or component populations.

NOTE In the clauses that follow, examples are given for particular fibre and component types. These examples are not necessarily broadly representative.

2 Normative references

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

IEC 60793-1-42: *Optical fibres – Part 1-42: Measurement methods and test procedures – Chromatic dispersion*

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

ITU-T Recommendation G.652: *Characteristics of a single-mode optical fibre cable*

ITU-T Recommendation G.655: *Characteristics of a non-zero dispersion shifted single-mode optical fibre cable*

ITU-T Recommendation G.671: *Transmission characteristics of optical components and subsystems*

ITU-T Recommendation G.691: *Optical interfaces for single-channel STM-64, STM-256 and other SDH systems with optical amplifiers*

3 Characterisation of chromatic dispersion coefficient versus wavelength

This clause outlines the characterisation of dispersion as a function of wavelength – for a given wavelength range. This function is often represented as a formula that includes parameters that can vary from fibre to fibre for a given fibre design. Characterisations of these formulas should give an indication of the wavelength range over which the formula applies. Extrapolation beyond these ranges can result in error.

For optical fibre, chromatic dispersion coefficient, D, can vary with wavelength, λ, according to a variety of formula types that are found in IEC 60793-1-42. The simplest is the linear representation which has just two parameters, zero-dispersion wavelength, λ_0, and zero-dispersion slope, S_0, as:

$$D(\lambda) = S_0(\lambda - \lambda_0) \text{ (ps/nm·km)} \tag{1}$$

Measurements are based either on fitting differential group delays (DGD) or by fitting the integral to the measured group delay.

Other forms defined in 60793-1-42 are the three-term Sellmeier (Equation (2)), and the five-term Sellmeier (Equation (3)). Note that for the five-term Sellmeier, parameters, C_j, different from the zero-dispersion wavelength and slope must be fitted.

$$D(\lambda) = \frac{S_0 \lambda}{4}\left(1 - \left(\frac{\lambda_0}{\lambda}\right)^4\right) \tag{2}$$

$$D(\lambda) = 2C_1\lambda - 2C_2\lambda^{-3} + 4C_3\lambda^3 - 4C_4\lambda^{-5} \tag{3}$$

For components, similar types of expressions can be used to characterise the chromatic dispersion value, d, as a function of wavelength. For components, however, the units are most often given as ps/nm (unadjusted for length). [The use of the term “coefficient,” for fibre indicates a length normalisation.]

Even for the products for which the linear representation of Equation (1) is appropriate for each individual fibre, the combination of the distributions of the zero-dispersion wavelength and slope will normally not lead to a very clear understanding of the distribution of chromatic dispersion. Figure 1 shows such a combined distribution that illustrates a correlation between the dispersion parameters.

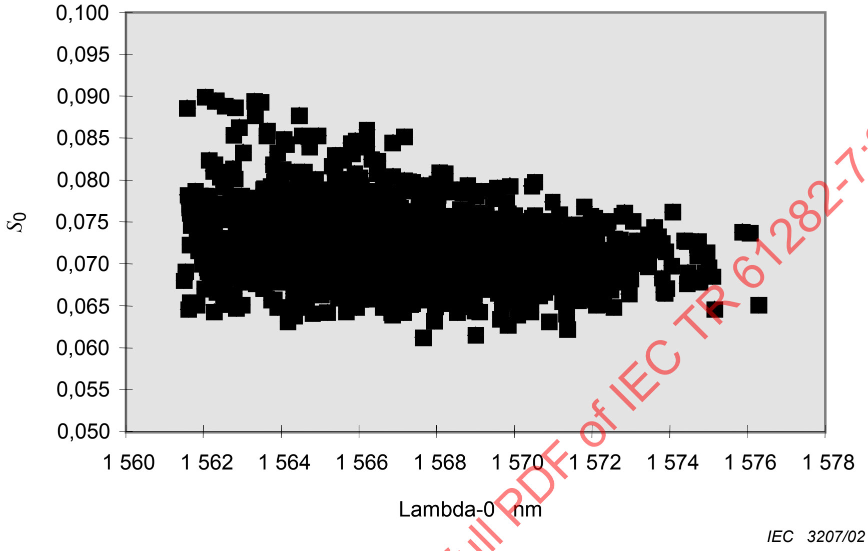

Figure 1 – Distribution of dispersion parameters

4 Characterisation of the chromatic dispersion coefficient statistics versus wavelength

This clause outlines the technique used to characterise the distribution of a single population of fibres. Similar approaches can be applied to components.

The fibre distribution shown in Figure 1 was intended for use in the wavelength range of 1 530 nm to 1 560 nm – a B4 type fibre (ITU-T G.655), see IEC 60793-2-50. The chromatic dispersion values for the lower end of this range are affected more by the variation of slope values for high zero-dispersion wavelength than for low zero dispersion wavelength. The combined contributions are therefore difficult to evaluate without some other means.

The characterisation methodology suitable for use in concatenation statistics for this distribution alone, or for combination with other distributions is to calculate the dispersion coefficient for each of the wavelengths in the range of the application – for each individual fibre. This creates a distribution of dispersion coefficient values for each wavelength. Figures 2 and 3 show these distributions at two selected wavelengths for the distribution shown in Figure 1.

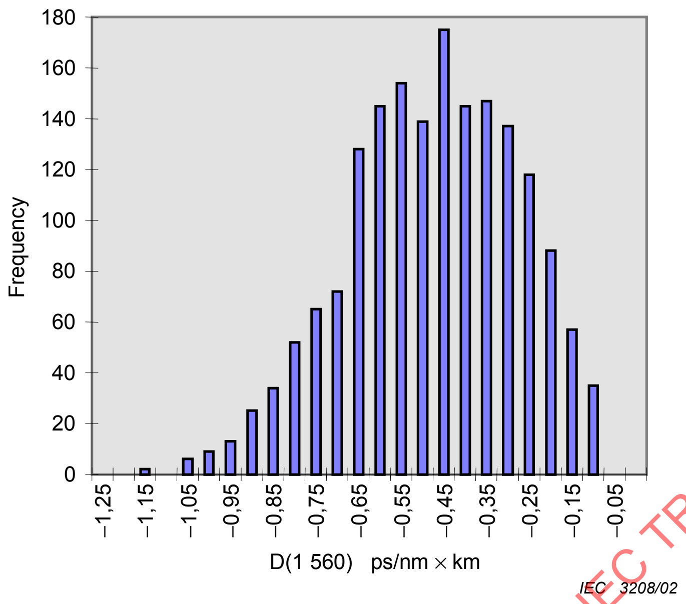

Figure 2 – Histogram of values at 1 560 nm

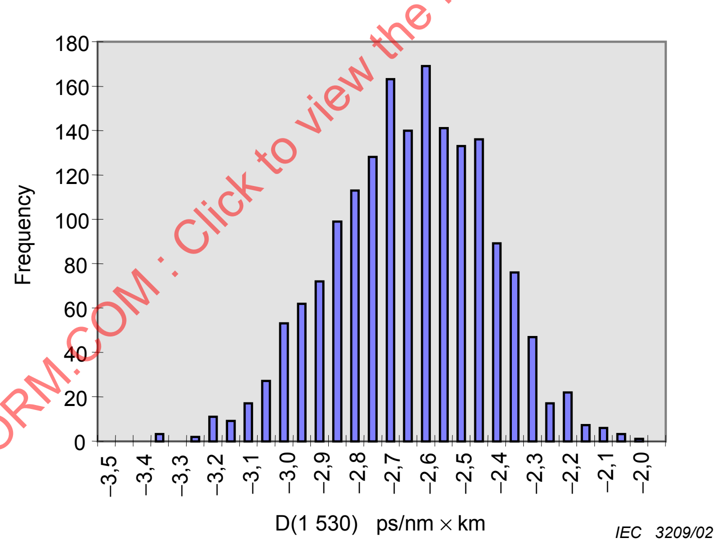

Figure 3 – Histogram of values at 1 530 nm

The distribution for each wavelength is characterised with an average and a standard deviation value. These statistics are then plotted versus wavelength. Figures 4 and 5 show the relationships.

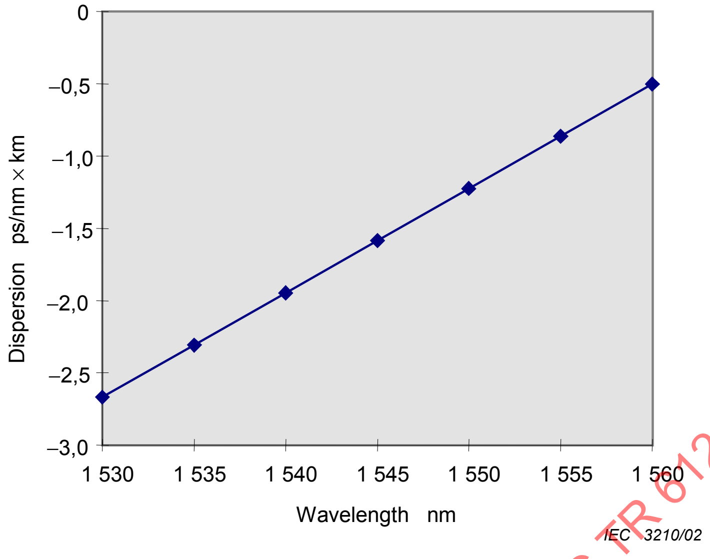

Figure 4 – Average dispersion coefficient versus wavelength

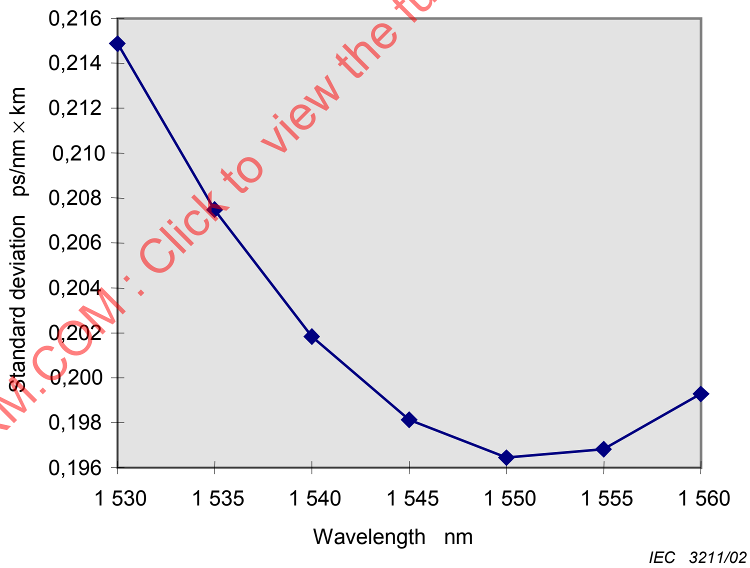

Figure 5 – Standard deviation of dispersion coefficient versus wavelength

Note that a linear relationship represents the average and a quadratic relationship represents the standard deviation. This is due in part to the linear representation of dispersion coefficient with wavelength. The other aspects of the distributions form more subtle adjustments. The data from the examples of Figures 4 and 5 can be empirically fitted to obtain formulas that represent the relationships versus wavelength, λ, (nm):

$$\mu(\lambda) = 0{,}072(\lambda - 1567) \quad \text{(ps/nm·km)} \tag{4}$$

$$\sigma(\lambda) = 0{,}1964 + 3{,}97 \cdot 10^{-5}(\lambda - 1\,551{,}6)^2 \quad \text{(ps/nm·km)} \tag{5}$$

where μ is the average and σ is the standard deviation

Similar characterisation functions are expected for distributions of installed links comprised of fibre of an unknown distribution. In this case, sample measurements of sub-sections of 20 or 40 km might be necessary determining the statistics.

Note that if actual dispersion coefficient values were available for each of the wavelengths of interest, the form of the functional dependence of chromatic dispersion to wavelength would not be an issue. The extrapolation of formulas like equations 2a and 2b beyond the wavelengths represented by the data could produce error, however.

5 Calculation of the concatenation statistics for a single population of optical fibres

This section outlines the concatenation statistics for a single distribution of fibre. These statistics are based on Gaussian assumptions and the central limit theorem. In this context, the examples are calculated at the "3 sigma" level for a risk of 0,13 % above and below the limits. Other risk levels could be selected.

Assuming equal lengths, the dispersion coefficient of the concatenation of fibres is the average of the dispersion coefficient of the individual fibres. That is:

$$\overline{D}(\lambda) = \frac{1}{n}\sum_i D(\lambda)_i \tag{6}$$

Using the central limit theorem, these averages can vary about the grand average according to a Gaussian random distribution with a standard deviation equal to the standard deviation of the population of the individual values divided by the square root of the number, n, used in the averaging process (the number of individual fibres in the link). Using a fixed probability limit on the Gaussian distribution which contains 99,7 % of the distribution, the limit of link dispersion coefficient values, D_{Tot}, is given as:

$$D_{\text{Tot}}(\lambda) = \mu(\lambda) \pm \frac{3}{\sqrt{n}}\sigma(\lambda) \tag{7}$$

Assuming a conservative value of n, associated with a maximum fibre length of L_{Cab} within a link of L_{Tot}, Equation (7) can be written as:

$$D_{\text{Tot}}(\lambda) = \mu(\lambda) \pm 3\left(\frac{L_{\text{Cab}}}{L_{\text{Tot}}}\right)^{1/2}\sigma(\lambda) \tag{8}$$

The limits on the link dispersion value, CD_{Tot}, are just the limits of the link dispersion coefficient values times the link length:

$$CD_{\text{Tot}}(\lambda) = L_{\text{Tot}}\mu(\lambda) \pm 3(L_{\text{Cab}}L_{\text{Tot}})^{1/2}\sigma(\lambda) \tag{9}$$

Table 1 shows the computed values for the population of the prior section for an assumed link length of 120 km and an assumed cable length of 5 km. These values are substantially below the –420 ps/nm value that would be deduced from the specifications.

Table 1 – Computed values at two selected wavelengths

Wavelength nm	CD_{min} ps/nm	CD_{max} ps/nm
1 530	–336	–304
1 540	–249	–219

If the distribution is based on measurements of sub-sections of installed links, replace the length, L_{Cab}, by the length of the sub-sections that were measured – or a larger value representative of the length of the longest sub-sections in the link. If the individual sub-sections or cable lengths L_i of an installed link are known, the accuracy of Equation 9 can be improved with the following substitution:

Replace $L_{\text{Cab}} L_{\text{Tot}}$ by $\sum_i L_i^2$ (10)

6 Generalisation of concatenation statistics for multiple populations – including components

This clause illustrates the extension of the concatenation to one which contains more than one fibre type and, in addition, components. The notation is expanded by subscripting the average and standard deviation functions with I, II, etc. as well as adding, for example, $L_{\text{Tot-I}}$, for the link length contribution of fibre type I and n_{A} for the number of components of type A.

The probability limits are, again, done with a probability limit associated with a Gaussian of ± 3 – but the equations are separated into the "average part" and the "standard deviation part" before combining them.

The average of the dispersion is given as:

$$\mu[CD_{\text{Tot}}(\lambda)] = L_{\text{I–Tot}}\mu_I(\lambda) + L_{\text{II–Tot}}\mu_{II}(\lambda) + n_A\mu_A(\lambda) + n_B\mu_B(\lambda) \quad (11)$$

The standard deviation of the total dispersion is given as:

$$\sigma[CD_{\text{Tot}}(\lambda)] = \left[L_{\text{I–Cab}}L_{\text{I–Tot}}\sigma_I^2(\lambda) + L_{\text{II–Cab}}L_{\text{II–Tot}}\sigma_{II}^2(\lambda) + n_{\text{A}}\sigma_{\text{A}}^2(\lambda) + n_{\text{B}}\sigma_{\text{B}}^2(\lambda)\right]^{1/2} \quad (12)$$

NOTE If the individual sub-lengths for an installed link are known, the substitution of Equation (10) can be used.

The limits are then given as:

$$CD_{\text{Tot}}(\lambda) = \mu[CD_{\text{Tot}}(\lambda)] \pm 3\sigma[CD_{\text{Tot}}(\lambda)] \quad (13)$$

Adding more fibre or component types can be done with a simple extension of the above formulas.

Note that these formulas present the situation in a fashion that could lead one to conclude that all the compensators could be co-located. In general this is not done. The compensators are normally distributed to reduce the maximum local dispersion along the link.

These formulas are illustrated for a combination of a distribution of B1.1 fibres (ITU-T G.652) (see IEC 60793-2-50) and a distribution of dispersion compensation components (ITU-T G.671). The assumed link parameters are:

L_{Tot} 400 km
L_{Cab} 10 km
n_{DC} 5