Appendix 1

Information about cabled fiber link attributes used for system design

A concatenated link usually includes a number of spliced factory lengths of optical fiber cable. The transmission parameters for concatenated links must take into account not only the performance of the individual cable lengths but also the statistics of concatenation.

The transmission characteristics of factory length optical fiber cables will have a certain probability distribution which can be taken into account if the most economic designs are to be obtained. This appendix should be read with the statistical nature of the various parameters in mind.

Link attributes such as end-to-end attenuation, chromatic dispersion, or PMD are affected by factors other than optical fiber cables, by such things as splices, passive components, and installation. These factors are not specified in this Appendix. The estimation methods of link parameters needed for system design are based on measurements, modeling or other considerations. The following provides additional description, methodology, and examples of how cabling link attenuation attributes specifically can be statistically estimated.

I.1 Attenuation

The mean attenuation, A, of a link is given by:

$$A = \alpha L + \alpha_s x + \alpha_c y$$

where:

- α mean attenuation coefficient of the fiber cables in a link;
- α_s mean splice loss;
- x number of splices in a link;
- α_c mean loss of line connectors;
- y number of line connectors in a link (if provided);
- L link length.

A suitable margin should be allocated for future modifications of cable configurations (additional splices, extra cable lengths, ageing effects, temperature variations, etc.). The above equation does not include the loss of equipment connectors. The attenuation budget used in designing an actual system should account for the statistical variations in these parameters.

The cabled fiber attenuation link design value (LDV) provides a statistical upper limit for the α parameter in the above equation.

The attenuation LDV calculation starts with establishing a statistical distribution. Let x_i and L_i be the attenuation coefficient (dB/km) and length, respectively, of a fiber in the i_{th} cable in a concatenated link of N cables. The attenuation coefficient, x_N (dB/km), of this link is:

$$x_N = \frac{\sum_{i=1}^{N} L_i x_i}{\sum_{i=1}^{N} L_i} = \frac{1}{L_{Link}} \sum_{i=1}^{N} L_i x_i \qquad [1]$$

If it is assumed that all cable section lengths are less than some common value, L_{Cab}, and simultaneously reducing the number of assumed cable sections to $M = L_{Link}/L_{Cab}$, then, for a link comprised of equal-length cables, $L_i = L_{Cab}$, equation above becomes

$$x_N \leq x_M = \frac{L_{Cab}}{L_{Link}} \sum_{i=1}^{M} x_i = \frac{1}{M} \sum_{i=1}^{M} x_i \qquad [2]$$

The variation in the concatenated link attenuation coefficient, x_M, will be less than the variation in the individual cable sections, xi, because of the averaging of the concatenated fibers.

Once the attenuation distribution has been established, the Monte Carlo method can be used to determine the probability density, f_{link}, of the concatenated link attenuation coefficients without making any assumption about its form. This method simulates the process of building links by sampling the measured attenuation population repeatedly.

Attenuation coefficients are measured on a sufficiently large number of segments so as to characterize the underlying distribution. This data is then used to compute the attenuation coefficient for a single path in a concatenated link.

Computation of the attenuation LDV is made by randomly selecting M values from the measured attenuation coefficients, and adding them according to equation [2]. The computed attenuation LDV is placed in a table or a histogram of values derived from other random samplings. The process is repeated until a sufficient number of attenuation LDV values has been computed to produce a high density (0.01 dB/km) histogram of the concatenated attenuation LDV distribution. If the histogram is used directly, without any additional characterization such as Gaussian fitting, the number of resamples should be at least 10,000.

Because of the central limit theorem, the histogram of cabled fiber attenuation LDV will tend to converge to distributions that can be described with a minimum of two parameters. Hence, the histogram can be fit to a parametric distribution that enables extrapolation to probability levels that are smaller than what would be implied by the sample size. The two parameters will invariably represent two aspects of the distributions: the central value and the variability about the central value.

To obtain probability levels of $Q = 10^{-3}$ using a pure numeric approach requires Monte Carlo simulations of at least 10^4 samples. Once this is complete, attenuation LDV can be interpolated from the associated cumulative probability density function.

Considerations of multiple distributions, multiple fiber types, and cable constructions led to the values shown in Table 1.

I.2 Chromatic dispersion

The chromatic dispersion in ps/nm can be calculated from the chromatic dispersion coefficients of the factory lengths, assuming a linear dependence on length, and with due regard for the signs of the coefficients (see clause 5.10).

A similar process to the attenuation LDV can be performed with chromatic dispersion for a particular wavelength, thus, establishing a chromatic dispersion LDV.

Table I-1: Attenuation and Chromatic Dispersion LDVs

Attribute	Detail	Value
Link Design Values (LDV)	M	8 cables (Note 1)
	Q	0.1%
Cabled Fibre Attenuation LDV	Maximum from 1490 nm to 1625 nm	0.24 dB/km
Chromatic Dispersion LDV	Maximum at 1550 nm Maximum at 1625 nm	17.4 ps/nm.km 21.8 ps/nm.km (Note 2)
Note 1 – This could be representative of a 40 km link using 5 km cable sections. The LDVs are conservative for links with more segments. Note 2 – Using linear interpolation, Chromatic dispersion can be calculated to be 20.2 ps/nm.km at 1598 nm, the maximum wavelength specified in Section XXX		