surement.

In any case, the modulating signal shall be such as to guarantee a sufficient time resolution in the group delay measurement.

(3201)

a) Reflection originated by the coupling device at the input end of the fibre

b) Zone of constant slope

c) Discontinuity due to local defect, splice or coupling

d) Reflection due to dielectric defect

e) Reflection at the end of the fibre.

B.4Second alternative test method: The insertion loss technique

Under consideration.

Section V: Test methods for chromatic dispersion coefficient measurement

B.1Reference test method for chromatic dispersion coefficient measurement
B.1.1Objective

The fibre chromatic dispersion coefficient is derived from the measurement of the relative group delay experienced by the various wavelengths during propagation through a known length of fibre.

The group delay can be measured either in the time domain or in the frequency domain, according to the type of modulation of the source.

In the former case the delay experienced by pulses at various wavelengths is measured; in the latter the phase shift of a sinusoidal modulating signal is recorded and processed to obtain the time delay.

The chromatic dispersion may be measured at a fixed wavelength or over a wavelength range.

B.1.2Test apparatus

A schematic diagram of the test apparatus is shown in Figure B-11/G.652.

B.1.2.1Source

The source shall be stable in position, intensity and wavelength over a time period sufficiently long to complete the measurement procedure. Laser diodes, LED's or broadband sources, (e.g., an Nd:YAG laser with a Raman fibre) may be used, depending on the wavelength range of the mea-

g) Rise time, width and repetition rate of the pulse

h) Kind of signal processing used

i) The recorded curve on a logarithmic scale, with the attenuation of the sample, and under certain conditions the attenuation coefficient in dB/km.

Note - The complete analysis of the recorded curve (Figure B-10b/G.652) shows that, independently from the attenuation measurement, many phenomena can be monitored using the backscattering technique:

B.3.2.5Cladding mode stripper

See § B.2.1.5.

B.3.2.6Procedure

1) The fibre under test is aligned to the coupling device.

2) Backscattered power is analyzed by a signal processor and recorded on a logarithmic scale. Figure B-10b/G.652 shows such a typical curve.

3) The attentuation between two points A and B of the curve corresponding to two cross-sections of the fibre is

$$A(+) = \frac{1}{A-B\ \ 2}(V_A - V_B) \qquad dB$$

where V_A and V_B are the corresponding power levels given in the logarithmic scale.

Note - Attention must be given to the scattering conditions at points A and B when calculating the attenuation in this way.

4) If so required, bi-directional measurements can be made, together with numerical computation to improve the quality of the result and possibly to allow the separation of attenuation from backscattering factor.

B.3.2.7Results

The following details shall be presented:

a) Measurement types and characteristics

b) Launching techniques

c) Test set-up arrangement

d) Relative humidity and temperature of the sample (when necessary)

e) Fibre identification

f) Length of sample

FIGURE B-9/G.652

The cutback technique

B.3.2.3Coupling device

The coupling device is needed to couple the source radiation to the fibre and the backscattered radiation to the detector, while avoiding a direct source-detector coupling. Several devices can be used, but devices based on polarization effects should be avoided.

B.3.2.4Optical detection

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A detector shall be used so that the maximum possible backscattered power should be intercepted. The detector response shall be compatible with the levels and wavelengths of the detected signal. For attenuation measurements the detector response shall be substantially linear.

Signal processing is required to improve the signal to noise ratio, and it is desirable to have a logarithmic response in the detection system.

A suitable amplifier shall follow the optical detector, so that the signal level becomes adequate for the signal processing. The bandwidth of the amplifier will be chosen as a trade-off between time resolution and noise reduction.

Care must be taken that higher order modes do not propagate.

An example of apparatus is shown in Figure B-10a/G.652.

B.3.2.2Optical source

A stable high power optical source of an appropriate wavelength should be used. The wavelength of the source should be recorded. The pulse width and repetition rate should be consistent with the desired resolution and the length of the fibre. Optical non-linear effects should not be present in the part of the fibre under test.

B.2.2.3Presentation of results

The following details shall be presented:

a) Test set-up arrangement, including source type, source wavelength, and linewidth (FWHM)

b) Fibre identification

c) Length of sample

d) Attenuation of the sample quoted in dB

e) Attenuation coefficient quoted in dB/km

f) Indication of accuracy and repeatability

g) Temperature of the sample and environmental conditions (if necessary).

B.3First alternative test method: The backscattering technique

Note - This test method describes a procedure to measure the attenuation of a homogeneous sample of single-mode optical fibre cable. The technique can be applied to check the optical continuity, physical defects, splices, backscattered light of optical fibre cables and the length of the fibre.

B.3.1Launching conditions

The launch beam shall be coaxially incident on the launch end of the fibre; various devices such as index matching materials can be used to reduce Fresnel reflections. The coupling loss shall be minimized.

B.3.2Apparatus and procedure

B.3.2.1 General considerations

The signal level of the backscattered optical signal will normally be small and close to the noise level. In order to improve the signal-to-noise ratio and the dynamic measuring range it is therefore customary to use a high power light source in connection with signal processing of the detected signal. Further, accurate spatial resolution may require adjustment of the pulse width in order to obtain a compromise between resolution and pulse energy. Special care should be taken to minimize the Fresnel reflections.

3) The attenuation of the fibre, between the points where P_1 and P_2 have been measured, can be calculated from the definition using P_1 and P_2.

B.2.1.3Launching conditions

The launching conditions used must be sufficient to excite the fundamental mode. For example, suitable launching techniques could be:

a) jointing with a fibre;

b) launching with a suitable system of optics.

B.2.1.4Mode filter

Care must be taken that higher order modes do not propagate through the cut-back length. In these cases it may be necessary to intoduce a bend in order to remove the higher modes.

B.2.1.5Cladding mode stripper

A cladding mode stripper encourages the conversion of cladding modes to radiation modes; as a result, cladding modes are stripped from the fibre.

B.2.1.6Optical detector

A suitable detector shall be used so that all of the radiation emerging from the fibre is intercepted. The spectral response should be compatible with spectral characteristics of the source. The detector must be uniform and have linear sensitivity characteristics.

B.2.2Measurement procedure

B.2.2.1Preparation of fibre under test

Fibre ends shall be substantially clean, smooth, and perpendicular to the fibre axis. Measurements on uncabled fibres shall be carried out with the fibre loose on the drum, i.e., microbending effects shall not be introduced by the drum surface.

B.2.2.2Procedure

1) The fibre under test is placed in the measurement set-up. The output power P_2 is recorded.

2) Keeping the launching conditions fixed, the fibre is cut to the cut-back length (for example, 2 m from the launching point). The cladding mode stripper, when needed, is refitted and the output power P_1 from the cut-back length is recorded.

A suitable radiation source shall be used as a lamp, laser or light emitting diode. The choice of source depends upon the type of measurement. The source must be stable in position, intensity and wavelength over a time period sufficiently long to complete the measurement procedure. The spectral linewidth (FWHM) shall be specified such that the linewidth is narrow compared with any features of the fibre spectral attenuation.

B.2.1.2Modulation

It is customary to modulate the light source in order to improve the signal/noise ratio at the receiver. If such a procedure is adopted, the detector should be linked to a signal processing system synchronous with the source modulation frequency. The detecting system should be substantially linear in sensitivity.

Section IV: Test methods for attenuation measurements

B.1Introduction

B.1.1Objectives

The attenuation tests are intended to provide a means whereby a certain attenuation value may be assigned to a fibre length such that individual attenuation values may be added together to determine the total attenuation of a concatenated length.

B.1.2Definition

The attenuation A(+) at wavelength + between two cross sections and separated by distance L of a fibre is defined, as

$$A(+) = 10 \log [P_1(+)/P_2(+)] \text{ (dB)} \qquad (1)$$

where $P_1(+)$ is the optical power traversing the cross section 1 and $P_2(+)$ is the optical power traversing the cross section 2 at the wavelength +.

For a uniform fibre, it is possible to define an attenuation per unit length, or an attenuation coefficient which is independent of the length of the fibre:

$$\propto(+) = A(+)/\Lambda \quad (\delta B/\upsilon\nu\iota\tau\ \lambda\varepsilon\nu\gamma\tau\eta) \qquad (2)$$

Note - Attenuation values specified for factory lengths should be measured at room temperature (i.e., a single value in the range 10• to 35•C).

B.2The reference test method: the cut-back technique

The cut-back technique is a direct application of the definition in which the power levels P_1 and P_2 are measured at two points of the fibre without change of input conditions. P_2 is the power emerging from the far end of the fibre and P_1 is the power emerging from a point near the input after cutting the fibre.

B.2.1Test apparatus

Measurements may be made at one or more spot wavelengths, or alternatively, a spectral response may be required over a range of wavelengths. Diagrams of suitable test equipments are shown as examples in Figure B-9/G.652.

B.2.1.1Optical source

Deployment condition for measurement of the cabled fibre cut-off wavelength

(3201)

B.3.2.2.4 Determination of cabled fibre cut-off wavelength

If method a) is used, $+_c$ is determined as the largest wavelength at which R(+) is equal to 0.1 dB (see Figure B-5). If method b) is used, + is determined by the intersection of a plot of R(+) and a straight line (2) displaced 0.1 dB and parallel to the straight line (1) fitted to the long wavelength portion of R(+) (see Figure B-6).

B.3.2.2.5 Presentation of results

a) Test set-up arrangement (including the radius XX of the loops)

b) Launching condition

c) Type of reference sample

d) Temperature of the sample and environmental conditions (if necessary)

e) Fibre and cable identification

f) Wavelength range of measurement

g) Cabled fibre cut-off wavelength, and plot of R(+) (if required)

h) Plot of R(+) (if required).

cable

FIGURE B-8/G.652

(3201)

Note - The value of XX is under study. Several administrations indicated that a value of 45 mm is appropriate. The loops are intended to simulate deployment conditions, and should be chosen according to the practice of a particular administration. One option to be considered is deleting the loops, if that is the administration's practice.

B.3.2.2.2 Transmission through the reference sample (as in B.1.2.2.2)

B.3.2.2.3 Calculations

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* Including image shearing optics, where appropriate

** When appropriate

c) Spectral characteristics of the source

d) Fibre identification and length

e) Magnification of the magnifying optics

f) Temperature of the sample and environmental conditions (when necessary)

g) Indication of the accuracy and repeatability

h) Resulting dimensional parameters, such as cladding diameters, cladding non-circularities, mode field concentricity error, etc.

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* The validity of the image shearing technique is under study and needs to be confirmed.

FIGURE B-4/G.652

Section III: Test methods for the cut-off wavelength

B.1 Reference test method for the cut-off wavelenth ($+_c$) of the primary coated fibre: The transmitted power technique

of the optics shall be compatible with the measuring accuracy required, and not lower than 0.3. The magnification shall be selected to be compatible with the desired spatial resolution, and shall be recorded.

Image shearing techniques could be used in the magnifying optics to facilitate accurate measurements.

B.4.2.6Detection

The fibre image shall be examined and/or analyzed. For example, either of the following techniques can be used:

a) image shearing*;

b) grey-scale analysis of an electronically recorded image.

B.4.2.7Data acquisition

The data can be recorded, processed and presented in a suitable form, according to the technique and to the specification requirements.

B.4.3Procedure

B.4.3.1Equipment calibration

For the equipment calibration the magnification of the magnifying optics shall be measured by scanning the image of a specimen whose dimensions are already known with suitable accuracy. This magnification shall be recorded.

B.4.3.2Measurement

The launch end of the fibre shall be aligned with the launch beam, and the output end of the fibre shall be aligned to the optical axis of the magnifying optics. For transmitted near field measurement, the focussed image(s) of the output end of the fibre shall be examined according to the specification requirements. Defocussing errors should be minimized to reduce dimensional errors in the measurement. The desired geometrical parameters are then calculated.

B.4.4Presentation of the results

a) Test set-up arrangement, with indication of the technique used

b) Launching conditions

B.4Alternative test method: The transmitted near field image technique

B.4.1General

The transmitted near field image technique shall be used for the measurement of the geometrical characteristics of single-mode optical fibres. Such measurements are performed in a manner compatible with the relevant definitions.

The measurement is based on analysis of the magnified image(s) of the output end of the fibre under test.

B.4.2Test appartatus

A schematic diagram of the test apparatus is shown in Figure B-4/G.652.

B.4.2.1Light Source

The light source for illuminating the core shall be adjustable in intensity and stable in position and intensity over a time period sufficiently long to complete the measurement procedure. A second light source with similar characteristics can be used, if necessary, for illuminating the cladding. The spectral characteristics of the second light source must not cause defocussing of the image.

B.4.2.2Launching conditions

The launch optics, which will be arranged to overfill the fibre, will bring the beam of light to a focus on the flat input end of the fibre.

B.4.2.3.Cladding mode stripper

A suitable cladding mode stripper shall be used to remove the optical power propagating in the cladding. When measuring the geometrical characteristics of the cladding only, the cladding mode stripper shall not be present.

B.4.2.4Specimen

The specimen shall be a short length of the optical fibre to be measured. The fibre ends shall be clean, smooth and perpendicular to the fibre axis.

B.4.2.5Magnifying optics

The magnifying optics shall consist of an optical system (e.g., a microscope objective) which magnifies the specimen output near field. The numerical aperture and hence the resolving power

rotation angle (deg)

FIGURE B-3/G.652

Measured value of the MFCE as a function of rotation angle

(3201)

Schematic diagram of measurement system

(3201)

FIGURE B-2/G.652

(3201)

B.3.3.2Measurement

The test fibre is fixed in the sample holder and set in the measuring system. The fibre is adjusted so that its axis is perpendicular to the optical axis of the measuring system.

Intensity distributions in the observation plane along the line perpendicular to the fibre axis (a - a ' in A , in Figure B-2/G.652) are recorded (shown as B) for different viewing directions, by rotating the fibre around its axis, keeping the distance between the fibre axis and the observation plane constant. Cladding diameter and the central position of the fibre are determined by analyzing the symmetry of the diffraction pattern (shown as b in Figure B). The central position of the core is determined by analyzing the intensity distribution of converged light (shown as C). The distance between the central position of the fibre and that of the core corresponds to the nominal observed value of MFCE.

As shown in Figure B-3/G.652, fitting the sinusoidal function to the experimentally obtained values of the MFCE plotted as a function of the rotation angle, the actual MFCE is calculated as the product of the maximum amplitude of the sinusoidal function and magnification factor with respect to the lens effect due to the cylindrical-structure of the fibre. The cladding diameter is evaluated as an averaged value of measured fibre diameters at each rotation angle, resulting in values for maximum and minimum diameters to determine the value of cladding non-circularity according to the definition.

B.3.3.3Presentation of the results

The following details shall be presented.

a) Test arrangement

b) Fibre identification

c) Spectral characteristics of the source

d) Indication of repeatability and accuracy

e) Plot of nominal MFCE vs. rotation angle

f) MFCE, cladding diameter and cladding non-circularity

g) Temperature of the sample and environmental conditions (if necessary)

B.3.3Procedure

B.3.3.1Equipment calibration

For equipment calibration the magnification of the magnifying optics shall be measured by scanning the length of a specimen whose dimensions are already known with suitable accuracy. This magnification shall be recorded.

B.3 Alternative test method: The side-view method

B.3.1 Objective

The side-view method is applied to single-mode fibres to determine geometrical parameters (mode field concentricity error (MFCE), cladding diameter and cladding non-circularity) by measuring the intensity distribution of light that is refracted inside the fibre.

B.3.2 Test apparatus

A schematic diagram of the test apparatus is shown in Figure B-2.

B.3.2.1 Light source

The emitted light shall be collimated, adjustable in intensity and stable in position, intensity and wavelength over a time period sufficiently long to complete the measuring procedure. A stable and high intensity light source such as a light emitting diode (LED) may be used.

B.3.2.2 Specimen

The specimen to be measured shall be a short length of single-mode fibre. The primary fibre coating shall be removed from the observed section
of the fibre. The surface of the fibre shall be kept clean during the measurement.

B.3.2.3 Magnifying optics

The magnifying optics shall consist of an optical system (e.g., a microscope objective) which magnifies the intensity distribution of refracted light inside the fibre onto the plane of the scanning detector. The observation plane shall be set at a fixed distance forward from the fibre axis. The magnification shall be selected to be compatible with the desired spatial resolution and shall be recorded.

B.3.2.4 Detector

A suitable detector shall be employed to determine the magnified intensity distribution in the observation plane along the line perpendicular to the fibre axis. A vidicon or charge coupled device can be used. The detector must have linear characteristics in the required measuring range. The detector's resolution shall be compatible with the desired spatial resolution.

B.3.2.5 Data processing

A computer with appropriate software shall be used for the analysis of the intensity distributions.
(3201)