The Recommendations in this Subsection relate to the specifications for submarine cables. The Recommendations concerning systems are in Subsection 3.7.

Supplement No. 11 contains documentation on the cable ships used in various countries.

Supplement No. 18 contains information on submarine cables used in deep water.

Recommendation G.631

TYPES OF SUBMARINE CABLE TO BE USED FOR SYSTEMS WITH LINE FREQUENCIES OF LESS THAN ABOUT 45 MHz

(Geneva, 1976)

6.3 Submarine cables

The CCITT,

recognizing

that the special complications of cable repair in the case of submarine cable systems laid in deep water (i.e. at depths where there is no need to use armoured cables) justify measures which would reduce the number of cable types with which repair ships have to deal;

appreciating

at the same time that system designers require flexibility in the choice of cables in order to optimize the overall cost per unit length of individual systems;

recognizing

that the most significant cable characteristics in determining whether any two cables may be joined together are:

— the inner diameter of the outer conductor,

— the characteristic impedance of the cable,

recommends

that for submarine systems handling line frequencies up to 45 MHz the cable used in the deep water sections of such systems should conform with the limits set out in Table 1/G.631.

H.T. [T1.631]

TABLE 1/G.631

{ Inner diameter of outer conductor } Characteristic impedance a) 53-54 ?73 b) 60-62 ?73 } a) 49-50 ?73 b) 53-54 ?73 c) 60-62 ?73 }	25.0-25.5 mm 43-46 ?73 {	37.0-38.5 mm {	43.2 mm

Table 1/G.631 [T1.631], p.

6.4 Waveguides

Recommendation G.641

WAVEGUIDE DIAMETERS

(Geneva, 1976)

The CCITT,

considering

(a) that large waveguides have advantages of lower basic attenuation and allow increased repeater spacings on relatively straight routes, but are more costly to manufacture and are more critical in laying requirements;

(b) that small diameter waveguides are cheaper, more tolerant of bends and less critical in laying requirements — thus offering advantages in urban areas or rough terrains — but require closer spacing of repeaters;

(c) that optimization of waveguide diameter for a specific case is a complex matter involving such aspects as a detailed analysis of the particular route involved, relative production and laying costs for various possible types and diameters of waveguide, relative costs of the types and varying number of repeaters required, and overall reliability targets;

(d) that it is appropriate to minimize wasteful proliferation by standardizing a small number of waveguide diameters,

recommends

that waveguide inner diameters should be chosen, as appropriate, from the series 30, 40, 50, 51, 60 and 70 mm.

6.5 Optical fibre cables

Recommendation G.651

CHARACTERISTICS OF A 50/125 µm MULTIMODE GRADED INDEX OPTICAL FIBRE CABLE

(Malaga-Torremolinos, 1984; amended at Melbourne, 1988)

The CCITT,

considering that

(a) graded index multimode optical fibre cables will be used widely in future telecommunication networks;

(b) the foreseen potential applications may require multimode fibres differing in:

— nature of material,

— geometrical characteristics,

— operating wavelength region(s),

— transmission and optical characteristics,

— mechanical and environmental aspects,

(c) Recommendations on different kinds of multimode fibres can be prepared when practical use studies have sufficiently progressed,

recommends

a graded index, multimode fibre, which may be used in the region of 850 nm or in the region of 1300 nm or alternatively may be used in both wavelength regions simultaneously.

This fibre can be used for analogue and for digital transmission.

Its geometrical, optical, and transmission characteristics are described below.

The meaning of the terms used in this Recommendation is given in Annex A and the guidelines to be followed in the measurements to verify the various characteristics are indicated in Annex B.

Annexes A and B may become separate Recommendations as additional multimode fibre Recommendations are agreed upon.

1 Fibre characteristics

The fibre characteristics dealt with in § 1 are those which ensure the interconnection of fibres with acceptable low losses.

Only the intrinsic fibre characteristics (not depending on the cable manufacture) are recommended in § 1. They will apply equally to individual fibres, fibres incorporated into a cable wound on a drum, and fibres in installed cables.

1.1 *Geometrical characteristics of the fibre*

1.1.1 *Core diameter*

The recommended nominal value of the core diameter is 50 µm.

The core diameter deviation should not exceed the limits of ± | % (±3 µm).

1.1.2 *Cladding diameter*

The recommended nominal value of the cladding diameter is 125 µm.

The cladding diameter deviation should not exceed the limits of ± 2.4% (±3 µm).

1.1.3 *Concentricity error*

The recommended concentricity error should be less than 6%.

1.1.4 *Non-circularity*

1.1.4.1 *Core non-circularity*

The recommended core non-circularity should be less than 6%.

1.1.4.2 *Cladding non-circularity*

The recommended cladding non-circularity should be less than 2%.

1.2 *Optical properties of the fibre*

1.2.1 *Refractive index profile*

For fibres dealt with in this Recommendation, the refractive index profiles are expected to be near parabolic.

1.2.2 *Numerical aperture*

The optimum value of the numerical aperture (NA) will depend on the particular application for which the fibre is to be used and in particular on the source coupling efficiency required, the increased attenuation due to microbending effects which can be tolerated, and the overall baseband response required.

Values commonly employed in practice lie within the range 0.18-0.24.

Whatever actual value is employed should not differ from the chosen nominal value by more than 0.02.

1.3 *Material properties of the fibre*

1.3.1 *Fibre materials*

The substances of which the fibres are made should be indicated.

Note — Care may be needed in fusion splicing fibres of different substances. Provisional results indicate that adequate splice loss and strength can be achieved when splicing different high-silica fibres.

1.3.2 *Protective materials*

The physical and chemical properties of the material used for the fibre primary coating, and the best way of removing it (if necessary), should be indicated. In the case of a single-jacketed fibre similar indications shall be given.

2 **Factory length specifications**

Since the geometrical and optical characteristics of fibres are barely affected by the cabling process, § 2 will give recommendations mainly relevant to transmission characteristics of cable factory lengths.

Transmission characteristics depend greatly on the wavelength used to convey the information.

Environmental and test conditions are paramount and are described in the guidelines for test methods.

The transmission characteristics of fibres will have a statistical probability distribution which will be a function of the design and manufacturing processes. The specification of limits for the transmission characteristics must therefore take this distribution into account. For instance for certain applications a particular limit may not embrace 100% of the production and indeed may only represent a very small fraction of the total production. Economic considerations will play a large part in the deciding of specification limits for particular applications.

2.1 *Attenuation coefficient*

Optical fibre cables covered by this Recommendation generally have attenuation coefficients in the 850 nm region below 4 dB/km and in the 1300 nm region below 2 dB/km.

Note 1 — The lowest values of the attenuation coefficient depend on the fabrication process, fibre composition and fibre and cable design; values in the range of 2-2.5 dB/km in the 850 nm region and 0.5-0.8 dB/km in the 1300 nm region have been achieved.

Note 2 — In certain cases, fibres could be used in both wavelength regions.

2.2 *Baseband response*

The baseband response includes both modal distortion and chromatic dispersion effects. For certain applications the effects of chromatic dispersion are negligible and can be ignored.

The baseband response is presented in the frequency domain. Administrations wishing to use the time domain will still be able to do so by means of mathematical operations. For this purpose the amplitude and phase response should be available.

By convention, the baseband response is linearly referred to 1 km.

2.2.1 *Modal distortion bandwidth: amplitude response*

The modal bandwidth amplitude response is specified in the form of —3 dB optical (—6 dB electrical) points of the bandwidth of the total amplitude/frequency curve corrected for chromatic dispersion. A more complete curve of the total bandwidth response should also be given.

Optical fibre cables covered by this Recommendation generally have normalized modal distortion bandwidths greater than 200 MHz | (mu | m in the 850 nm region and in the 1300 nm region, but not necessarily simultaneously.

Note 1 — The upper values of the normalized modal distortion bandwidth depend on the fabrication process, fibre composition and fibre and cable design; values greater than 1000 MHz | (mu | m in the 850 nm region and 2000 MHz | (mu | m in the 1300 nm region have been achieved.

Note 2 — In certain cases, fibres could be used in both wavelength regions.

2.2.2 *Modal distortion bandwidth: phase response*

No recommended value is given as phase response information is only required in special cases.

2.2.3 *Chromatic dispersion*

When required, the manufacturer of the optical fibres should indicate the chromatic dispersion coefficient values of the fibre type in the operating wavelength region(s). The test method is contained in Annex B, section V, to Recommendation G.652.

Note 1 — For multimode fibres the dominant chromatic dispersion mechanism is material dispersion.

Note 2 — Typical values of the chromatic dispersion coefficient for high grade silica optical fibres are the following:

H.T. [T1.651]

Wavelength (nm) Chromatic dispersion coefficient [ps/(nm×km)] }	{
850 1300	120 6

Table [T1.651],p.

3 Elementary cable sections

An elementary cable section as defined in Recommendation G.601 (term 1008) usually includes a number of spliced factory lengths. The requirements for factory lengths are given in § 2 of this Recommendation. The transmission parameters for elementary cable sections must take into account not only the performance of the individual cable lengths but also, amongst other factors, such things as splices, connectors (if applicable) and mode coupling effects which can affect bandwidth and attenuation.

In addition the transmission characteristics of the factory length fibres as well as such items as splices and connectors etc., will all have a certain probability distribution which often needs to be taken into account if the most economic designs are to be obtained. The following sub-paragraphs in this section should be read with this statistical nature of the various parameters in mind.

3.1 *Attenuation*

The attenuation A of an elementary cable section is given by

$$A = \sum_{n=1}^{m} \alpha_n \times L_n + a_s \times x + a_c \times y$$

where

α_n = attenuation coefficient of nth fibre in elementary cable section,

L_n = length of nth fibre,

m = total number of concatenated fibres in elementary cable section,

a_s = mean splice loss,

x = number of splices in elementary cable section,

a_c = mean loss of line connectors,

y = number of line connectors in elementary cable section if provided.

Note 1 — The losses a_s and a_c of splices and line connectors are generally defined in equilibrium mode distribution conditions. In operating conditions appreciable differences may occur.

Note 2 — The above expression does not include the loss of equipment connectors.

Note 3 — In the overall design of a system, allowance must be made for a suitable cable margin for future modifications of cable configurations (additional splices, extra cable lengths, ageing effects, temperature variations, etc.).

Note 4 — The mean loss is taken for the loss of splices and connectors. The attenuation budget used in designing an actual system should account for the statistical variations in these parameters.

3.2 *Baseband response (overall —3 dB optical bandwith)*

The baseband response is given in the frequency domain and includes the effects of both modal distortion and chromatic dispersion and can be represented by the expression:

$$B_T =$$

$\left[B_{modal}^{-2} + B_{chromatic}^{-2} \right]$

[Formula Deleted]

where

B_T = overall bandwidth (including modal distortion and chromatic dispersion),

B_{modal} = modal distortion bandwidth,

$B_{chromatic}$ = chromatic dispersion bandwidth (see Note 3).

Note 1 — Both the fibre modal distortion baseband response and the source spectrum are assumed to be Gaussian.

Note 2 — For certain applications the effect of chromatic dispersion is negligible, in which case chromatic dispersion can be ignored.

Note 3 — $B_{chromatic}$, the chromatic bandwidth, is inversely proportional to the section length and, if the source spectrum is assumed to be Gaussian, can be expressed as:

$$B_{chromatic} \text{ (MHz)} = (\Delta\lambda \times D(\lambda) \times 10^{-6} \times L / 0.44)^{-1}$$

where

$\Delta\lambda$ = FWHM source line width (nm),

$D(\lambda)$ = chromatic dispersion coefficient [ps/(nm | (mu | m)],

L = section length (km).

3.2.1 *Modal distortion bandwidth*

The modal distortion bandwidth values for individual cable lengths in an elementary cable section are obtained from the relevant fibre specification. However, the overall modal distortion bandwidth of the elementary cable section may not be a linear addition of the individual responses due to mode coupling and other effects at splices and, sometimes, along the length of the fibre.

The modal distortion bandwidth for an elementary cable section is therefore given by:

$$B_{modal\ total} = \left\{ \sum_{n=1}^{x} B_{modal\ n}^{-1/\gamma} \right\}^{-\gamma}$$

where

$B_{modal\ total}$ = overall modal distortion bandwidth of an elementary cable section,

$B_{modal\ n}$ = modal distortion bandwidth of nth fibre in elementary cable section,

x = total number of concatenated fibres in elementary cable section,

γ = modal distortion bandwidth concatenation factor.

Note — The value of γ, the modal distortion bandwidth concatenation factor, is typically in the range 0.5 to 1.0 depending on the effects of mode coupling at splices, alpha profile compensation, wavelength of maximum bandwidth etc. Values below this range can also be obtained in certain circumstances. For a given fibre, the appropriate value of γ which should be employed can be empirically derived, and can usually be obtained from the fibre/cable manufacturer.

ANNEX A
(to Recommendation G.651)

Meaning of the terms used in the Recommendation

A.1 **alternative test method (ATM)**

A test method in which a given characteristic of a specified class of optical fibres or optical fibre cables is measured in a manner consistent with the definition of this characteristic and gives results which are reproducible and relatable to the reference test method and to practical use.

A.2 **attenuation coefficient**

In an optical fibre it is the attenuation per unit length.

Note — The attenuation is the rate of decrease of average optical power with respect to distance along the fibre and is defined by the equation:

$$P(z) = P(0)\, 10^{-(\alpha z/10)}$$

where

$P(z)$ = power at distance z along the fibre,

$P(0)$ = power at $z = 0$,

α = attenuation coefficient in dB/km if z is in km.

From this equation the attenuation coefficient is

$$\alpha = -\frac{0 \log_{10} [P(z)/P(0)]}{f Iz}$$

This assumes that α is independent of z .

A.3 bandwidth (of an optical fibre)

That value numerically equal to the lowest frequency at which the magnitude of the baseband transfer function of an optical fibre decreases to a specified fraction, generally to —3 dB optical (—6 dB eletrical), of the zero frequency value.

Note — The bandwidth is limited by several mechanisms: mainly modal distortion and chromatic dispersion in multimode fibres.

A.4 chromatic dispersion

The spreading of a light pulse in an optical fibre caused by the different group velocities of the different wavelengths composing the source spectrum.

Note — The chromatic dispersion may be due to one or more of the following: material dispersion, waveguide dispersion, profile dispersion. Polarization dispersion does not give appreciable effects in circularly-symmetric fibres.

A.5 chromatic dispersion coefficient

The chromatic dispersion per unit source spectrum width and unit length of fibre. It is usually expressed in ps/(nm | (mu | m).

A.6 cladding

That dielectric material of an optical fibre surrounding the core.

A.7 cladding mode stripper

A device that encourages the conversion of cladding modes to radiation modes.

A.8 core

The central region of an optical fibre through which most of the optical power is transmitted.

A.9 core area

For a cross section of an optical fibre the area within which the refractive index everywhere (excluding any index dip) exceeds that of the innermost homogeneous cladding by a given fraction of the difference between the maximum of the refractive index of the core and the refractive index of the innermost homogeneous cladding.

Note — The core area is the smallest cross-sectional area of a fibre excluding any index dip, which is contained within the locus of points where the refractive index n_3 is given by

$$n_3 = n_2 + k\ (n_1 - n_2)$$ (see Figure A-1/G.651)

where:

n_1	=	maximum refractive index of the core,
n_2	=	refractive index of the innermost homogenous cladding,
k	=	a constant.

Note — Unless otherwise specified, a k value of 0.05 is assumed.

Figure A-1/G.651, p.

A.10 **core (cladding) centre**

For a cross-section of an optical fibre it is the centre of that circle which best fits the outer limit of the core area (cladding).

Note 1 — These centres may not be the same.

Note 2 — The method of best fitting has to be specified.

A.11 **core (cladding) diameter**

The diameter of the circle defining the core (cladding) centre.

A.12 **core (cladding) diameter deviation**

The difference between the actual and the nominal values of the core (cladding) diameter.

A.13 **core/cladding concentricity error**

The distance between the core centre and the claddling centre divided by the core diameter.

A.14 **core (cladding) tolerance field**

For a cross-section of an optical fibre it is the region between the circle circumscribing the core (cladding) area and the largest circle, concentric with the first one, that fits into the core (cladding) area. Both circles shall have the same centre as the core (cladding).

A.15 **four concentric circles near field template**

A template comprising four concentric circles applied to a near field radiation pattern from a fibre.

Note — The template is normally used as a global check of the acceptability of the various geometrical parameters of the fibre in one simple process.

A.16 **four concentric circles refractive index template**

A template comprising four concentric circles applied to a complete refractive index profile of the fibre.

Note — The template is normally used as a global check of the acceptability of the various geometrical parameters of the fibre in one simple process.

A.17 **maximum theoretical numerical aperture**

A theoretical value of numerical aperture calculated using the values of refractive index of the core and cladding given by:

$$NA_{t\,|ax} = (n_1^2 - n_2^2)$$

[Formula Deleted]

where

n_1= maximum refractive index of the core,

n_2= refractive index of the innermost homogeneous cladding.

Note — The relationship between NA (§ A.21) and $NA_{t\,|ax}$ is given in Section I of Annex B, § B.2.2.

A.18 **mode filter**

A device designed to accept or reject a certain mode or modes.

A.19 **mode scrambler; mode mixer**

A device for inducing transfer of power between modes in an optical fibre, effectively scrambling the modes.

Note — Frequently used to provide a mode distribution that is independent of source characteristics.

A.20 **non-circularity of core (cladding)**

The difference between the diameters of the two circles defined by the core (cladding) tolerance field divided by the core (cladding) diameter.

A.21 **numerical aperture**

The numerical aperture NA is the sine of the vertex half-angle of the largest cone of rays that can enter or leave the core of an optical fibre, multiplied by the refractive index of the medium in which the vertex of the cone is located.

A.22 **reference surface**

The cylindrical surface of an optical fibre to which reference is made for jointing purposes.

Note — The reference surface is typically the cladding or primary coating surface. In rare circumstances it could be the core surface.

A.23 **reference test method (RTM)**

A test method in which a given characteristic of a specified class of optical fibres or optical fibre cables is measured stricly according to the definition of this characteristic and which gives results which are accurate, reproducible and relatable to practical use.

A.24 **(refractive) index profile**

The distribution of the refractive index along a diameter of an optical fibre.

ANNEX B

(to Recommendation G.651)

Test methods

Both reference and alternative test methods are usually given in this Annex for each parameter and it is the intention that both the RTM and the ATM may be suitable for normal product acceptance purposes. However, when using an ATM, should any discrepancy arise, it is recommended that the RTM be employed as the technique for providing the definitive measurement results.

Section I — *Reference test method and alternative test method for geometrical and optical parameters measurements*

B.1 *Introduction*

B.1.1 *General*

It is assumed that the geometrical and optical parameters, which are the subject of this Recommendation, would be measured only in the factory or in the laboratories of certain Administrations wishing to verify these parameters for system design or other purposes. Hence, it is anticipated that the measurements will be conducted either on sample fibre lengths or on samples extracted from cable factory lengths.

The core diameter and non-circularity are defined using the refractive index profile as a basis. The remaining parameters can be derived from the refractive index profile. Hence, it follows that all the geometrical and optical parameters that are the subject of this Recommendation, and their tolerances as appropriate, can be obtained by one single basic test.

B.1.1.1 *The four circle tolerance field*

A simple means of verifying the geometrical parameters of the fibre is the ‘‘ four circle tolerance field ´geometrical characteristics, but is an alternative global check of these characteristics. If any inconsistency appears between this method and the check of the individual characteristics, the latter will constitute the reference.

The ‘‘four circle tolerance field’’ method is based on the template shown in Figure B-1/G.651 where the two concentric circles concerning the core (whose diameter is $D_{c\backslash do}$) have diameters respectively of $D_{c\backslash do}$ — 4 µm and $D_{c\backslash do}$ + 4 µm and the two concentric circles concerning the cladding (whose diameter is $D_{C\backslash dL}$) have diameters respectively of $D_{C\backslash dL}$ — 5 µm and $D_{C\backslash dL}$ + 5 µm. This method can be applied to data obtained either by the Reference Test Method (four concentric circle refractive index template) or by the Alternative Test Method (four concentric circle near field template).

Figure B-1/G.651, p.

B.1.1.2 *Intrinsic quality factor*

The maximum theoretical NA, core diameter, concentricity error, and core non-circularity deviate simultaneously in ways that can either compound or compensate one another. To properly account for these effects, a theoretical splice loss can be calculated, using the values of these geometrical and optical parameters measured by existing test methods. Either a Gaussian or steady-state distribution of power vs. angle may be assumed. The intrinsic quality factor (IQF) can be calculated as the mean of the theoretical splice losses in the two directions when the test fibre is spliced to a nominal fibre with zero misalignment of the reference surfaces. A value of IQF of 0.27 dB is compatible with the individual tolerances recommended in section 1 of Recommendation G.651. If any inconsistency appears between the IQF method and the check of the individual characteristics, the latter will constitute the reference.

B.1.2 *Geometrical characteristics*

The core diameter and the cladding diameter of the fibre under test, as well as the core and cladding centres, can be determined from an adequate number of points suitably distributed on the core/cladding and on the cladding boundaries respectively.

If a raster scan is adopted, a higher number of points should be selected, in order to guarantee a sufficiently regular distribution.

The concentricity error can be evaluated from the distance between the core and cladding centres.

Core and cladding non-circularities can be determined from the tolerance field.

B.2 *The reference test methods for geometrical parameters and the alternative test method for numerical aperture: the refracted near-field technique*

B.2.1 *General*

The refracted near-field measurement is straightforward, accurate and gives directly the refractive index variation across the entire fibre (core and cladding). The measurement is capable of good resolution and can be calibrated to give absolute values of refractive index.

A schematic diagram of the measurement method is shown in Figure B-2a/G.651. The technique involves scanning a focussed spot of light across the end of the fibre. The launch optics are arranged to overfill the NA of the fibre. The fibre end is immersed in a liquid of slightly higher index than the cladding. Part of the light is guided down the fibre and the rest appears as a hollow cone outside the fibre. A disc is placed on the axis of the core to ensure that only refracted light reaches the detector. The detector output is amplified and displayed as the y-axis of an *x-y* recorder; the *x* -axis drive is derived from monitoring the position of the focussed spot of light on the end of the fibre. A typical index profile of a multimode graded index fibre is shown in Figure B-2b/G.651.

The optical resolution and hence the ability to resolve detail in the profile depends on the size of the focussed spot of light. This depends both on the numerical aperture of the focussing lens and on the size of the disc. However, the position of sharp features can be resolved to much better accuracy than this, dependent on stop size for stepped motor systems, or position monitoring accuracy of analogue drives.

B.2.2 *Numerical aperture and refractive index difference*

The maximum theoretical numerical aperture is defined as:

$$NA_{t\max} = \sqrt{n_1^2 - n_2^2}$$

The index difference is defined as:

$$\Delta n = n_1 - n_2$$

The relative index difference is defined as:

$$\Delta = (n_1 - n_2)/n_1$$

where

n_1 = maximum refractive index of the fibre core,

n_2 = refractive index of the innermost cladding.

The values of n_1 and n_2 can be determined using the refracted near-field technique, hence $NA_{t\max}$, Δn and Δ.

The maximum theoretical numerical aperture $NA_{t\max}$, determined in this way can be higher (typically by about 5% to 7%) than the numerical aperture NA determined by the RTM.

B.2.3 *Test apparatus*

A schematic diagram of the test apparatus is shown in Figure B-3/G.651.

B.2.3.1 *Source*

A stable laser giving a few milliwatts of power in the $TEM_{o\backslash do}$ mode is required.

A HeNe laser, which has a wavelength of 633 nm, may be used, but a correction factor must be applied to the results for extrapolation at different wavelengths. It shall be noted that measurement at 633 nm may not give complete information at longer wavelengths, in particular non-uniform fibre doping can affect the correction.

A quarter-wave plate is introduced to change the beam from linear to circular polarization because the reflectivity of light at an air-glass interface is strongly angle- and polarization-dependent.

A pinhole placed at the focus of lens 1 acts as a spatial filter.

B.2.3.2 *Launch conditions*

The launch optics, which are arranged to overfill the NA of the fibre, bring a beam of light to a focus on the flat end of the fibre. The optical axis of the beam of light should be within 1° of the axis of the fibre. The resolution of the equipment is determined by the size of the focussed spot, which should be as small as possible in order to maximize the resolution, e.g. less than 1.5 μm. The equipment enables the focussed spot to be scanned across the fibre diameter.

B.2.3.3 *Liquid cell*

The liquid in the liquid cell should have a refractive index slightly higher than that of the fibre cladding.

B.2.3.4 *Sensing*

The refracted light is collected and brought to the detector in any convenient manner provided that all the refracted light is collected. By calculation the required size of disc and its position along the central axis can be determined.

B.2.4 *Preparation of fibre under test*

A length of fibre of about 1 metre is required.

Primary fibre coating shall be removed from the section of fibre immersed in the liquid cell.

The fibre ends shall be clean, smooth and perpendicular to the fibre axis.

B.2.5 *Procedure*

Refer to the schematic diagram of the test apparatus (Figure B-3/G.651).

B.2.5.1 *Fibre profile plot*

The launch end of the fibre to be measured is immersed in a liquid cell whose refractive index is slightly higher than that of the fibre cladding. The fibre is back illuminated by light from a tungsten lamp. Lenses 2 and 3 produce a focussed image of the fibre.

The position of lens 3 is adjusted to centre and focus the fibre image, the laser beam is simultaneously centred and focussed on the fibre.

The disc is centred on the output cone. For multimode fibre the disc is positioned on the optic axis to just block the leaky modes. Refracted modes passing the disc are collected and focussed onto a photodiode.

The focussed laser spot is traversed across the fibre end and a plot of fibre refractive index variation is directly obtained.

B.2.5.2 *Equipment calibration*

The equipment is calibrated with the fibre removed from the liquid cell. During the measurement the angle of the cone of light varies according to the refractive index seen at the entry point to the fibre (hence the change of power passing the disc). With the fibre removed and the liquid index and cell thickness known, this change in angle can be simulated by translating the disc along the optic axis. By moving the disc to a number of predetermined positions one can scale the profile in terms of relative index. Absolute index, i.e. n_1 and n_2 can only be found if the cladding or liquid index is known accurately at the measurement wavelength and temperature.

B.2.6 *Presentation of results*

The following details shall be presented:

a) Test set-up arrangement, wavelength correction procedure and indication of the scanning technique used;

b) Fibre identification;

c) Depending on specification requirements:

i) profiles through core cladding centres calibrated for the operating wavelength,

ii) profiles along the core major and minor axes calibrated for the operating wavelength,

iii) profiles along the cladding major and minor axes calibrated for the operating wavelength,

iv) raster scan across the entire fibre, if adopted, See Appendix I.

v) core diameter

vi) cladding diameter

vii) core/cladding concentricity error,

viii) core non-circularity,

ix) cladding non-circularity,

x) maximum theoretical numerical aperture: $NA_{t\,max}$,

xi) index difference: Δn ,

xii) relative index difference: Δ.

d) Indication of accuracy and repeatability;

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

Figure B-2a/G.651, p.

Figure B-2b/G.651, p.

Figure B-3/G.651, p.

B.3 *Alternative test method for geometrical parameters: the near-field technique*

B.3.1 *General*

The near-field technique can be used for the measurement of geometrical characteristics and of the refractive index profile of multimode optical fibres. Such measurements are performed in a manner consistent with the definition and the results are reproducible and relatable to the reference test method and to practical use.

The measurement is based on the scanning of a magnified image of the output and of the fibre under test over a cross-section where the detector is placed.

When measuring the geometrical characteristics of the fibre, the four concentric circle near-field template can be applied to an enlarged image of the fibre detected with objective evaluation methods, suitable to obtain a high degree of accuracy and reproducibility. In particular the core diameter shall be measured taking into account the same k factor agreed for the reference test method.

B.3.2 *Test apparatus*

A schematic diagram of the test apparatus is shown in Figure B-4/G.651.

B.3.2.1 *Light source*

The light source shall be incoherent, adjustable in intensity and stable in position, intensity and wavelength over a time period sufficiently long to complete the measurement procedure. The full width half maximum (FWHM) spectral linewidth, shall be recorded. A second light source can be used, if necessary, for illuminating the cladding.

B.3.2.2 *Launching conditions*

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

For 50/125 μm graded-index fibres the overfill launching conditions are obtained with a light cone whose FWHM intensity measured from the near-field be greater than 70 μm and whose FWHM in the numerical aperture (NA) measured from the far-field be greater than an NA of 0.3.

B.3.2.3 *Cladding mode stripper*

A suitable cladding mode stripper shall be used to remove the optical power propagating in the cladding, and to ensure that all the leaky modes are stripped away from the fibre. When measuring the geometrical characteristics of the cladding only, the cladding mode stripper shall not be present.

B.3.2.4 *Specimen*

The specimen shall be a short length of the optical fibre to be measured. Primary fibre coating shall be removed from the section of the fibre inserted in the mode stripper. The fibre ends shall be clean, smooth and perpendicular to the fibre axis.

Note — This measurement can be done on very short pieces of fibre (e.g. a few centimetres). In this case the launching conditions shall be adjusted to obtain a uniform intensity in the cladding below 15% of the maximum light intensity in the core.

B.3.2.5 *Magnifying optics*

The magnifying optics shall consist in an optical system (e.g. a microscope objective) which magnifies the specimen output near-field, focussing it onto the plane of the scanning detector. The numerical aperture and hence the resolving power 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.

B.3.2.6 *Detector*

A suitable detector shall be employed which provides the point-to-point intensity of the magnified near-field pattern. For example, any of the following techniques can be used:

a) scanning photodetector with pinhole aperture;

b) scanning mirror with fixed pinhole aperture and photodetector;

c) scanning vidicon, charge coupled devices or other pattern/intensity recognition devices.

The detector shall be linear in behaviour (or shall be linearized) over the range of intensities encountered. The sensitive area of the detector shall be small with respect to the enlarged image of the output end of the fibre and shall be recorded.

B.3.2.7 *Amplifier*

An amplifier shall be employed in order to increase the signal level. The bandwidth of the amplifier shall be chosen accordingly to the type of scanning used. When scanning the output end of the fibre with mechanical or optical systems, it is customary to modulate the optical source. If such a procedure is adopted, the amplifier should be linked to the source modulation frequency. The detecting system should be substantially linear in sensitivity.

B.3.2.8 *Data storage*

The measured near-field intensity distribution can be recorded and presented in a suitable form, according to the scanning technique and to the specification requirements.

B.3.3 *Procedure*

B.3.3.1 *Equipment calibration*

The magnification of the optical system shall be measured by scanning the length of a specimen whose dimensions are already known with suitable accuracy. This magnification shall be recorded.

B.3.3.2 *Measurement*

The launch end of the fibre shall be aligned to the launch beam, and the output end of the fibre shall be aligned to the optical axis of the magnifying optics. The focussed image of the output end of the fibre shall be scanned by the detector, according to the specification requirements. The focussing shall be performed with maximum accuracy, in order to reduce dimensional errors due to the scanning of a misfocussed image.

B.3.4 *Presentation of the results*

The following details shall be presented:

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

b) Launching characteristics (dimension and NA of the launching cone).

c) Wavelength and FWHM spectral linewidth of the source(s).

d) Fibre identification and length.

e) Type of cladding mode stripper (if applicable).

f) Magnification of the apparatus.

g) Type and dimensions of the scanning detector.

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

i) Indication of the accuracy and repeatability.

j) Depending upon the specification requirements:

i) profiles through core and cladding centres;

ii) profiles along the core major and minor axes;

iii) profiles along the cladding major and minor axes;

iv) raster scan across the entire end face of the fibre, if adopted;

v) resulting dimensional parameters, like: core and cladding diameters, non-circularities of the core and of the cladding, core/cladding concentricity error, etc.

Figure B-4/G.651, p.

B.4 *Reference test method for the numerical aperture: far-field distribution*

B.4.1 *Object*

This measuring method is applied to graded index fibres in order to determine the numerical aperture by measuring the far field light distribution.

B.4.2 *Specimen preparation*

From the fibre to be measured at one end, a sample of approximately 2 m length is taken. The sample shall be straight enough to avoid bending losses. The ends of the sample should be substantially clean, flat and perpendicular to the fibre axis.

B.4.3 *Apparatus*

B.4.3.1 *Source*

The light source shall be incoherent, adjustable in intensity and stable in position, intensity and wavelength over a time period sufficiently long to complete the measurement procedure.

B.4.3.2 *Detector*

The detector must have a linear characteristic in the required measuring range. (The output current of the detector must be linear to the received light power.)

B.4.3.3 *Launching conditions*

See § B.3.2.2.

B.4.3.4 *Cladding mode stripper*

See § B.3.2.3.

B.4.3.5 *Display*

For example, XY-recorder, screen.

B.4.4 *Procedure*

B.4.4.1 *Principle of measurement* | (Figure B-5/G.651)

The radiant intensity (light power per solid angle element) is determined as a function of the polar angle of one plane of the fibre axis (radiation pattern). The distance d between the end of the sample and the detector must be large compared to the core diameter of the optical fibre.

Possible solutions are:

— sample fixed, large-area detector fixed;

— sample fixed, small-area detector linear displaceable;

— sample linear displaceable, small-area detector fixed;

— sample fixed, small-area detector angular displaceable;

— sample and rotatable, small-area detector fixed.

Figure B-5/G.651, p.

B.4.4.2 *Preparation*

The sample is fixed in the sample holder and the light is launched in accordance with § B.4.3.3.

B.4.4.3 *Measurement*

The radiant intensity is determined as a function of the polar angle in one plane of the fibre axis.

B.4.5 *Results*

Fibres covered by this Recommendation have a near parabolic refractive index profile. Therefore, for the launching conditions recommended in § B.4.3.3 (uniform mode distribution) the far-field radiant intensity curve can be approximated in the region above 10% of the maximum intensity by the following parabola:

$$P(\phi) = P(0)\,[1 - (\sin\phi/\mathrm{NA})^2]$$

The angle ϕ is then determined by the point of intersection of this parabola with the abscissa. In general, it is sufficient to determine the angle ϕ by the 5% value of the maximum radiant intensity out of the full radiant intensity curve.

The numerical aperture is

$$\mathrm{NA} = \sin\phi.$$

B.4.6 *Presentation of results*

The following details shall be presented:

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

b) Launching characteristics (dimension and NA of the launching cone);

c) Wavelength and FWHM spectral width of the source;

d) Type of cladding mode stripper (if used);

e) Scanning conditions;

f) Fibre identification and length;

g) Temperature of the sample and environmental conditions, if necessary;

h) Indication of the accuracy and repeatability;

i) Resulting numerical aperture.

APPENDIX I
(to Section I)

A possible way to obtain the positions of core and cladding centres as well as the diameters is given in this Appendix.

I.1 *Core centre and diameter*

The core centre and diameter are determined from an adequate number of scans across a fibre section with the appropriate k value. Two points on the core/cladding interface are obtained at each scan. The points should be uniformly distributed on the perimeter of the core, at least approximately.

Let

x_i, y_i be the Cartesian coordinates of the i-th point of the interface,

a_c, b_c be the Cartesian coordinates of the core centre,

R_c be the core radius,

z, m_i be the intermediate variables $z = a_c^2 + b_c^2 - R_c^2$ and $m_i = x_i^2 + y_i^2$.

The unknown parameters a_c, b_c and R_c are obtained by finding the circle which best represents, in the sense of the least squares, the experimental interface between the core and the cladding. The calculation algorithm consists of minimizing, with respect to parameters a_c, b_c and z, the quantity:

$$M = \sum_i \left[(x_i/R - a_c/R)^2 + (y_i/R - b_c/R)^2 - (R_c/R)^2 \right]^2$$

$$M = \sum_i (x_i^2 + y_i^2 - 2a_c x_i - 2b_c y_i + z)^2$$

Cancellation of the three partial derivatives of M in relation to a_c, b_c and z gives a system of three linear equations, in the following matrix form:

$$\begin{bmatrix} 2\sum_i x_i^2 & 2\sum_i x_i y_i & -\sum_i x_i \\ 2\sum_i x_i y_i & 2\sum_i y_i^2 & -\sum_i y_i \\ 2\sum_i x_i & 2\sum_i y_i & -N \end{bmatrix} \begin{bmatrix} a_c \\ b_c \\ z \end{bmatrix} = \begin{bmatrix} \sum_i m_i x_i \\ \sum_i m_i y_i \\ \sum_i m_i \end{bmatrix}$$

The sums are performed from i = 1 to i = N,

N being the total number of measured points

Digital inversion of this system gives the values of a_c, b_c and z , from which the value of R_c is deduced.

The core centre is the point of coordinates a_c and b_c and its diameter is the quantity $D_c = 2R_c$.

I.2 *Cladding centre and diameter*

The same calculation process and definitions as for the core apply to finding:

— the coordinates of the cladding centre a_g and b_g;

— the cladding radius R_g.

The cladding centre is the point of coordinates a_g and b_g and its diameter is the quantity $D_g = 2R_g$.

Section II — *Reference test method and alternative test methods for attenuation measurements*

B.1 *Introduction*

B.1.1 *Objectives*

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.1.2 *Definition*

The **attenuation A (λ)** at wavelength λ between two cross-sections 1 and 2 separated by distance L of a fibre is defined as:

$$A(\lambda) = 10 \log \frac{P_1(\lambda)}{P_2(\lambda)} \quad \text{(dB)}$$

where $P_1(\lambda)$ is the optical power traversing the cross-section 1 and $P_2(\lambda)$ is the optical power traversing the cross-section 2 at the wavelength λ. For a uniform fibre under equilibrium condition, it is possible to calculate the attenuation per unit length, or the attenuation coefficient.

$$\alpha(\lambda) = \frac{A(\lambda)}{L}$$

$$\left[\frac{B}{nit\ \ length}\right]$$

which is independent of the chosen length of the fibre.

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

B.1.3 *Description*

Three methods have been suggested for attenuation measurements.

B.1.3.1 *The cut-back technique* | s 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 end of the guide and P_1 is the power emerging from a point near the input after cutting the fibre.

B.1.3.2 *The insertion loss technique* | s in principle similar to the cut-back technique, but P_1 is the power emerging from the output of the launching system. The measured attenuation is the sum of the attenuation of the inserted length of fibre and the attenuation caused by the connection between launching system and the fibre under test. It is necessary to correct the result for connection losses.

B.1.3.3 *The backscattering technique* | s an indirect way of measuring the attenuation by the measurements of the backscattered powers traversing two cross-sections of the fibre.

B.1.4 *Field of application*

The cut-back technique is generally recognized as yielding accurate results. In many situations its destructive nature is a disadvantage.

The insertion loss technique avoids cutting a part of the fibre at the expense of accuracy.

The backscattering technique is a single ended, non-destructive method, but is limited in range and sometimes in accuracy.

Considering the advantages and disadvantages of the three methods, the cut-back technique has been chosen as the reference test method.

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

B.2.1 *Launching conditions*

B.2.1.1 *Definition of launching conditions*

The launching conditions are of paramount importance in meeting the stated objectives. Launching conditions should be such as to approximate equilibrium mode distribution (EMD) which is understood to exist when the power distribution of field patterns at the output of the fibre is substantially independent of the length of the fibre.

B.2.1.2 *Launching techniques*

A generic set-up to achieve the launchings of the EMD is shown in Figure B-6/G.651.

Figure B-6/G.651, p.

B.2.1.2.1 *Cladding 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.2.1.2.2 *Mode filter*

The mode filter is a device used to select, reject or attenuate a certain number of modes, and should assure the establishment of a mode distribution close to the EMD.

B.2.1.2.3 *Mode scrambler*

The mode scrambler is a device used for inducing transfer of power between modes in an optical fibre, and should provide a mode distribution independent of source characteristics.

Note — Suitable optical arrangements can be used which produce a distribution close to the EMD directly on the input end of the fibre under test. In this case a unique device is needed for the implementation of the three functions of Figure B-6/G.651.

B.2.1.3 *Example*

For a 50/125 µm low loss homogeneous graded index fibre with a NA of 0.2 operating at 850 nm wavelength, an approximation of the equilibrium mode distribution can be achieved after the cut-back length of the fibre to be measured, when the following characteristics are observed:

a) the full width half maximum intensity value of the light spot, measured from the near field is 26 µm;

b) the full width half maximum value of the numerical aperture measured from the far field is 0.11 µm.

Both near-field and far-field patterns are assumed to be approximately Gaussian.

To obtain this equilibrium of the modal distribution the arrangement shown in Figure B-6/G.651 can be used.

The launch beam is incident on the launch end of the fibre in the form of a spot, centrally located on the fibre core with the near field FWHM intensity not less than 70 µm and the far field FWHM Numerical Aperture not less than 0.3 across the central 70 µm of the cone. (For fibre with an NA < 0.25.)

The axis of the launch beam is coincident with the axis of the fibre.

The mode scrambler should comprise a suitable fibre arrangement (e.g., a step-graded-step sequence or a bending sequence).

The mode filter takes the form of a mandrel around which the fibre under test is wound, with low tension and within a 20 mm length of the mandrel.

The diameter of the mandrel may differ from fibre to fibre and values in the range 18-22 mm, with 5 turns of fibre, are common.

The exact diameter of the mandrel is determined by the fibre/cable supplier such that the near field and far field patterns from two metres of fibre following the mode filter and cladding mode stripper, are the same as those obtained from a stable mode distribution length of fibre or jointed fibres (typically greater than 5 km).

The cladding mode stripper often consists of a material having a refractive index equal to or greater than that of the fibre cladding.

B.2.2 *Apparatus and procedure*

B.2.2.1 *Types of measurement*

Measurements may be made at one or more spot wavelengths, alternatively a spectral response may be required over a range of wavelengths. Diagrams of suitable test equipments are shown as examples in Figures B-7/G.651 and B-8/G.651.

Figure B-7/G.651, p.

Figure B-8/G.651, p.

B.2.2.2 *Optical source*

A suitable radiation source shall be used, such as a lamp, laser or light emitting diode (LED). 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 FWHM spectral line-width shall be specified such that it is narrow compared with any features of the fibre spectral attenuation.

The fibre shall be aligned to the launch cone, or connected coaxially to a launch fibre.

B.2.2.3 *Optical detector*

A large area detector shall be used so that all of the radiation in the output cone(s) is intercepted. The spectral response should be compatible with the spectral characteristics of the source. The detection must be uniform and the detection must have linear characteristics.

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.

B.2.2.4 *Launching set-up*

See § B.2.1.

B.2.2.5 *Procedure*

1) The fibre under test is set 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 output power P_1 from the cut-back length of the fibre is recorded.

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.2.3 *Presentation of results*

The following details shall be presented:

a) Measurement type, and characteristics.

b) Launching technique.

c) Test set-up arrangement.

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

e) Fibre identification.

f) Length of sample and the cut-back length.

g) Attenuation measured (for the sample) at the selected wavelength.

h) Attenuation quoted in dB. In some cases it is possible to convert it into attenuation coefficient in dB/km.

i) For spectral loss measurements the results should be presented as a plot of attenuation against wavelength.

B.3 *First alternative test method: the insertion loss technique*

B.3.1 *Launching conditions*

The required launching conditions are similar as those described under § B.2.1.

B.3.2 *Apparatus and procedure*

B.3.2.1 *Types of measurements*

Measurements may be done at one or more spot wavelengths, alternatively a spectral response may be required over a range of wavelengths. A diagram of a suitable test set-up is shown as an example in Figure B-9/G.651 (a — calibration, b — measurement).

B.3.2.2 *Optical source*

See § B.2.2.2.

B.3.2.3 *Optical detector*

See § B.2.2.3.

B.3.2.4 *Launching set-up*

See § B.2.1.

B.3.2.5 *Coupling device*

The insertion loss technique requires the use of a very precise fibre to fibre coupling device to minimize the coupling losses and to ensure reliable results.

This coupling device can be a mechanical adjustment visually inspected or a connector with a core-to-core positioning.

Figure B-9/G.651, p.

B.3.2.6 *Procedure*

1) The measurement set-up is initially calibrated in order to obtain an input reference level P_1.

2) The fibre under test is set in the measurement set-up and the coupling adjusted to give a maximum level on the optical detector. The output power P_2 is recorded.

3) An attenuation is calculated according to § 1.2. This attenuation is the sum of the attenuation of the inserted length of fibre and the attenuation caused by the connection between the coupling device and the fibre under test.

B.3.3 *Presentation of results*

The following details shall be presented:

a) Measurement type and characteristics.

b) Launching technique.

c) Test set-up arrangement.

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

e) Fibre identification.

f) Length of sample.

g) Attenuation measured (for the sample) at the selected wavelength.

h) Connector loss with its tolerance.

i) Attenuation quoted in dB. In some cases it is possible to convert it into an attenuation coefficient in dB/km.

j) For spectral loss measurements the results should be presented as a plot of attenuation versus wavelength.

B.4 *Second alternative test method: the backscattering technique*

Note — This test method describes a procedure to measure the attenuation of a homogeneous sample of 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.4.1 *Launching conditions*

For the attenuation measurement, the techniques described under § 2.1 can be applied. For the other controls, the launching conditions may be dependent on the characteristics to be tested.

In all cases, in order to reduce the Fresnel reflections on the input of the fibre, various devices could be used such as polarizers or index matching materials. Insertion losses should be minimized.

B.4.2 *Apparatus and procedure*

B.4.2.1 *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. An example of an apparatus is shown in Figure B-10/G.651.

B.4.2.2 *Optical source*

A stable high power optical source of an appropriate wavelength should be used, such as a semiconductor laser. The wavelength of the source should be registered. The pulse width and repetition rate should be consistent with the desired resolution and the length of the fibre. Optical non-linear effects should be eliminated in the part of the fibre under test.

B.4.2.3 *Optical detection*

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.

A 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 shall be chosen as a trade off between time resolution and noise reduction.

B.4.2.4 *Launching set-up*

See §§ B.2.1 and B.4.1.

B.4.2.5 *Procedure*

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

2) Backscattered power is analyzed by a signal processor and recorded in logarithmic scale. Figure B-10/G.651 shows such a typical curve.

3) If the recorded curve has an approximately constant slope (zone b of Figure B-10b/G.651), the attenuation between two points *A* and *B* of the curve corresponding to two cross sections of the fibre is

200.if 317>253 .nr 14 317

$$A_{AB}^{\text{fIA *l)}} =$$

[Formula Deleted]

$$(V_A — V_B) \text{ dB}$$

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

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.4.3 *Presentation of results*

The following details shall be presented:

a) Measurement types and characteristics.

b) Launching techniques.

c) Test set-up arrangement.

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

e) Fibre identification.

f) Length of sample.

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.

The complete analysis of the recorded curve B-10/G.651 shows that, independently from the attenuation measurement, many phenomena can be monitored using the backscattering technique:

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.

Figure B-10/G.651, p.

Section III — *Reference test method for baseband response measurements*

B.1 *Object*

The fibre baseband response may be described in either the time domain by means of its impulse response $g(t)$ or in the frequency domain by means of its frequency response $G(f)$. The function $g(t)$ may be described as that function which, when convolved with the optical power input pulse to the fibre, gives the optical power output pulse from the fibre. $G(f)$ is the ratio, at any frequency, between the sinusoidal modulation of the optical power input to the fibre and the sinusoidal modulation of the optical power output from the fibre.

The baseband responses in the frequency and time domain in a linear system are related by:

$$G(f) = \int_{-\infty}^{\infty} g(t) \exp(-j2\pi ft)\, dt$$

The baseband response is presented in the frequency domain.

Those wishing a representation in the time domain will still be able to obtain it by means of mathematical operations. For this purpose the amplitude and phase response would both be needed.

The amplitude response is specified in the form of the —3 dB optical (—6 dB electrical) bandwith of the amplitude/frequency curve. A more complete curve should also be given.

To minimize measurement variations associated with irregular shaped baseband responses a Gaussian function may be fitted to the baseband response $G(f)$.

No recommended values of phase response are given, phase response is only required in special cases.

B.2 *Reference test method*

B.2.1 *Test apparatus*

A schematic diagram of the test arrangement is shown in Figure B-11/G.651.

B.2.1.1 *Light source*

A laser light source shall be used. It must be stable in position, intensity and wavelength. Its centre wavelength (λ) shall be within ±20 nm of the nominal value selected from the ranges given in Table B-1/G.651, in addition, the FWHM line width ($\Delta\lambda$) shall not exceed the corresponding value given in this Table.

H.T. [T2.651]
TABLE B-1/G.651
Source line width

λ (nm)	$\Delta\lambda$ (nm)
800-900	5
1200-1350	10

Table B-1/G.651 [T2.651], p.

The means whereby the laser is modulated (pulse or sinusoidal) shall be capable of operating at frequencies beyond the frequency at which the response of the fibre under test has fallen to the —3 dB optical level.

The maximum emission shall substantially exceed spontaneous emission and the depth of modulation shall be as great as the extinction ratio permits in order to secure maximum signal-to-noise ratio. Care shall be taken that the source does not chirp.

If the modulation waveform chosen is sinusoidal, the output modulation is divided, frequency by frequency, by the input modulation. If the modulation waveform chosen is a multicomponent pulse, it is necessary, as a preliminary step, to perform the Fourier transformation, using either analogue filtering or digital processing of the received signal.

B.2.1.2 *Launching conditions*

The appropriate measurement condition can be achieved by two means:

a) uniform mode power distribution (overfilled launch) with a uniform spatial distribution larger than the fibre core, and a Lambertian angular distribution within the numerical aperture of the fibre under test;

b) steady-state launch that closely approximates the actual steady-state condition.

Note to point b) — Care should be taken that the launching conditions do not restrict mode excitation below steady-state especially for lengths shorter than 2 km.

B.2.1.3 *Detector*

A high speed photodiode shall be used to intercept the full mode volume of the fibre output.

The bandwidth of the photodiode and the subsequent electronics shall be sufficient to preserve the required signal to noise ratio up to the highest frequency at which results are to be reported. The detector system shall be linear with respect to input power over the measured limits. In the event that the detector has an inadequate linear range, a neutral density filter previously calibrated at the operating wavelength may be required to attenuate an excessively large signal, in such a way that the detector is always used in its range of linear sensitivity.

B.2.1.4 *Output presentation system*

The output presentation system shall be capable of recording or displaying the output modulation amplitude against calibrated power or log-power and frequency scales. In the case of pulse modulation, an intermediate stage may involve the recording of a pulse waveform against a calibrated time scale.

B.2.2 *Procedure*

B.2.2.1 *Preparation of fibre for tests*

Primary coatings shall be removed from portions of fibre to be immersed in the cladding mode strippers.

Fibre ends shall be substantially clean, smooth and perpendicular to the fibre axis. Measurements on uncabled fibres shall be made with the fibre loose on the drum to avoid externally induced mode coupling.

B.2.2.2 *Measurement*

Initially, the transmitter and the receiver are connected by a short optical test lead, and the transmitter power adjusted to give a signal in the linear range of the receiver. For use as a field reference test method, the specific response of the instrument should be stored at this stage for subsequent use, in the form of either an impulse — or a frequency — response as appropriate.

The fibre to be tested is then inserted between the transmitter and receiver and the output measured and recorded. For use as a reference test method for single fibres, the fibre is then cut back to a point, a convenient distance from the transmit and cladding mode stripper (if used) or from the mode filter and, taking care not to disturb the launching conditions, the output from the cutback length is measured and recorded. The operational area of the receiver photodiode shall, as far as possible, be the same at all stages.

The sets of frequency domain amplitude data, whether obtained directly or by transformation from the time domain, corresponding to the output signal from the fibre under test and to the specific response of the instrument (including the cut back length) are then divided, (or subtracted if presented in logarithmic scale) frequency by frequency, the former by the latter, to yield the frequency response of the fibre.

B.2.3 *Presentation of results*

The following details shall be presented:

a) Measurement type and characteristics.

b) Launching technique.

c) Test set-up arrangement including source wavelength and FWHM linewidth.

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

e) Fibre identification.

f) Length of sample.

g) The bandwidth (including chromatic dispersion effects) defined by —3 dB optical point of the amplitude-frequency characteristic, and if necessary, the full amplitude-frequency characteristic, and/or the phase characteristic.

h) For factory length the value, if needed, of the bandwidth referred to 1 km (the applied formula must be given).

i) As stated at g), the measured bandwidth includes both modal and chromatic dispersion effects. If needed, the modal bandwidth B_{modal} (MHz) can be obtained as follows, if both the modal fibre baseband response and the source spectrum are assumed to be Gaussian.

$$B_{modal} = \left[(1/B_T)^2 - \left(D(\lambda)\Delta\lambda \cdot L \cdot 10^{-6}/0.44 \right)^2 \right]^{-1/2}$$

where:

B_T = fibre measured bandwidth,

$D(\lambda)$ = chromatic dispersion coefficient [ps/(nm · km)],

$\Delta\lambda$ = FWHM source linewidth (nm),

L = fibre length (km).

Note — The apparatus and procedure given above cover only the essential basic features of the reference test method. It is assumed that the detailed instrumentation will incorporate all necessary measures to ensure stability, noise elimination etc., and that in any data processing procedures including sampling, weighting functions, truncation etc., care will be taken to ensure a satisfactory balance of advantages and disadvantages of the chosen techniques.

Details of these procedures, together with quantitative information, should be included in the Results.

Figure B-11/G.651, p.