INTERNATIONAL TELECOMMUNICATION UNION

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THE INTERNATIONAL
TELEGRAPH AND TELEPHONE
CONSULTATIVE COMMITTEE

BLUE BOOK

VOLUME III – FASCICLE III.3

TRANSMISSION MEDIA CHARACTERISTICS

RECOMMENDATIONS G.601-G.654

IXTH PLENARY ASSEMBLY
MELBOURNE, 14-25 NOVEMBER 1988

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ISBN 92-61-03331-8

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APPLICABLE AFTER THE NINTH PLENARY ASSEMBLY (1988)

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Part I – Section 6 – Recommendations G.601 to G.654

Characteristics of transmission media

PRELIMINARY NOTE

In this Fascicle, the expression "Administration" is used for shortness to indicate both a telecommunication Administration and a recognized private operating agency.

PART I

Recommendations G.601 to G.654

CHARACTERISTICS OF TRANSMISSION MEDIA

(Section 6 of the G. Series Recommendations)

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SECTION 6

CHARACTERISTICS OF TRANSMISSION MEDIA

This Section contains the Recommendations on physical transmission media, both for the analogue or digital mode. It does not deal with open-wire lines or radio relays. It relates to VF cables only as physical transmission media in the digital mode.

6.0 General

Recommendation G.601

TERMINOLOGY FOR CABLES

(Geneva, 1980)

1 General terms: repeaters, power feeding, etc.

1001 **repeater**

F: répéteur

S: repetidor

An equipment essentially including one or several amplifiers and/or *regenerators*, and associated devices, inserted at a point in a transmission medium.

Note – A repeater may operate in one or both directions of transmission.

1002 **analogue repeater; analog repeater**

F: répéteur analogique

S: repetidor analógico

A *repeater* for amplifying analogue signals or *digital signals* and capable of other functions, but excluding *regeneration* of *digital signals.*

1003 **regenerative repeater**

F: répéteur régénérateur

S: repetidor regenerativo

A *repeater* ensuring *regeneration* of *digital signals*, and capable of other functions.

Note – This definition is different from that given in Recommendation G.701 [1]. At the time when Recommendation G.701 was drafted, a suitable CCITT definition of *repeater* was not available. The ensemble of definitions given here makes it desirable to incorporate the *regenerative repeater* in the family of transmission systems, instead of defining it only as a device, as is the case in Recommendation G.701.

1004 **directly powered (repeater) station**

F: station (de répéteurs) à alimentation indépendante

S: estación (de repetidores) alimentada directamente

A *repeater station* which receives its electric power directly from the local mains or from a local generator.

1005 **power feeding (repeater) station**

F: station d'alimentation (de répéteurs)

S: estación (de repetidores) de telealimentación

A *directly powered repeater station* which supplies electric power to other *repeater stations.*

1006 **dependent (repeater) station**

F: station (de répéteurs) téléalimentée

S: estación (de repetidores) telealimentada

A *repeater station* which receives its electric power supply from a *power feeding repeater station.*

Note – Electric power may be conveyed to the dependent station either by the physical transmission medium itself, or by conductors in the same cable sheath, or by exterior cables.

1007 **section termination**

F: extrémité de section

S: extremo de sección

A point selected conventionally to be the interface between the physical transmission medium and associated equipment such as *repeaters.*

Note – The precise selection of the point to constitute the section termination should take into account associated accessories such as splices, connectors or flexible connecting cables in order to include them, as the case may be, on one side or on both sides of the termination.

1008 **elementary cable section**

F: section élémentaire de câble

S: sección elemental de cable

All of the physical transmission media and accessories such as splices, connectors or flexible connecting cables included between two consecutive *section terminations.*

1009 **elementary repeatered section**

F: section élémentaire amplifiée

S: sección elemental con amplificación

In a given direction of transmission an *elementary cable section* together with the immediately following *analogue repeater,* all included between two *section terminations.*

1010 **elementary regenerated section**

F: section élémentaire régénérée

S: sección elemental con regeneración

In a given direction of transmission, an *elementary cable section* together with the immediately following *regenerative repeater,* all included between two *section terminations.*

1011 **take-up factor**

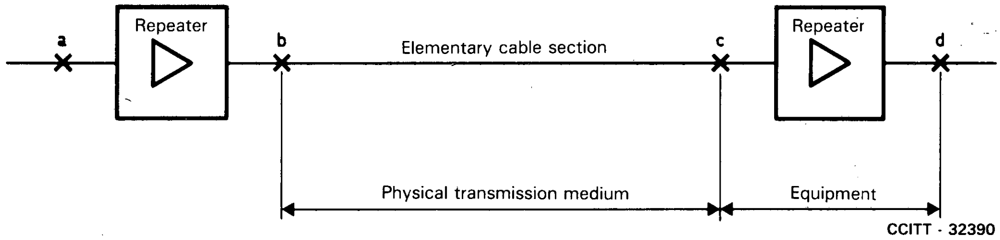
F: facteur de câblage

S: factor de cableado

Ratio between the value of a linear parameter measured on the length unit of a cable and the value of the same parameter measured on the length unit of a pair of that cable.

The result of cabling (assembly of components and possibly twisting of wires in pairs and then in quads) is that the length of the cable components is greater than that of the axial length of the cable. The take-up factor is the ratio between these two lengths.

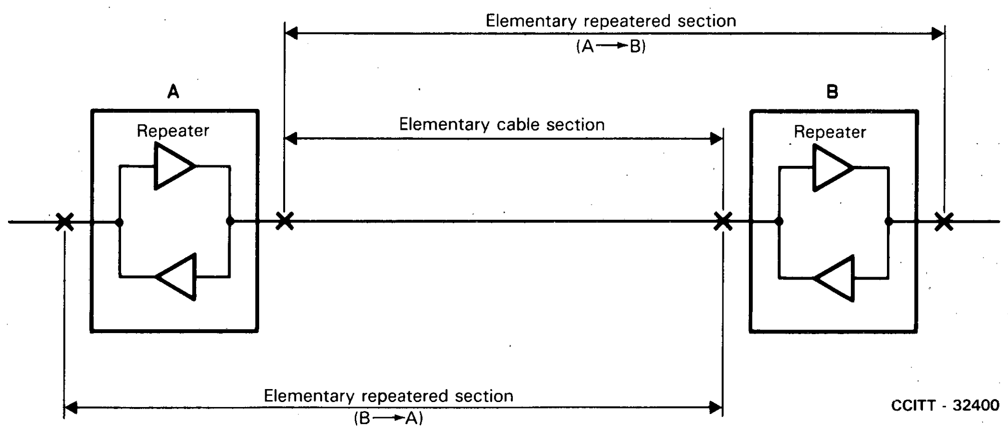
1012 Graphic illustration of the use of some terms in § 1.



a, b, c, d Section terminations

FIGURE 1/G.601

Terminology for generic reference to repeaters and cable sections



✕ Section termination

FIGURE 2/G.601

Terminology for elementary repeatered section

2 Terms concerning cables measurements

2.1 *Use of the word echo, in cable testing only*

2101 **echo**

F: écho

S: eco

An electric, acoustic or electromagnetic wave which arrives at a given point, after reflection or indirect propagation, with sufficient magnitude and delay for it to be perceptible at the given point, as a wave distinct from that directly transmitted.

2102 **backward echo**

F: écho (vers l'amont)

S: eco hacia atrás

An *echo* arriving at a defined point and having a direction of transmission opposite to that of the direct signal.

2103 **forward echo**

F: écho vers l'aval; traînage

S: eco hacia adelante

An *echo* arriving at a defined point and having the same direction of transmission as that of the direct signal.

2.2 *Pulse measurements*

2201 **echometric measurement**

F: mesure échométrique

S: medición ecométrica

A measurement made by studying the *echo* which follows the emission of a signal of limited duration, known as a "measuring signal", with a view to analyzing all the causes of reflections.

2202 **pulse duration**

F: durée d'une impulsion

S: duración del impulso

The interval of time between the first and last instant at which the instantaneous value of a pulse (or of its envelope if a carrier frequency pulse is concerned) reaches a specified fraction of the peak amplitude.

2203 **sine-squared**

F: impulsion en sinus carré

S: impulso en seno cuadrado

A unidirectional pulse defined by the expression:

$$y = K \sin^2 (\pi t/2T); \; 0 \leqslant t \leqslant 2T$$

$$y = 0; \; t < 0 \text{ and } t > 2T$$

where

K is the amplitude

T is the *pulse duration* at half-amplitude

t is the time.

2204 **pulse echo meter**

F: échomètre à impulsions

S: ecómetro de impulsos

Apparatus designed to take *echometric measurements* by means of pulses.

2205 **elementary echo**

F: écho élémentaire

S: eco elemental

In an *echometric measurement*, the state of the echo in a time interval of a duration comparable to that of the test signal.

2206 **peak amplitude of an elementary echo**

F: amplitude de crête d'un écho élémentaire

S: amplitud de cresta de un eco elemental

Maximum value of echo amplitude reached in the duration of an *elementary echo.*

2207 **relative amplitude of an elementary echo**

F: amplitude relative d'un écho élémentaire

S: amplitud relativa de un eco elemental

Ratio between the *peak amplitude of an elementary echo* and the maximum amplitude of the measuring signal, evaluated at the emission point.

2208 **pulse echo return loss; pulse echo attenuation**

F: affaiblissement d'écho

S: pérdida de retorno para el eco; atenuación de eco

Relative amplitude of an elementary echo expressed in transmission units.

2209 **amplitude-corrected echo**

F: écho corrigé en amplitude

S: eco corregido en amplitud

An *echo* observed, after processing to carry out at least partial correction of propagation effects.

2210 **amplitude- and phase-corrected echo**

F: écho corrigé en amplitude et phase

S: eco corregido en amplitud y en fase

An *echo* observed, after processing has been made to correct the propagation effects on the amplitude and shape of the echo.

2211 **echo curve**

F: courbe d'écho

S: curva de eco

A graphic or oscilloscopic representation of *echo* amplitude function of time.

Note – The echo may be corrected in amplitude or in amplitude and phase; the curve is then called, as the case may be, "amplitude-corrected echo curve" or "amplitude- and phase-corrected echo curve".

2212 **equivalent resistance error**

F: écart équivalent

S: error de resistencia equivalente

The value of a hypothetical impedance deviation which, if situated at the end of a section of a transmission medium, would produce in an echometric measurement at that end the same reflected energy as all the irregularities of the section.

2213 **corrected equivalent resistance error**

F: écart équivalent corrigé

S: error de resistencia equivalente corregido

Equivalent resistance error evaluated by an echometric measurement comprising echo correction. The correction may be effected in amplitude or in amplitude and phase or according to other criteria (e.g. in energy).

Note – *The corrected equivalent resistance error* may be evaluated in terms of one kilometre, as the ratio Δ_k between corrected equivalent resistance error Δ_e as measured on a cable section, and the square root of the length L of this section, in km.

$$\Delta_k = \Delta_e/\sqrt{L}\ \Omega \cdot \mathrm{km}^{-1/2}$$

2.3 *Measurements made with sine-wave signals*

2301 **irregularity reflection coefficient**

F: facteur de réflexion sur les irrégularités

S: coeficiente de reflexión de las irregularidades

The reflection coefficient measured at one end of a section of a transmission medium, for a specified mode of propagation, under conditions allowing for the elimination of the effects of reflections other than those due to irregularities inherent in the section concerned.

2302 **regularity loss**

F: affaiblissement de l'onde réfléchie sur les irrégularités

S: pérdida de retorno por irregularidades

The expression in transmission units of the modulus of *irregularity reflection coefficient* P_i. Its value in decibels is equal to:

$$A_i = -20 \log_{10} |P_i|.$$

Reference

[1] CCITT Recommendation *Vocabulary of pulse code modulation (PCM) and digital transmission terms*, Vol. III, Rec. G.701.

Recommendation G.602

RELIABILITY AND AVAILABILITY OF ANALOGUE CABLE TRANSMISSION SYSTEMS AND ASSOCIATED EQUIPMENTS

(Malaga-Torremolinos, 1984)

1 General section

Transmission system: all that is necessary in order to provide an adequately operational transmission path (e.g. 4 kHz channel) between the terminating interfaces. It includes translating equipment, line terminal equipment, line intermediate equipment, cable, power feeding, primary power and standby power supplies and might also include the changeover equipment when automatic protection switching is provided.

2 Definitions

a) **reliability in analogue cable transmission systems**

The reliability of a single unit of an analogue transmission equipment or of a complete transmission system is defined as the probability that this item can perform its required function for a given time interval. One parameter to quantify this reliability is the mean time between failures (MTBF). A failure of the system is considered to occur when there is:

1) complete loss of signal;
2) one in which the pilot level drops by 10 dB below nominal value;
3) when the total unweighted noise power, measured or calculated with an integrating time of 5 ms exceeds 1 million pW (10^6 pW) on the 2500 km hypothetical reference circuit (see Recommendation G.222).

In all instances, this condition must last at least 10 [1] seconds.

[1] This value should be considered as being provisional.

b) **availability in analogue cable transmission systems**

The availability of an analogue transmission system is defined as the ability of the system to be in a state to perform adequately (operating) at a given instant of time or at any instant of time within a given time interval. In this Recommendation, the availability of an analogue transmission system is quantified by the ratio of the time during which the system is operating to a specified total time.

Four factors influencing availability are:

- reliability of the equipment;
- automatic protection switching;
- maintenance procedures;
- cable routing and protection.

In considering the importance to be attached to the individual factors, economic aspects should play an important role.

Note – Experience has shown that in many cases the cable faults are dominating (in the order of 95% of the unavailability time) over the equipment faults and that the length of the line section and the kind of route (running along roads with heavy traffic, etc.) have a decisive influence on the achievable availability values.

3 Objectives

a) *Reliability*

As indicated in the definition of availability, reliability is but one of the factors involved in obtaining an availability objective. Therefore, no specific objective for reliability is recommended.

b) *Availability*

1) *Hypothetical reference circuit (2500 km)*

The objective for the availability of a 2500 km hypothetical reference circuit in one direction should be greater than 99.6% for a one year duration. This takes into account outages for both translating and line equipment and the cable and associated powering equipments. To achieve this objective, appropriate protection switching may be required.

2) *Translating equipment*

The design objective for the availability of translating equipment in the Annex and in Figure A-1/G.602, for a 2500 km hypothetical reference circuit as recommended for the different transmission systems, should be greater than 99.9% measured for a period of one year for one direction of transmission.

3) *Line section*

The design objective for the availability of a 280 km homogeneous section for one direction shall be derived from the overall requirement for the hypothetical reference circuit. The exact value is dependent on the network design.

ANNEX A

(to Recommendation G.602)

Calculation example

Example of Reliability and Availability calculations for a line section in one direction based on the following assumptions:

1) Line repeater MTBF $= 2 \times 10^5$ hours (one way);
2) 100 line repeaters in section;
3) Each failure lasts 4 hours;
4) 12 tube cable with 1 : 5 protection switching.

a) *Reliability* (MTBF)

- 100 repeaters will have failure in $\left(\dfrac{2 \times 10^5}{100} \right) = 2000$ hours

b) *Availability* (A)

– This is approximately 4½ failures per year × 4 hours = 18 hours outage per year (0.2%)

– Without protection switching A_1 = 99.8%

Non-available $X_0 = 2 \times 10^{-3}$

– With automatic protection switching: $A_2 = \left[1 - \frac{(N + M)!}{(M + 1)!N!} X_0^{M+1}\right] \times 100\%$

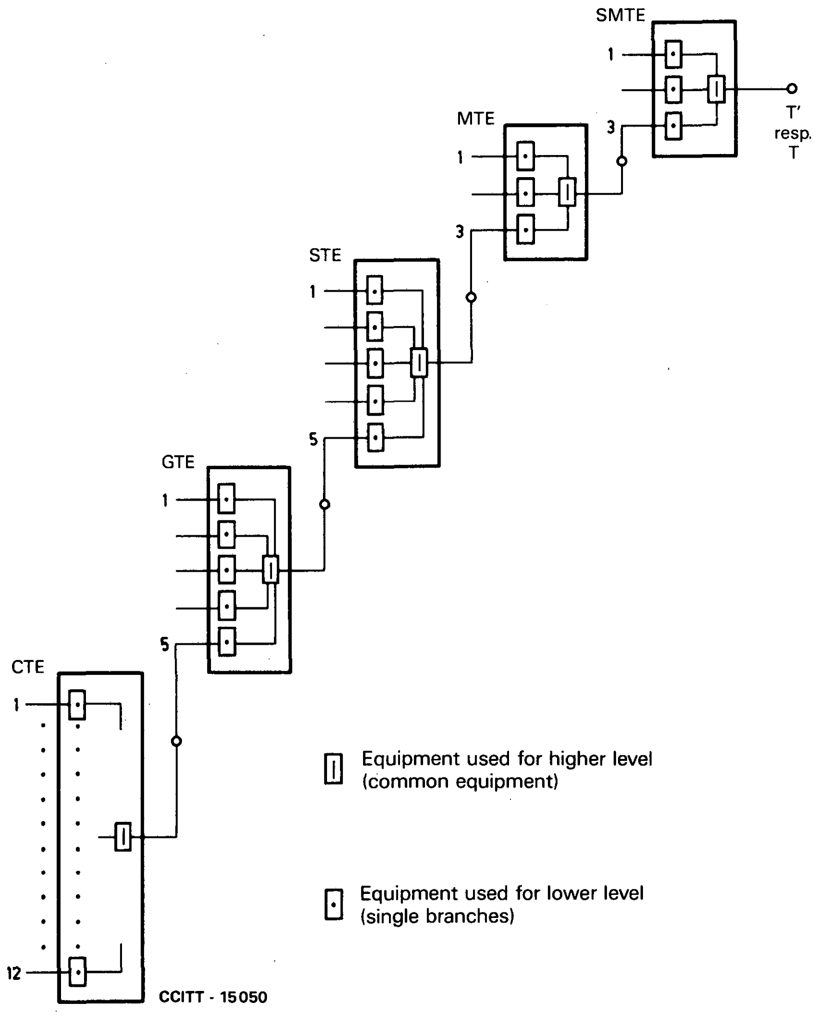
where

N = 5 (number of systems in service)

M = 1 (number of protection systems)

$$A_2 = \left[1 - \frac{6!}{2!\ 5!} (2 \times 10^{-3})^2\right] \times 100\% = \left[1 = (12 \times 10^{-6})\right] \times 100\% = 99.999\%$$

Note – Calculations are for electronics only and do not take into account cable cuts.



CTE = Channel translating equipment
GTE = Group translating equipment
STE = Supergroup translating equipment
MTE = Mastergroup translating equipment
SMTE = Supermastergroup translating equipment

FIGURE A-1/G.602

Plan of modulator stages showing common equipment and single branches
(Plan one of Recommendation G.211 has been shown as an example)

6.1 Symmetric cable pairs

Recommendation G.611

CHARACTERISTICS OF SYMMETRIC CABLE PAIRS FOR ANALOGUE TRANSMISSION

(former Recommendation G.321, Geneva, 1974; amended at Geneva, 1980)

1 Cable specification – Examples of the electric characteristics of a star-quad cable designed to provide 12, 24, 36, 48, 60 or 120 carrier telephone channels on each quad pair

1.1 *Types of cable*

Administrations which decide to equip their symmetric pair cable network should, wherever possible, choose those which conform to the types of cable defined below.

New cables laid in the European and North-African international telephone network include unloaded symmetric pairs, designed to be used for 12, 24, 36, 48, 60 or 120 carrier telephone channels on each pair. These pairs are laid up in star quads and all unloaded pairs of the same cable are one of the types whose nominal characteristics are shown in Table 1/G.611.

It is essential that a repeater section crossing a frontier should be of a uniform type throughout its length. When a frontier section is between a large and a small country, the Administration of the larger country should do everything possible to use whichever of the three types has been adopted by the smaller country, so as not to oblige the Administrations of small countries to use sections of international cable of a different type from that of their national cables.

Note 1 – Some Administrations, by paying special attention to crosstalk balance and adopting appropriate repeater spacing, have been able to set up systems with 2 supergroups, in accordance with Recommendation G.322, on paper-insulated symmetric pairs conforming with this present specification.

Note 2 – It is also possible to set up 2 supergroup systems that conform with Recommendation G.322 on pairs of type II *bis* and type III *bis*. Type II *bis* pairs are insulated by polythene and type III *bis* pairs by styroflex.

TABLE 1/G.611

	Type I	Type II	Type II *bis*	Type III	Type III *bis*
Diameter of conductors (mm)	0.9	1.2	1.2	1.3	1.3
Effective capacity (nF/km)	33	26.5	21	28	22
Characteristic impedance (Ω)					
to 60 kHz	153	178	206	170	196
to 120 kHz	148	174	203	165	193
to 240 kHz	–	172	200	163	190
to 550 kHz	–	–	198	–	188
Attenuation per unit length at 10 °C in dB/km					
to 60 kHz	2.3	–	–	–	–
to 120 kHz	3.1	2.0	1.5	1.8	1.4
to 240 kHz	–	2.9	2.1	2.7	2.0
to 552 kHz	–	4.8	3.1	4.4	3.0

1.2 *Regularity of factory lengths*

The regularity may be characterized by one or other of the equivalent methods below, the choice of which is left to the Administrations concerned.

1.2.1 *Effective capacity*

The "effective capacity" is measured between the two conductors of the pair, all other cable conductors being connected together and to the sheath.

Ratios of the effective capacity

Type I cable – The average of the effective capacities of all the pairs in any factory length should not differ from the nominal value by more than ± 5%.

In any factory length, the difference between any individual value of effective capacity and the average value obtained for this factory length should not exceed ± 7.5%; the arithmetic mean of the magnitudes of these differences should not exceed 2.5%.

Types II, II bis, *III and III* bis *cables* – The average effective capacity of any length should not differ by more than ± 3% from the nominal value.

In any length, the difference between the effective capacity of any pair and the average capacity for the cable length should not exceed ± 5%.

1.2.2 *Impedance* (types II, II *bis*, III and III *bis* cables)

The real part of the characteristic impedance of any circuit, measured with a frequency of 120 kHz, should not depart by more than ± 5% from the mean value of all the pairs of the first manufacturing batch of each type. This mean value should not depart by more than ± 5% from the nominal value at 120 kHz.

The impedance will be measured on the factory lengths using a bridge, the circuits being terminated by an impedance equal to that which is measured by the bridge.

1.3 *Crosstalk*

The quality of the cable from the point of view of crosstalk may be characterized by one or other of the two equivalent methods below, the choice of which is left to the Administrations concerned.

1.3.1 *Direct measurements of crosstalk*

For a factory length of 230 metres the crosstalk between any two side circuits should satisfy the following conditions:

- far-end crosstalk ratio should be greater than 68 dB;
- near-end crosstalk attenuation should be greater than 56 dB.

For cables to be used with 5 groups or 2 supergroups these values should hold up to 240 kHz; and for cables with two groups, up to 120 kHz.

During these measurements, the circuits will be terminated by the real part of the nominal impedance for the frequency considered.

For factory lengths greater than 230 metres, the above limits will be reduced by

$$20 \log_{10} \frac{L}{230} \text{ dB},$$

L being the length in metres. Lengths shorter than 230 metres should satisfy the same conditions as a length of 230 metres.

1.3.2 *Capacity unbalance and mutual inductances*

All the capacity unbalance measurements should be made with an alternating current of 800 Hz. The mutual impedance measurements should be made with an alternating current of 5000 Hz. All the measurements should be made at the ambient temperature, without applying corrections; but in case of dispute, the results obtained at 10 °C will be considered as final. All the conductors, other than those under test, should be connected to the cable sheath.

For a factory length of 230 metres the capacity unbalance should not exceed the values given in Table 2/G.611 and the mutual inductances should not exceed the values given in Table 3/G.611. These tables show different values for type I cables in one column, and for types II, II *bis*, III and III *bis* in the other.

TABLE 2/G.611

Capacity unbalance

	Mean of all readings (ignoring signs)		Maximum individual reading	
	Type I	Types II, II *bis*, III and III *bis*	Type I	Types II, II *bis*, III and III *bis*
Capacity unbalance in picofarads:				
between pairs of the same quad	33	17	125	60
beetween pairs of adjacent quads in the same layer	10	5	60	25
between pairs in nonadjacent quads in the same layer	mean value not specified because all possible combinations are not measured		20	10
between pairs in quads in adjacent layers	10	5	60	25
between any pair and earth	100	100	400	400

Note – The limits shown for the mean values do not apply to cables which have four or less quads.

TABLE 3/G.611

Mutual inductances

	Mean of all readings (ignoring signs)		Maximum individual reading	
	Type I	Types II, II *bis*, III and III *bis*	Type I	Types II, II *bis*, III and III *bis*
Mutual inductances in nanohenrys:				
between pairs of the same quad	150	125	600	500
between pairs of adjacent quads in the same layer	100	40	400	150
between pairs in nonadjacent quads	50	20	350	150
between pairs in quads in adjacent layers	100	40	600	250

Note – The limits shown for the mean values do not apply to cables which have four or less quads.

For lengths greater than 230 metres, it is necessary to apply the following rules:

The average values from pair to pair given in Tables 2/G.611 and 3/G.611 should be multiplied by the square root of the ratio between the length in question and 230 metres.

All the maximum values, as well as the average values between a pair and earth, should be multiplied by the ratio between the length in question and 230 metres.

Lengths shorter than 230 metres should satisfy the same conditions as the length of 230 metres.

1.4 *Dielectric strength*

When specially requested, cables will have a construction such that the insulation of any cable length should be capable of withstanding, without breakdown, a potential difference specified in each particular case but not exceeding 2000 volts r.m.s., applied for at least 2 seconds between all the conductors connected together and the earthed sheath. The test can be made with a 50-Hz alternating current. The value of the test voltage should not exceed by more than 10% the peak value of a sinusoidal voltage having the same r.m.s. value.

The test can also be carried out using direct current (see [1]). In such a case, the limit for the voltage will be 1.4 times the r.m.s. value of the voltage when using alternating current [1)].

1.5 *Insulation resistance*

In a length of cable, the insulation resistance measured between a conductor and all the other conductors connected together, and to the earthed sheath, should not be less than 10 000 MΩ-km, the potential difference used being at least 100 volts and not greater than 500 volts. The reading shall be made after electrification for one minute, the temperature being at least 15 °C.

2 Specification of a repeater section

2.1 *Maximum attenuation in a repeater section*

The maximum attenuation at the highest frequency transmitted to line of a normal repeater section shall be 41 dB for low-gain systems with 1, 2 or 3 groups and 36 dB for low-gain systems with 4 or 5 groups or 2 supergroups.

2.2 *Crosstalk*

The far-end crosstalk ratio between circuits in the same direction, measured on the repeater sections of a carrier system on unloaded symmetric pairs, terminated at their two ends by impedances equal to their characteristic impedance, should not be less than the values shown below (which allow for the existence of any crosstalk balancing networks).

1) For the classical method of balancing, the repeater section far-end crosstalk ratio for low gain transistorized systems up to 120 channels on type II and III cables (or similar cables) or low-gain 120-channel systems on type II *bis* or III *bis* cables should not be less than 69.5 dB.
2) When a "balancing section" comprises several repeater sections, an equivalent result can be obtained from the formula 69.5 − 10 $\log_{10} n$ (dB), where n is the number of repeater sections in the balancing section.

2.3 *Regularity of impedance*

The impedance of any circuit in a repeater section forming part of a carrier system on unloaded symmetric pairs should not differ from the nominal value by more than the values shown below:

± 5% (value measured at 60 kHz) for a repeater section forming part of a 12-channel system;

± 8% (value measured at 108 kHz) for a repeater section forming part of a 24-channel system;

± 8% (value measured at 120 kHz) for a repeater section forming part of a 36- or 48-channel system;

± 8% (value measured at 240 kHz) for a repeater section forming part of a 60-channel system;

± 8% (value measured at 552 kHz) for a repeater section forming part of a 120-channel system.

1) In reference [2], the CCITT does not recommend a formula for general application for tests on mixed dielectrics. However, for tests of telephone cables, the CCITT recommends the use of the factor 1.4 as representative of current commercial practice.

2.4 *Dielectric strength*

If it is desired to check the dielectric strength of a repeater section after laying, direct current will be applied to the cable at a voltage equal to the specified r.m.s. alternating current test voltage for tests on factory lengths (see § 1.4 above).

2.5 *Insulation resistance*

The insulation resistance measured at the end of the cable between any one conductor and all the other conductors bunched and connected to the earthed sheath (excluding internal repeater station wiring) should not be less than 10 000 MΩ-km measured at a potential difference of at least 100 volts and not more than 500 volts. The reading shall be made after electrification for one minute.

References

[1] *Dielectric strength tests*, Blue Book, Vol. III, Part 4, Annex 19, ITU, Geneva, 1965.

[2] *Ibid.*, § 4.

Recommendation G.612

CHARACTERISTICS OF SYMMETRIC CABLE PAIRS DESIGNED FOR THE TRANSMISSION OF SYSTEMS WITH BIT RATES OF THE ORDER OF 6 TO 34 Mbit/s

(Geneva, 1976; amended at Geneva, 1980)

1 Preamble

This Recommendation relates to symmetric pair cables which have been developed for the transmission of signals with bit rates of the order of 6 to 34 Mbit/s, but they are not ruled out for the transmission of lower or higher bit rates, subject to the use of an appropriate regeneration section; in most cases they can also be used for baseband transmission of videophone or television signals.

These cables fall into two categories, according to whether or not the cable is intended for use in both directions of transmission in the same cable.

2 Parameters to be measured

Those parameters which, for digital system transmission, have to be measured by a particular method or at frequencies different from those defined in Recommendation G.611, are: characteristic impedance, attenuation coefficient, and far-end crosstalk between pairs on the same direction of transmission. If the cable is intended for use with both directions of transmission within the same cable, it is also necessary to measure the near-end crosstalk between pairs intended for different directions of transmission.

2.1 *Characteristic impedance*

The characteristic impedance may be measured:

- either in the sinusoidal mode, when the measured pair will be terminated by an impedance constantly equal to that measured by the bridge, except when the length is sufficient for the measurement result to be independent of the termination impedance;
- or by a pulse echo meter[1], when the impedance of the pair being measured is compensated by an adjustable balancing network graduated to show the impedance value. The pair being measured is terminated by an identical network.

[1] This method is similar to the one used for coaxial pairs, but with a symmetrical measuring head and networks. The pulse duration is equal to 100 ns; the echo is not corrected.

2.2 *Attenuation coefficient*

The attenuation per km of the pairs is derived from that value to be obtained on an elementary cable section, allowance being made for the tolerance accepted on the length of these sections.

Note – In the case of looped measurement, a check should be carried out to ensure that the near-end crosstalk attenuation between the ends of the circuit being measured is sufficient.

2.3 *Crosstalk*

Crosstalk may be specified either in sinusoidal mode, at a frequency near the timing half-frequency of the system concerned, or in digital mode[2].

2.3.1 *Far-end crosstalk measurement*

The far-end crosstalk measurements are carried out on pairs used in the same direction of transmission at a frequency above about 100 kHz; if this frequency is not the timing half-frequency of the system, the value to be specified will be corrected to the factor $20 \log_{10} f$[3].

2.3.2 *Near-end crosstalk measurements*

If it is intended to transmit in both directions on the same cable, these measurements are conducted on a prototype length, either in sinusoidal mode or digital mode, between pairs used for opposite directions of transmission.

3 Description of pairs and cables

Administrations which decide to use symmetrical pairs to transmit digital signals with a bit rate of the order of 6 to 34 Mbit/s should, wherever possible, choose one of the types of cable described in §§ 3.1 and 3.2 below.

3.1 *Cable designed for use with one cable for each direction of transmission*

3.1.1 The basic characteristics of the pairs are given in Table 1/G.612.

3.1.2 The characteristics of cables constructed with these pairs are given in Table 2/G.612.

3.2 *Cables designed for transmission in both directions in the same cable*

Tables 3/G.612 and 4/G.612 indicate the characteristics of the pairs which make up cable pairs and quad cables respectively.

All these cables consist of bundles protected by one or more copper or aluminium screens, the pairs in each bundle being used for the same direction of transmission. For this reason, near-end crosstalk values relate only to pairs in different bundles.

Note 1 – To make the presentation of Tables 3/G.612 and 4/G.612 uniform, the values of characteristic impedance are given at 1 MHz (real part of Z_1). The ratio between impedance $Z_1 = X_1 - jY_1$ at 1 MHz and impedance $Z_f = X_f - jY_f$ at f MHz is

$$X_f = X_1 - Y_1 + Y_1/\sqrt{f} \text{ and } Y_f = Y_1/\sqrt{f}.$$

The differencee between the value of the real part of the impedance at 1 MHz and its value at 4 MHz is between 2 and 3 Ω. At 1 MHz, the imaginary part of the impedance is between 4 and 6 Ω; for frequencies above about 0.3 MHz, it varies in the inverse ratio to the square root of the frequency.

Note 2 – For the same reason as in Note 1 above, the attenuation value is given at 1 MHz. At a frequency f MHz ($f > 1$), attenuation α_f is related to attenuation α_1 at 1 MHz by the ratio $\alpha_f = \alpha_1 \sqrt{f}$.

Note 3 – The value of far-end crosstalk is reduced to a length of 1000 m by a correction of $10 \log_{10} L$ if the cable length L being measured is different from 1000 m. The crosstalk values indicated are the minimum limit values for the specification of systems. Where either of the above conditions is not fulfilled, the values are shown between brackets.

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[2] An example of a digital technique is given in Supplement No. 19.

[3] For symmetrical pair star-quad cables the correction law $20 \log_{10} f$ is used for pairs of the same quad only up to a certain characteristic frequency, above this frequency the law $40 \log_{10} f$ must be used.

TABLE 1/G.612

Pair characteristics	Type I cable
Diameter of conductors (mm)	0.64
Average mutual capacitance of pairs (nF/km)	24.2
Characteristic impedance (Ω) [a]	178
Attenuation coefficient at 24 °C (dB/km) [a]	13.5

[a] The attenuation and impedance measurement frequency is 3150 kHz.

TABLE 2/G.612

	Set 1 [a]	Set 2 [a]
Nominal characteristic impedance Z_0 (Ω) (desired average at 3150 kHz)	178	
Attenuation and crosstalk		
Attenuation at 3150 kHz to 24 °C (dB/km)		
pair minimum	11.8	11.8
pair maximum	14.35	14.6
Far-end crosstalk (FEXT) loss at 3150 kHz dB for a 300 m (1000 feet length)		
pair minimum power sum	37.5	39.0
minimum pair-to-pair (0.1% point)	40.5	40.5
DC resistance at 24 °C (Ω/km)		
maximum conductor	56.8	
desired average	54.5	
Cable average mutual capacitance (nF/km)		
maximum	25.4	
minimum	23.0	
desired average	24.2	
r.m.s. standard deviation (σ) of pairs within a cable (%)	⩽ 7	
Capacitance unbalance to ground (pF/km)		
maximum pair	⩽ 443	
cable average	⩽ 164	
DC dielectric strength		
between conductors for ARPAP [b] sheath	⩾ 1 500 V (applied for 1 s)	
core and inner aluminium to shield	⩾ 20 000 V (applied for 3 s)	
core to inner aluminium and shield	⩾ 5 000 V (applied for 3 s)	

[a] Two sets of values for attenuation and far-end crosstalk are given. The cable may meet either one of these sets, thus allowing a cable with lower loss to meet a less stringent crosstalk requirement.

[b] Aluminium-resin-polythene-aluminium-polythene.

TABLE 3/G.612

Cable pairs

Characteristics		Cable type				
		I	II	III	IV	V
Nominal characteristic impedance Z_0 at 1 MHz (Ω)		160	160	140	120	145
Far-end crosstalk (minimum values referred to 1000 m) (dB)	1 MHz 4 MHz 17 MHz	43 [a]	43 [a]	40	56 44 31	64 52 40
Near-end crosstalk from 1 to 17 MHz (minimum values, dB)		119	119	98	116	125
Nominal attenuation coefficient at 1 MHz [b] (dB/km at 10 °C)		7.0	9.3	10.5	9.5	5.2
Nominal capacity (nF/km)		28.5	28.5	31.5	38	30
Diameter of conductors (mm)		0.8	0.6	0.65	0.9	1.2

[a] Far-end crosstalk measurements on elementary cable sections for pairs of this type are made in the digital mode only (see Supplement No. 19). The maximum value specified is 30 mV.

[b] The real values should make it possible to meet the conditions required for an elementary cable section (Type I: 56 ± 2 dB at 4.2 MHz and 10 °C for 4 km; Type II: 56 ± 2 dB at 4.2 MHz and 10 °C for 3 km; Type III: below 55 dB at 3.15 MHz for 2.8 km).

TABLE 4/G.612

Quad cables

Characteristics			Cable type	
			I	II
Nominal characteristic impedance Z_0 at 1 MHz (Ω)			165	120
Far-end crosstalk (minimum values referred to 1000 m) (dB)	Different quads	1 MHz 4 MHz 13 MHz 17 MHz	 46 34 31	56 44 31
	Same quad	1 MHz 4 MHz 13 MHz 17 MHz	 (45) (25) [a] (21)	46 34 [c]
Near-end crosstalk, from 1 to 17 MHz (minimum values, dB)			125 [b]	116
Nominal attenuation coefficient at 1 MHz (dB/km at 10 °C)			8.8	9.5
Nominal capacity (nF/km)			28	38
Diameter of conductors (mm)			0.65	0.9

[a] For 34 Mbit/s transmission over each pair of a star quad, a balancing method is applied to the elementary cable section of 2 km by means of systematic crossings every 500 m, which improves the far-end crosstalk values by at least 15 dB. Hence the values given in this box correspond to 500 m of cable.

[b] The value must be above 130 dB in 99% of cases.

[c] The transmission of 34 Mbit/s over each pair of a star quad is studied.

Recommendation G.613

CHARACTERISTICS OF SYMMETRIC CABLE PAIRS USABLE WHOLLY FOR THE TRANSMISSION OF DIGITAL SYSTEMS WITH A BIT RATE OF UP TO 2 Mbits

(Malaga-Torremolinos, 1984)

1 Preamble

This Recommendation deals with cables designed for the transmission of standard digital systems (Recommendations of the G.900 series), although these cables can also be used to transmit digital signals with a lower bit rate and voice frequency signals. The cables described carry signals in both transmission directions simultaneously. The provisions of this Recommendation apply to cables designed to allow for digital operation of all the cable circuits. However, some of the provisions may be used to assess the possibility of (partial or full) digital operation of existing cables.

2 Parameters to be measured

2.1 *Direct current resistance*

The following formula is used to correct the value R_t of direct current resistance measured at t °C for 20 °C:

$$R_{20} = R_t/(1 + 0.004\,(t - 20))$$

2.2 *Capacitance per unit length*

This is measured at 800 Hz or 1000Hz.

2.3 *Attenuation coefficient*

The value of the attenuation coefficient is obtained either by direct measurement of the attenuation or by calculation on the basis of the mutual capacitance and direct current resistance of the pair. The attenuation coefficient is measured at one frequency only, f_0, near the timing half-frequency.

System	Recommendation	f_0
1544 kbit/s	G.951	772 kHz
2048 kbit/s	G.952	1 MHz

For cables with polyolefin insulation, the value of the attenuation coefficient at frequency f (for values of f above with a few hundred kHz) can be related to α_0 by the equation $\alpha_f = \alpha_0\sqrt{\frac{f}{f_0}}$.

The value of the attenuation coefficient measured at t °C is corrected for 20 °C by the equation:

$$\alpha_{20} = \alpha_t/(1 + 0.002\,(t - 20))$$

2.4 *Characteristic impedance*

2.4.1 *Echometric measurement*

When a pulse echometer is used, the impedance of the pair measured must be compensated by a calibrated balancing network which can be set in steps of about 0.5 Ω. Pulse duration will be equal to or less than 500 ns. With this method, which is both fast and simple, the value of the end impedance of the pair measured is read off directly on the scale of the balancing network.

2.4.2 *Sinusoidal measurement*

In this case, the pair tested will be terminated across an impedance, which is constantly equal to that measured by the bridge, unless it is long enough for the result of the measurement to be independent of end impedance (as for elementary cable sections).

2.5 *Crosstalk*

Crosstalk can be measured sinusoidally or digitally. The assignment of pairs to the direction of transmission depends on the structure and type of manufacture of the cable.

2.5.1 *Sinusoidal measurement*

2.5.1.1 *Far-end crosstalk*

The measurements are made between pairs assigned to the same direction of transmission, at frequency f_0. If the frequency at which measurement is carried out is not the timing half-frequency, the value is corrected using the $20 \log_{10} f$ law. When the measurement is carried out on a pair of length, L, which is different from the specified reference length L_0, the measured value is corrected using $\sqrt{L/L_0}$ when the value is expressed in mV or $10 \log_{10} \frac{L}{L_0}$ when the value is expressed in dB.

2.5.1.2 *Near-end crosstalk*

The measurements are made between pairs assigned to transmission in opposite directions, at a frequency near the system's timing half-frequency.

2.5.2 *Digital measurement*

By means of digital measurement, it is possible to estimate the total noise on an elementary section, taking account of both near-end and far-end crosstalk. This estimate can be made on the basis of separate near-end and far-end crosstalk measurements on either factory lengths or elementary sections.[1] These measurements can be made either in factory conditions or on installed cables.

2.5.2.1 *Far-end crosstalk*

The measurements are carried out between pairs assigned to the same direction of transmission. When the measurement is carried out on a pair of length, L, which is different from the specified reference length L_0, the measured value is corrected using $\sqrt{L/L_0}$ when the value is expressed in mV or $10 \log_{10} (L/L_0)$ when the value is expressed in dB.

2.5.2.2 *Near-end crosstalk*

The measurements are made between pairs *assigned* to transmission in opposite directions.

3 Circuit characteristics

These are given in Table 1/G.613.

4 Characteristics of connected cable sections

These are given in Table 2/G.613.

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[1] One advantage of digital measurements is that it is possible to make a direct overall measurement of the total noise on an elementary section if enough generators are available.

TABLE 1/G.613

Circuit characteristics *

Characteristics			Type of cable				
			Type I	Type II	Type II *bis*	Type III ****	f)
Operational bit rate (kbit/s)			2048	2048	2048	2048	
Repeaters gain **			34 dB				
Elements constituting the cable			star quad	pairs	pairs	pairs	
Nominal conductor diameter (mm)			0.8	0.7	1	0.6	
Nominal impedance *** at f_0 MHz (Ω)		1 MHz	100	130	130		
		772 kHz					
Nominal attenuation coefficient at f_0 and at 20 °C *** (dB/km)		1 MHz	16	11.5 b)	8.5 b)	15.5	
		772 kHz					
Crosstalk in digital operation		a)	c)	–	–	–	
Total noise voltage (maximum value)		a)					
Minimum near-end crosstalk (mV)		a)	–	60 d, g)	60 d, g)		
		a)					
Minimum far-end crosstalk (mV)		a)	–	45 e, g)	45 e, g)		
		a)					
Sinusoidal crosstalk	Near-end (dB)	1 MHz				78 ± 3 h)	
		772 kHz					
	Far-end (dB)	1 MHz				64 ± 3 h)	
		772 kHz					
Nominal direct current resistance at 20 °C (Ω/km)			68.6	94.1 b)	46.1 b)	63	
Nominal mutual capacitance (nF/km)			50	39	39	44	

Notes of Table 1/G.613

* At the present stage the values are given for information.

** Reference value for the numerical data of the cable in question.

*** A standard deviation or margins will be given at a later stage.

**** Cable with diametral screen separating the pairs assigned to the two directions of transmission.

a) To be specified.

b) Maximum value.

c) The specification value for factory controls is calculated to ensure compliance with the characteristics of connected cable.

d) Between pairs of different groups.

e) Between pairs belonging to one and the same group.

f) Other columns will contain the data supplied by administrations.

g) Values given in dB.

h) The value given here depends on the content of the cable. It is the rounded-down mean of a standard deviation of the total production and is therefore not a specification for individual cable lengths.

TABLE 2/G.613

Characteristics of connected cable sections *

Characteristics			Type of cable				
			Type I	Type II	Type II *bis*	Type III	a)
Operational bit rate (kbit/s)			2048	2048	2048		
Nominal impedance at f_0 MHz (Ω)		1 MHz	100	130	130		
		772 kHz					
Nominal attenuation coefficient at f_0 and at 20 °C (dB/km)		1 MHz	16	11.5	8.5		
		772 kHz					
Crosstalk in digital operation Total noise voltage (maximum value)		b)	40 mV				
		b)					
Minimum near-end crosstalk (mV)		b)					
		b)					
Minimum far-end crosstalk (mV)		b)					
		b)					
Sinusoidal crosstalk	Near-end (dB)	1 MHz					
		772 kHz					
	Far-end (dB)	1 MHz					
		772 kHz					

* At the present stage the values are given for information.

a) Other columns will contain the data supplied by Administrations.

b) To be specified.

CHARACTERISTICS OF SYMMETRIC PAIR STAR-QUAD CABLES DESIGNED EARLIER FOR ANALOGUE TRANSMISSION SYSTEMS AND BEING USED NOW FOR DIGITAL SYSTEM TRANSMISSION AT BIT RATES OF 6 TO 34 Mbit/s

(Melbourne, 1988)

1 Introduction

This Recommendation relates to symmetric pair star-quad cables which have been designed earlier and used to provide 60 or 120 carrier telephone channels of analogue transmission systems on each quad pair. Further, after reconstruction of the line, these cables are used for digital system transmission at bit rates of 6 to 34 Mbit/s. The cables concerned have no screened pairs and quads.

For digital transmission systems with a bit rate of 8 Mbit/s both one-cable and two-cable operations may be used. For systems with a bit rate of 34 Mbit/s two-cable operation is used only.

For digital transmission systems both several, or all cable pairs may be used.

2 Parameters to be measured

All parameters specified in Recommendation G.612, namely characteristic impedance, attenuation coefficient, far-end crosstalk between pairs on the same direction of transmission, and near-end crosstalk between pairs of two different cables intended for different directions of transmission are to be measured. If the cable is intended for use with both directions of transmission it is also necessary to measure the near-end crosstalk between pairs intended for different directions of transmission.

2.1 *Characteristics impedance*

The characteristics impedance is measured according to § 2.1 of Recommendation G.612.

2.2 *Attenuation coefficient*

The attenuation coefficient is measured according to § 2.2 of Recommendation G.612.

2.3 *Crosstalk*

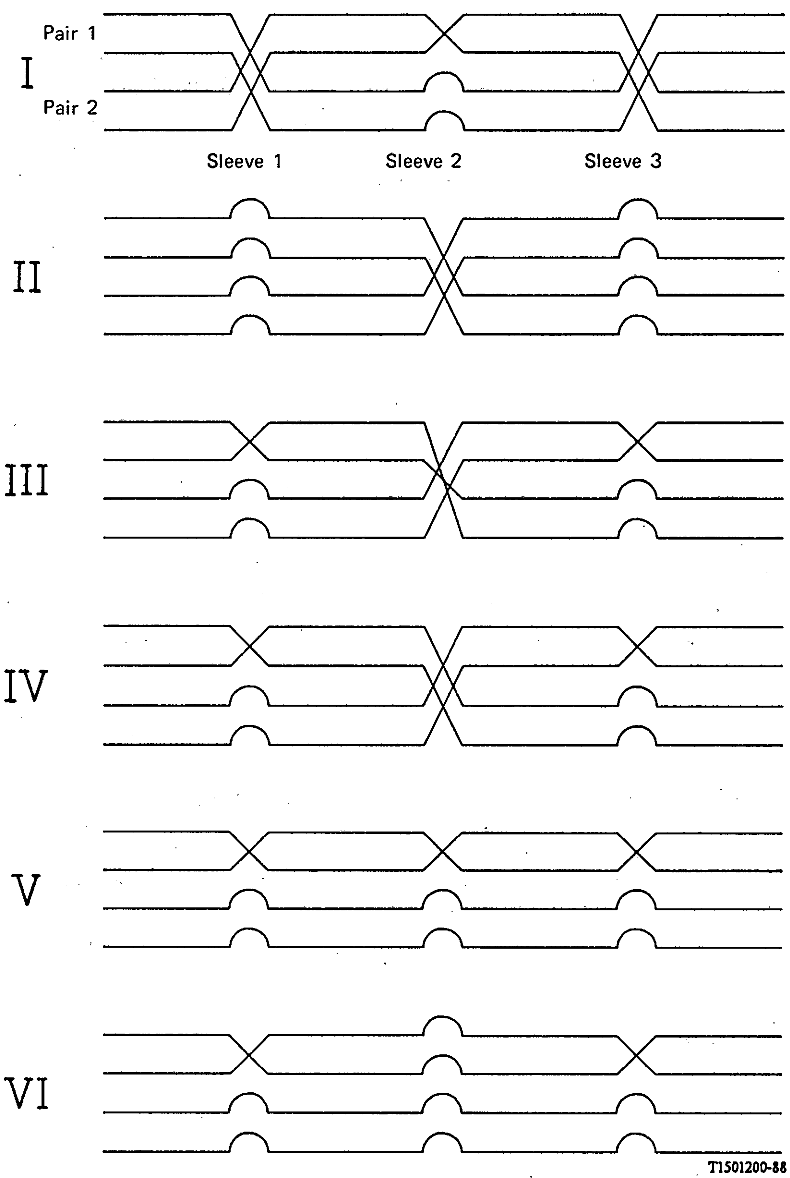
The crosstalk is specified in sinusoidal mode at a frequency near the timing half-frequency of the digital system and/or at other frequencies. Digital mode of measuring may be used also.

2.3.1 *Measurement of far-end crosstalk between pairs of different quads*

The measurement of the far-end crosstalk is carried out on pairs used in the same direction of transmission at a frequency above about 0.1 MHz when a length of cable is L. If the frequency of measurements differs from the timing half-frequency of the digital transmission system the value to be measured will be corrected to the factor $20 \log_{10} f$. The values are corrected to the length of 1000 m by the factor $10 \log_{10} L$.

2.3.2 *Measurement of far-end crosstalk between pairs of the same quad*

This measurement is carried out at a cable length equal to maximum permissible length of regenerator section of digital transmission system with bit rates of 6 to 34 Mbit/s at a frequency above about 1.0 MHz (measurement is carried out for each rate of digital transmission system separately) with systematic component of crosstalk in the same quad compensated. The compensation of systematic crosstalk component is carried out by one of the approximately equivalent transposition patterns (see Figure 1/G.614). When regenerator sections are of less length these methods of falling the elementary cable sections into separate parts and of transposition in quad provide the greater values of the far-end crosstalk between pairs than those values when measurements are carried out at a maximum length of regenerator section.



Note 1 — Transposition pattern No. 1 was proposed by the Netherlands Administration in 1978 (see COM XV-135, period 1977-1980).

Note 2 — Transposition pattern No. 2 has been proposed by the German Democratic Republic Administration.

Note 3 — Transposition patterns Nos. 3, 4, 5 and 6 are proposed by the USSR Administration.

FIGURE 1/G.614

2.3.3 *Measurement of near-end crosstalk between pairs of the same or different cables intended for different directions of transmission*

This measurement is carried out either between pairs of the same cable (when one-cable operation is used), or between pairs of two different cables intended for different directions of transmission (when two-cable operation is used). The measurements are carried out both in sinusoidal and digital modes.

3 Cable specification

Administrations which decided to use cables designed earlier and used for analogue carrier systems with up to 120 channels in digital operation at bit rates 6 to 34 Mbit/s are recommended to choose cables with characteristics given in Tables 1/G.614 and 2/G.614.

3.1 *Tables used for digital transmission systems with bit rates of 6 to 8 Mbit/s in one-cable operation*

See Table 1/G.614.

TABLE 1/G.614

Characteristics	Requirements		
Types of cable	I (Note 1)	II (Note 1)	III (Note 1)
Operational bit rate C, kbit/s	8448	8448	8448
Line code	HDB-3	HDB-3	HDB-3
Modulation rate, kbaud	8448	8448	8448
Tolerate attenuation of regenerator section at a frequency of C/2 when pairs of cable are of maximum use and directions of transmission are set in different quads (maximum permissible value), dB	23	23	45 (Note 3)
Diameter of copper conductor, mm	1.2	1.2	1.3
Previous cable operating range	HF	HF	AF, HF
Type of insulation	Pl	Pl	Pl, P
Number of star quads	4	7 (Note 2)	3, 4, 8
Characteristic impedance at 1 MHz, ohms	165	165	170
Nominal capacity, nF/km	24.5	24.5	21.0
Attenuation coefficient, dB/km at 10 °C			
– at 1 MHz	4.8	4.5	3.7
– at a frequency C/2	10.6	9.7	8.0
Near-end crosstalk at a frequency of C/2, dB			
– mean value	48	50	50
– minimum value	34	34	44
Far-end crosstalk between pairs of different quads (minimum value referred to 1,000 m), dB			
– at 1 MHz	54	54	60
– at a frequency of C/2	42	42	48
Far-end crosstalk between pairs of the same quad (minimum value at regenerator section of maximum length), dB			
– at 1 MHz	60	60	60
– at a frequency of C/2	43	43	48

Note 1 – These characteristics relate to cables with aluminium covering.

Note 2 – Central quad not used for digital system transmission.

Note 3 – Regenerators of the transmission direction B-A installed in midpoint of the section of the opposite direction A-B.

HF High-frequency

AF Audio-frequency

Pl String polysterene

P Paper

3.2 *Cables used for digital transmission systems with bit rates of 6 to 34.368 Mbit/s in two-cable operation*

See Table 2/G.614.

TABLE 2/G.614

Characteristics	Requirements		
Type of cable	I (Note 1)	II (Note 1)	III (Note 1)
Operational bit rate C, kbit/s	8448	34 368	34 368
Line code	HDB-3	5B6B	5B6B
Modulation rate, kbaud	8448	41 242	41 242
Attenuation of regenerator section at a frequency of C/2 when all pairs of cable are used (maximum permissible value), dB	70	85	85
Diameter of copper conductor, mm	1.2	1.2	1.3
Number of star quads	4	4	3. 4. 8
Characteristic impedance at 1 MHz, ohms	165	165	170
Nominal capacity, nF/km	24.5	24.5	21.0
Attenuation coefficient, dB/km at 10 °C			
– at 1 MHz	4.8	4.8	3.7
– at a frequency C/2	10.6	24.0	17.0
Far-end crosstalk between pairs of different quads (minimum value referred to 1,000 m), dB			
– at 1 MHz	54	51	60
– at 4 MHz	42	42	48
– at 12 MHz	–	32	30
– at 17 MHz	–	30	26
Far-end crosstalk between pairs of the same quad (minimum value at a regenerator section of maximum length), dB			
– at 1 MHz	42	–	60 (Note 3)
– at 4 MHz	30	33 (Note 2)	48 (Note 3)
– at 12 MHz	–	17 (Note 2)	27 (Note 3)
– at 17 MHz	–	13 (Note 2)	17 (Note 3)

Note 1 – These characteristics relate to cables with aluminium covering.

Note 2 – These values are obtained by means of transposition pattern No. 5 (see Figure 1/G.614) for four cable lengths (0.825 km).

Note 3 – These values are obtained by means of transposition pattern No. 2 (see Figure 1/G.614).

6.2 Land coaxial cable pairs

The coaxial cables described in the following Recommendations of this section 6.2 can be used for different kinds of systems. The following tables illustrate the possible uses of the various pairs.

TABLE 1

Cables in analogue systems

Designation of system types (MHz)	Typical frequency band (MHz)	Types of coaxial cables that might be used (mm)
1.3	0.06 to 1.3	1.2/4.4
4 or 6	0.06 to 6	1.2/4.4 2.6/9.5
12 or 18	0.3 to 12 or 18	1.2/4.4 2.6/9.5
60	4 to 60	2.6/9.5

TABLE 2

Cables in digital systems

Proposed designation of system types	Possible bandwidth (MHz)	Typical example of bit rate of system (Mbit/s)	Types of coaxial cables that might be used (mm)
Medium bit rate	8.5	8	0.7/2.9
	35	34	0.7/2.9 1.2/4.4
High bit rate	100	140	1.2/4.4 [a] 2.6/9.5
Very high bite rate	700	565	2.6/9.5

[a] For high bit rate systems a hybrid system might be employed, i.e. there are several analogue type repeaters between each regenerator. In this case the effective bandwidth could be reduced (for examplee within 35 MHz).

CHARACTERISTICS OF 0.7/2.9 mm COAXIAL CABLE PAIRS

(Geneva, 1976; amended at Geneva, 1980)

Administrations which decide to use for digital transmissions, and possibly also for particular types of analogue transmission, coaxial pairs smaller than the 1.2/4.4-mm coaxial pair should as far as possible choose pairs complying with the specifications given in this Recommendation. The use of these pairs is defined in Tables 1 and 2 given in the introduction to Subsection 6.2.

1 Pair characteristics

1.1 *Electrical characteristics of the coaxial pair*

1.1.1 *Characteristic impedance*

The nominal value of the real part of the characteristic impedance at 1 MHz should be 75 Ω.

The mean real part of the impedance of a coaxial pair at 1 MHz should not differ from the nominal figure by more than ± 2.5 Ω.

Table 1/G.621 shows the general trend of the variation of the impedance as a function of frequency.

TABLE 1/G.621

Mean real part of the impedance measured at various frequencies

Frequency (MHz)	0.2	0.5	1	2	5	10	20	∞
Impedance (Ω)	77.7	75.9	75	74.2	73.4	73	72.8	72.2

1.1.2 *Attenuation coefficient*

The nominal value of the attenuation coefficient, at 10 °C and at 1 MHz, is equal to 8.9 dB/km.

Table 2/G.621 shows the general trend of the variation in attenuation coefficient as a function of frequency at the temperature 10 °C.

TABLE 2/G.621

Mean values of the attenuation coefficient at various frequencies

Frequency (MHz)	0.2	0.5	1	2	5	10	20
Attenuation coefficient (dB/km)	4.5	6.5	8.9	12.6	19.8	28.0	39.6

1.2 *Mechanical construction of the coaxial pair*

The pair has the following constitution:

a) nominal diameter of solid-copper wire inner conductor: 0.7 mm;

b) nominal internal diameter of outer conductor: 2.9 mm;

c) outer conductor consisting of a copper tape with a thickness of the order of 0.1 mm, laid lengthwise with overlap [1];

d) screen consisting of a steel tape with a thickness of the order of 0.1 mm, laid lengthwise with overlap [1].

2 Cable specification (factory lengths of about 500 m)

2.1 *Characteristic impedance*

To check that the value given in § 1.1.1 is met, pulse measurements can be made. The mean real part of the impedance at 1 MHz is to be taken as meaning the resistive component of the impedance at 1 MHz of the network with the best balance against the coaxial pair measured.

2.2 *Impedance regularity*

Routine control measurements of impedance regularity are carried out by means of pulse echometers from one or both ends of the factory lengths. The echo curve should be plotted with correction in amplitude and if possible in amplitude and phase.

Table 3/G.621 shows the various values to be obtained according to the purpose for which the cable is intended.

TABLE 3/G.621

Echometric measurement of factory lengths [a]

Type of system			Digital
Bit rate			Medium bit rate (6 to 34 Mbit/s)
Maximum pulse duration			100 ns
General provisions	Maximum peak	100%	36 dB
		95%	39 dB
Additional optional provisions [a]	A	Mean of 3 maximum peaks	39 dB
	B	Equivalent resistance error	

[a] It is enough to check that one of the two conditions A or B is fulfilled.

Note 1 – The percentage figures given in the table relate to all the pairs of a batch of cables submitted for control or delivered at the same time.

Note 2 – With the construction techniques used so far, systematic faults do not give rise, in steady-state measurements of regularity return loss, to peaks at frequencies below 60 MHz. For this reason, and taking into account the bit rate envisaged, steady-state measurements of regularity return loss do not seem necessary. For other types of construction which might be used in future, supervision of the regularity return loss might be wise; in such cases, the value should be 20 dB from 4 to 60 MHz.

2.3 *Attenuation coefficient*

The attenuation of pairs should be such as to allow compliance with the provisions of § 3.3 below [2].

[1] A single bimetallic copper-steel-copper tape may also be used to serve as outer conductor and screen.

[2] At this stage of manufacture, attenuation measurements are merely prototype measurements.

2.4 *Near-end crosstalk attenuation*

The near-end crosstalk attenuation between coaxial pairs used for different transmission directions, measured in the frequency band 0.5-20 MHz on factory lengths, must be above 135 dB for 100% of measurements.

2.5 *Dielectric strength*

The pair should withstand an a.c. voltage of 1000 r.m.s. at 50 Hz (or a d.c. voltage of 1500 volts) applied for at least 1 minute between the centre and the outer conductor.

If in normal service the outer conductors of the coaxial pairs are not to be earthed, a dielectric strength test must be carried out between the outer conductors and the earthed metal sheath. For this test, an a.c. voltage of at least 2000 volts r.m.s. at 50 Hz or a d.c. voltage of not less than 3000 V will be applied.

2.6 *Insulation resistance*

The insulation resistance between the centre and outer conductors of the coaxial pair, measured with a perfectly steady voltage of between 100 and 500 V, should not be less than 10 000 MΩ-km after electrification for one minute at a temperature not lower than 15 °C. The measurement of the insulation resistance should be made after the dielectric strength test. This measurement should be made on every factory length.

3 Elementary cable section specification

It will be a matter for agreement between the Administration and the supplier whether tests are to be carried out on all sections or whether some percentage or even a type-approval test alone will be sufficient, especially in the case of measurements which are different to carry out under field conditions.

3.1 *Mean impedance*

The mean real part of the impedance of a coaxial pair at 1 MHz must not differ from the nominal value (as defined in § 1.1.1) by more than 3 Ω. Measurements should be affected as described in § 2.1.

3.2 *Impedance regularity*

Measurements are effected as described in § 2.2 above. Table 4/G.621 indicates the various values to be obtained according to the purpose for which the cable is intended. Note 1 of § 2.2 remains valid.

TABLE 4/G.621

Echometric measurement of elementary cable sections

<table>
<tr><td colspan="4">Type of system</td><td>Digital</td></tr>
<tr><td colspan="4">Bit rate</td><td>Medium bit rate
(6 to 34 Mbit/s)</td></tr>
<tr><td colspan="4">Maximum pulse duration</td><td>100 ns</td></tr>
<tr><td rowspan="2">General provisions</td><td rowspan="2" colspan="2">Maximum peak</td><td>100%</td><td>30 dB</td></tr>
<tr><td>95%</td><td>33 dB</td></tr>
<tr><td rowspan="2">Additional optional provisions [a)]</td><td>A</td><td colspan="2">Mean of 3 maximum peaks</td><td>33 dB</td></tr>
<tr><td>B</td><td colspan="2">Equivalent resistance error</td><td></td></tr>
</table>

[a)] It is enough to check that one of the two conditions A or B is fulfilled.

3.3 *Attenuation coefficient*

At 1 MHz, the real attenuation coefficient must not differ from the nominal figure, as defined in § 1.1.1, by more than ± 0.4 dB.

Attenuation measured on a cable at an average temperature of t °C is referred to 10 °C by the formula:

$$\alpha_{10} = \alpha_t \frac{1}{1 + k_\alpha (t - 10)}$$

The coefficient of the variation in attenuation as a function of temperature k_α is about $1.8 \cdot 10^{-3}$ per °C for frequencies above 2 MHz and about $1.9 \cdot 10^{-3}$ per °C for 1 MHz.

3.4 *Crosstalk*

The near-end crosstalk attenuation between coaxial pairs used for different transmission directions, measured in the frequency band 0.5-20 MHz on 2- and 4-km sections, should be above 130 dB.

3.5 *Dielectric strength*

The pair must withstand a d.c. voltage of at least 1000 V applied during at least 1 minute between the internal and external conductors.

In addition, a test of dielectric strength between the coaxial pair and earth shall be made as described in § 2.5 using a d.c. voltage of at least 2000 V applied for 1 minute.

3.6 *Insulation resistance*

The insulation resistance between the centre and outer conductors of the coaxial pair, measured with a perfectly steady voltage of between 100 and 500 V should not be less than 5000 MΩ-km after electrification for 1 minute. The measurement of the insulation resistance should be made after the dielectric strength test. This measurement should be made on every elementary cable section.

Recommendation G.622

CHARACTERISTICS OF 1.2/4.4 mm COAXIAL CABLE PAIRS

(former Recommendation G.342; further amended)

The following Recommendation describes the 1.2/4.4 mm coaxial pair recommended by the CCITT for the international service. The use of this pair is defined in Tables 1 and 2 given in the introduction to Subsection 6.2. When the possibility of television or digital transmission has been envisaged, it is expressly mentioned in each provision.

1 Characteristics of the pair

1.1 *Electrical characteristics of the coaxial pair*

1.1.1 *Characteristic impedance*

The nominal real part of the characteristic impedance is 75 Ω at 1 MHz.

The tolerance is ± 1.5 Ω for telephony or ± 1 Ω for pairs that may be used for television transmissions.

For information, the impedance values in Table 1/G.622 were obtained at various frequencies on coaxial pairs manufactured by different processes.

TABLE 1/G.622

Means real part of the characteristic impedance measured at various frequencies

Frequency (MHz)	0.06	0.1	0.2	0.5	1	1.3	4.5	12	18
Impedance (Ω)	79.8	78.9	77.4	75.8	75	74.8	74	73.6	73.5

1.1.2 *Attenuation coefficient*

The nominal value of the attenuation coefficient of the pair, at 12 MHz and at 10 °C, is 18.0 ± 0.4 dB/km.

Table 2/G.622 shows the general trend of the variation of the attenuation coefficient as a function of frequency for all pairs which conform to the present Recommendation.

TABLE 2/G.622

Nominal values of the attenuation coefficient at various frequencies

Frequency (MHz)	0. 06	0.1	0.3	0.5	1	1.3	4.5	12	18
Attenuation coefficient (dB/km)	1.5	1.8	2.9	3.7	5.3	6.0	11	18	22

The following equation, in which α is expressed in dB/km and f in MHz, gives an approximation of the attenuation coefficient from 2 MHz onwards:

$$\alpha = 0.07 + 5.15 \sqrt{f} + 0.005 f.$$

Note – By way of information, Annex A shows the values measured or specified in various countries, with the corresponding deviations or tolerances. In any case, amplifier design must be based on the values measured on the type of cable which will actually be used.

1.1.3 *Attenuation distortion*

The attenuation distortion required in particular for digital transmission is checked by calculating the ratio $\frac{\alpha_{f1}}{\alpha_{f2}}$ between attenuation values α_{f1} and α_{f2} measured at two frequencies f_1 and f_2.

One of the following three limits should be observed: [1)]

$$\frac{\alpha_{16\ \mathrm{MHz}}}{\alpha_{4\ \mathrm{MHz}}} \leqslant 2.005$$

$$\frac{\alpha_{24\ \mathrm{MHz}}}{\alpha_{6\ \mathrm{MHz}}} \leqslant 2.009$$

$$\frac{\alpha_{48\ \mathrm{MHz}}}{\alpha_{12\ \mathrm{MHz}}} \leqslant 2.016$$

The attenuation distortion is checked in the factory on a small percentage of factory lengths.

1) These three conditions are equivalent. Accordingly, only one of them is to be used for checking attenuation distortion.

1.2 *Mechanical construction of the coaxial pair*

The nominal dimensions are the following:

– diameter of solid copper centre conductor: 1.2 mm;

– inner diameter of outer conductor: 4.4 mm.

The cylindrical outer conductor is obtained using a copper tape with a thickness of 0.15 or 0.18 mm.

2 Cable specification

2.1 *Characteristic impedance*

To check that the value given in § 1.1.1 above is met, pulse measurements can be made. The real part of impedance at 1 MHz is to be taken as meaning the resistive component of the impedance at 1 MHz of the network with the best balance against the coaxial pair measured.

2.2 *Impedance regularity*

Routine control measurements of impedance regularity are carried out by means of pulse echometers from one or both ends of the factory lengths. The echo curve should be plotted with correction in amplitude and if possible in amplitude and phase. If the equivalent resistance error is measured, it must be corrected. However, for routine measurements, correction may be dispensed with if the test length is so short that the correction is small.

Table 3/G.622 shows the various values to be obtained according to the purpose for which the cable is intended.

TABLE 3/G.622

Echometric measurement of factory lengths

Type of system			Analogue		Digital	
Frequency range or bit rate			0.06-6 MHz	0.3-20 MHz	Medium bit rate (6-34 Mbit/s)	Hight bit rate (140 Mbit/s)
Maximum pulse duration			100 ns	50 ns	50 ns	10 ns
General provisions	Maximum peak	100%	45 dB	48 dB	48 dB	48 dB
		95%	50 dB	50 dB	50 dB	49 dB
Additional optional provisions [a]	A	Mean of 3 maximum peaks	48 dB	51 dB	51 dB	47 dB
	B	Equivalent resistance error	1.2 Ω	1.6 Ω	1.6 Ω	2.5 Ω

[a] It is enough to check that one of the two conditions A or B is fulfilled.

Note 1 – For 0.06-1.3 MHz analogue systems, the provisions are the same as for 0.06-6 MHz analogue systems.

Note 2 – To detect systematic irregularities, return wave attenuation measurements should be carried out on a small proportion of factory lengths. The limits to be observed are set out in Table 4/G.622.

Note 3 – The percentage figures given in the table relate to all the pairs of a batch of cables submitted for control or delivered at the same time.

TABLE 4/G.622

Return wave attenuation on irregularities

Type of system		Digital	
Frequency range or bit rate		Medium bit rate (6-34 Mbit/s)	High bit rate (140 Mbit/s)
Percentage of lengths concerned		about 5%	about 5%
Frequency band explored		1-40 MHz	20-100 MHz
Minimum measured value	100%	20 dB	20 dB
	95%	23 dB	23 dB

2.3 *Attenuation coefficient*

The attenuation of pairs should be such as to allow compliance with the provision of § 3.3 below[2].

If reference is made to the length measured along a generatrix of the cable sheath, the attenuation coefficient should be multiplied by the take-up factor, the values of which for different numbers of pairs contained in the cable are given as an indication in Table 5/G.622.

TABLE 5/G.622

Take-up factor values

Number of pairs in cable	Take-up factor last layer	Weighted take-up factor, entire cable
4 or 6		1.002
8		1.003
12-18	1.004	1.003
24	1.005	1.004
48	1.008	1.006

2.4 *Crosstalk*

The crosstalk between pairs should be such as to allow compliance with the provisions of § 3.4 below[2].

[2] At this stage of manufacture, attenuation and crosstalk measurements are merely prototype measurements.

2.5 *Dielectric strength*

The pair should withstand an a.c. voltage of 1000 V r.m.s. at 50 Hz (or a d.c. voltage of 1500 V) applied for at least one minute between the centre and outer conductors.

If, in normal use, the outer conductors of the coaxial pair are not earthed, a dielectric strength test is made between the outer conductors and the earthed metallic sheath. The conductors of the auxiliary quads or pairs are connected to the outer conductors of the coaxial pairs or to the sheath, according to the kind of system used for these quads or pairs. Under these conditions, an a.c. voltage of 2000 V r.m.s. or more at 50 Hz will be applied for at least one minute (or a d.c. voltage of 3000 V or more).

Note – The test voltages recommended take account of the normal safety margins applied in the various countries. Polythene insulation, however, might reasonably withstand considerably higher test voltages. In any case, some other dielectric might conceivably be used in the future.

2.6 *Insulation resistance*

The insulation resistance between the centre and outer conductors of the coaxial pair, measured with a perfectly steady voltage of between 100 and 500 V, should not be less than 5000 MΩ-km after electrification for one minute, at a temperature not lower than 15 °C. The measurement of the insulation resistance should be made after the dielectric strength test. This measurement should be made on each factory length.

3 Elementary cable section specification

3.1 *End impedance*

The conditions described in §§ 1.1.1 and 2.1 above are applicable.

3.2 *Impedance regularity*

Impedance regularity measurements are carried out from each end of the elementary cable section. Reference should be made to one of the columns in Table 6/G.622, according to the purpose for which the cable is intended.

3.3 *Attenuation coefficient*

At 1 MHz, the real attenuation coefficient must not differ from the nominal figure by more than ± 0.2 dB.

Attenuation measured on a cable at an average temperature of t °C is referred to 10 °C by the formula:

$$\alpha_{10} = \alpha_t \frac{1}{1 + k_\alpha (t - 10)}.$$

The coefficient k_α of the variation in attenuation with temperature is about 2×10^{-3} per °C at frequencies of 500 kHz or more. It increases slightly at lower frequencies (about 2.8×10^{-3} per °C at 60 kHz).

3.4 *Crosstalk*

The far-end crosstalk ratio between two coaxial pairs in a cable transmitting in the same direction at any frequency in the band actually transmitted must be not less than the values given in Table 7/G.622.

TABLE 6/G.622

Echometric measurement of elementary cable sections[a)]

Type of system				Analogue		Digital	
Frequency range or bit rate				0.06-6 MHz	0.3-20 MHz	Medium bit rate (6-34 Mbit/s)	High bit rate (140 Mbit/s)
Maximum pulse duration				200 ns	100 ns	100 ns	50 ns
General provisions	Maximum peak	100%		42 dB	42 dB	42 dB	40 dB
		95%		46 dB	46 dB	46 dB	44 dB
Additional optional provisions[a)]		A	Mean of 3 maximum peaks.	45 dB	45 dB	45 dB	43 dB
			Uncorrected maximum	48 dB	48 dB	48 dB	46 dB
	Equivalent resistance error	B	Energy corrected ($\Omega \cdot km^{-1/2}$)	2	2.5	2.5	3.5
		C	Uncorrected (Ω)	1.8	2.0	2.0	2.5

a) It is enough to check that one of the three conditions A, B or C is fulfilled.

Note 1 – Notes 1 and 2 to Table 3/G.622 still hold good. However, for 0.06 to 1.3 MHz analogue systems, the provisions of column 0.06 to 6 MHz apply, but the pulse duration may attain 400 ns for elementary cable sections longer than 4 km.

Note 2 – Measurements using sine-wave signals on elementary cable sections are unnecessary unless there are serious grounds for believing that systematic irregularities may have been introduced during the laying or installation of the cable. In such cases, the measurement results should not be less than 20 dB.

TABLE 7/G.622

Minimum far-end crosstalk ratio between two 1.2/4.4 mm coaxial pairs

Length of the section (km)	Far-end crosstalk ratio (dB)	
	Without phase inversion	With phase inversion at repeaters
8	87	–
6	89	80
4	93	–
3	95	83
2	99	–

There is no need to specify a near-end crosstalk ratio when the former limits are chosen for the far-end crosstalk ratio.

When phase inversion is used, the near-end crosstalk ratio for pairs transmitting in opposite directions must be at least 84 dB for a section about 6 km long, and 87 dB for a section about 3 km long.

Note – These limits enable a far-end crosstalk ratio of 65 dB to be obtained on the worst homogenous 280-km section, assuming that for the frequencies in question only far-end crosstalk due to the cable is to be considered[3]. It is assumed that the variation in the minimum far-end crosstalk ratio as a function of the distance approximately follows a 20 dB/decade law for distances below a limit distance L_1 and a 10 dB/decade law for distances above L_1. The values depend on a number of factors, mainly the system used, the type of cable and the considered frequency. A value of 30 km appears suitable in most cases, although values of L_1 ranging from a few kilometers to 30 kilometers have been observed in practice, ensuring the consistency of the limits in Table 7/G.622 with the 65 dB limit on a 280 km section.

3.5 *Dielectric strength*

The pair must withstand a d.c. voltage of at least 1000 V applied during at least one minute between the inner and the outer conductors.

In addition, a test of dielectric strength between the coaxial pair and earth shall be made as described in § 2.5, using a d.c. voltage of at least 2000 V applied for one minute.

Note – The recommended test voltages take account of the normal safety margins applied in the various countries. Polythene insulation, however, might reasonably withstand considerably higher test voltages. In any case, some other dielectric might conceivably be used in the future.

3.6 *Insulation resistance*

The insulation resistance between the centre and outer conductors of the coaxial pair, measured with a perfectly steady voltage of between 100 and 500 V, should not be less than 5000 MΩ-km after electrification for one minute. The measurement of the insulation resistance should be made after the dielectric strength test. This measurement should be made on every elementary cable section.

ANNEX A

(to Recommendation G.622)

Examples of attenuation coefficient measured or specified in some countries

(Values given as an indication)

TABLE A-1/G.622

Values measured on a type of pair whose outer conductor is 0.15 mm thick

Frequency (MHz)	0.060	0.1	0.3	0.5	1	4	12	18	52
Attenuation (dB/km)	1.54	1.85	2.89	3.67	5.21	10.4	18.0	22.0	37.5
Tolerance (dB/km)	±0.1	±0.1	±0.1	±0.1	±0.1	±0.1	±0.2	±0.2	±0.5
Temperature coefficient	0.0028	0.0026	0.0024	0.00225	0.0020	0.0020	0.0020	0.0020	0.0020

[3] In practice it is possible to forget the influence of line equipment on intelligible crosstalk, but this is only true for low frequencies of the band (less than 300 kHz).

TABLE A-2/G.622

Values specified in certain countries for a type of pair whose outer conductor is 0.18 mm thick

Frequency (MHz)	60	100	200	300	500	700	1000	1300	4500
Specific attenuation (dB/km)	1.49	1.80	2.42	2.91	3.73	4.43	5.30	6.05	11.2
Tolerance (dB/km)	±0.1	±0.1	[a]	[a]	[a]	[a]	±0.2	±0.2	±0.2

[a] Not specified.

Recommendation G.623

CHARACTERISTICS OF 2.6/9.5 mm COAXIAL CABLE PAIRS

(former Recommendation G.331; further amended)

1 Pair characteristics

It is necessary to have throughout the international network types of coaxial pairs having the same electrical characteristics, in order to enable transmission systems to operate on any cable meeting the specifications of this Recommendation. The use of these pairs is defined by Tables 1/G.623 and 2/G.623 given in the introduction to § 6.2.

1.1 *Electrical characteristics of the coaxial pair*

1.1.1 *Characteristic impedance*

The characteristic impedance of the coaxial pair follows a well-defined law depending on frequency given by:

$$Z = 74.4 \left[1 + \frac{0.0123}{\sqrt{f}} (1 - \mathrm{j}) \right] \Omega$$

where f is the frequency measured in MHz[1]. There is therefore no point in specifying values at all frequencies.

The figure of 74.4 Ω (impedance at infinite frequency) is subject to a tolerance of ± 1 Ω.

1.1.2 *Attenuation coefficient*

The nominal attenuation coefficient of the coaxial pair at a frequency of 60 MHz and a temperature of 10 °C should be within the limits of 18.00 ± 0.3 dB/km[2].

The rate of the variation of the attenuation with frequency, for a nominal value of 18.00 dB/km at 60 MHz, is indicated in Table 1/G.623.

[1] This formula is equivalent to $Z = 74.4 + (0.92/\sqrt{f}\,)\,(1 - \mathrm{j})\ \Omega$. If this latter formula is used, a correcting factor should be applied to the tolerance indicated in the text.

[2] For internal reasons, some Administrations considered it advantageous to use pairs of larger dimensions, with smaller attenuation, making it possible to use longer repeater sections (2 km). Cables manufactured by assembly of these pairs may be regarded as meeting the requirements of this Recommendation for 60-MHz systems provided the electrical characteristics of the repeater sections built up with these cables comply with this Recommendation and provided the line equipments are exactly the same as those used with the cables referred to in this Recommendation. The French Administration's 3.7/13.5-mm pairs described in [1] fall within this category.

TABLE 1/G.623

Nominal attenuation coefficient at various frequencies

Frequency (MHz)	0.06	0.3	1	4	12	20	40	60	150	300
Attenuation (dB/km)	0.59	1.27	2.32	4.62	8.01	10.35	14.67	18.00	28.6	40.7

The following equation, in which α is expressed in dB/km and f in MHz, gives an approximaion of the attenuation coefficient from 1 MHz onwards:

$$\alpha = 0.01 + 2.3 \sqrt{f} + 0.003 f$$

Note – In designing amplifiers, the values measured on the cable to be used must be taken as reference.

1.1.3 *Attenuation coefficient tolerances – Attenuation distortion*

To guarantee proper adaptation between the coaxial pair and the transmission equipment, in addition to the tolerances at frequency 60 MHz, set at ± 0.3 dB/km, it is also necessary to establish the limits of attenuation distortion according to frequency.

Table 2/G.623 gives the nominal values and tolerances of the quantity δ_f (in mB · km^{-1} · MHz$^{-1/2}$)

$$\delta_f = \frac{\alpha_{60}}{\sqrt{60}} - \frac{\alpha_f}{\sqrt{f}}$$

at various frequencies (f in MHz).

TABLE 2/G.623

Nominal values and tolerances of the quantity δ_f characterizing attenuation distortion at various frequencies

Frequency (MHz)	4	12	20	40	60
Nominal value	1.1	1	0.8	0.4	0
Tolerances	±1.5	±1.1	±0.8	±0.4	±0

To check the attenuation distortion beyond 60 MHz, which is necessary in particular for digital transmission, it is necessary to calculate the ratio between the attenuation values measured at the frequencies of 240 MHz and 60 MHz (after eliminating any peaks). The limit to be observed is:

$$\frac{\alpha_{240\text{ MHz}}}{\alpha_{60\text{ MHz}}} \leqslant 2.045$$

The attenuation distortion is checked in the factory on a small percentage of factory lengths.

1.2 *Mechanical construction of coaxial pairs*

a) The inner conductor is a solid copper wire 2.6 mm in diameter.

b) The insulation is such that the permittivity of the combination of gas and low-loss solid dielectric material is low enough to meet the requirements of this specification.

c) The outer conductor consists of a copper tape 0.25-mm thick formed into a cylinder of internal diameter 9.5 mm around the insulation.

d) For reasons of crosstalk, the outer conductor should be surrounded by soft steel tapes.

Another form of construction having the same electrical characteristics but with an inner copper conductor of 2.8-mm diameter and an aluminium outer conductor of 10.2-mm internal diameter is used by some Administrations. This type of construction is described in detail in Annex A.

2 Cable specification

2.1 *Characteristic impedance*

To check that the value given in § 1.1.1 above is met, either sine-wave signal measurements or pulse measurements can be made.

For sine-wave signal measurements, the check is often made in terms of the smooth impedance/frequency curve.

For pulse measurements, a sine-squared pulse having a half-amplitude duration of less than 100 ns should be used. One may either balance the impedance against a variable reference impedance or measure the reflection coefficient against a fixed reference standard.

2.2 *Impedance regularity*

Routine control measurements of impedance regularity are carried out by means of pulse echometers from one or both ends of the factory lengths. The echo curve should be plotted with correction in amplitude and if possible in amplitude and phase. If the equivalent error is measured, it must be corrected. However, for routine measurements, correction may be dispensed with if the test length is so short that the correction is small.

Table 3/G.623 shows the various values to be obtained, according to the purpose for which the cable is intended.

Note 1 – For 0.06-6 MHz analogue systems, the provisions are the same as for 0.3-20 MHz analogue systems.

Note 2 – To detect systematic irregularities, return wave attenuation measurements should be carried out on a small proportion of fabricator lengths. The limits to be observed are given in Table 4/G.623.

Note 3 – The percentage figures given in the tables relate to all the pairs of a batch of cables submitted for control or delivered at the same time.

TABLE 3/G.623

Echometric measurement of factory lengths

<table>
<tr><td colspan="4">Type of system</td><td colspan="2">Analogue</td><td colspan="2">Digital</td></tr>
<tr><td colspan="4">Frequency range or bit rate</td><td>0.3-20 MHz</td><td>4-70 MHz</td><td>Hight bit rate (140 Mbit/s)</td><td>Very high bit rate (565 Mbit/s)</td></tr>
<tr><td colspan="4">Maximum pulse duration</td><td>50 ns</td><td>10 ns</td><td>10 ns</td><td>10 ns [a)]</td></tr>
<tr><td rowspan="2">General provisions</td><td rowspan="2" colspan="2">Maximum peak</td><td>100%</td><td>50 dB</td><td>48 dB</td><td>48 dB</td><td></td></tr>
<tr><td>95%</td><td>56 dB</td><td>54 dB [b)]</td><td>54 dB [b)]</td><td></td></tr>
<tr><td rowspan="2">Additional optional provisions [c)]</td><td>A</td><td colspan="2">Mean of 3 maximum peaks</td><td>53 dB</td><td>51 dB</td><td>51 dB</td><td></td></tr>
<tr><td>B</td><td>Equivalent resistance error</td><td>$L < 300$ m
$300 \leq L \leq 500$ m
$L > 500$ m</td><td>0.6 Ω
0.8 Ω
0.8 Ω</td><td>1 Ω
1.2 Ω
1.6 Ω</td><td>1 Ω
1.2 Ω
1.6 Ω</td><td></td></tr>
</table>

TABLE 4/G.623

Measurement of factory lengths using sine-wave signals

Type of system		Analogue		Digital	
Frequency range or bite rate		0.3-20 MHz	4-70 MHz	High [d]	Very high
Return wave attenuation on irregularities					
Percentage of lengths concerned		none	about 5%	about 5%	about 5%
Frequency band explored			4-62 MHz	20-100 MHz	62-500 MHz
Minimum measured value	100%		35 dB	30 dB	20 dB
	95%		38 dB		
Mean return power in a 10-MHz band (Transmission of television signals in the 60-MHz system)					
Frequency band concerned		None	52-62 MHz		
Mean power return coefficient	$L \approx 250$ m		41 dB	35 dB	28 dB
	$L > 500$ m		40 dB		

Notes to Tables 3/G.623 and 4/G.623

[a] If investigations or definition studies show that measurements with shorter pulse durations are required, the duration of 2 ns will be adopted.

[b] Provided that no more than one value between 48-54 dB is encountered on one and the same coaxial pair of an elementary cable section.

[c] It is enough to check that one of the two conditions A or B is fulfilled.

[d] The provisions for 4-70 MHz analogue systems are certainly adequate. However, much lower values have also been proposed. Agreement should be reached on the values to be specified and the frequency band to be explored (4-100 MHz or 62-500 MHz).

2.3 *Attenuation coefficient*

The attenuation of pairs should be such as to allow of compliance with the provisions of § 3.3 below[3].

If reference is made to the length measured along a generation of the cable sheath, the linear attenuation coefficient should be multiplied by the take-up factor, the values of which are given as an indication in Table 5/G.623.

TABLE 5/G.623

Take-up factor values

Number of pairs in cable	Take-up factor, last layer	Weighted take-up factor, entire cable
4 or 6		1.003
8		1.005
12	1.009	1.007
18 or 20	1.012	1.010

2.4 *Crosstalk*

The crosstalk between pairs should be such as to allow of compliance with provisions of § 3.4 below[3].

2.5 *Dielectric strength*

The pair should withstand for one minute an a.c. voltage of 2000 V r.m.s. at 50 Hz (or 3000 V d.c.) applied between the centre conductor and the outer conductor connected to the sheath. This dielectric strength test should be made on each factory length.

2.6 *Insulation resistance*

The insulation resistance between the centre and outer conductors of the coaxial pair, measured with a perfectly steady voltage of between 100 and 500 V, should not be less than 5000 MΩ-km after electrification for one minute at a temperature not lower than 15 °C. The measurement of the insulation resistance should be made after the dielectric strength test. This measurement should be made on each factory length.

3 Elementary cable section specification

The Administration and the supplier must agree on whether tests are to be carried out on all sections or whether some percentage or even a type-approval test alone will be sufficient, especially in the case of measurements which are difficult to carry out under field conditions.

3.1 *End impedance*

The conditions described in §§ 1.1.1 and 2.1 above are applicable.

[3] At this stage of manufacture, attenuation and crosstalk measurements are merely prototype measurements.

3.2 *Impedance regularity*

Impedance regularity measurements are carried out from each end of the elementary cable section. Reference should be made to one of the columns in Table 6/G.623, according to the purpose for which the cable is intended.

Note 1 – Notes 1 and 3 to § 2.2 in connection with Table 3/G.623 still hold good. However, for 0.06-6 MHz analogue systems, the provisions of column 0.3-20 MHz apply, but the pulse duration may attain 200 ns for elementary cable sections longer than 5 km.

Note 2 – Measurements using sine-wave signals on elementary cable sections are unnecessary unless there are serious grounds for believing that systematic irregularities may have been introduced during the laying or installation of the cable. In such cases, the measurement results should not be less than 33 dB for the 4-62 MHz band.

3.3 *Attenuation coefficient*

For a cable of any given manufacture with a nominal attenuation coefficient defined by the limits given in § 1.1.2 above, the difference between the maximum and minimum attenuation coefficient values measured at 60 MHz on the coaxial pairs of all elementary sections of 1.5 km must be below 0.4 dB/km (referred to 10 °C).

Attenuation measured on a cable at an average temperature of t °C is referred to 10 °C by the formula:

$$\alpha_{10} = \alpha_t \frac{1}{1 + k_\alpha (t - 10)}$$

TABLE 6/G.623

Echometric measurement of elementary cable sections

Type of system				Analogue		Digital	
Type of system				0.3-20 MHz	4-70 MHz	High bit rate (140 Mbit/s)	Very high bit rate (565 Mbit/s)
Maximum pulse duration				50 ns	10 ns	10 ns [c]	10 ns [a]
General provisions	Maximum peak	100%		50 dB	46 dB	46 dB	46 dB
		95%			50 dB	50 dB	50 dB
Additional optional provisions [b]		A	Mean of 3 maximum peaks.	51 dB	49 dB	49 dB	49 dB
		A	Uncorrected maximum	54 dB	52 dB	52 dB	52 dB
	Equivalent resistance error	B	Energy corrected ($\Omega \cdot km^{-1/2}$)	0.8	2	2	2
		C	Uncorrected (Ω)	1	1.5	1.5	1.5

a) If investigations or definition studies show that measurements with shorter pulse durations are required, the duration of 2 ns will be adopted.

b) It is enough to check that one of the three conditions A, B or C is fulfilled.

c) As long as there does not exist an echometer with impulses of 10 ns capable to explore half a repeater section, the measurement will be done with 50 ns impulses.

3.4 *Crosstalk*

The far-end crosstalk ratio between two coaxial pairs of a cable at any frequency in the band transmitted should be at least equal to the values listed in Table 7/G.623.

TABLE 7/G.623

Lengths (km)	Frequency band (MHz)	Far-end crosstalk radio (dB)
9	0.06-4.3	85
4.5	0.3-12.5	94 [a)]
1.5	4-62	130

a) If the cable operates both in the 0.3-12 MHz frequency band and the lower frequency band with longer repeater sections, the value of the far-end crosstalk should be increased by a few decibels to frequencies higher than 300 kHz to allow for the differences in levels across some points of the cable. A limit of 100 dB suffices.

With cables operating at 60 MHz, the near-end crosstalk attenuation at 60 MHz between pairs transmitted in opposite directions should be at least 140 dB. No limit is fixed for other systems, previous studies having shown that the near-end crosstalk ratio under service conditions was greater than the far-end crosstalk ratio. These values include the contribution of accessories which are associated to elementary cable section, such as flexible cords and coaxial connector.

Note 1 – The values given for cables operating at 60 MHz are derived from general considerations on crosstalk between sound-programme circuits given in Recommendation J.18 [2]. These values are easy to obtain, although in the present state of the art it is difficult to test them with ordinary measuring equipments.

Note 2 – The values given for cables operating at 12 MHz or less suffice for telephone transmission. For sound-programme circuit transmission, this value must be increased to 105 dB, a value which is easily obtained with all types of cable at frequencies above 300 kHz.

Note 3 – These limits enable at far-end crosstalk ratio of 65 dB to be obtained on the worst homogeneous 280-km section, assuming that for the frequencies in question only far-end crosstalk due to the cable is to be considered[4)]. When there is no phase inversion, it is assumed that the variation in the minimum far-end crosstalk ratio as a function of the distance approximately follows a 20 dB/decade law for distances below a limit distance L_1 and a 10 dB/decade law for distances above L_1. The value of L_1 depends on a number of factors, mainly the system used, the type of cable and the considered frequency. A value of 30 km appears suitable in most cases, although values of L_1 ranging from a few kilometers to 30 kilometres have been observed in practice, ensuring the consistency of the limits in Table 7/G.623 with a 65 dB limit on a 280 km section.

3.5 *Dielectric strength*

The pair should withstand for one minute a d.c. voltage of 2000 V applied between the centre conductor and the outer conductor connected to the sheath. This dielectric strength test should be made on each elementary cable section on completion of laying.

3.6 *Insulation resistance*

The insulation resistance between the centre and outer conductors of the coaxial pair, measured with a perfectly steady voltage of between 100 and 500 V, should not be less than 5000 MΩ-km after electrification for one minute; the measurement of the insulation resistance should be made after the dielectric strength test. This measurement should be made on every section.

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4) In practice, it is possible to forget the influence of line equipments on intelligible crosstalk, but this is only true for low frequencies of the band (less than 300 kHz).

ANNEX A

(to Recommendation G.623)

Description of a copper-aluminium coaxial pair having the same electrical characteristics as the 2.6/9.5-mm copper coaxial pair

The constitution of this copper-aluminium coaxial pair is as follows:

- The centre conductor is a solid copper wire 2.8 mm in diameter.
- The insulation is such that the permittivity of the combination of gas and low-loss solid dielectric material is low enough to meet the requirements of this Recommendation.
- The outer conductor consists of an aluminium tape 0.7-mm thick formed into a cylinder of internal diameter 10.2 mm around the insulation and welded longitudinally.

Such coaxial pairs can be jointed with each other or with 2.6/9.5-mm copper pairs easily and reliably. They meet with all the electrical characteristics of this Recommendation. In particular, the values of far-end crosstalk of § 3.4 of the text are obtained between pairs transmitting in the same direction.

References

[1] Annex 2 to CCITT Question 17/XV, Green Book, Vol. III.3, ITU, Geneva, 1973.

[2] CCITT Recommendation *Crosstalk in sound-programme circuits set up on carrier systems*, Vol. III, Rec. J.18.

6.3 Submarine cables

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)

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.

TABLE 1/G.631

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

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 ± 6% (±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 · km 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 · km in the 850 nm region and 2000 MHz · km 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:

Wavelength (nm)	Chromatic dispersion coefficient [ps/(nm · km)]
850	⩽ 120
1300	⩽ 6

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

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

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:

$$B_T = \left[B_{\text{modal}}^{-2} + B_{\text{chromatic}}^{-2} \right]^{-\frac{1}{2}}$$

where

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

B_{modal} = modal distortion bandwidth,

$B_{\text{chromatic}}$ = 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:

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

where

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

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

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:

$$B_{modal_{total}} = \left\{ \sum_{1}^{x} B_{modal_n}^{\frac{-1}{\gamma}} \right\}^{-\gamma}$$

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

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

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 · km).

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.

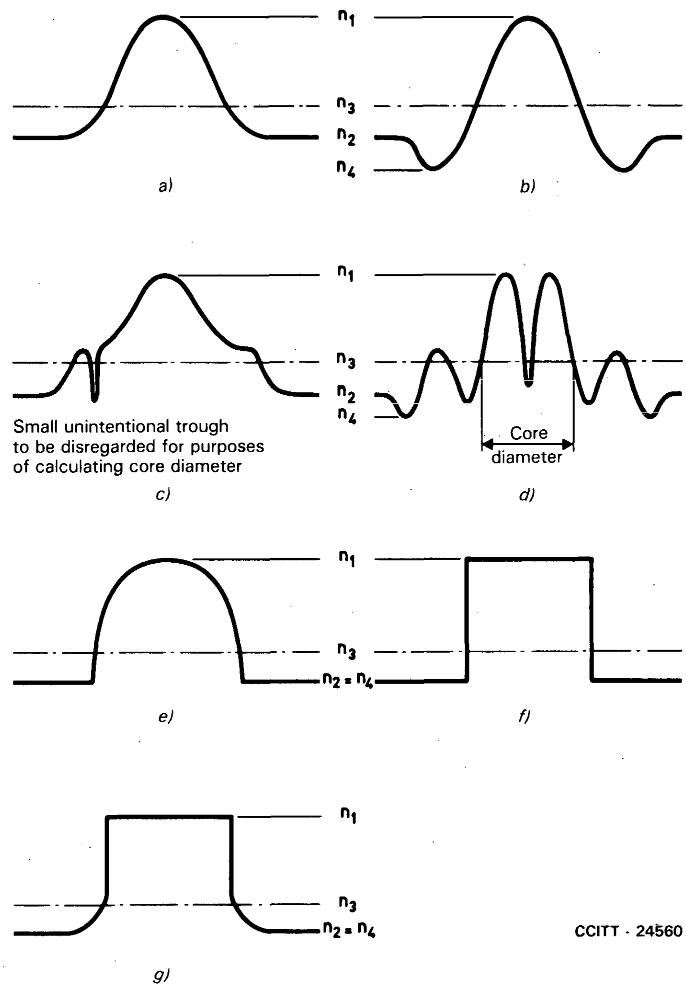


FIGURE A-1/G.651

Some refractive index profiles

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:

$$NA_{t\,\max} = (n_1^2 - n_2^2)^{\frac{1}{2}}$$

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 $NA_{t\,\max}$ 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*

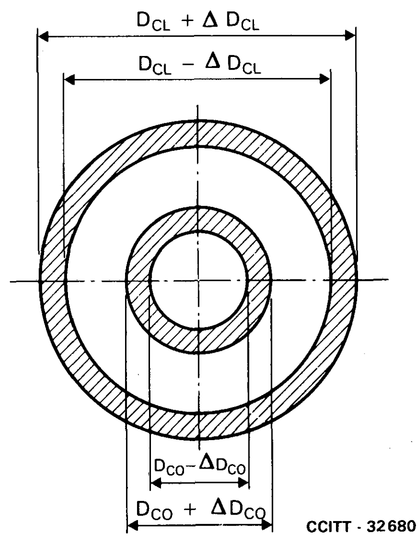
It is assumed that the geometrical and optical parameters, which are the subject of this Recommendation, would be measured only in the factory or in the laboratories of certain Administrations wishing to verify these parameters for system design or other purposes. Hence, it is anticipated that the measurements 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" method. This does not constitute an additional requirement on the fibre 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_{co}) have diameters respectively of $D_{co} - 4$ µm and $D_{co} + 4$ µm and the two concentric circles concerning the cladding (whose diameter is D_{CL}) have diameters respectively of $D_{CL} - 5$ µm and $D_{CL} + 5$ 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).



D_{CO} Nominal core diameter

ΔD_{CO} Tolerance of the circle concerning the core = 4 μm

D_{CL} Nominal cladding diameter

ΔCL_G Tolerance of the circle concerning the cladding = 5 μm

FIGURE B-1/G.651

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_{00} 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,
   v) core diameter [1]
   vi) cladding diameter [1]
   vii) core/cladding concentricity error,
   viii) core non-circularity,

---

[1] See Appendix I.

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).

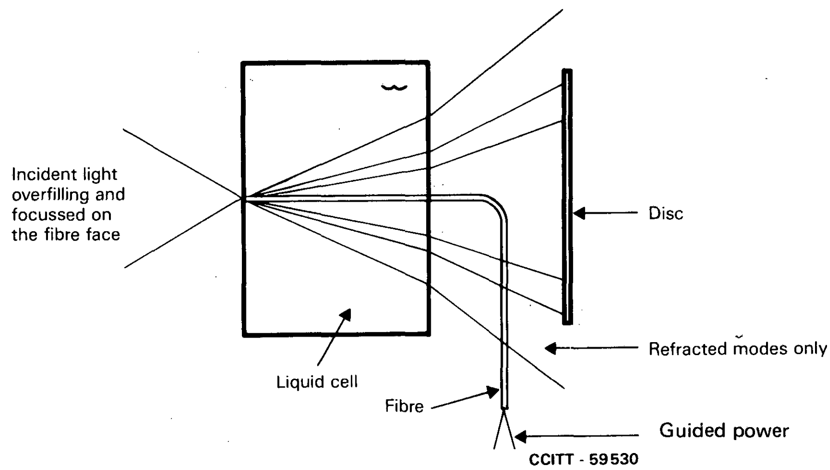


FIGURE B-2a/G.651

Refracted near-field technique – Schematic diagram

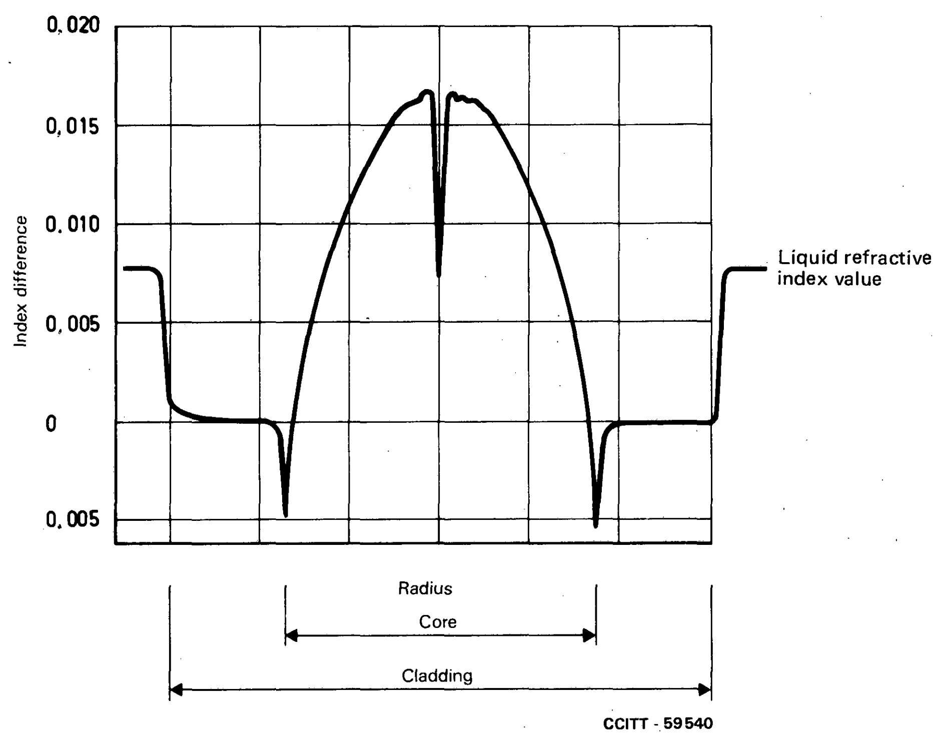


FIGURE B-2b/G.651

Typical index profile of a graded index fibre obtained by the refracted near-field technique

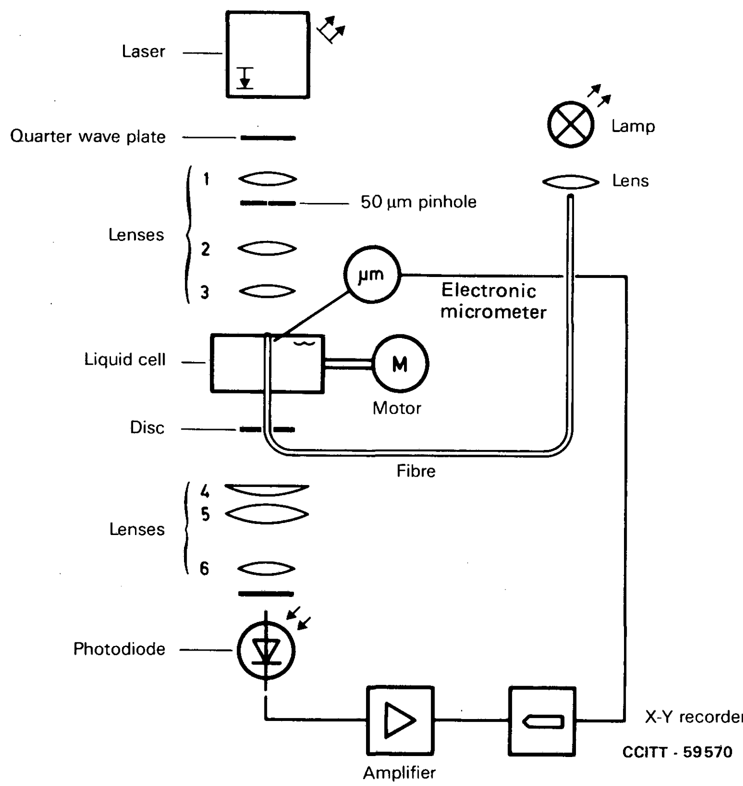


FIGURE B-3/G.651

Typical arrangement of the refracted near-field test set-up

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,[2] non-circularities of the core and of the cladding, core/cladding concentricity error, etc.

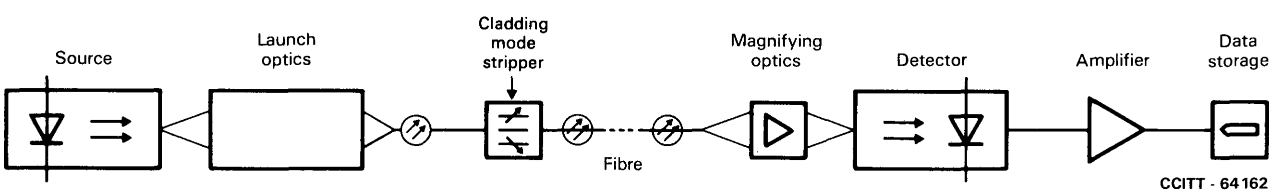


FIGURE B-4/G.651

Typical arrangement of the near-field test set-up

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.

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[2] See Appendix I.

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.

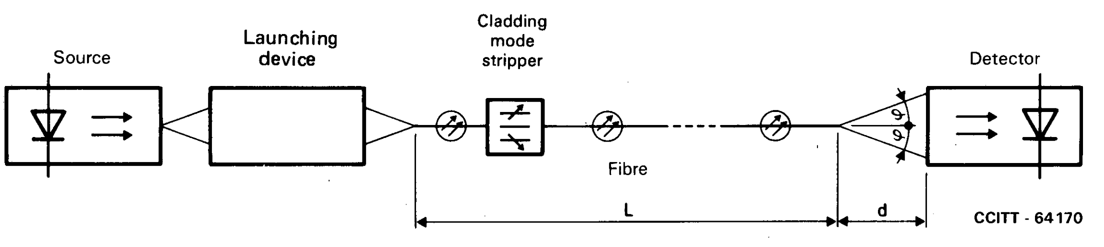


FIGURE B-5/G.651

Principle of measurement for far field distribution

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:

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

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

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

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:

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

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

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:

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

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:

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

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.

$$\alpha(\lambda) = \frac{A(\lambda)}{L} \left[\frac{\text{dB}}{\text{unit length}}\right]$$

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 °C to +35 °C).

B.1.3 *Description*

Three methods have been suggested for attenuation measurements.

B.1.3.1 *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 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* is 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* is 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.

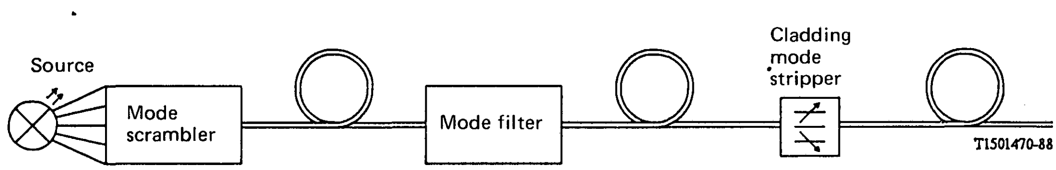


FIGURE B-6/G.651

Generic launching conditions

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.

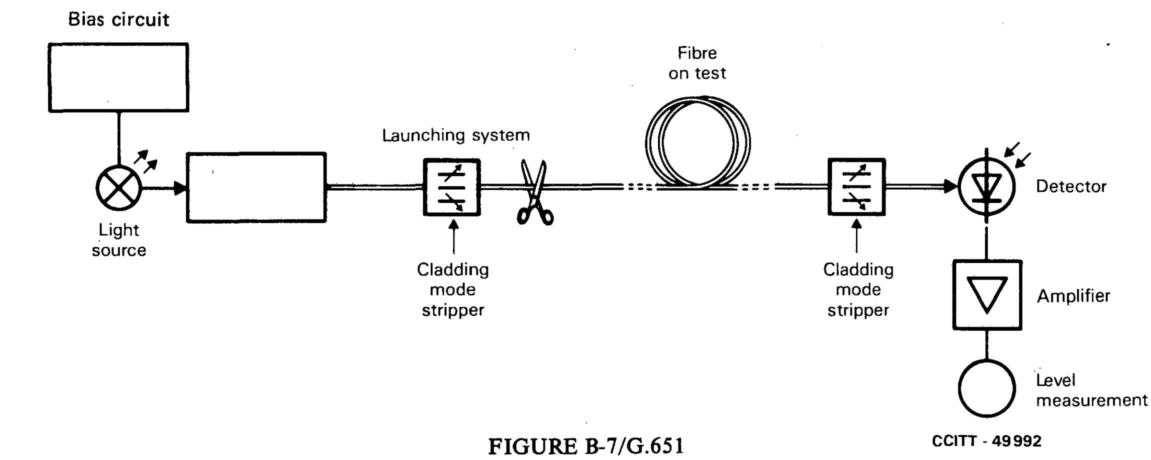
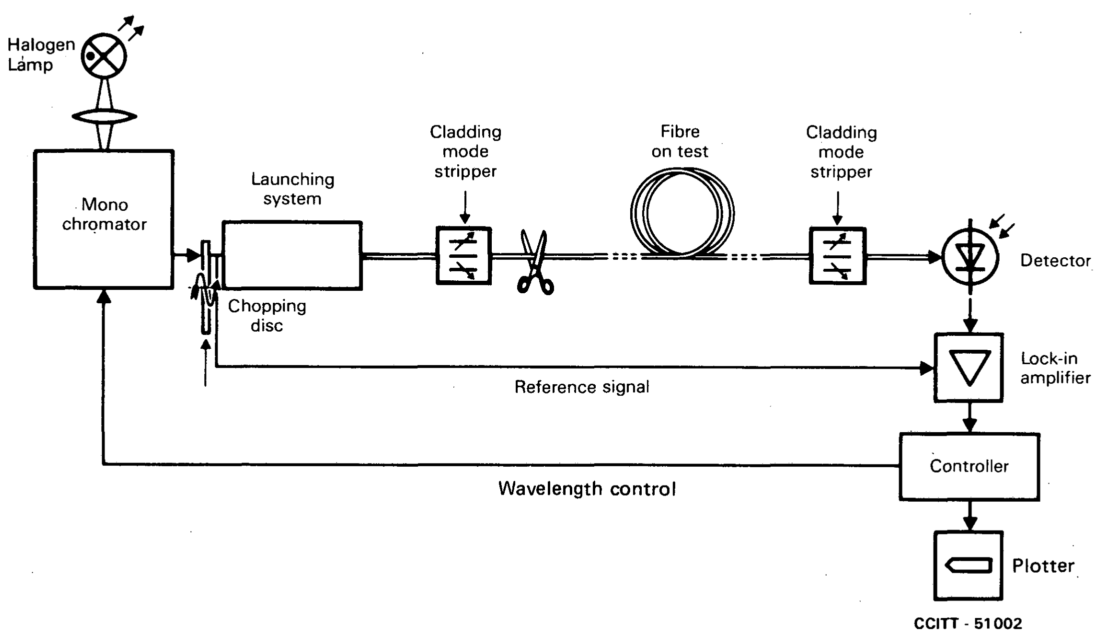


FIGURE B-7/G.651

Arrangement of test equipment to make spot loss measurement



Arrangement of test equipment used to obtain the loss spectrum

FIGURE B-8/G.651

The cutback technique

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.

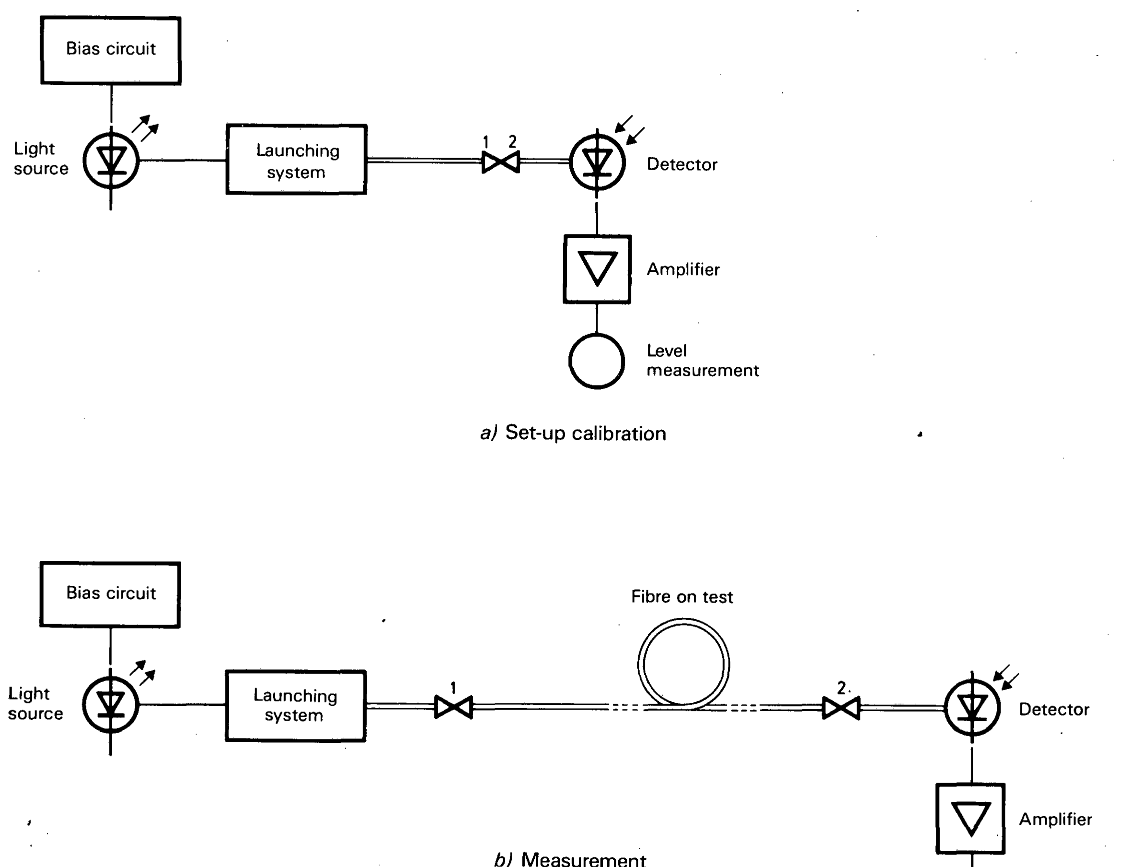


FIGURE B-9/G.651

The insertion loss technique

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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

$$\underset{A \to B}{A(\lambda)} = \frac{1}{2} \left(V_A - V_B \right) \qquad \text{dB}$$

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.

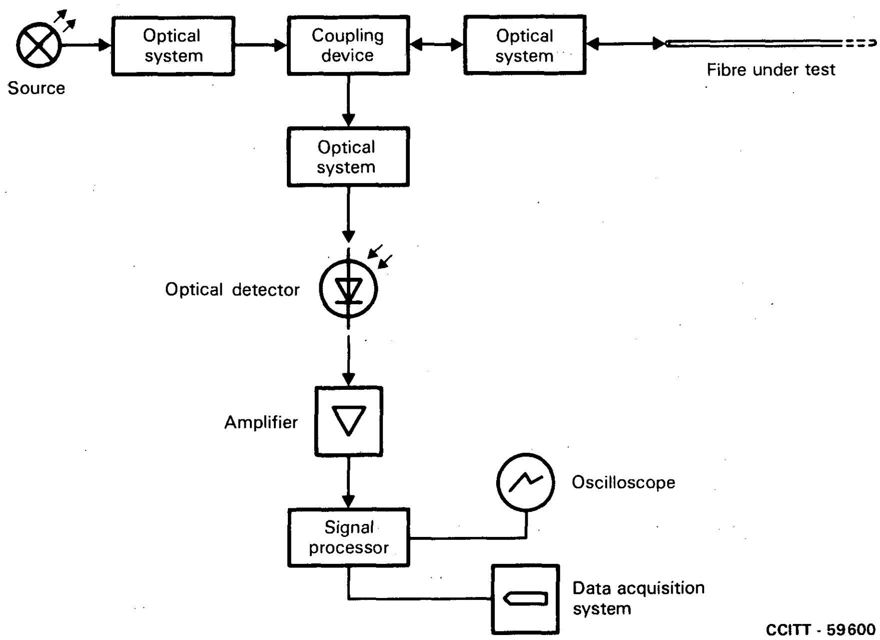
B.4.3 *Presentation of results*

The following details shall be presented:

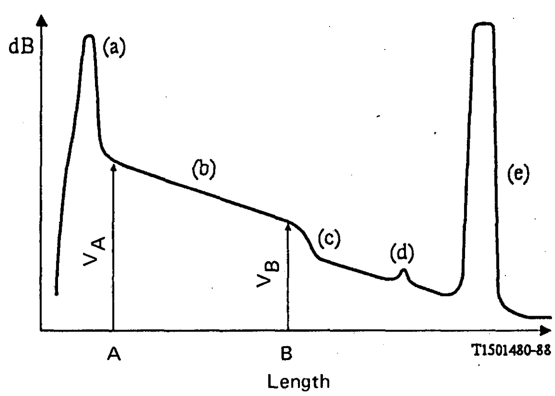
a) Measurement types and characteristics.
b) Launching techniques.
c) Test set-up arrangement.
d) Temperature of the sample and environmental conditions (if necessary).
e) Fibre identification.
f) Length of sample.
g) Rise time, width and repetition rate of the pulse.
h) Kind of signal processing used.
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.



a) Scheme of apparatus



b) Example of a backscattered power curve

FIGURE B-10/G.651

The backscattering technique

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.

TABLE B-1/G.651

Source line width

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

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.

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

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.

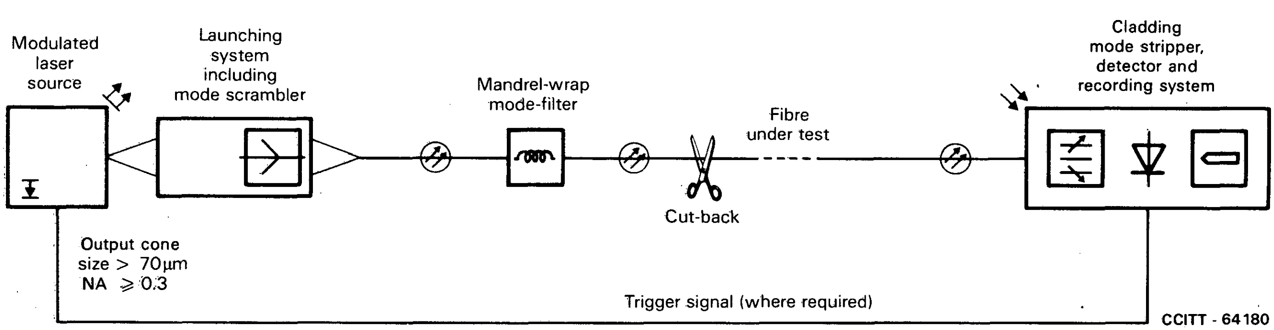


FIGURE B-11/G.651

Typical arrangement of test set-up

Recommendation G.652

CHARACTERISTICS OF A SINGLE-MODE OPTICAL FIBRE CABLE

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

The CCITT,

considering

(a) that single-mode optical fibre cables are widely used in telecommunication networks;

(b) that the foreseen potential applications may require several kinds of single-mode fibres differing in:

- geometrical characteristics;
- operating wavelength;
- attenuation dispersion, cut-off wavelength, and other optical characteristics;
- mechanical and environmental aspects;

(c) that recommendations on different kinds of single-mode fibres can be prepared when practical use studies have sufficiently progressed,

recommends

a single-mode fibre which has the zero-dispersion wavelength around 1300 nm and which is optimized for use in the 1300 nm wavelength region, and which can also be used in the 1550 nm wavelength region (where this fibre is not optimized).

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

The geometrical, optical and transmission characteristics of this fibre are described below, together with applicable test methods.

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 single-mode fibre Recommendations are agreed upon.

1 Fibre characteristics

Only those characteristics of the fibre providing a minimum essential design framework for fibre manufacture are recommended in § 1. Of these, the cable fibre cut-off wavelength may be significantly affected by cable manufacture or installation. Otherwise, the recommended characteristics will apply equally to individual fibres, fibres incorporated into a cable wound on a drum, and fibres in installed cable.

This Recommendation applies to fibres having a nominally circular mode field.

1.1 *Mode field diameter*

The nominal value of the mode field diameter at 1300 nm shall lie within the range 9 to 10 μm. The mode field diameter deviation should not exceed the limits of ± 10% of the nominal value.

Note 1 – A value of 10 μm is commonly employed for matched cladding designs, and a value of 9 μm is commonly employed for depressed cladding designs. However, the choice of a specific value within the above range is not necessarily associated with a specific fibre design.

Note 2 – It should be noted that the fibre performance required for any given application is a function of essential fibre and systems parameters, i.e., mode field diameters, cut-off wavelength, total dispersion, systems operating wavelength, and bit rate/frequency of operation, and not primarily of the fibre design.

Note 3 – The mean value of the mode field diameter, in fact, may differ from the above nominal values provided that all fibres fall within ± 10% of the specified nominal value.

1.2 *Cladding diameter*

The recommended nominal value of the cladding diameter is 125 μm. The cladding deviation should not exceed the limits of ± 2.4%.

For some particular jointing techniques and joint loss requirements, other tolerances may be appropriate.

1.3 *Mode field concentricity error*

The recommended mode field concentricity error at 1300 nm should not exceed 1 μm.

Note 1 – For some particular jointing techniques and joint loss requirements, tolerances up to 3 μm may be appropriate.

Note 2 – The mode field concentricity error and the concentricity error of the core represented by the transmitted illumination using wavelengths different from 1300 nm (including white light) are equivalent. In general, the deviation of the centre of the refractive index profile and the cladding axis also represents the mode field concentricity error but, if any inconsistency appears between the mode field concentricity error, measured according to the reference test method (RTM), and the core concentricity error, the former will constitute the reference.

1.4 *Non-circularity*

1.4.1 *Mode field non-circularity*

In practice, the mode field non-circularity of fibres having nominally circular mode fields is found to be sufficiently low that propagation and jointing are not affected. It is therefore not considered necessary to recommend a particular value for the mode field non-circularity. It is not normally necessary to measure the mode field non-circularity for acceptance purposes.

1.4.2 *Cladding non-circularity*

The cladding non-circularity should be less than 2%. For some particular jointing techniques and joint loss requirements, other tolerances may be appropriate.

1.5 *Cut-off wavelength*

Two useful types of cut-off wavelengths can be distinguished:

a) the cut-off wavelength λ_c of a primary coated fibre according to the relevant fibre RTM;

b) the cut-off wavelength λ_{cc} of a cabled fiber in a deployment condition according to the relevant cable RTM.

The correlation of the measured values of λ_c and λ_{cc} depends on the specific fibre and cable design and the test conditions. While in general $\lambda_{cc} < \lambda_c$, a quantitative relationship cannot easily be established. The importance of ensuring single-mode transmission in the minimum cable length between joints at the minimum system operating wavelength is paramount. This can be approached in two alternate ways:

1) recommending λ_c to be less than 1280 nm; when a lower limit is appropriate, λ_c should be greater than 1100 nm;

2) recommending λ_{cc} to be less than 1270 nm.

Note – A sufficient wavelength margin should be assured between the lowest-permissible system operating wavelength λ_s of 1270 nm, and the highest-permissible cable cut-off wavelength λ_{cc}. Several Administrations favour a maximum λ_{cc} of 1260 nm to allow for fibre sampling variations and source wavelength variations due to tolerance, temperature, and ageing effects.

These two specifications need not both be invoked; users may choose to specify λ_c or λ_{cc} according to their specific needs and the particular envisaged applications. In the latter case, it should be understood that λ_c may exceed 1280 nm.

In the case where the user chooses to specify λ_c as in 1), then λ_{cc} need not be measured.

In the case where the user chooses to specify λ_{cc}, it may be permitted that λ_c be higher than the minimum system operating wavelength, relying on the effects of cable fabrication and installation to yield λ_{cc} values below the minimum system operating wavelength for the shortest length of cable between two joints.

In the case where the user chooses to specify λ_{cc}, a qualification test may be sufficient to verify that the λ_{cc} requirement is being met.

1.6 *1550 nm loss performance*

In order to ensure low-loss operation of deployed 1300 nm-optimized fibres in the 1550 nm wavelength region, the loss increase of 100 turns of fibre loosely-wound with a 37.5 mm radius, and measured at 1550 nm, shall be less than 1.0 dB.

Note 1 – A qualification test may be sufficient to ensure that this requirement is being met.

Note 2 – The above value of 100 turns corresponds to the approximate number of turns deployed in all splice cases of a typical repeater span. The radius of 37.5 mm is equivalent to the minimum bend-radius widely accepted for long-term deployment of fibres in practical systems installations to avoid static-fatigue failure.

Note 3 – If for practical reasons fewer than 100 turns are chosen to implement this test, it is suggested that not less than 40 turns, and a proportionately smaller loss increase be used.

Note 4 – If bending radii smaller than 37.5 mm are planned to be used in splice cases or elsewhere in the system (for example, R = 30 mm), it is suggested that the same loss value of 1.0 dB shall apply to 100 turns of fibre deployed with this smaller radius.

Note 5 – The 1550 nm bend-loss recommendation relates to the deployment of fibres in practical single-mode fibre installations. The influence of the stranding-related bending radii of cabled single-mode fibres on the loss performance is included in the loss specification of the cabled fibre.

Note 6 – In the event that routine tests are required a small diameter loop with one or several turns can be used instead of the 100-turn test, for accuracy and measurement ease of the 1550 nm bend sensitivity. In this case, the loop diameter, number of turns, and the maximum permissible bend loss for the several-turn test, should be chosen, so as to correlate with the 1.0 dB loss recommendation of the 37.5 mm radius 100-turn functional test.

1.7 *Material properties of the fibre*

1.7.1 *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.

1.7.2 *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.

1.8 *Refractive index profile*

The refractive index profile of the fibre does not generally need to be known; if one wishes to measure it, the reference test method in Recommendation G.651 may be used.

1.9 *Examples of fibre design guidelines*

Supplement No. 33 gives an example of fibre design guidelines for matched-cladding fibres used by two organizations.

2 Factory length specifications

Since the geometrical and optical characteristics of fibres given in § 1 are barely affected by the cabling process, § 2 will give recommendations mainly relevant to transmission characteristics of cabled factory lengths.

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

2.1 *Attenuation coefficient*

Optical fibre cables covered by this Recommendation generally have attenuation coefficients in the below 1.0 dB/km in the 1300 nm wavelength region, and below 0.5 dB/km in the 1550 nm wavelength region.

Note — The lowest values depend on the fabrication process, fibre composition and design, and cable design. Values in the range 0.3-0.4 dB/km in the 1300 nm region and 0.15-0.25 dB/km in the 1550 nm region have been achieved.

2.2 *Chromatic dispersion coefficient*

The maximum chromatic dispersion coefficient shall be specified by:

– the allowed range of the zero-dispersion wavelength between λ_{omin} = 1295 nm and λ_{omax} = 1322 nm;
– the maximum value S_{omax} = 0.095 ps/(nm^2 · km) of the zero-dispersion slope.

The chromatic dispersion coefficient limits for any wavelength λ within the range 1270-1340 nm shall be calculated as

$$D_1(\lambda) = \frac{S_{omax}}{4}\left[\lambda - \frac{\lambda_{omin}^4}{\lambda^3}\right]$$

$$D_2(\lambda) = \frac{S_{omax}}{4}\left[\lambda - \frac{\lambda_{omax}^4}{\lambda^3}\right]$$

Note 1 — The values of λ_{omin}, λ_{omax}, and S_{omax} yield chromatic dispersion coefficient magnitudes $|D_1|$ and $|D_2|$ equal to or smaller than the maximum chromatic dispersion coefficients in the table:

Wavelength (nm)	Maximum chromatic dispersion coefficient [ps/(nm·km)]
1285 - 1330	3.5
1270 - 1340	6
1550	20

(An exception occurs at 1285 nm, where the value of $|D_2|$ is 3.67 ps/(nm · km). A smaller value would be achieved by reducing S_{omax} or λ_{omax}; this item requires further study.)

Note 2 — Use of these equations in the 1550 nm region should be approached with caution.

Note 3 – For high capacity (for example, 4 × 140 Mb/s or above) or long length systems, a narrower range of λ_{omin}, λ_{omax} may need to be specified, or if possible, a smaller value of S_{omax} be chosen.

Note 4 – It is not necessary to measure chromatic dispersion coefficient of single mode fibre on a routine basis.

3 Elementary cable sections

An elementary cable section 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 splice losses and connector losses (if applicable).

3.1 *Attenuation*

The attenuation A of an elementary cable section is given by:

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

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).

A suitable allowance should be allocated for a suitable cable margin for future modifications of cable configurations (additional splices, extra cable lengths, ageing effects, temperature variations, etc.).

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

The mean loss is used 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 *Chromatic dispersion*

The chromatic dispersion in ps 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 and system source characteristics (see § 2.2).

ANNEX A

(to Recommendation G.652)

Meaning of the terms used in the Recommendation

The terms listed in this Annex are specific for single-mode fibres. Other terms used in this Recommendation have the same meaning as given in Annex A to Recommendation G.651.

A.1 mode field diameter

The mode field diameter $2w$ is found by applying one of the following definitions. The integration limits are shown to be 0 to ∞, but it is understood that this notation implies that the integrals be truncated in the limit of increasing argument. While the maximum physical value of the argument q is $\frac{1}{\lambda}$, the integrands rapidly approach zero before this value is reached.

i) FAR-FIELD DOMAIN: In this domain theree different measurement implementations are possible:

a) FAR-FIELD SCAN: The far-field intensity distribution $F^2(q)$ is measured as a function of the far-field angle θ, and the mode field diameter (MDF) at the wavelength λ is

$$2w = \frac{2}{\pi}\left[2\,\frac{\int_0^\infty q^3F^2(q)dq}{\int_0^\infty qF^2(q)dq}\right]^{-1/2}, \text{ where } q = \frac{1}{\lambda}\sin\theta \tag{1}$$

b) KNIFE-EDGE SCAN: The knife-edge power transmission function $K(x)$ is measured as a function of knife-edge lateral offset x with the plane of the knife-edge separated by a distance D from the fibre, and the MFD is

$$2w = \frac{2}{\pi}\left[4\,\frac{\int_0^\infty K'(x)q^2dq}{\int_0^\infty K'(x)dq}\right]^{-1/2}, \text{ where } x = D\tan\theta,\ K'(x) = \frac{dK(x)}{dx} \text{ and } q = \frac{1}{\lambda}\sin\theta \tag{2}$$

c) VARIABLE APERTURE TECHNIQUE: The complementary aperture power transmission function $\alpha(x)$ is measured as a function of aperture radius x with the plane of the aperture separated by a distance D from the fibre, and the MFD is

$$2w = \frac{2}{\pi}\left[4\int_0^\infty a(x)qdq\right]^{-1/2}, \text{ where } x = D\tan\theta \text{ and } q = \frac{1}{\lambda}\sin\theta \tag{3}$$

ii) OFFSET JOINT DOMAIN: The power transmission coefficient $T(\delta)$ is measured as a function of the transverse offset δ and

$$2w = 2\left[-2\frac{T(0)}{\left[\frac{d^2T}{d\delta^2}\right]_{\delta=0}}\right]^{1/2} \tag{4}$$

iii) NEAR-FIELD DOMAIN: The near field intensity distribution $f^2(r)$ is measured as a function of the radial coordinate r and

$$2w = 2\left[2\,\frac{\int_0^\infty rf^2(r)dr}{\int_0^\infty r\left[\frac{df(r)}{dr}\right]^2dr}\right]^{1/2} \tag{5}$$

Note – The mathematical equivalence of these definitions results from transform relations between measurement results obtained by different implementation. These are summarized in Figure A-1/G.652.

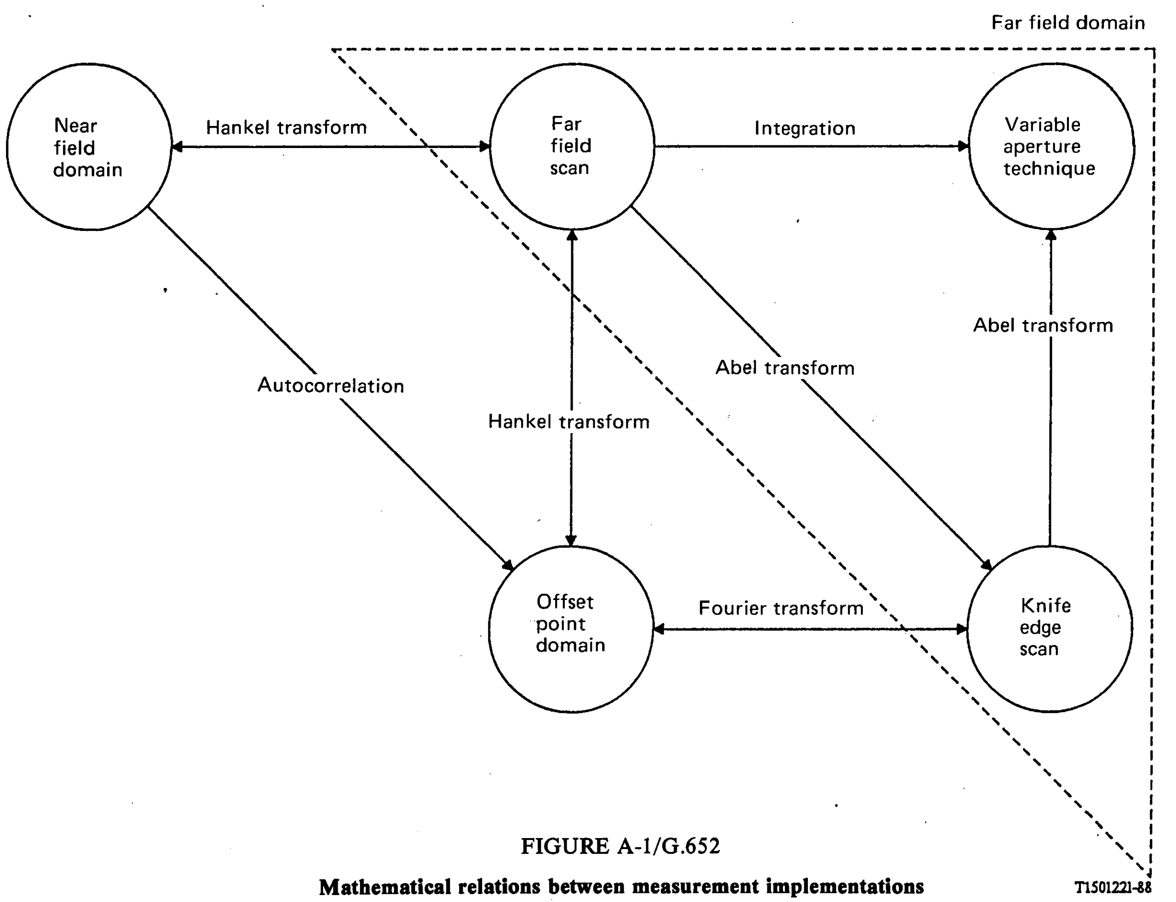


FIGURE A-1/G.652

Mathematical relations between measurement implementations

A.2 **cladding surface**

The outer surface of the glass that comprises the optical fibre.

A.3 **cladding surface centre**

For a cross-section of an optical fibre, it is the position of the centre of the circle which best fits the locus of the cladding surface in the given cross-section.

Note – The best fit method has to be specified, and is currently under study.

A.4 **cladding surface diameter**

The diameter of the circle defining the cladding centre.

Note – For a nominally circular fibre, the cladding surface diameter in any orientation of the cross-section is the largest distance across the cladding.

A.5 **non-circularity of the cladding surface**

The difference between the maximum cladding surface diameter D_{max} and minimum cladding surface diameter D_{min} (with respect to the common cladding surface centre) divided by the nominal cladding diameter, D, i.e.,

$$\textit{Non-circularity} = (D_{max} - D_{min}) / D$$

Note – The maximum and minimum cladding surface diameters are respectively the largest and smallest distances between the two intersections of a line through the cladding centre with the cladding surface.

A.6 **mode field**

The mode field is the single-mode field distribution giving rise to a spatial intensity distribution in the fibre.

A.7 **mode field centre**

The mode field centre is the position of the centroid of the spatial intensity distribution in the fibre.

Note 1 – The centroid is located at $\bar{r}_c$, and is the normalized intensity-weighted integral of the position vector $\vec{r}$.

$$\bar{r}_c = \iint_{\text{AREA}} \vec{r}\ I(\vec{r})\,\mathrm{dA} \Big/ \iint_{\text{AREA}} I(\vec{r})\,\mathrm{dA}$$

Note 2 – For fibres considered in this Recommendation, the correspondence between the position of the centroid as defined and the position of the maximum of the spatial intensity distribution requires further study.

A.8 **mode field concentricity error**

The distance between the mode field centre and the cladding surface centre.

A.9 **mode field non-circularity**

Since it is not normally necessary to measure mode field non-circularity for acceptance purposes (as stated in § 1.4.1) a definition of mode field non-circularity is not necessary in this context.

A.10 **cut-off wavelength**

The cut-off wavelength is the wavelength greater than which the ratio between the total power, including launched higher order modes, and the fundamental mode power has decreased to less than a specified value, the modes being substantially uniformly excited.

Note 1 – By definition, the specified value is chosen as 0.1 dB for a substantially straight 2 metre length of fibre including one single loop of radius 140 mm.

Note 2 – The cut-off wavelength defined in this Recommendation is generally different from the theoretical cut-off wavelength that can be computed from the refractive index profile of the fibre. The theoretical cut-off wavelength is a less useful parameter for determining fibre performance in the telecommunication network.

Note 3 – In § 1.5, two types of cut-off wavelength are described:

i) a cut-off wavelength λ_c measured in a short length of uncabled primary-coated fibre;

ii) a cut-off wavelength λ_{cc} measured in a cabled fibre in a deployment condition.

To avoid modal noise and dispersion penalties, the cut-off wavelength λ_{cc} of the shortest cable length (including repair lengths when present) should be less than the lowest anticipated system wavelength, λ_s:

$$\lambda_{cc} < \lambda_s \tag{1}$$

This ensures that each individual cable section is sufficiently single mode. Any joint that is not perfect will create some higher order (LP_{11}) mode power and single mode fibres typically support this mode for a short distance (of the order of metres, depending on the deployment conditions). A minimum distance must therefore be specified between joints, in order to give the fibre sufficient distance to attenuate the LP_{11} mode before it reaches the next joint. If inequality (1) is satisfied in the shortest cable section, it will be satisfied *a fortiori* in all longer cable sections, and single mode system operation will occur regardless of the elementary cable section length.

Specifying $\lambda_{cc} < \lambda_s$ for the shortest cable length (including loops in the splice enclosure) ensures single mode operation. It is frequently more convenient, however, to measure λ_c, which requires only a two-metre length of uncabled fibre. λ_c depends on the fibre type, length, and bend radius, and λ_{cc}, in addition, depends on the structure of a particular cable. The relationship between λ_c and λ_{cc}, therefore, is dependent on both the fibre and cable designs. In general, λ_c is several tens of nm larger than λ_{cc}; λ_c can even be larger than the system wavelength, without violating inequality (1). Higher values of λ_c produce tighter confinement of the LP_{01} mode and, therefore, help to reduce potential bending losses in the 1550 nm wavelength region.

Short fibre lenghts (<20m) are frequently attached to sources and detectors, and are also used as jumpers for interconnections. The cut-off wavelength of these fibres, as deployed, should also be less than λ_s. Among the means of avoiding modal noise in this case are:

a) selecting only fibres with sufficiently low λ_c for such uses;

b) deployment of such fibres with small radius bends.

A.11 **chromatic dispersion**

The spreading of a light pulse per unit source spectrum width 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 the following contributions: material dispersion, waveguide dispersion, profile dispersion. Polarization dispersion does not give appreciable effects in circularly-symmetric fibres.

A.12 **chromatic dispersion coefficient**

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

A.13 **zero-dispersion slope**

The slope of the chromatic dispersion coefficient versus wavelength curve at the zero-dispersion wavelength.

A.14 **zero-dispersion wavelength**

That wavelength at which the chromatic dispersion vanishes.

ANNEX B

(to Recommendation G.652)

Test methods for single-mode fibres

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(s) 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.

B.1 – Section I – *Test methods for the mode field diameter of single-mode fibres*

B.1.1 *Reference test method for the mode field diameter of single-mode fibres*

B.1.1 *Objective*

The mode field diameter may be determined in the far-field domain from the far field intensity distribution, $F^2(q)$, from the knife-edge transmission function, $K(x)$, or from the complementary aperture power transmission function, $\alpha\,(x)$; in the offset join domain from the square of the autocorrelation function, $T(\delta)$; in the near-field domain from the near-field intensity distribution, $f^2(r)$; according to the equivalent definitions shown in § A.1 in Annex A to Recommendation G.652.

B.1.1.2 *Test apparatus*

B.1.1.2.1 *General*

For near-field measurements, the magnifying optics are required to create an image of the output end of the fibre in the plane of the detector. For offset joint measurements a means of traversing one fibre end face across another is required. For the three far-field measurements, appropriate scanning devices are required.

B.1.1.2.2 *Light source*

The light source shall be stable in position, intensity and wavelength over a time period sufficiently long to complete the measurement procedure. The spectral characteristics of the source should be chosen to preclude multimode operation.

B.1.1.2.3 *Modulation*

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 to the source modulation frequency. The detecting system should have substantially linear sensitivity characteristics.

B.1.1.2.4 *Launching conditions*

The launching conditions used must be sufficient to excite the fundamental (LP_{01}) mode. For example, suitable launching techniques could be:

a) jointing with a fibre,

b) launching with a suitable system of optics.

Care should be taken that higher order modes do not propagate. For this purpose it may be necessary to introduce a loop of suitable radius or another mode filter in order to remove higher order modes.

B.1.1.2.5 *Cladding mode strippers*

Precautions shall be taken to prevent the propagation and detection of cladding modes.

B.1.1.2.6 *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, if used. The fibre ends shall be clean, smooth and perpendicular to fibre axes. It is recommended that the end faces be flat and perpendicular to the fibre axes to within 1°. For the offset joint technique, the fibre will be cut into two approximately equal lengths.

B.1.1.2.7 *Offset or scan apparatus*

Due to the characteristically narrower near-field intensity distributions and wider far-field intensity distributions of G.653 fibres compared with G.652 fibres, additional precautions must be taken as detailed below.

One of the following shall be used:

I *Far-field domain*

a) *Far field scan system*

A mechanism to scan the far-field intensity distribution shall be used (for example, a scanning photodetector with pinhole aperture or a scanning pig-tailed photodetector). The scan may be either angular or linear. The detector should be at least 20 mm from the fibre end, and the detector's active area should not subtend too large an angle in the far field. This can be assured by placing the detector at a distance from the fibre end greater than $20wb/\lambda$, where $2w$ is the expected mode field diameter of the fibre to be measured, and b is the diameter of the active area of the detector. The scan half-angle should be 25° or greater. Alternatively, the scan should extend to at least -50 dB of the zero-angle intensity.

b) *Knife-edge assembly*

A mechanism to scan a knife-edge linearly in a direction orthogonal to the fibre axis and to the edge of the blade is required. Light transmitted by the knife-edge is collected and focused onto the detector. The collection optics should have a NA of 0.4 or greater.

c) *Aperture assembly*

A mechanism containing at least twelve apertures spanning the half-angle range of numerical apertures from 0.02 to 0.4 should be used. Light transmitted by the aperture is collected and focused onto the detector.

II *Offset joint domain*

Traversing joint

The joint shall be constructed such that the relative offset of the fibre axes can be adjusted. A means of measuring the offset to within 0.1 μm is recommended. The optical power transmitted through the traversing joint is measured by a detector. Particular care should be taken with regard to the precision and accuracy of the offset apparatus.

III *Near-field domain*

Near-field imaging optics

Magnifying optics (e.g., a microscope objective) shall be employed to enlarge and focus an image of the fibre near field onto the plane of a scanning detector (for example, a scanning photodetector with a pinhole aperture or a scanning pig-tailed photodetector). The numerical aperture and magnification shall be selected to be compatible with the desired spatial resolution. For calibration, the magnification of the optics should have been measured by scanning the length of a specimen whose dimensions are indepently known with sufficient accuracy.

Note – The NA of the collecting optics in I b) and I c) must be large enough not to affect the measurement results.

B.1.1.2.8 *Detector*

A suitable detector shall be used. The detector must have linear characteristics.

B.1.1.2.9 *Amplifier*

An amplifier should be employed in order to increase the signal level.

B.1.1.2.10 *Data acquisition*

The measured signal level shall be recorded and processed according to the technique used.

B.1.1.2.11 *Measurement procedure*

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 appropriate output device.

One of the following procedures should be followed.

I *Far-field domain*

a) By scanning the detector in fixed steps, the far-field intensity distribution $F^2(q)$ is measured, and the mode field diameter is calculated from § A.1, Equation (1) in Annex A.

b) The power transmitted by the knife-edge is measured as a function of knife-edge position. This function, $K(x)$, is differentiated and the mode field diameter is found from § A.1, Equation (2) in Annex A.

c) The power transmitted by each aperture, $P(x)$, is measured, and the complementary aperture transmission function, $a(x)$, is found as:

$$a(x) = 1 - \frac{P(x)}{P_{max}}$$

where P_{max} is the power transmitted by the largest aperture and x is the aperture radius. The mode field diameter is computed from § A.1, Equation (3) in Annex A.

II *Offset joint domain*

By offsetting the joint transversely in discrete steps, the power transmission coefficient $T(\delta)$, is measured, and the mode field diameter is calculated from § A.1, Equation (4) in Annex A.

III *Near-field domain*

The near field of the fibre is enlarged by the magnifying optics and focused onto the plane of the detector. The focusing shall be performed with maximum accuracy, in order to reduce dimensional errors due to the scanning of a defocused image. The near field intensity distribution, $f^2(r)$, is scanned and the mode field diameter is calculated from § A.1, Equation (5) in Annex A. Alternatively, the near field intensity distribution $f^2(r)$ may be transformed into the far field domain using a Hankel transform and the resulting transformed far field $F^2(q)$ may be used to compute the mode field diameter from § A.1, Equation (1) in Annex A.

B.1.1.2.12 *Presentation of the results*

The following details shall be presented:

a) Measurement technique used, including test set-up arrangement, dynamic range of the measurement system, processing algorithms, and a description of the imaging, offsetting, or scanning devices used.

b) If the offset joint technique is used, the employed fitting method should be indicated (including the scan angle or NA, if applicable).

c) Launching conditions.

d) Wavelength and spectral linewidth FWHM of the source.

e) Fibre identification and length.

f) Type of cladding mode stripper and filter (if applicable).

g) Magnification of the apparatus (if applicable).

h) Type and dimensions of the detector.

i) Temperature of the sample and environmental conditions (when necessary).

j) Indication of the accuracy and repeatability.

k) Mode field diameter.

Note – As with other test methods, 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, signal-to-noise ratio, etc.

B.2 – Section II – *Test methods for the geometrical characteristics excluding the mode field diameter*

B.2.1 *Reference test method: The transmitted near-field technique*

B.2.1.1 *General*

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

The measurement is based on the scanning of the magnified image(s) of the output end of the fibre under test over the cross-section(s) where the detector is placed.

B.2.1.2 *Test apparatus*

A schematic diagram of the test apparatus is shown in Figure B-1/G.652.

B.2.1.2.1 *Light source*

A nominal 1550 nm light source for illuminating the core shall be used. The light source shall be adjustable in intensity and stable in position, intensity and wavelength over a time period sufficiently long to complete the measurement procedure. The spectral characteristics of this source should be chosen to preclude multimode operation. 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.2.1.2.2 *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.

B.2.1.2.3 *Mode filter*

In the measurement, it is necessary to assure single-mode operation at the measurement wavelength. In these cases, it may be necessary to introduce a bend in order to remove the LP_{11} mode.

B.2.1.2.4 *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.2.1.2.5 *Specimen*

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

B.2.1.2.6 *Magnifying optics*

The magnifying optics shall consist of 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.

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

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

B.2.1.2.7 *Detector*

A suitable detector shall be employed which provides the point-to-point intensity of the transmitted near-field pattern(s). 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 (or shall be linearized) in behaviour over the range intensities encountered.

B.2.1.2.8 *Amplifier*

An amplifier may be employed in order to increase the signal level. The bandwidth of the amplifier shall be chosen according 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.

B.2.1.2.9 *Data acquisition*

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

B.2.1.3 *Procedure*

B.2.1.3.1 *Equipment 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.2.1.3.2 *Measurement*

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 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 defocussed image. The desired geometrical parameters are then calculated according to the definitions.

B.2.1.4 *Presentation of the results*

The following details shall be presented:

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

b) launching conditions;

c) spectral characteristics of the source(s);

d) fibre identification and length;

e) type of mode filter (if applicable);

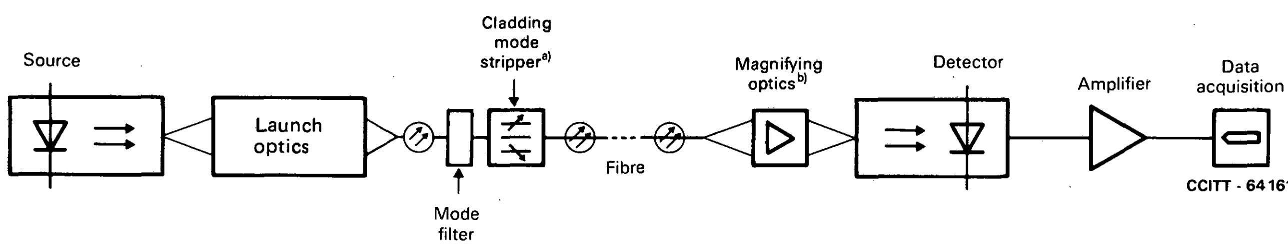
f) magnification of the magnifying optics;

g) type and dimensions of the scanning detector;

h) temperature of the sample and environmental conditions (when necessary);

i) indication of the accuracy and repeatability;

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



a) When appropriate.

b) Including image shearing optics, where appropriate.

FIGURE B-1/G.652

Typical arrangement of the transmitted near field set-up

B.2.2 *Alternative test method: the refracted near-field technique*

This technique is described in Recommendation G.651. The decision levels on the various refractive index difference interfaces are defined as:

Core/cladding	50%
Cladding/index matching fluid	50%

Geometry analyses consistent with the terms in Annex A, G.652, can be achieved by raster scanning of the input light spot.

B.2.3 *Alternative test method: the side-view method*

The validity of the side-view method for Recommendation G.653 fibres needs to be confirmed.

B.2.3.1 *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.2.3.2 *Test apparatus*

A schematic diagram of the test apparatus is shown in Figure B-2/G.652.

B.2.3.2.1 *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.2.3.2.2 *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.2.3.2.3 *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.2.3.2.4 *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.2.3.2.5 *Data processing*

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

B.2.3.3 *Procedure*

B.2.3.3.1 *Equipment 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.2.3.3.2 *Measurement*

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 $\boxed{A}$, in Figure B-2/G.652) are recorded (shown as $\boxed{B}$) 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). 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.

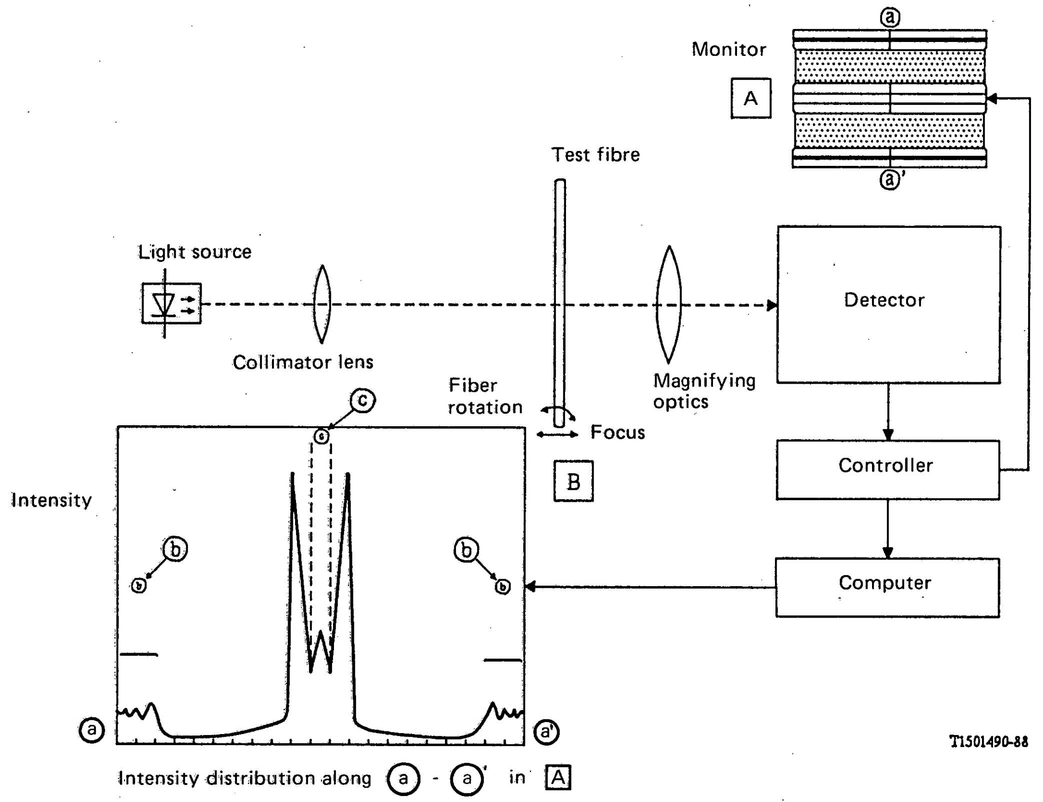


FIGURE B-2/G.652

Schematic diagram of measurement system

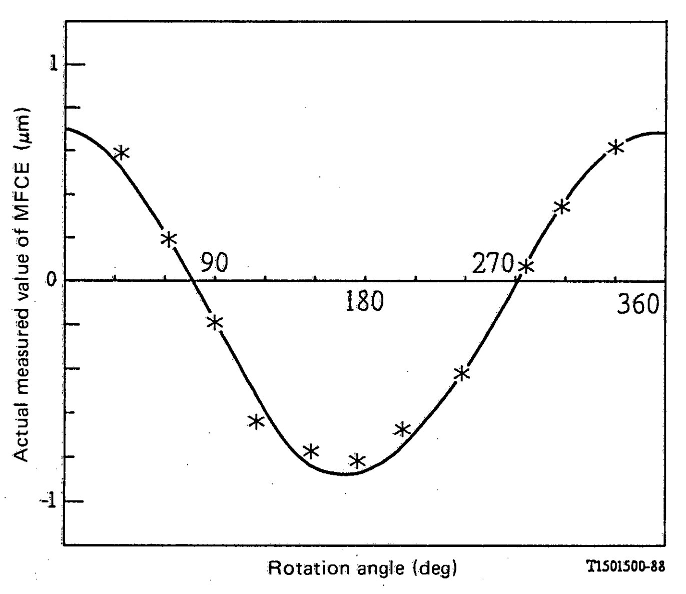


FIGURE B-3/G.652

Measured value of the MFCE as a function of rotation angle

B.2.3.3.3 *Presentation 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 versus rotation angle;

f) MFCE, cladding diameter and cladding non-circularity;

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

B.2.4 *Alternative test method: the transmitted near-field image technique*

B.2.4.1 *General*

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.2.4.2 *Test apparatus*

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

B.2.4.2.1 *Light 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.2.4.2.2 *Launching 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.2.4.2.3 *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.2.4.2.4 *Specimen*

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.2.4.2.5 *Magnifying 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 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.2.4.2.6 *Detection*

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

a) image shearing [1];

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

B.2.4.2.7 *Data acquisition*

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

B.2.4.3 *Procedure*

B.2.4.3.1 *Equipment 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.2.4.3.2 *Measurement*

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 ouput 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.2.4.4 *Presentation of the results*

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

b) launching conditions;

c) spectral characteristics of the source;

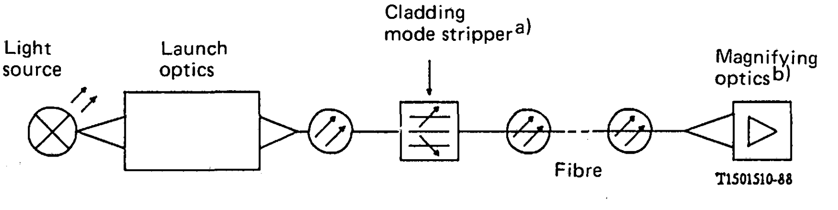
d) fibre identification and length;

e) magnification of the magnifying optics;

f) temperature of the sample and environmental conditions (when necessary);

g) indication of the accuracy and repeatibility;

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



a) When appropriate.

b) Including image shearing optics, where appropriate.

FIGURE B-4/G.652

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

B.3 – **Section III** – *Test methods for the cut-off wavelength*

B.3.1 *Reference test method for the cut-off wavelength (λ_c) of the primary coated fibre: the transmitted power technique*

B.3.1.1 *Objective*

This cut-off wavelength measurement of single-mode fibres is intended to assure effective single-mode operation above a specified wavelength.

B.3.1.2 *The transmitted power technique*

This method uses the variation with wavelength of the transmitted power of a short length of the fibre under test, under defined conditions, compared to a reference transmitted power. There are two possible ways to obtain this reference power:

a) the test fibre with a loop of smaller radius, or

b) a short (1-2 m) length of multimode fibre.

B.3.1.2.1 *Test apparatus*

B.3.1.2.1.1 *Light source*

A light source with linewidth not exceeding 10 nm (FWHM), stable in position, intensity and wavelength over a time period sufficient to complete the measurement procedure, and capable of operating over a sufficient wavelength range, shall be used.

B.3.1.2.1.2 *Modulation*

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 to the source modulation frequency. The detecting system should be substantially linear.

B.3.1.2.1.3 *Launching conditions*

The launching conditions must be used in such a way to excite substantially uniformly both LP_{01} and LP_{11} modes. For example, suitable launching techniques could be:

a) jointing with a multimode fibre, or

b) launching with a suitable large spot – large NA optics.

B.3.1.2.1.4 *Cladding mode stripper*

The cladding mode stripper is a device that encourages the conversion of cladding modes to radiation modes; as a result, cladding modes are stripped from the fibre. Care should be taken to avoid affecting the propagation of the LP_{11} mode.

B.3.1.2.1.5 *Optical 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 the spectral characteristics of the source. The detector must be uniform and have linear sensitivity.

B.3.1.2.2 *Procedure*

B.3.1.2.2.1 *Standard test sample*

The measurement shall be performed on a 2 m length of fibre. The fibre is inserted into the test apparatus and bent to form a loosely constrained loop. The loop shall complete one full turn of a circle of 140 mm radius. The remaining part of the fibre shall be substantially free of external stresses. While some incidental bends of larger radii are permissible, they must not introduce a significant change in the measurement result. The ouput power P_1 (λ) shall be recorded versus λ in a sufficiently wide range around the expected cut-off wavelength.

Note – The presence of a primary coating on the fibre usually does not affect the cut-off wavelength. However, the presence of a secondary coating may result in a cut-off wavelength that may be significantly shorter than that of the primary coated fibre.

B.3.1.2.2.2 *Transmission through the reference sample*

Either method a) or b) may be used.

a) Using the test sample, and keeping the launch conditions fixed, an output power P_2 (λ) is measured over the same wavelength range with at least one loop of sufficiently small radius in the test sample to filter the LP_{11} mode. A typical value for the radius of this loop is 30 mm.

b) With a short (1-2 m) length of multimode fibre, an output power P_3 (λ) over the same wavelength range.

Note – The presence of leaky modes may cause ripple in the transmission spectrum of the multimode reference fibre, affecting the result. To reduce this problem, light-launching conditions may be restricted to fill only 70% of the multimode fibre's core diameter and NA or a suitable mode filter may be used.

B.3.1.2.2.3 *Calculations*

The logarithmic ratio between transmitted powers P_1 (λ) and P_i (λ) is calculated as:

$$R(\lambda) = 10 \log [P_1(\lambda)/P_i(\lambda)]$$

where

i = 2 or 3, methods a) or b) respectively.

Note – In method a) the small mode filter fibre loop eliminates all modes except the fundamental for wavelengths greater than a few tens of nm below the cut-off wavelength λ_c. For wavelengths more than several hundred nm above λ_c, even the fundamental mode may be strongly attenuated by the loop. $R(\lambda)$ is equal to the logarithmic ratio between the total power emerging from the sample, including the LP_{11} mode power, and the fundamental mode power. When the modes are uniformly excited in accordance with B.1.2.1.3, $R(\lambda)$ then also yields the LP_{11} mode attenuation $A(\lambda)$ in dB in the test sample:

$$A(\lambda) = 10 \log [(P_1(\lambda)/P_2(\lambda) - 1)/2]$$

B.3.1.2.2.4 *Determination of cut-off wavelength*

If method a) is used, λ_c is determined as the largest wavelength at which $R(\lambda)$ is equal to 0.1 dB (see Figure B-5/G.652).

If method b) is used, λ_c is determined by the intersection of a plot of $R(\lambda)$ and a straight line (2) displaced 0.1 dB and parallel to the straight line (1) fitted to the long wavelength portion of $R(\lambda)$ (see Figure B-6/G.652).

Note – According to the definition, the LP_{11} mode attenuation in the test sample is 19.3 dB at the cut-off wavelength.

B.3.2.1.2.2.5 *Presentation of results*

a) test set-up arrangement;

b) launching condition;

c) type of reference sample;

d) temperature of the sample and environmental conditions (if necessary);

e) fibre identification;

f) wavelength range of measurement;

g) cut-off wavelength;

h) plot of $R(\lambda)$ (if required).

B.3.2 *Alternative test method for λ_c: the split-mandrel technique*

B.3.2.1 *Objective* through B.3.2.2.1.5 *Optical detector* (as in B.3.1.1 through B.3.1.2.1.5)

B.3.2.2.2 *Procedure*

B.3.2.2.2.1 *Standard test sample*

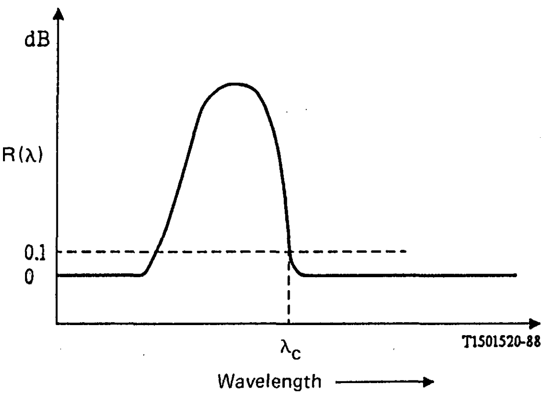


FIGURE B-5/G.652

Typical cut-off wavelength plot using single-mode reference

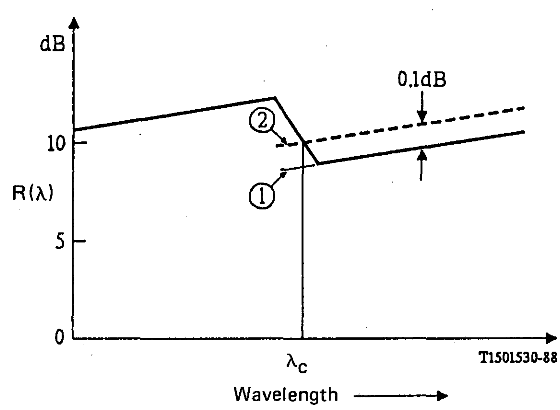


FIGURE B-6/G.652

Typical cut-off wavelength plot using multimode reference

The measurement shall be performed on a 2 m length of fibre. The fibre is inserted into the test apparatus and bent to form a loosely constrained loop. The loop shall contain a full turn (360 degrees) consisting of two arcs (180 degrees each) of 140 mm radius connected by tangents. The remaining part of the fibre shall be substantially free of external stresses. While some incidental bends of larger radii are permissible, they must not introduce a significant change in the measurement result. The output power P_1 (λ) shall be recorded versus λ in a sufficiently wide range around the expected cut-off wavelength.

As shown in Figure B-7/G.652, the lower semicircular mandrel moves to take any slack from the fibre loop without requiring movement of the launch or receive optics or placing the fibre sample under any significant tension.

B.3.2.2.2.2 through B.3.2.2.2.5 (as in B.3.1.2.2.2 through B.3.1.2.2.5)

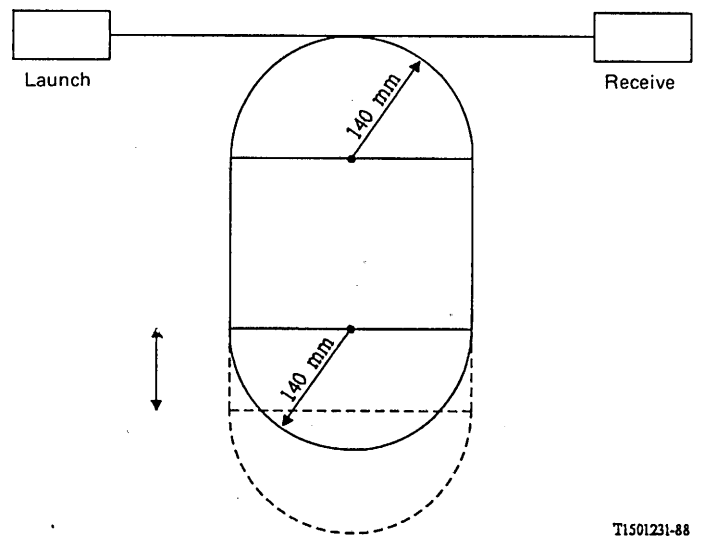


FIGURE B-7/G.652

Fibre deployment: Cut-off wavelength by the split-mandrel technique

B.3.3 *Reference test method for the cut-off wavelength (λ_{cc}) of the cable fibre: the transmitted power technique*

B.3.3.1 *Objective*

This cut-off wavelength measurement which is performed on cabled single-mode fibres in a deployment condition which stimulates outside plant minimum cable lengths, is intended to assure effective single-mode operation above a specified wavelength.

B.3.3.2 *The transmitted power technique*

This method uses the variation with wavelength of the transmitted power of the fibre cable under test, under defined conditions, compared to a reference transmitted power. There are two possible ways to obtain this reference power.

a) the cabled test fibre with a loop of smaller radius;

b) a short (1-2 m) length of multimode fibre.

B.3.3.2.1 *Test apparatus*

B.3.3.2.1.1 *Light source* (as in B.3.1.2.1.1)

B.3.3.2.1.2 *Modulation* (as in B.3.1.2.1.2)

B.3.3.2.1.3 *Launching conditions* (as in B.3.1.2.1.3)

B.3.3.2.1.4 *Cladding mode stripper* (as in B.3.1.2.1.4)

B.3.3.2.1.5 *Optical detector* (as in B.3.1.2.1.5)

B.3.3.2.2 *Procedure*

B.3.3.2.2.1 *Standard test sample*

The measurement shall be performed on a length of single-mode fibre in a cable. A cable length of 22 m shall be prepared by exposing 1 m uncabled fibre length at each end, and the resulting 20 m cabled portion shall be laid without any small bends which could affect the measurement value. To simulate the effects of a splice organizer, one loop of XX mm radius shall be applied to each uncabled fibre length (see Figure B-8/G.652). While some incidental bends of larger radii are permissible in the fibre or cable, they must not introduce a significant change in the measurements. The output power $P_1(\lambda)$ shall be recorded versus λ in a sufficiently wide range around the expected cut-off wavelength.

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

B.3.3.2.2.3 *Calculations*

The logaritmic ratio between the transmitted powers $P_1(\lambda)$ and $P_i(\lambda)$ is calculated as

$$R(\lambda) = 10 \log [P_1(\lambda)/P_i(\lambda)] \qquad \text{(dB)} \qquad (1)$$

where $i = 2$ or 3 for methods a) or b), respectively.

B.3.3.2.2.4 *Determination of cabled fibre cut-off wavelength*

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

B.3.3.2.2.5 *Presentation of results*

a) test set-up arrangment (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 $R(\lambda)$ (if required);

h) plot of $R(\lambda)$ (if required).

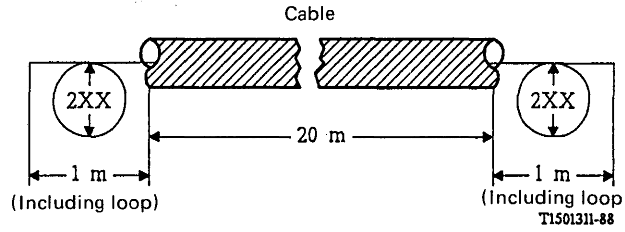


FIGURE B-8/G.652

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

B.4 – Section IV – *Test methods for attenuation measurements*

B.4.1 *Introduction*

B.4.1.1 *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.4.1.2 *Definition*

The attenuation $A(\lambda)$ at wavelength λ between two cross-sections and separated by distance L of a fibre is defined, as

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

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, it is possible to define an attenuation per unit length, or an attenuation coefficient which is dependent of the length of the fibre:

$$\alpha(\lambda) = A(\lambda)/L \qquad \text{(dB/unit of length)} \qquad (2)$$

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.4.2 *The 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.4.2.1 *Test 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.4.2.1.1 *Optical source*

A suitable radiation source shall be used, such 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.4.2.1.2 *Modulation*

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 to the source modulation frequency. The detecting system should be substantially linear.

B.4.2.1.3 *Launching 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.4.2.1.4 *Mode 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 introduce a bend in order to remove the higher modes.

B.4.2.1.5 *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.4.2.1.6 *Optical 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 characteristics.

B.4.2.2 *Measurement procedure*

B.4.2.2.1 *Preparation 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.4.2.2.2 *Procedure*

1) The fibre under test is placed in the measurements 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.
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.4.2.2.3 *Presentation 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.4.3 *First alternative test method; the backscattering technique*

Note – This test method describes a procedure to measure the attenuation of a homogenous 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.4.3.1 *Launching 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.4.3.2 *Apparatus and procedure*

B.4.3.2.1 *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 pulse width in order to obtain a compromise between resolution and pulse energy. Special care should be taken to minimize the Fresnel reflections.

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

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

B.4.3.2.2 *Optical source*

A stable high power optical source of an appropriate wavelength should be used. 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 not be present in the part of the fibre under test.

B.4.3.2.3 *Coupling device*

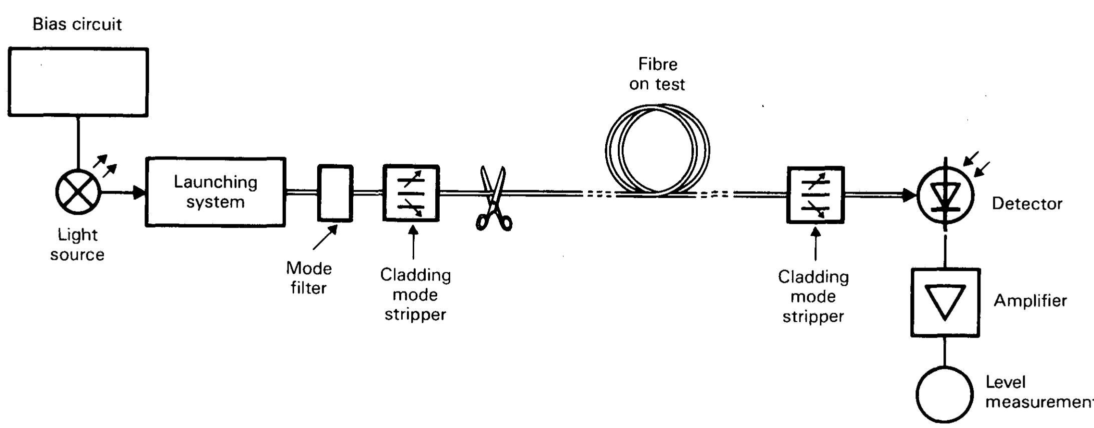
The coupling device is needed to couple the source radiation to the fibre and the backscattered radiation to the detector, while avoiding a direct source-detector coupling. Several devices can be used, but devices based on polarization effects should be avoided.

B.4.3.2.4 *Optical detection*

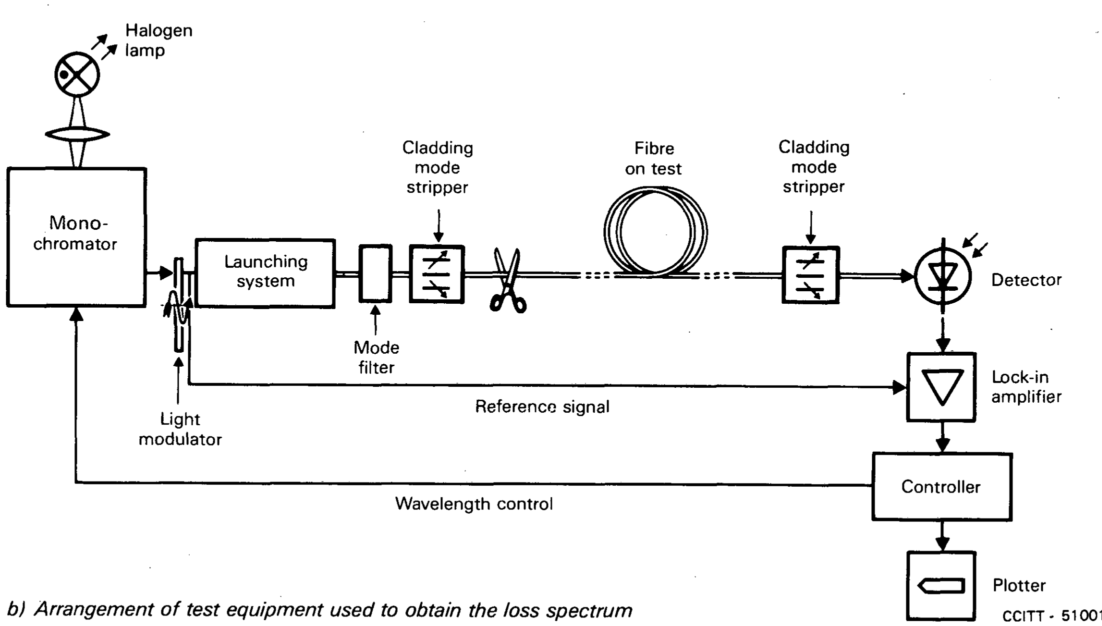
A detector shall be used so that the maximum possible backscattered power should be intercepted. The detector response shall be compatible with the levels and wavelengths of the detected signal. For attenuation measurements the detector response shall be substantially linear.

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.



a) Arrangement of test equipment to make one loss measurement



b) Arrangement of test equipment used to obtain the loss spectrum

FIGURE B-9/G.652

The cutback technique

B.4.3.2.5 *Cladding mode stripper*

See § B.2.1.5.

B.4.3.2.6 *Procedure*

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 attenuation between two points A and B of the curve corresponding to two cross-sections of the fibre is

$$\underset{A \to B}{A(\lambda)} = \frac{1}{2} (V_A - V_B) \qquad \text{(dB)}$$

where V_A and V_B are the corresponding power levels given on a 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.4.3.2.7 *Results*

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;
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:

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.4.4 *Second alternative test method: the insertion loss technique*

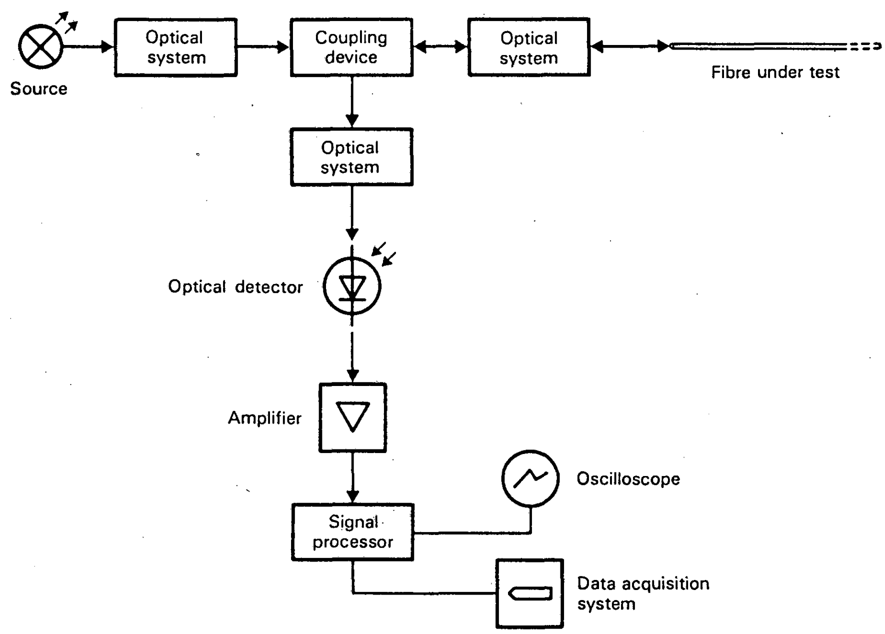
Under consideration.

B.5 – Section V – *Test methods for chromatic dispersion coefficient measurement*

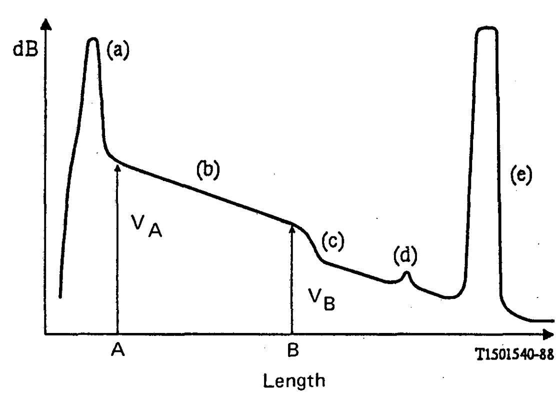
B.5.1 *Reference test method for chromatic dispersion coefficient measurement*

B.5.1.1 *Objective*

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.



a) Schematic of apparatus



b) Example of a backscattered power curve

FIGURE B-10/G.652

The backscattering technique

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.5.1.2 *Test apparatus*

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

B.5.1.2.1 *Source*

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

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

B.5.1.2.2 *Wavelength selection*

A wavelength selector is used to select the wavelength at which the group delay is to be measured. Optical switch, monochromator, dispersive devices, optical filters, optical coupler, connectors, etc., may be used, depending on the type of light sources and measurement set-up. The selection may be carried out by switching electrical driving signals for different wavelength light sources. The wavelength selector may be used either at the input or at the output end of the fibre under test.

B.5.1.2.3 *Detector*

The light emerging from the fibre under test, the reference fibre or the optical divider etc., is coupled to a photo detector whose signal-to-noise ratio and time resolution are adequate for the measurement. The detector is followed by a low noise amplifier if needed.

B.5.1.2.4 *Reference channel*

The reference channel may consist of electrical signal line or optical signal line. A suitable time delay generator may be interposed in this channel. In certain cases, the fibre under test itself can be used as the reference channel line.

B.5.1.2.5 *Delay detector*

The delay detector shall measure the delay time or the phase shift between the reference signal and the channel signal. In the case of sinusoidal modulation, a vector voltmeter could be used. In the case of pulse modulation, a high speed oscilloscope or a sampling oscilloscope could be used.

B.5.1.2.6 *Signal processor*

A signal processor can be added in order to reduce the noise and/or the jitter in the measured waveform. If needed, a digital computer can be used for purposes of equipment control, data acquisition and numerical evaluation of the data.

B.5.1.3 *Procedure*

The fibre under test is suitably coupled to the source and to the detector through the wavelength selector or the optical divider, etc. If needed, a calibration of the chromatic delay of the source may be performed. A suitable compromise between wavelength resolution and signal level must be achieved. Unless the fibre under test is also used as the reference channel line, the temperature of the fibre must be sufficiently stable during the measurement.

The time delay or phase shift between the reference signal and the channel signal at the operating wavelength are to be measured by the delay detector. Data processing appropriate to the type of modulation is used in order to obtain the chromatic dispersion coefficient at the operating wavelength. When needed, a spectral scan of the group delay versus wavelength can be performed; from the measured values a fitting curve can be completed.

The measured group delay per unit fibre length versus wavelength shall be fitted by the quadratic expression:

$$\tau(\lambda) = \tau_0 + \frac{S_0}{2} (\lambda - \lambda_0)^2$$

where τ_0 is the relative delay minimum at the zero-dispersion wavelength λ_0. The chromatic dispersion coefficient $D(\lambda) = d\tau/d\lambda$ can be determined from the differentiated quadratic expression:

$$D(\lambda) = (\lambda - \lambda_0)S_0$$

where S_0 is the (uniform) zero-dispersion slope, i.e., the value of the dispersion slope $S(\lambda) = dD/d\lambda$ at λ_0.

Note 1 – These equations for $\tau(\lambda)$ and $D(\lambda)$ are sufficiently accurate over the 1500-1600 nm range. They are not meant to be used in the 1300 nm region.

Note 2 – Alternatively, the chromatic dispersion coefficient can be measured directly, for example by the differential phase shift method. In this case, a straight line shall be fitted directly to the dispersion coefficient for determining λ_0 and S_0.

B.5.1.4 *Presentation of results*

The following details shall be presented:

a) test set-up arrangement;

b) type of modulation used;

c) source characteristics;

d) fibre identification and length;

e) characteristics of the wavelength selector (if present);

f) type of photodetector;

g) characteristics of the delay detector;

h) values of the zero-dispersion wavelength and the zero-dispersion slope.

If the frequency domain technique is used, the time group delay τ will be deduced from the corresponding phase shift φ through the relation $\tau = \varphi/(2\pi f)$, f being the modulation frequency;

i) fitting procedures of relative delay data with the used fitting wavelength range;

j) temperature for the sample and environment conditions (if necessary).

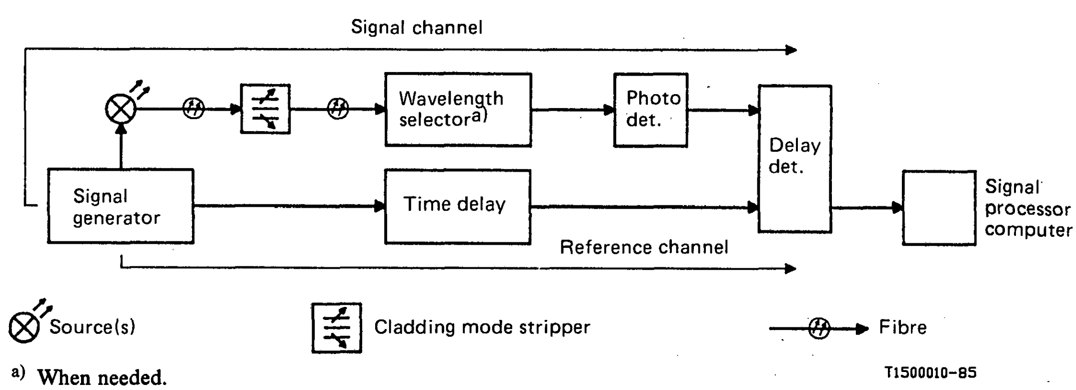


FIGURE B-11/G.652

Typical arrangement of the test apparatus

B.5.2 *Alternative test method for chromatic dispersion coefficient measurement: the interferometric test method*

B.5.2.1 *Objective*

The interferometric test method allows the dispersion to be measured, using a short piece of fibre (several metres). This offers the possibility of measuring the longitudinal chromatic dispersion homogeneity of optical fibres. Moreover, it is possible to test the effect of overall or local influences, such as temperature changes and macrobending losses, on the chromatic dispersion.

According to the interferometric measuring principle, the wavelength-dependent time delay between the test sample and the reference path is measured by a Mach-Zehnder interferometer. The reference path can be an air path or as a single-mode fibre with known spectral group delay.

It should be noted that the extrapolation of the chromatic dispersion values derived from the interferometric test on fibres of a few metres length, to long fibre sections assumes longitudinal homogeneity of the fibre. This assumption may not be applicable in every case.

B.5.2.2 *Test apparatus*

Schematic diagrams of the test apparatus using a reference fibre and an air path reference are shown in Figures B-12/G.652 and B-13/G.652 respectively.

B.5.2.2.1 *Optical source*

The source should be stable in position, intensity and wavelength for a time period sufficiently long to complete the measurement procedure. The source must be suitable, e.g. a YAG laser with a Raman fibre or a lamp and LED optical sources etc. For the application of lock-in amplification techniques, a light source for low-frequency modulation (50 to 500 Hz) is sufficient.

B.5.2.2.2 *Wavelength selector*

A wavelength selector is used to select the wavelength at which the group delay is measured. A monochromator, optical interference filter, or other wavelength selector may be used depending on the type of optical sources and measurement systems. The wavelength selector may be used either at the input or the output end of the fibre under test.

The spectral width of the optical sources is to be restricted by the dispersion measuring accuracy, and it is about 2 to 10 nm.

B.5.2.2.3 *Optical detector*

The optical detector must have a sufficient sensitivity in that wavelength range in which the chromatic dispersion has to be determined. If necessary, the received signal has to be upgraded, with for example a transimpedance circuit.

B.5.2.2.4 *Test equipment*

For the recording of the interference patterns, a lock-in amplifier may be used. Balancing of the optical length of the two ways of the interferometer is performed with one linear positioning device in the reference path. Concerning the positioning device, attention should be paid to the accuracy, uniformity and stability of linear motion. The variation of the length should cover the range from 20 to 100 mm with an accuracy of about 2 μm.

B.5.2.2.5 *Specimen*

The specimen for the test can be uncabled and cabled single-mode fibres. The length of the specimen should be in the range 1 m to 10 m. The accuracy of the length should be about ± 1 mm. The preparation of the fibre endfaces should be carried out with reasonable care.

B.5.2.2.6 *Data processing*

For the analysis of the interference patterns, a computer with suitable software should be used.

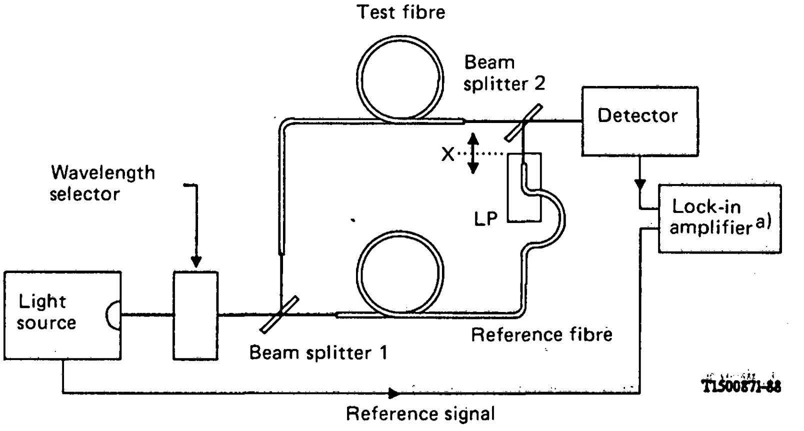
B.5.2.3 *Test procedure*

1) The fibre under test is placed in the measurement set-up (Figures B-12/G.652, B-13/G.652). The positioning of the endfaces is carried out with 3-dimensional micro-positioning devices by optimizing the optical power received by the detector. Errors arising from cladding modes are not possible.

2) The determination of the group delay is performed by balancing the optical lengths of the two interferometer paths with one linear positioning device in the reference path for different wavelengths. The difference between position x_i of the maximum of the interference pattern for wavelength λ_i and position x_0 (Figure B-14/G.652) determines the group delay difference $\Delta t_g(\lambda_i)$ between the reference path and the test path as follows:

$$\Delta t_g(\lambda_i) = \frac{x_0 - x_i}{c_0}$$

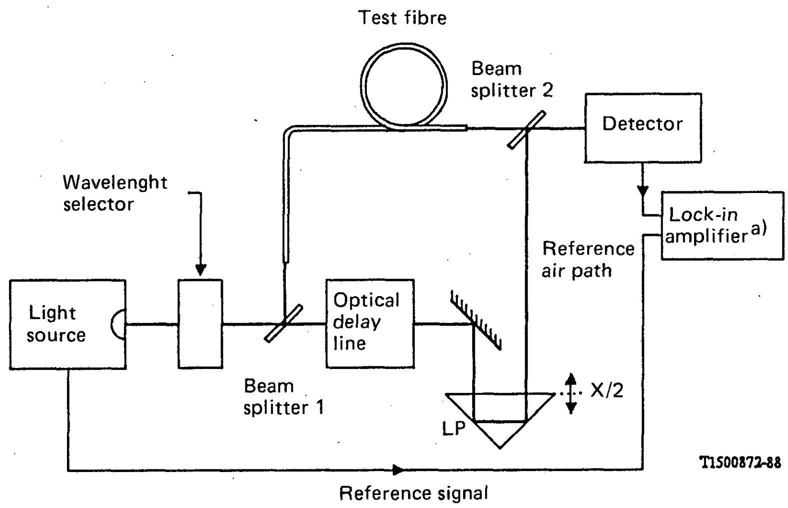
where c_0 is the velocity of light in the vacuum. The group delay of the test sample is calculated by adding the value $\Delta t_g(\lambda_i)$ and the spectral group delay of the reference path. Dividing this sum by the test fibre length then gives the measured group delay per unit length $\tau(\lambda)$ of the test fibre.



LP Linear positioning device
X Positioning distance
a) When needed.

FIGURE B-12/G.652

Schematic diagram of measurement set-up with reference fibre



LP Linear positioning device
X Positioning distance
a) When needed.

FIGURE B-13/G.652

Schematic diagram of measurement set-up with air path reference

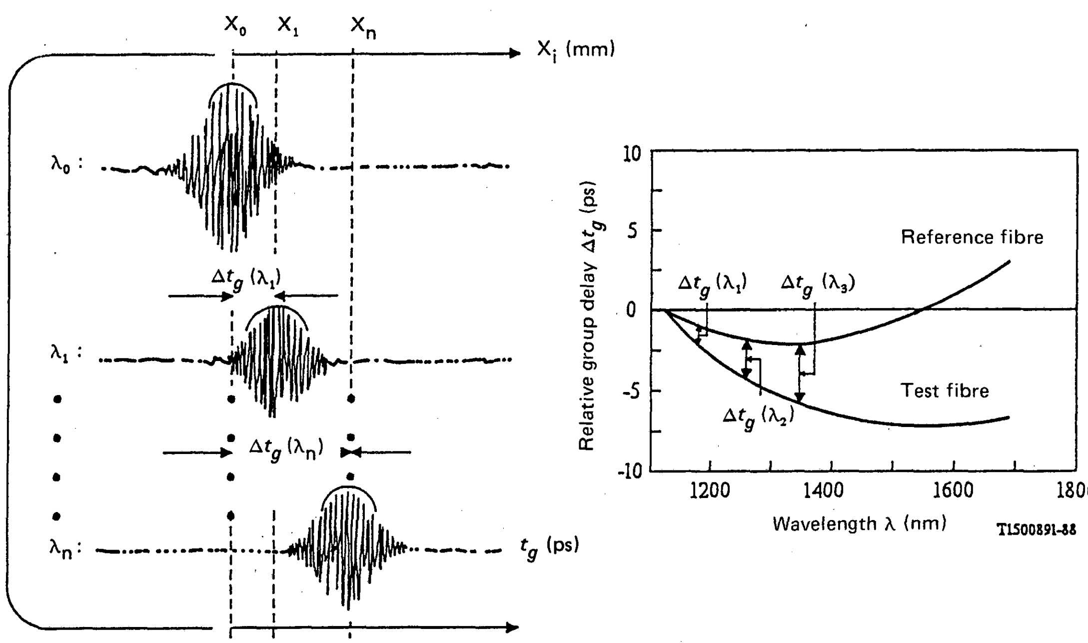


FIGURE B-14/G.652

Determination of the spectral group delay

The measured group delay per unit fibre length versus wavelength shall be fitted by the quadratic expression

$$\tau(\lambda) = \tau_0 + \frac{S_0}{2} (\lambda - \lambda_0)^2$$

where τ_0 is the relative delay minimum at the zero-dispersion wavelength λ_0. The chromatic dispersion coefficient $D(\lambda) = d\tau/d\lambda$ can be determined from the differentiated quadratic expression:

$$D(\lambda) = (\lambda - \lambda_0) S_0$$

where S_0 is the (uniform) zero-dispersion slope, i.e., the value of the dispersion slope $S(\lambda) = dD/d\lambda$ at λ_0.

Note – These equations for $\tau(\lambda)$ and $D(\lambda)$ are sufficiently accurate over the 1500-1600 nm range. They are not meant to be used in the 1300 nm region.

B.5.2.4 *Presentation of results*

The following details shall be presented:

a) test set-up arrangement;

b) source characteristics;

c) fibre identification and length;

d) characteristics of the wavelength selector (if present);

e) type of the photodetector;

f) values of the zero-dispersion wavelength and the zero-dispersion slope;

g) fitting procedures of relative delay date with the used fitting wavelength range;

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

Recommendation G.653

CHARACTERISTICS OF A DISPERSION-SHIFTED SINGLE-MODE OPTICAL FIBRE CABLE

(Melbourne, 1988)

The CCITT,

considering

(a) that dispersion-shifted optical fibre cables are going to be used widely in telecommunication networks;

(b) that the foreseen potential applications may require several kinds of single-mode fibres differing in operation wavelength geometrical and optical characteristics, and attenuation dispersion and other transmission characteristics,

recommends

a dispersion-shifted single-mode fibre which has the zero-dispersion wavelength in the 1550 nm wavelength region and which is optimized for use at wavelengths around 1550 nm. This fibre may also be used at around 1300 nm subject to the constraints which are outlined in this Recommendation.

Its geometrical, optical and transmission parameters are described below.

The meaning of the terms used in this Recommendation are given in Annex A to Recommendation G.652 and the guidelines to be followed in the measurements to verify the various characteristics are indicated in Annex B to Recommendation G.652. The characteristics of this fibre and the relevant values will be refined as studies and experience progress.

1 Fibre characteristics

Only those characteristics of the fibre providing a minimum essential design framework for fibre manufacture are recommended in § 1. Of these, the cabled fibre cut-off wavelength may be significantly affected by cable manufacture or installation. Otherwise, the recommended characteristics will apply equally to individual fibres, fibres incorporated into a cable wound on a drum, and fibres in an installed cable.

This Recommendation applies to fibres having a nominally circular mode field.

1.1 *Mode field diameter*

The nominal value of the mode field diameter at 1550 nm shall lie within the range of 7.0 to 8.3 μm. The mode field diameter deviation should not exceed the limits of ± 10% of the nominal value.

Note 1 – The choice of a specific value within the above range is not necessarily associated with a specific fibre design.

Note 2 – It should be noted that the fibre performance required for any given application is a function of essential fibre and systems parameters, i.e., mode field diameters, cut-off wavelength, chromatic dispersion, system operating wavelength, and bit rate/frequency of operation, and not primarily of the fibre design.

Note 3 – All the above needs further study.

1.2 *Cladding diameter*

The recommended nominal value of the cladding diameter is 125 μm. The cladding deviation should not exceed the limits of ± 2.4% (± 3 μm).

For some particular jointing techniques and joint loss requirements, other tolerances may be appropriate.

1.3 *Mode field concentricity error*

The recommended mode field concentricity error at 1550 nm should not exceed 1 μm.

Note – For some particular jointing techniques and joint loss requirements, tolerances up to 3 μm may be approrpriate.

1.4 *Non-circularity*

1.4.1 *Mode field non-circularity*

In practice, the mode field non-circularity of fibres having nominally circular mode fields is found to be sufficiently low that propagation and jointing are not affected. It is therefore not considered necessary to recommend a particular value for the mode field non-circularity. It is not normally necessary to measure the mode field non-circularity for acceptance purposes.

1.4.2 *Cladding non-circularity*

The cladding non-circularity should be less than 2%. For some particular jointing techniques and joint loss requirements, other tolerances may be appropriate.

1.5 *Cut-off wavelength*

Under study.

1.6 *1550 nm bend performance*

The loss increase for 100 turns of fibre, loosely wound with a 37.5 mm radius and measured at 1550 nm, shall be less than 0.5 dB.

Note 1 – A qualification test may be sufficient to ensure that this requirement is being met.

Note 2 – The above value of 100 turns corresponds to the approximate number of turns deployed in all splice cases of typical repeater span. The radius of 37.5 mm is equivalent to the minimum bend-radius widely accepted for long-term deployment of fibres in practical systems installations to avoid static-fatigue failure.

Note 3 – If for pratical reasons fewer than 100 turns are chosen to implement this test, it is suggested that not less than 40 turns, and a proportionately smaller loss increase be used.

Note 4 – If bending radii smaller than 37.5 mm are planned to be used in splice cases or elsewhere in the system (for example, R = 30 mm) it is suggested that the same loss value of 0.5 dB shall apply to 100 turns of fibre deployed with this smaller radius.

Note 5 – The 1550 nm bend-loss recommendation relates to the deployment of fibres in practical single-mode fibre installations. The influence of the stranding-related bending radii of cabled single-mode fibres on the loss performance is included in the loss specification of the cabled fibre.

Note 6 – In the event that routine tests are required, a small diameter loop with one or several turns can be used instead of the 100-turn test, for accuracy and measurement ease of the 1550 nm bend sensitivity. In this case, the loop diameter, number of turns, and the maximum permissible bend loss for the several-turn test, should be chosen, so as to correlate with the 0.5 dB loss recommendation of the 37.5 mm radius 100 turn functional test.

1.7 *Material properties of the fibre*

1.7.1 *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.

1.7.2 *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.

1.8 *Refractive index profile*

The refractive index profile of the fibre does not generally need to be known: if one wishes to measure it, the Reference Test Method in Recommendation G.651 may be used.

2 **Factory length specifications**

Since the geometrical and optical characteristics of fibres given in § 1 are barely affected by the cabling process, § 2 will give recommendations mainly relevant to transmission characteristics of cabled factory lengths.

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

2.1 *Attenuation coefficient*

Optical fibre cables covered by this Recommendation generally have attenuation coefficients in the 1550 nm region below 0.5 dB/km. When they are intended for use in the 1300 nm region, their attenuation coefficient in that region is genrally below 1 dB/km.

Note – The lowest values depend on the fabrication process, fibre composition and design, and cable design. Values in the rage 0.19-0.25 dB/km in the 1550 nm region have been achieved.

2.2 *Chromatic dispersion coefficient*

Under study.

Note 1 – The maximum chromatic dispersion coefficient of single-mode fibres covered in this Recommendation shall be:

Longitud de onda (nm)	Máximo coeficiente de dispersión cromática [ps/(nm·km)]
1525-1575	3,5
Región de 1300 nm	En estudio

Note 2 – The value of 3.5 ps/(nm · km) allows for attenuation limited section lengths at 560 Mbit/s, using suitable multi-longitudinal mode lasers and adequate line coding.

Note 3 – For higher capacity (larger than 560 Mbit/s) or longer length systems, operation closer to the zero-dispersion wavelength is required (unless single-longitudinal mode laser diodes are used). Additional fibre parameters may then have to be specified (such as zero-dispersion wavelength, dispersion-slope, etc.). Further studies are needed to identify these parameters.

Note 4 – It is not necessary to measure the chromatic dispersion coefficient on a routine basis.

3 Elementary cable sections

An elementary cable section 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 section must take into account not only the performance of the individual cable lengths but also amongst the other factors, such things as splice losses and connector losses (if applicable).

3.1 *Attenuation*

The attenuation A of an elementary cable section is given by:

$$A = \sum_{n=1}^{m} a_n \cdot L_n + a_s \cdot X + a_c \cdot y$$

where

a_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 = 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).

A suitable allowance should be allocated for a suitable cable marging for future modifications of cable configurations (additional splices, extra cable lengths, aging effects, temperature variations, etc.). The above equation does not include the loss of equipment connectors.

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

3.2 *Chromatic dispersion*

The chromatic dispersion in ps 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 and system source characteristics (see § 2.2).

ANNEX A

(to Recommendation G.653)

Meaning of the terms used in the Recommendation

Most of the definitions contained in Annex A to Recommendation G.652 are in principle applicable also to dispersion-shifted fibre. Because of limited experience with this type of fibre, further study of the suitability of some definitions is needed.

ANNEX B

(to Recommendation G.653)

Test Methods for dispersion-shifted single-mode fibres

The present experience on dispersion-shifted single-mode fibres is rather limited; therefore further study is needed on some Reference and Alternative Test Methods for this type of fibre. Nevertheless, most of the test methods described in Annex B to Recommendation G.652 are in principle applicable also to dispersion-shifted fibres. Therefore, for this Annex, reference is made to the corresponding Test Methods of Annex B in Recommendation G.652; the specifics of each test procedure need further study. It should be noted that the working wavelength for G.653 fibres is in the 1550 nm region.

Recommendation G.654

CHARACTERISTICS OF A 1550 nm WAVELENGTH LOSS-MINIMIZED SINGLE-MODE OPTICAL FIBRE CABLE

(Melbourne, 1988)

The CCITT,

considering

(a) that very low loss fibres are required in some telecommunication network applications;

(b) that the foreseen potential applications may require several kinds of single-mode fibres differing in:

- geometrical characteristics;
- operation wavelength;
- attenuation, dispersion and other optical characteristics,

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

recommends

a single-mode fibre which has the zero dispersion wavelength in the 1300 nm wavelength region, which is loss minimized at a wavelength around 1550 nm and which is designed for use in this region.

The geometrical, optical and transmission characteristics of this fibre are described below.

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

Note – The characteristics of this fibre and the relevant values will be refined as studies and experience progress.

1 Fibre characteristics

1.1 *Mode field diameter*

The nominal value of the mode field diameter at 1550 nm shall be xx μm. The mode field diameter deviation should not exceed the limits of ± 10% of the nominal value.

Note – The value for xx has to be specified. A value of 10.5 for xx is one possibility.

1.2 *Cladding diameter*

The recommended nominal value of the cladding diameter is 125 μm. The cladding deviation should not exceed the limits of ± 2.4%[1] (± 3 μm).

1.3 *Mode field concentricity error*

The recommended mode field concentricity error at 1550 nm should not exceed 1 μm[1].

1.4 *Non-circularity*

1.4.1 *Mode field non-circulatory*

In practice, the mode field non-circularity of fibres having nominally circular mode fields is found to be sufficiently low that propagation and jointing are not affected. It is therefore not considered necessary to recommend a particular value for the mode field non-circularity. It is not normally necessary to measure the mode field non-circularity for acceptance purposes.

1.4.2 *Cladding non-circularity*

The cladding non-circularity should be less than 2%. For some particular jointing techniques and joint loss requirements, other tolerances may be appropriate.

1.5 *Cut-off wavelength*

The cut-off wavelength values shall be between xxxx nm and yyyy nm for λ_c, and smaller than zzzz nm for λ_{cc}.

Note – The values for xxxx, yyyy and zzzz have to be specified; values of 1350 for xxxx, 1600 for yyyy and 1530 for zzzz are one possibility.

1.6 *1550 nm bend loss performance*

Under study.

Note – The performance of this fibre should not be worse than fibre designed to meet Recommendation G.653.

1.7 *Material properties of the fibre*

This is given in § 1.7 of Recommendation G.652.

1.8 *Example of fibre design guidelines*

Supplement No. 33 gives an example of fibre design guidelines for matched cladding fibres used by one organization.

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[1] Under study.

2 Factory length specifications

2.1 *Attenuation coefficient*

Optical fibre cables covered by this Recommendation shall have attenuation coefficients in the 1550 nm region [2].

Note – The lowest values depend on fabrication process, fibre composition and design, and cables design. Values of 0.15 to 0.20 dB/km in the 1550 nm region have been achieved.

2.2 *Chromatic dispersion coefficient*

The maximum chromatic dispersion coefficient in the 1550 nm wavelength region of single-mode fibres covered in this Recommendation shall be 20 ps/(nm · km).

3 Elementary cable sections

As given in § 3 of Recommendation G.652.

ANNEX A

(to Recommendation G.654)

Meaning of the terms used in the Recommendation

Most of the definitions contained in Annex A to Recommendation G.652 are in principle applicable also to loss-minimized fibre. Because of limited experience with this type of fibre, further study of the suitability of some definitions is needed.

ANNEX B

(to Recommendation G.654)

Test methods for loss-minimized single-mode fibres

The present experience on loss-minimized single-mode fibres is rather limited; therefore further study is needed on some Reference and Alternative Test Methods for this type of fibre. Nevertheless, most of the test methods described in Annex B to Recommendation G.652 are in principle applicable also to loss-minimized fibres. Therefore, for this Annex, reference is made to the corresponding Test Methods of Annex B in Recommendation G.652; the specifics of each test procedure need further study. It should be noted that the working wavelength for G.654 fibres is in the 1550 nm region.

[2] Under study.

PART II

SUPPLEMENTS TO RECOMMENDATIONS IN SECTION 6 OF THE SERIE G RECOMMENDATIONS

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DATA ON CABLE SHIPS AND SUBMERSIBLE EQUIPMENTS OF VARIOUS COUNTRIES

(Mar del Plata, 1968, amended at Geneva, 1972, 1976, 1980, 1984 and 1988; referred to in Subsection 6.3 of the Series G Recommendations)

Section 1 – CABLE SHIPS

Name of ship	Year of construction	Displacement (tons)	Overall length (m)	Draft (m)	Normal speed (knots)	Range (autonomy) (nautical miles)	Number of tanks	Cable capacity: Cable: Cubic metres (m^3)	Cable capacity: Cable: Weight (tons)	Cable capacity: Repeaters	Cable gear: Forward cable drum (diameter) (m)	Cable gear: Unwinding pulley: Bow sheave (diameter) (m)	Cable gear: Unwinding pulley: Stern sheave (diameter) (m)	Maximum operating depth (m)	Capability
								CANADA							
John Cabot	1985	6400	95	7	13/16	6500	3	614	800	24	1 × 3.0 (30 t) + linear engine (18 pairs of wheels)	3.0	–	All	Repair ship. Plough capabilities.
								DENMARK							
								Ship belonging to Telecom Denmark							
Peter Faber	1982	Open 750 Closed 1830	78.4	Open 3.8 Closed 5.0	14.0	7000	1 tank 1 hold	310 230	600 400	App. 10	3.0	3.0	–	4000	Reinforced for operation in ice-filled waters. On the aft deck: one A-frame with hydraulic topping. Max. load 35 tons. One hydraulic towing and general purpose winch. Two hydraulic double-drum warping winches.

Name of ship	Year of con-struc-tion	Displace-ment (tons)	Overall length (m)	Draft (m)	Normal speed (knots)	Range (auto-nomy) (nautical miles)	Number of tanks	Cable capacity			Cable gear			Maximum operating depth (m)	Capability
								Cable		Repeaters	Forward cable drum (diameter) (m)	Unwinding pulley			
								Cubic metres (m^3)	Weight (tons)			Bow sheave (diameter) (m)	Stern sheave (diameter) (m)		
								FRANCE							
Vercors	1974	10 670	133	7.3	16.5	13 000	3	2535	6000*	140	2 × 3.0 (30t)	3.0	4.0 + linear engine (18 pairs of wheels)	All	Laying and repair of all types of telephone (coaxial and optical fibre) and power cables. Capacity: 3500 km deep-sea optical fibre cables, 1300 nautical miles 1-inch cable; 650 nautical miles 1.5-inch cable; 500 nautical miles 1.7-inch cable. * A different weight in the case of power cable.
Léon Thévenin	1983	6200	107	6.25	15.0	10 000	2	1060	1000	30	2 × 3.4 (40t)	3.0	4.0 + linear engine (18 pairs of wheels)	All	Repair ship, armoured coaxial and optical fibre cables.
Raymond Croze	1983	6200	107	6.25	15.0	10 000	2	1400	1300	70	2 × 3.4 (40t)	3.0	4.0 + linear engine (8 pairs of wheels)	All	Lays/repairs – approx. half the strage capacity of the *Vercors.* *Note* – *Léon Thévenin* and *Raymond Croze* are identical except for the positioning of the cable tanks.

Name of ship	Year of construction	Displacement (tons)	Overall length (m)	Draft (m)	Normal speed (knots)	Range (autonomy) (nautical miles)	Number of tanks	Cable capacity			Cable gear			Maximum operating depth (m)	Capability
								Cable		Repeaters	Forward cable drum (diameter) (m)	Unwinding pulley			
								Cubic metres (m^3)	Weight (tons)			Bow sheave (diameter) (m)	Stern sheave (diameter) (m)		
								ITALY							
								Ships belonging to Pirelli/Euroshipping							
Arabella	1975	2620	76.66	5.18	11	2000	2	1100	2000	–	–	–	3	All	Lay/repair
G. Verne	1983	13 000	127.5	5.37	10	5000	3	5000	12 000	–	–	–	6	All	Stern only
								JAPAN							
								1. Ship belonging to KDD							
KDD Maru	1967	6026	113.83	6.3	16	7000	3	1012	2700	70	3.6	3.0	Shute 4.0	All	Lays and repairs all types of telephone cables.
								2. Ships belonging to NTT							
NTT Tsugaru Maru	1969	1961	84.6	4.60	13.5	4000	1	320	650	50	3.3	2.5	1.8	5000	Lays and repairs all types of telephone cables.
NTT Kuroshio Maru	1974	3345	119.3	5.60	16.5	6883	3	887	1200	95	3.8	3.0	2.0	All	Laying by linear engine. Lays and repairs all types of telephone cables.
NTT Setouchi Maru	1979	819	64.8	3.50	12.0	3690	2	139	250	20	2.5	–	1.5	5000	Lays and repairs all types of telephone cables.
NTT Koyo Maru	1983	1295	74.0	43.50	13.5	4500	2	169	250	20	3.0	2.5	2.0	All	Laying by linear engine. Lays and repairs all types of telephone cables (especially optical cables).

Section 1 – CABLE SHIPS *(cont.)*

Name of ship	Year of construction	Displacement (tons)	Overall length (m)	Draft (m)	Normal speed (knots)	Range (autonomy) (nautical miles)	Number of tanks	Cable capacity			Cable gear			Maximum operating depth (m)	Capability
								Cable		Repeaters	Forward cable drum (diameter) (m)	Unwinding pulley			
								Cubic metres (m^3)	Weight (tons)			Bow sheave (diameter) (m)	Stern sheave (diameter) (m)		
						UNITED KINGDOM									
						1. Ships belonging to British Telecom (Marine) Limited									
Alert	1961	9477	130	7.1	14	10 000	3	1509	3100	48	2.98	2.98	2.98	All	Laying by linear engine and sea-bed burial by plow. Lays/repairs all types of coaxial and optical fibre cables.
Monarch	1975	4639	97	5.5	14	7000	4	417	850	12	3.00	3.00	None	All	Lays/repairs armoured coaxial and optical fibre cables. Repairs lightweight coaxial and optical fibre cables. Detrenching/reburial by submersible jetting.
Iris	1976	4639	97	5.5	14	7000	4	417	850	12	3.00	3.00	None	All	Lays/repairs armoured coaxial and optical fibre cables. Repairs lightweight coaxial and optical fibre cables.
						2. Ships belonging to Cable & Wireless (Marine) Limited									
Retreiver	1961	5650	112	5,82	13	8000	3	629	1568	11	3.0	3.0	Shute 3.05	All	Lays/repairs armoured cables. Repairs lightweight cables.
Northern	1962	3363	83.5	5.3	10	7200	3	480	1000	3	3.0	3.0	None	3500	Bow only, repair ship.

Note – Only relatively short cables are laid and only shore-ends.

Name of ship	Year of construction	Displacement (tons)	Overall length (m)	Draft (m)	Normal speed (knots)	Range (autonomy) (nautical miles)	Number of tanks	Cable capacity			Cable gear			Maximum operating depth (m)	Capability
								Cable		Repeaters	Forward cable drum (diameter) (m)	Unwinding pulley			
								Cubic metres (m^3)	Weight (tons)			Bow sheave (diameter) (m)	Stern sheave (diameter) (m)		
2. Ships belonging to Cable & Wireless (Marine) Limited (cont.)															
Cable Venture	1962	16 983	153	8.97	12.5	10 000	4+1 (spare)	5086	9000	400	2.80	3.00	3.39	All	Laying by linear cable engine. Lays and repairs armoured and lightweight coaxial cables.
Mercury	1962	11 683	144	7.5	14.5	8000	3	2970	3500	144	3.05	3.50	Shute 3.05	All	Ditto
Cable Enterprise	1964	5759	113	5.84	13	8000	3	887	2150	30	2.8	3.00	Shute 3.05	All	Lays/repairs armoured cables. Repairs lightweight cables. (See Note)
Cable Protector	1976	4608	86	4.7	10.0	7200	2	1272	1060	Nil	Nil	Nil	3.00	1000	2.6 m stern cable drum and small LCE.
Pacific Guardian	1984	7526	116	6.32	14.0	8000	3	1416	3470	96	3.5	3.00	3.00	All	Laying by linear cable engine. Lays and repairs armoured and lightweight coaxial cables.
UNITED STATES OF AMERICA															
Ships belonging to AT&T															
Charlie Brown	1952	2881	99.9	5.8	15	7000	3	660	2122	–	3.66	3.66	N/A	All	Repairs all types of telephone cables. Lays short and shore systems.
Long Lines	1963	11 326	156	7.9	15	10 000	3	4420	7000	125	3.66	3.05	3.66	All	Lays/repairs all types of telephone cables.

Note – Only relatively short cables are laid and only shore-ends.

Type of submersible	Displacement (tons)	Overall length (m)	Width (m)	Height	Trenching system	Trenching	Propulsion	Max. operating depth (m)	Capability
					FRANCE				
Submersible plough system	23	9.06	3	2.90	Ploughshare	Immediate burial of cable (up to 0.7 m) on ploughing	Towed by support ship	950	Lay and bury cables and small pipes.
Self-advancing buried system	11.3	5.50	2.45	3.50	Trenching wheel or chain	Burial of existing cables down to 2 m	Tracked vehicle	150	Burial of cables and pipes.
					JAPAN *1. Submersibles belonging to KDD*				
KS-2 cable plough	9.3	11.2	2.56	2.0	–	Immediate burial of cable on ploughing	Towed by support ship	200	Lay and bury cable in one action.
MARCAS crawler	4.7	4.0	3.0	2.15	Fluidisation jets	Fluidisation jets	Track drive	200	Trench in existing cable.
MARCAS-2500	3.6	2.65	1.8	1.9	Fluidisation jets	Fluidisation jets	2 vertical and 4 horizontal thrusters	2500	Post-lay burial, maintenance of cable and survey of senbed.
					2. Submersibles belonging to NTT				
Plough-type Mark IV submarine cable burying system	16.8	8.4	4.0	4.0	–	Up to 1.5 m depth, immediate burial of cable on ploughing	Towed by support ship	500	Simultaneous or post-lay burial of cable.
Self-advancing burying system	3.5	3.4	2.3	1.8	Fluidisation, and cutting jets, and dredge pump	Up to 1.5 m depth with cutting and fluidisation jets	Self-advancing by water jets	40	Trench in existing cable.

Type of submersible	Displacement (tons)	Overall length (m)	Width (m)	Height (m)	Tranching system	Trenching	Propulsion	Max. operating depth (m)	Capability
				UNITED KINGDOM *1. Submersibles belonging to British Telecom (Marine) Ltd.*					
Submersible trencher	17.0	6.6	4	3.4	Fluidisation and cutting jets and dredge pump	Up to 1 m depth with cutting and fluidisation jets	Three vertical and four horizontal thrusters, track drive differential steering	274	Trench in existing cable and pipe.
Submersible plough system	9.75	6.1	2.6	2.6	Ploughshare preceded by disc	Immediate burial of cable on ploughing	Towed by support ship	900	Lay and bury cable, umbilical and pipe in one action giving full cable protection.
Modular plough system	40	14	6	4.5	Ploughshare preceded by disc	Immediate burial of cable on ploughing	Towed by support ship	350	Simultaneous or post lay burial of cable and umbilicals post lay burial of pipeline.
				2. Submersibles belonging to Cables & Wireless (Marine) Ltd.					
Remote control submersible, Cirrus	3.2	3.5	2.1	2.3	Water jets	Trenching capability 0.3 m	Thrusters (7)	1000	Visual inspection cable location/inspection/ deburial. Manipulation.
CWM sea bed plough	12.0	7.2	4.0	2.5	Passive blade	Trenching capability 0.9 m	Towed	1000	Steerable. Backfill Capability Partial Repeater burial.

Type of submersible	Displacement (tons)	Overall length (m)	Width (m)	Height (m)	Tranching system	Trenching	Propulsion	Max. operating depth (m)	Capability
				UNITED STATES OF AMERICA					
Sea plough IV A	–	–	–	–	–	–	–	–	Plough trench 16" wide to maximum 24" depth.
Sea plough V	–	–	–	–	–	–	–	–	Same as *sea plough IV A*.
Scarab I/II	–	–	–	–	–	–	–	–	Multi owners used for maintenance.

Supplement No. 14

METHODS FOR MEASURING REGULARITY RETURN LOSS

(referred to in Recommendation G.623;
this Supplement is to be found on page 669 of Fascicle III.3
of Orange Book, Geneva, 1977)

Supplement No. 18

INFORMATION ON SUBMARINE CABLES USED IN DEEP WATER

(referred to in Subsection 6.3;
this Supplement is to be found on page 313 of Fascicle III.2
of the Red Book, Geneva, 1985)

Supplement No. 19

DIGITAL CROSSTALK MEASUREMENT (METHOD USED BY THE ADMINISTRATIONS OF FRANCE, THE NETHERLANDS AND SPAIN)

(referred to in Recommendation G.612;
this Supplement is to be found on page 326 of Fascicle III.2
of the Red Book, Geneva, 1985)

Supplement No. 33

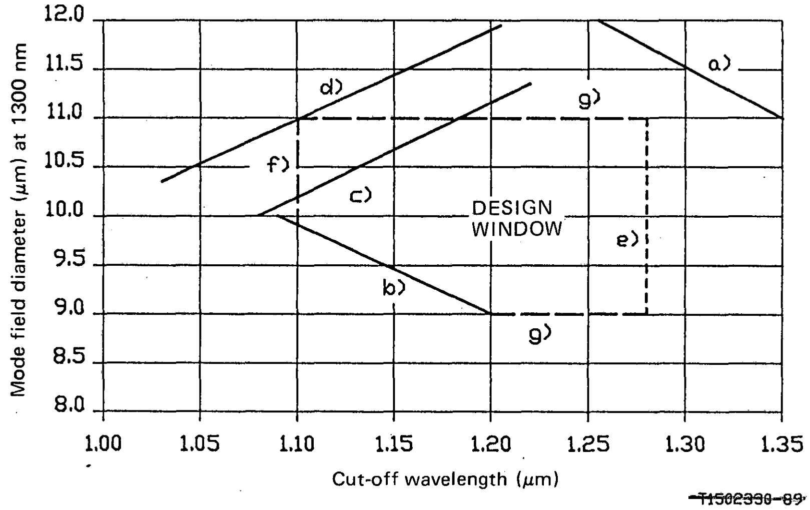
EXAMPLES OF FIBRE DESIGN GUIDELINES

(Diagrams used in Japan and in the United Kingdom)
(referred to in Recommendations G.652 and G.654)

The following two diagrams provide and overview of the characteristics of two particular types of fibre. The aim of these diagrams is to give guidance to potential fibre users when preparing optical fibre specifications.

Figure 1, which is used in Japan and in the United Kingdom, gives empirically determined relationships between mode field diameter and cut-off wavelength, as independent variables, with 1550 nm bend loss performance and chromatic dispersion coefficients at 1285 nm and 1330 nm for matched-clad, single-mode fibre compliant with Rec. G.652. Two types of 1550 nm bend loss performance tests are described, the Rec. G.652 test (37.5 mm radius mandrel/100 turns, maximum loss 1.0 dB) and the test most commonly specified in the United Kingdom (30 mm radius mandrel/10 turns, maximum loss 0.2 dB).

Figure 2, which is used by KDD, Japan, gives relationships between mode field diameter and cut-off wavelength with theoretical 1550 nm bend loss performance and various chromatic dispersion coefficients. This information is for matched-clad, single-mode fibre which is compliant with Rec. G.654.



a) Dispersion coefficient +3.5 ps/nm · km at 1330 nm.

b) Dispersion coefficient −3.5 ps/nm · km at 1285 nm.

c) Bend loss of 0.2 dB at 1550 nm on 30 mm radius mandrel/10 turns.

d) Bend loss of 1.0 dB at 1550 nm on 37.5 mm radius mandrel/100 turns.

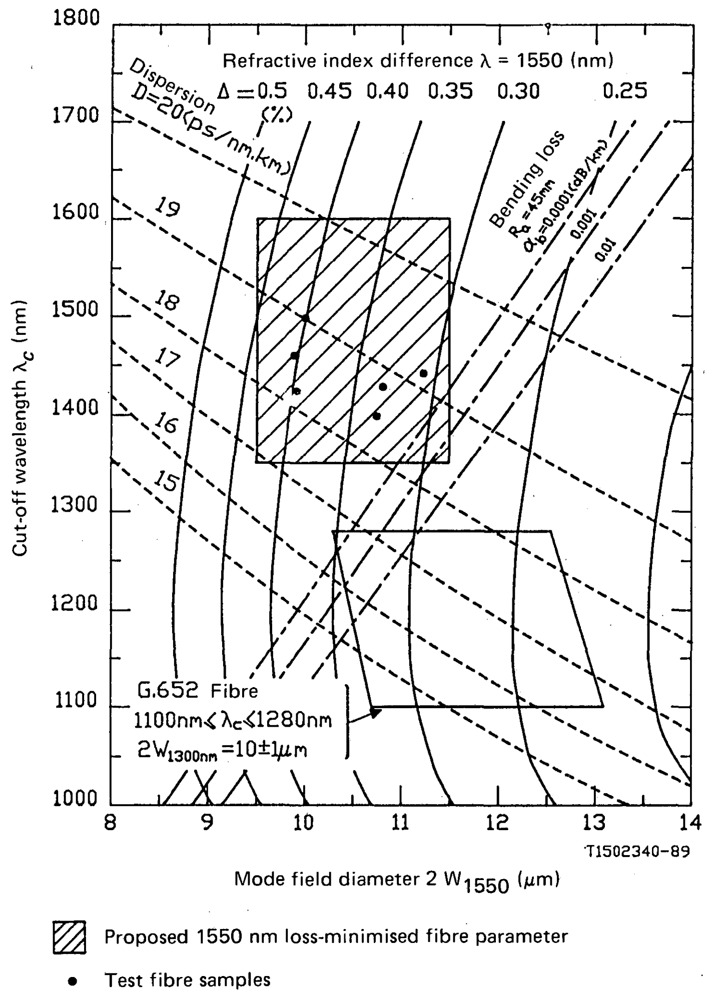
e) Upper limit for cut-off wavelength λ_c (1280 nm).

f) Lower limit for cut-off wavelength λ_c (1100 nm).

g) G.652 limits for mode field diameter (10 ± 1 μm).

FIGURE 1

Design guidelines for matched-clad, single-mode fibres
(Rec. G.652)



Equi-bending loss α_b, dispersion D and refractive index Δ curves at wavelength of 1550 nm as parameters of the mode field diameter 2 W and cut-off wavelength λ_c.

Note – The mode field diameter at 1300 nm (2 $W_{1300\ nm}$ = 10 ±1 μm) corresponds approximately to a mode field diameter 2 $W_{1550\ nm}$ at 1550 nm between 10.5 μm and 13 μm as shown in Figure 2.

FIGURE 2

Design guideline for 1550 nm loss-minimized single-mode fibre
(Rec. G.654)

ISBN 92-61-03331-8