
British Standard

Optical fibres and cables

Part 1. Specification for general requirements

Fibres optiques et câbles
Partie 1. Prescriptions générales

Optische Fasern und Kabel
Teil 1. Allgemeine Anforderungen

Foreword

This Part of BS 6558 has been prepared under the direction of the Electronic Components Standards Committee.

This Part specifies the general requirements and describes the methods of test for optical fibres and cables. The requirements for specific classes of optical fibres and cables are specified in other Parts of BS 6558.

There is no significant optical radiation hazard to the public from the use of fibre optic systems. However, there may be hazards to personnel involved in testing, installation or maintenance procedures and attention is drawn to the safety aspects discussed in appendix A.

This British Standard does not specify requirements for the establishment of quality assurance by quality control procedures which will ensure that the product will comply with this standard and this is usually the responsibility of the manufacturer. It is not intended that all tests listed should be carried out on every length of optical fibre or cable manufactured, but that a suitable quality plan should be agreed for the particular product and application, by the time of ordering.

Certain requirements and methods of test in this new field are still at the development stage. At present they are given in the appropriate appendices. When suitable methods of test have been developed, these requirements will be incorporated into the main body of the standard.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Contents

	Page		Page
Foreword		Inside front cover	
Committees responsible		Back cover	
Section one. General		Figures	
1.1 Scope	2	1 Classes of multimode fibre	5
1.2 Definitions	2	2 Maximum permissible average power emitted by class 1 products for continuous viewing	9
Section two. Optical fibres		3 Flow chart for hazard evaluation	11
2.1 Classification of optical fibres	5	4 Mask for four concentric circles test	14
2.2 Fibre properties	5	5 Test arrangements for measurement of fibre length by propagation time of optical pulses	15
2.3 Fibre dimensions	5	6 Test arrangement for spot wavelength attenuation using the cut-back method	17
2.4 Transmission and optical characteristics	6	7 Test arrangement for spectral attenuation measurements using the cut-back method	17
2.5 Mechanical characteristics	6	8 Test arrangements for insertion loss measurements	19
2.6 Packaging	6	9 Backscattering measurements	20
Section three. Optical fibre cables		10 Test arrangement for impulse response measurements	22
3.1 Materials	7	11 Test arrangement for frequency response measurements	22
3.2 Cable construction	7	12 Typical acceptance and radiation angle results for 100 µm A2.1 fibre	24
3.3 Cable dimensions	7	13 Example of suitable launch optics for radiation angle measurements	26
3.4 Transmission and optical characteristics	7	14 Examples of suitable fibre holders for radiation angle measurements	27
3.5 Electrical characteristics	7	15 Layout of radiation angle test apparatus at output end of fibre	29
3.6 Mechanical characteristics	8	16 Example of XY plotter output for radiation angle test	30
3.7 Environmental resistance	8	17 Radiation angle test: example of angular dependence of far field power from launch spot	31
3.8 Identification	8	18 Radiation angle test: example of near field scan of launch spot	32
3.9 Packaging	8	19 Schematic diagram of refractive index profile test method	33
Appendices		20 Typical optical arrangement for refractive index profile measurements	34
A Safety aspects of optical fibre systems for telecommunications	9	21 Block diagram of electronic arrangement for refractive index profile measurements	36
B Preferred fibre dimensions	12	22 Propagation geometry for refractive index profile test	37
C Dimensional tests	12	23 Test arrangement for measurement of change in optical transmittance	38
D Optical tests	16	24 Optical fibre fracture strength and crack size	40
E Mechanical tests	39	25 Apparatus for constant stress proof test	41
F Environmental tests	53	26 Apparatus for constant strain proof test	41
Tables		27 Apparatus for bending strain proof test	41
1 Classes of multimode fibre	5	28 Apparatus for cable abrasion test	42
2 Dimensional tests for optical fibres	6	29 Apparatus for cable tensile test	43
3 Optical tests for optical fibres	6	30 Apparatus for cable bend test	45
4 Dimensional tests for optical fibre cables	7	31 Apparatus for cable cyclic bend test	46
5 Optical tests for optical fibre cables	7	32 Apparatus for cyclic bend test for cable assembly with connector	46
6 Electrical tests for optical fibre cables	7	33 Apparatus for cable flexing test	47
7 Mechanical tests for optical fibre cables	8	34 Apparatus for cable torque test	48
8 Environmental tests for optical fibre cables	8	35 Apparatus for cable impact test	49
9 Maximum permissible average power emitted by class 1 products for continuous viewing	10	36 Apparatus for cable crush test	51
10 Examples of minimum safe viewing distance for multimode fibre to meet the MPE limits	10	37 Apparatus for cable snatch test	52
11 Preferred fibre dimensions	12		
12 Error caused by refraction within cover glass window	30		

Index to methods of test

Section one. General

1.1 Scope

This Part of BS 6558 specifies the general requirements and describes the methods of test for optical fibres and for cables that may contain one or more optical fibres or a combination of optical fibres and electrical conductors.

NOTE 1. For information on safety aspects of optical fibre systems, see appendix A.

NOTE 2. The titles of the publications referred to in this standard are listed on the inside back cover.

1.2 Definitions

For the purposes of this Part of BS 6558 the following definitions apply.

1.2.1 acceptance angle. For a uniformly illuminated optical waveguide, half the vertex angle of that cone within which the power coupled into a waveguide is 99 % of the total power coupled into the waveguide.

NOTE. The maximum theoretical acceptance angle, θ_A , is given by:

$$\sin \theta_A = \frac{n_1^2 - n_2^2}{n}$$

where

n_1 is the maximum refractive index of the fibre core;

n_2 is the refractive index of the cladding;

n is the refractive index of the homogeneous isotropic space that contains the specified point.

1.2.2 attenuation. The diminution of signal optical power.

NOTE. The attenuation between two points, $A(\lambda)$, in decibels is usually expressed as:

$$A(\lambda) = -10 \log_{10} \frac{P_2}{P_1}$$

where

P_1 is the optical power at point 1;

P_2 is the optical power at point 2;

λ is the wavelength.

1.2.3 attenuation coefficient. For a uniform fibre under equilibrium conditions, the attenuation coefficient, $\alpha(\lambda)$, in dB per unit length is given by:

$$\alpha(\lambda) = -\frac{10 \log_{10} \left(\frac{P_2}{P_1} \right)}{L}$$

where

P_1 is the optical power at point 1;

P_2 is the optical power at point 2;

λ is the wavelength;

L is the distance along the waveguide separating the cross sections 1 and 2.

NOTE. The attenuation coefficient, α , is generally expressed in dB/km, assuming linear length dependence.

1.2.4 bandwidth. The lowest frequency at which the magnitude of the fibre transfer function decreases to a specified fraction of the zero frequency value.

NOTE. The specified fraction is very often the point at which the optical power is one half of that at zero frequency, i.e. 3 dB down. For purposes of measurement (see 1.2.3) it is also the -6 dB electrical point of the amplitude v frequency characteristic (see also 1.2.5).

1.2.5 baseband response. A complex transfer function of both magnitude and phase, equal to the ratio of output to input power as a function of modulation frequency.

NOTE. The frequency response, $G(\omega)$, is the function given by:

$$G(\omega) = \frac{P_2(\omega)}{P_1(\omega)}$$

where

$P_1(\omega)$ is the power spectrum of the modulation signal at cross section 1 (normally at the input);

$P_2(\omega)$ is the power spectrum of the modulation signal at cross section 2 (normally at the output).

The amplitude and phase responses are the absolute value and argument of $G(\omega)$ respectively.

1.2.6 cladding. The dielectric material surrounding the core of an optical fibre.

1.2.7 cladding centre. The centre of the smallest circle within which the whole of the cladding can be contained (see also C.1.1).

1.2.8 cladding diameter. The diameter of the circle defining the cladding centre (see also C.1.1).

1.2.9 core to cladding concentricity error. The distance between the core and cladding centres divided by the core diameter and expressed as a percentage.

1.2.10 core to reference surface concentricity error.

The distance between the core centre and the reference surface centre divided by the nominal core diameter and expressed as a percentage.

1.2.11 core. The centre region of an optical waveguide having a refractive index higher than that of the cladding through which it is intended that the majority of the optical power be transmitted.

NOTE. For the measurement of core dimensions as described in C.1.1., the core is the smallest cross-sectional area of a fibre, excluding any centre dip, contained within the locus of points where the refractive index n_3 is given by:

$$n_3 = n_2 + k(n_1 - n_2)$$

where

n_1 is the maximum refractive index of the fibre core;

n_2 is the refractive index of the cladding;

k is a constant. (For multimode fibres, $k = 0.05$.)

1.2.12 core centre. The centre of the smallest circle within which the whole of the core can be contained.

1.2.13 core diameter. The diameter of the circle defining the core centre.

1.2.14 equilibrium mode distribution. The distribution of power among the modes after transmission through a requisite length of multimode optical waveguide such that thereafter, in distance, the relative power distribution among the various modes remains constant.

NOTE. The requisite length, which typically varies from several hundred metres to a few kilometres, is dependent upon various parameters of the waveguide, the wavelength and the initial launching conditions.

1.2.15 equilibrium mode simulator (EMS). A device used to create an approximation of the equilibrium mode distribution (see 1.2.14).

1.2.16 fibre buffer. A material or materials that may be used to protect an individual optical fibre waveguide from physical damage or distortion, providing mechanical isolation and/or protection.

1.2.17 fibre bundle. An assembly of unbuffered optical fibres usually used as a single transmission channel.

1.2.18 fibre break. A discontinuity that divides a single length of fibre and gives rise to an increase in the loss of optical power transmitted between the ends of the fibre.

NOTE. Fibre breaks arise from mechanical stress applied to the fibre.

1.2.19 graded index optical fibre. A waveguide whose core has a graded index profile (see 1.2.20; see also 1.2.39).

1.2.20 graded index profile. Any refractive index profile that varies smoothly with radius and is usually near parabolic, as distinguished from a step index profile (see 1.2.40; see also 1.2.39).

1.2.21 impulse response. The function $g(t)$ describing the response of an initially relaxed system to an applied impulse.

1.2.22 maximum theoretical numerical aperture. The square root of the difference of the squares of the maximum refractive index (n_1) of the fibre core and the refractive index (n_2) of the fibre cladding, i.e.:

$$\sqrt{(n_1^2 - n_2^2)}$$

(see also 1.2.30).

1.2.23 microbending loss. The attenuation arising in an optical waveguide, due to sharp curvatures involving local axial displacements of a few micrometres and spatial wavelengths of a few millimetres.

NOTE. Such bends may result from waveguide coating, cabling, packaging, installation, etc.

1.2.24 minimum bore. For connecting purposes, the minimum bore diameter in a joint or connector required to enable it to accommodate an optical fibre.

NOTE. For most multimode optical fibres, the minimum bore will normally be the reference surface diameter on the maximum tolerance, together with a small allowance for clearance purposes.

1.2.25 mode. One of the allowed electromagnetic field distributions.

NOTE. The field pattern of a given mode depends on the wavelength, refractive index and waveguide geometry.

1.2.26 monomode optical fibre. An optical fibre that is only capable of sustaining the propagation of a single mode at a given wavelength.

1.2.27 multimode optical fibre. An optical fibre that is capable of sustaining the propagation of more than one mode at a given wavelength.

1.2.28 multifibre cable. An optical cable that contains two or more optical fibres, each of which provides a separate information channel. It may contain electrical conductors in addition to optical fibres.

1.2.29 non-circularity. In the case of core non-circularity, the difference in length between two chords each passing the core centre, one chord ($D_{co,max.}$) connecting the most distantly separated points on the core/cladding interface and the other chord ($D_{co,min.}$) connecting the most closely separated points on the core/cladding interface, divided by the nominal core diameter, D_{co} , and expressed as a percentage, i.e.:

$$\frac{D_{co,max.} - D_{co,min.}}{D_{co}} \times 100$$

NOTE. Similar expressions apply for reference surface and cladding non-circularity.

1.2.30 numerical aperture (NA). The property given by:

$$NA = n \sin \theta$$

where

θ is, at a specified point, half the vertex angle of the largest cone of meridian rays that can enter or leave an optical element or system;

n is the refractive index of the homogeneous isotropic space that contains the specified point.

NOTE 1. The specified point is usually an object or image point.

NOTE 2. The term 'numerical aperture' is sometimes used imprecisely to describe an optical waveguide. The precise term 'acceptance angle' is preferred (see 1.2.1; see also 1.2.34 and 1.2.35).

1.2.31 optical fibre cable. A fibre, multiple fibres, or fibre bundle in a structure fabricated to comply with optical, mechanical and environmental specifications.

1.2.32 optical fibre. Any filament or fibre made of dielectric materials that guides light whether or not it is used to transmit signals.

1.2.33 primary coating. The coating applied in intimate contact with the cladding surface, to retain the initial integrity of that surface.

1.2.34 radiation angle. Half the vertex angle of the cone of light emitted from a fibre.

NOTE. For purposes of practical measurement (see D.4), the cone is that containing a specified proportion of the power radiated from the output end of the fibre under specified launch conditions applied to the input end.

1.2.35 radiation pattern. The output radiation of an optical waveguide or source as a function of angle or distance from the axis of the waveguide or source.

NOTE. Far field radiation pattern is normally specified as a function of angle. Near field radiation pattern is normally specified as a function of distance from the waveguide or source.

1.2.36 reference surface. The quasi-cylindrical outer surface of the optical fibre or the cladding to which reference is made for connecting purposes.

NOTE. In many cases the reference surface is the quasi-cylindrical outer surface of the cladding and in other cases it may include the primary coating.

1.2.37 reference surface centre. The centre of the smallest circle within which the whole of the reference surface can be contained (see C.1.1).

1.2.38 refractive index profile. The distribution of the refractive index across a straight line perpendicular to and through the core axis.

1.2.39 step index optical fibre. An optical waveguide having a step index profile.

1.2.40 step index profile. A refractive index profile characterized by a nominally uniform refractive index within the core and a sharp decrease in refractive index at the core/cladding interface.

1.2.41 waveguide. A transmission line consisting of a system of material boundaries or structures for guiding electromagnetic waves.

Section two. Optical fibres

2.1 Classification of optical fibres

2.1.1 Class A: multimode fibres

Multimode fibre classes shall be based on the refractive index profile parameter α given in the following equation:

$$\delta(x) = 1 - x\alpha$$

where

$$\delta(x) = \frac{n(x) - n(1)}{n(0) - n(1)};$$

$n(x)$ is the refractive index at x ;

$$x = \frac{r}{a} \quad (0 \leq r < a);$$

a is the core radius.

Multimode fibres shall be classed as given in table 1 and as shown in figure 1.

2.1.2 Class B: monomode fibres

NOTE. The basis for the classification of monomode fibres is under consideration.

2.2 Fibre properties

2.2.1 Fibre materials

Fibres shall be dimensionally uniform and free from lumps, kinks, splits, scraped or abraded surfaces and inclusions.

2.2.2 Fibre characteristics

The construction and dimensions and mechanical, optical and environmental properties of each type of optical fibre shall be as specified in the relevant Part of BS 6558.

2.3 Fibre dimensions

The dimensions and geometrical characteristics of optical fibres shall be determined by subjecting samples to tests selected from table 2. The tests applied and the fibre dimensions, non-circularities and concentricity error shall be within the tolerances specified in the relevant Part of BS 6558.

NOTE. Details of preferred fibre dimensions are given in appendix B.

Table 1. Classes of multimode fibre				
Class	Index type	Material		Limits of α
		Core	Cladding	
A1	Graded	Glass	Glass	$1 \leq \alpha < 3$
A2.1	Quasi-step	Glass	Glass	$3 < \alpha < 10$
A2.2	Step	Glass	Glass	$10 \leq \alpha < \infty$
A3	Step	Glass	Plastics	$10 \leq \alpha < \infty$
A4	Step	Plastics	Plastics	—

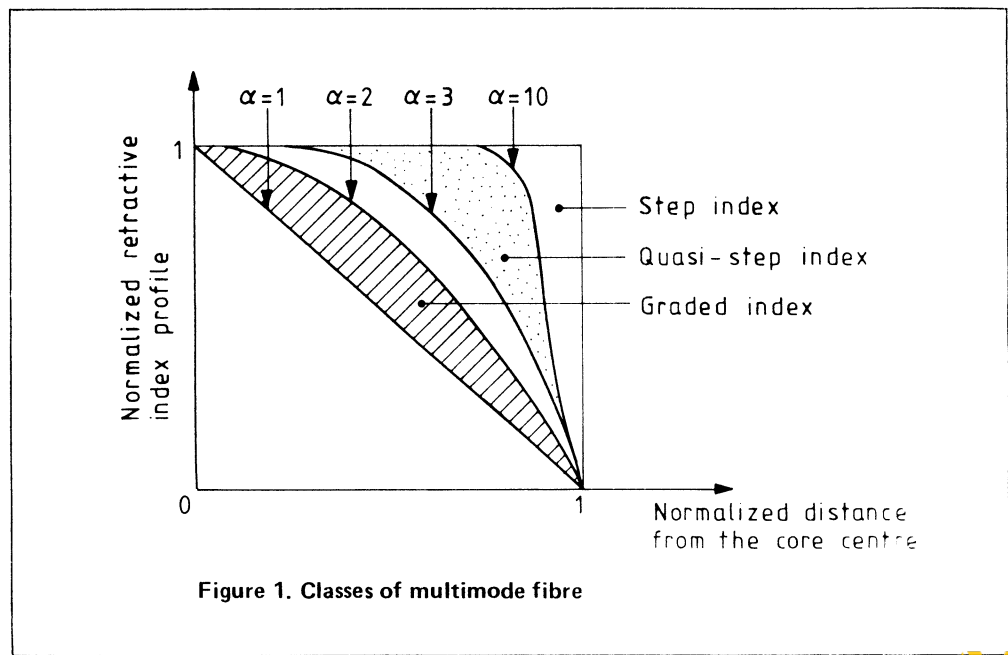


Figure 1. Classes of multimode fibre

Table 2. Dimensional tests for optical fibres

Test	Method reference
Diameter of fibre core	C.1
Diameter of fibre cladding	C.1
Diameter of fibre buffer	C.1
Diameter of fibre primary coating	C.1
Fibre core non-circularity	C.1
Non-circularity of fibre reference surface	C.1
Fibre core/reference surface concentricity error	C.1
Fibre length	C.2

2.4 Transmission and optical characteristics

The transmission and optical characteristics of optical fibres shall be verified by carrying out tests selected from table 3. The tests applied and the acceptance criteria shall be as specified in the relevant Part of BS 6558.

Table 3. Optical tests for optical fibres

Test	Method reference
Attenuation	D.1
Bandwidth	D.3
Radiation angle	D.4
Refractive index profile	D.5
Optical continuity	D.6

2.5 Mechanical characteristics

If specified in the relevant Part of BS 6558, the mechanical characteristics of optical fibres shall be verified by carrying out a proof test in accordance with E.1.

2.6 Packaging

If specified in the relevant Part of BS 6558, the optical fibre shall be wound so that both ends of the fibre are available for purposes of test and/or inspection.

NOTE. The optical fibre should be wound so that it can withstand normal transport and environmental conditions.

Section three. Optical fibre cables

3.1 Materials

3.1.1 Fibre material

Fibres shall be dimensionally uniform, free from lumps, kinks, splits, scraped or abraded surfaces and inclusions and shall comply with the requirements of section two.

3.1.2 Other materials

Materials used in the construction of optical fibre cables shall not affect the physical or optical properties of the fibres and shall be compatible with each other.

3.1.3 Electrical conductors

Any electrical conductors shall be uniform in quality and free from defects and shall comply with BS 3573, BS 4109, BS 4808 or BS 6360, as appropriate.

3.2 Cable construction

The construction, dimensions and mass and mechanical, optical, electrical and environmental properties of each type of optical fibre cable shall be as specified in the relevant Part of BS 6558.

3.3 Cable dimensions

The dimensions of the fibres, electrical conductors and cables shall be determined by subjecting samples to tests selected from table 4. The tests applied, the number of samples and the acceptance criteria shall be as specified in the relevant Part of BS 6558.

3.4 Transmission and optical characteristics

The optical and transmission characteristics of fibres in optical fibre cables shall be verified by carrying out tests

selected from table 5. The tests applied and the acceptance criteria shall be as specified in the relevant Part of BS 6558.

Table 5. Optical tests for optical fibre cables

Test	Method reference
Attenuation	D.1
Bandwidth	D.3
Radiation angle	D.4
Refractive index profile	D.5
Optical continuity	D.6

3.5 Electrical characteristics

When electrical conductors are incorporated in an optical fibre cable, various electrical characteristics shall be verified, where specified in the relevant Part of BS 6558, by carrying out tests selected from table 6. The tests applied and the acceptance criteria shall be as specified in the relevant Part of BS 6558.

Table 6. Electrical tests for optical fibre cables

Test	Method reference
Conductor resistance	BS 6360
Voltage	BS 6004
Insulation resistance	BS 6004

Table 4. Dimensional tests for optical fibre cables

Test	Method reference
Diameter of fibre core	C.1
Diameter of fibre reference surface	C.1
Diameter of fibre buffer	C.1
Diameter of fibre primary coating	C.1
Fibre core non-circularity	C.1
Non-circularity of fibre reference diameter	C.1
Fibre core/reference diameter concentricity error	C.1
Diameter of electrical conductors	BS 6360 and BS 4808
Thickness of insulation	BS 6004 and BS 4808
Thickness of sheath	BS 6004 and BS 4808
Diameter of finished cable	BS 6004 and BS 4808
Length of finished cable	C.3

3.6 Mechanical characteristics

The ability of the optical fibre cable construction to withstand mechanical hazards and protect the optical fibres and electrical conductors from damage shall be verified by subjecting samples to tests selected from table 7. The tests applied and the relevant severity, duration, acceptance criteria and number of samples for each test shall be as specified in the relevant Part of BS 6558.

Table 7. Mechanical tests for optical fibre cables	
Test	Method reference
Abrasion	E.2
Tensile	E.3
Bend	E.4
Cyclic bend	E.5
Flexing	E.6
Torque	E.7
Impact	E.8
Crush	E.9
Snatch	E.10

3.7 Environmental resistance

The ability of an optical fibre cable to comply with environmental requirements without deterioration of its physical or optical properties shall be verified by subjecting samples to tests selected from table 8. The test applied, the relevant temperatures, the number of samples and the acceptance criteria shall be as specified in the relevant Part of BS 6558.

3.8 Identification

Identification of individual fibres, electrical conductors and the cable shall be as specified in the relevant Part of BS 6558.

3.9 Packaging

Means shall be provided to prevent movement of the cable during transport.

Cable ends shall be sealed against the ingress of moisture. Both ends of the cable shall be available for test and inspection if specified in the relevant Part of BS 6558.

NOTE. The cable should be wound so that it can withstand normal transport and environmental conditions.

Table 8. Environmental tests for optical fibre cables	
Test	Method reference
Mould growth	BS 2011 : Part 2.1J
Solar radiation	BS 2011 : Part 2.1Sa (Procedure B)
Flame retardance	F.2.8

Appendices

Appendix A. Safety aspects of optical fibre systems for telecommunications

A.1 Introduction

With optical fibre transmission systems operating in the visible or near infra-red wavelength bands, there is a possibility of damage to the human eye. There is no significant optical radiation hazard to the public from the use of optical fibre systems at the present time, or in the foreseeable future. However, there may be hazards to personnel involved in testing, installation, or maintenance procedures.

These may arise from:

- (a) high levels of optical radiation damaging the eyes; or
- (b) direct injury by fibres or particles of fibres, particularly to the eyes.

A.2 Safety requirements and hazard evaluation

A.2.1 Optical radiation

The radiation safety of laser products, or systems utilizing laser products, is covered by BS 4803 : Parts 1 to 3. For the purpose of this specification, the same requirements and recommendations should be applied to other optical sources, such as LEDs (light emitting diodes) and IREDs (infra-red emitting diodes), where these are used in optical fibre systems for telecommunications or data transmission.

Class 1 products, i.e. those that are inherently safe either because of their low power or their engineering design, may not emit average power levels in excess of those given in table 9 and figure 2.

It should be noted that these values have been calculated from average irradiance consideration. Where single pulses

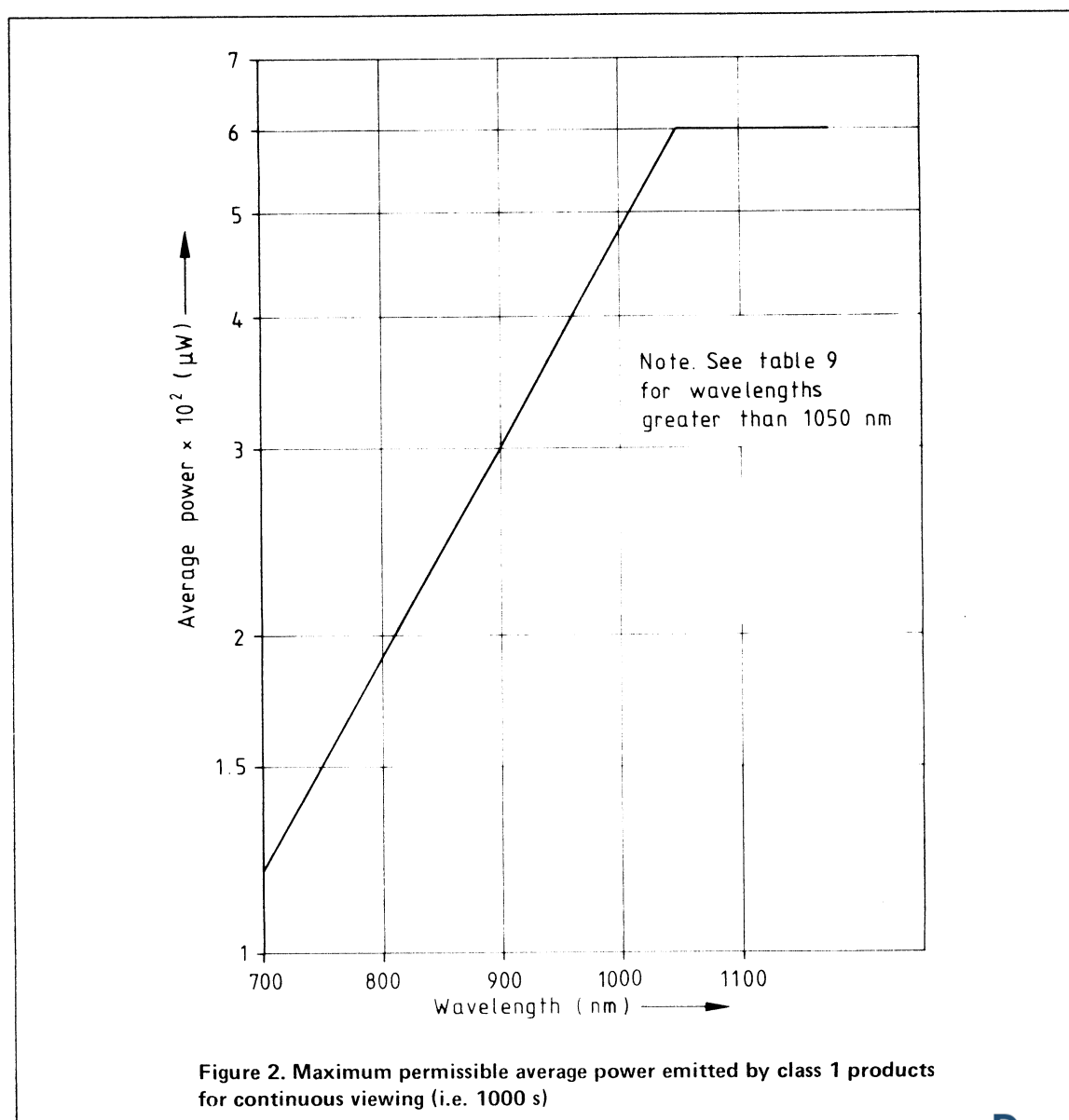


Table 9. Maximum permissible average power emitted by class 1 products for continuous viewing
(derived from the requirements of BS 4803)

Wavelength	Average power
nm	μW
750	150
850	240
900	300
1050 to 1400	600
> 1400	800

or single pulse trains with a high energy content are employed, for example as in time domain reflectometry (TDR) measurements, the maximum power permissible for class 1 classification should be calculated in accordance with BS 4803.

A.2.1.1 Divergent beam sources. With divergent beam sources, such as semi-conductor laser diodes, LEDs, IREDs,

and also radiation emitted from the ends of optical fibres, the closer the source is viewed, the greater is the irradiance at the eye.

Where output of a source exceeds the values stated in table 9, the device should not be viewed closer than the distance at which power in excess of the values in table 9 is measured within a 7 mm aperture.

For optical fibre ends, assuming a uniform conical radiation pattern and a given average power, a minimum safe viewing distance can be calculated (1), at which the maximum permissible exposure (MPE) limits will not be exceeded. Examples of minimum safe viewing distance for different radiation cone angles, average power levels and wavelengths are given in table 10.

A.2.1.2 Collimated beam sources. Collimated beams can be encountered, for example, where lasers are used, where lens couplers are employed or where lasers or fibre ends are viewed through optical instruments. For a truly collimated beam there is no significant reduction of power entering the eye as distance from the source is increased; hence if the power density in the launched beam is greater than the MPE, the arrangement should be considered a potential hazard. In practical situations, there will be some beam divergence and the minimum safe viewing distance should be calculated in accordance with BS 4803. The distance will

Table 10. Examples of minimum safe viewing distance for multimode fibre to meet the MPE limits

Wavelength	Average power	Minimum distance for continuous viewing					
		Step index fibres				Graded index fibres	
		$\sin \theta = 0.13$	$\sin \theta = 0.2$	$\sin \theta = 0.3$	$\sin \theta = 0.4$	$\sin \theta = 0.13$	$\sin \theta = 0.2$
nm	mW	mm	mm	mm	mm	mm	mm
750	0.3	37	24	16	12	53	34
	1.0	68	44	30	22	97	63
	3.0	118	76	51	38	167	109
850	0.3	30	19	12	10	42	27
	1.0	54	35	23	17	77	50
	3.0	94	61	41	30	133	86
900	0.5	34	22	15	12	48	31
	1.0	48	31	21	16	68	44
	3.0	84	54	36	27	118	77
1050 to 1400	1.0	34	22	15	11	49	32
	3.0	59	39	26	19	84	55
> 1400	1.0	4.3	2.8	1.9	1.4	6.1	4.0
	3.0	7.5	4.9	3.3	2.4	10.6	6.9

NOTE 1. The eye is virtually opaque to radiation at wavelengths greater than 1400 nm. Risk is limited to corneal damage.

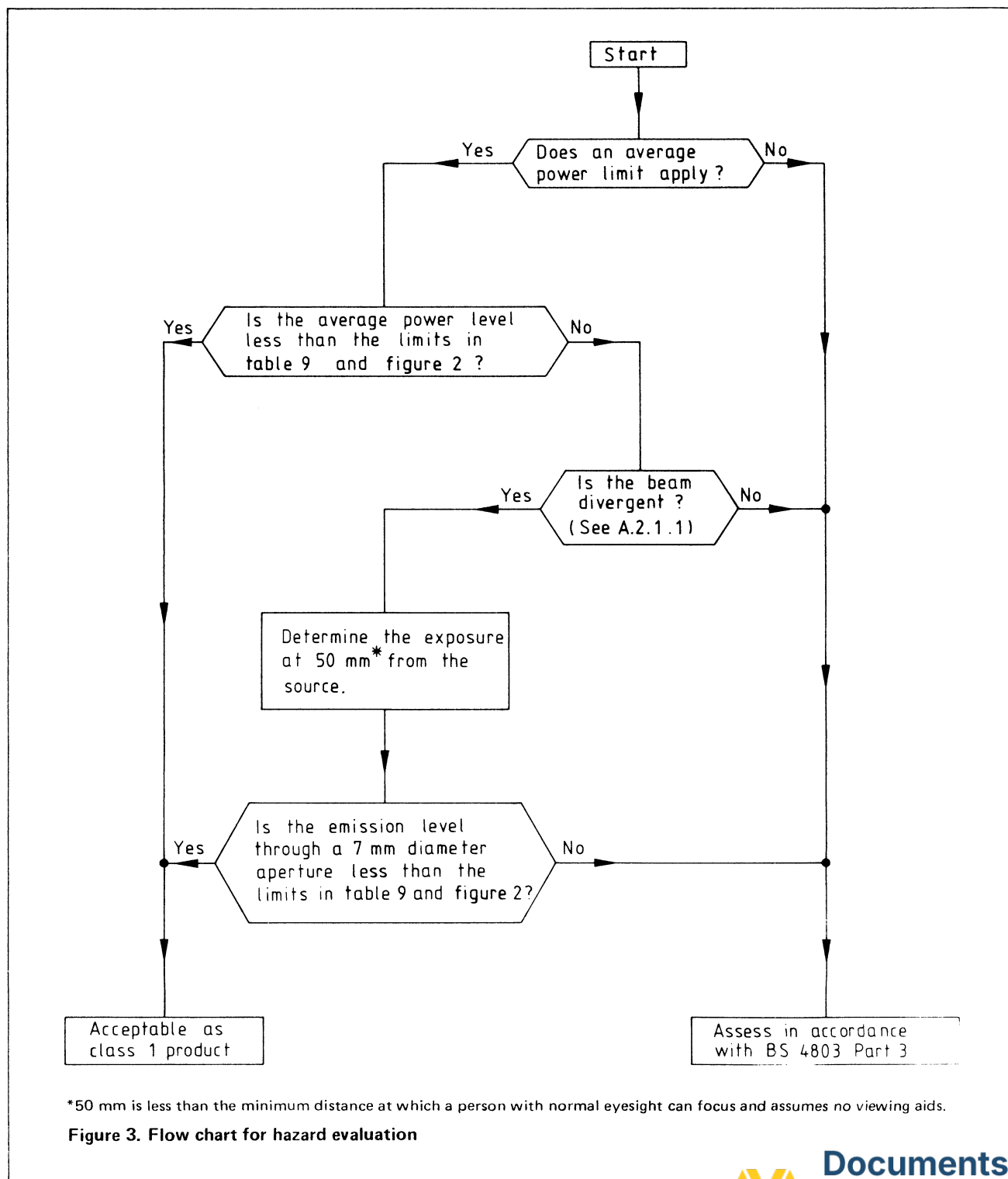
NOTE 2. θ is half the vertex angle of the radiation cone pattern.

be much larger than for truly divergent sources, assuming the same launched power, and is thus more likely to be within the focusing range of a normally-sighted person.

A.2.1.3 Focused radiation sources. Beam focusing is often used when carrying out measurements of optical sources and optical fibre parameters. If the power density

in the focused beam is greater than the MPE, then the arrangement should be considered a potential hazard.

A.2.1.4 Hazard evaluation procedure. The sequence shown in figure 3 should be followed when evaluating any optical radiation hazard from optical fibre systems or test equipment.



A.2.1.5 Skin damage by optical radiation. The risk of serious damage to the skin is insignificant. Normally, any person whose skin was exposed to an excess level of optical radiation would feel a sharp burning sensation, and be warned by that. However, because there is insufficient experience of the cumulative effects of skin exposure, personnel should not be exposed to high levels of optical radiation on a regular basis. (See BS 4803 and (2) for further information.)

A.2.2 Direct injury by fibres

As well as the possible hazards to the human eye from optical radiation, there is also some risk of direct injury from small lengths or particles of fibre, particularly during a cleaving operation. All personnel should be warned of this hazard. The use of protective guards or shields should be considered, especially during cleaving or jointing operations. Where practicable, discarded pieces of fibre should be collected in a suitable container to avoid them subsequently becoming embedded in clothing or skin.

References

1. Timmerman, C.C. Handling optical cables: safety aspects *Applied Optics*, 1977, **16**, (9), 2380–2382.
2. World Health Organization. Environmental Health Criteria 23, *Lasers and optical radiation*, 1982.

Appendix B. Preferred fibre dimensions

The preferred sizes of optical fibres are given in table 11 and should be compatible with connectors having the minimum bore dimensions given in table 11.

Sizes other than the preferred range are available from suppliers, and may be specified for certain applications with the agreement of the purchaser and the supplier.

Table 11. Preferred fibre dimensions

Fibre class	Nominal fibre dimensions		Minimum bore for connecting purposes
	Core	Reference diameter	
A1	µm 50	µm 125	µm 130
A2.1	50 100 100	125 140 250	130 150 260
A2.2	160 200	200 250	210 260
A3	200		210

Appendix C. Dimensional tests

C.1 Cross-sectional dimensions of optical fibres

C.1.1 Near field light distribution test

C.1.1.1 Principle. This test measures the cross-sectional dimensions of an optical fibre from an image of the fibre end magnified by a microscope. The image produced by the microscope may be viewed directly via the eye-piece or indirectly via television monitors, recorded as a photograph or displayed as a video image.

NOTE. These methods also provide practical measurement techniques for purposes of trade and commerce.

C.1.1.2 Reference test method. A reference test method against which these methods may be calibrated is the refracted ray near field technique described in D.5.

C.1.1.3 Preparation of test specimen. Prepare a test specimen that is a short length of fibre and record its length. Cut the ends of the specimen so that they are substantially flat across the whole cross section and normal to the axis of the fibre.

C.1.1.4 Apparatus

C.1.1.4.1 Optical source, incoherent and adjustable in intensity.

C.1.1.4.2 Microscope, with a resolution near to the diffraction limit and a magnification in the range of $\times 100$ to $\times 600$. A precision scale of warranted accuracy shall be used to calibrate the microscope.

NOTE. Inverted metallurgical or biological microscopes are acceptable.

C.1.1.4.3 Micrometer-controlled image-splitting eye-piece.

C.1.1.4.4 Television camera.

C.1.1.4.5 Photomicrographic camera, with a suitably calibrated scale for deriving the dimensional data, and a minimum photographic image of 30 mm $\times$ 30 mm.

C.1.1.4.6 Target vidicon, linked to an image display via a video digitizer that encodes grey levels along any selected line of the image.

C.1.1.5 Procedure

C.1.1.5.1 General. Mount the specimen in such a way that one end surface is in the object plane of the microscope (C.1.1.4.2) and the other is uniformly illuminated by the optical source (C.1.1.4.1).

NOTE. Index matching materials may be used in coupling the output of the optical source to the specimen and the intensity of the source adjusted to give a clear image. A cladding mode stripper may also be incorporated for better definition of the core/cladding boundary.

Select objective lenses with suitable numerical apertures and magnifications to be compatible with the measuring accuracy required and to ensure that the fibre dimension

being measured is within the appropriate field of vision. Measure minimum and maximum diameters by turning the object or the graticule circumferentially.

C.1.1.5.2 Direct viewing. Determine the dimensions to be measured from the micrometer readings (C.1.1.4.3) and the calibration of the micrometer.

C.1.1.5.3 Indirect viewing. Determine the dimensions to be measured from the television picture, using the known calibration.

C.1.1.5.4 Photomicrography. Select the intensity of the front and back illumination, the shutter speed and aperture of the camera (C.1.1.4.5) and the film to obtain a clear image of the appropriate dimension.

Ensure that the photographic image is greater than 30 mm × 30 mm. Take care to ensure that the calibration is appropriate to all magnifications used, that the calibration remains constant across the whole image and that changes in temperature, humidity, etc. do not affect calibration.

C.1.1.5.5 Video analysis. Display the image produced by the microscope on the video screen (C.1.1.4.6). Derive the dimensions by use of a cursor related to a known calibration technique.

C.1.1.6 Expression of results. The results of core-related measurements are derived from the near field light distribution. Its relationship to the definition of core diameter may be obtained by cross-calibration for the fibre type in the case of photomicrography and by use of a fixed contrast level relationship for the video analyser, the accuracy of such measurements depending both on the resolution of the method and the accuracy of cross-calibration with the reference test method (see C.1.1.2).

C.1.2 Four concentric circles test

C.1.2.1 Principle. This test is used to show that an optical fibre complies with the requirements for cross-sectional dimensions by projecting the image of the fibre on to a mask marked with four concentric circles which define the tolerance fields for the core and for the cladding.

NOTE. This test is intended for use as an inspection test and is not valid for the measurement of dimensions.

C.1.2.2 Preparation of test specimen. Prepare a test specimen that is a short length of fibre and record its length. Cut the ends of the specimen so that they are substantially flat across the whole cross section and normal to the axis of the fibre.

C.1.2.3 Apparatus

C.1.2.3.1 Optical source, in accordance with C.1.1.4.1.

C.1.2.3.2 Microscope, in accordance with C.1.1.4.2.

C.1.2.3.3 Micrometer-controlled image-splitting eye-piece.

C.1.2.3.4 Television camera.

C.1.2.3.5 Photomicrographic camera, in accordance with C.1.1.4.5.

C.1.2.3.6 Target vidicon, in accordance with C.1.1.4.6.

C.1.2.3.7 Mask, marked with four concentric circles, as shown in figure 4, which define the tolerance fields for core and cladding. The values for core and cladding diameters and their tolerances shall be as specified in the relevant Part of BS 6558.

The mask shall be suitable for use in one of the following configurations.

- (a) The mask located in the ocular of the microscope.
- (b) A microscope with two objectives, one for the mask and one for the specimen.
- (c) The mask superimposed on a photograph.

NOTE. A hardware mask may not be necessary with a video analysis.

The accuracy of the mask markings shall comply with the dimensional tolerances specified in the relevant Part of BS 6558 and the configuration used.

C.1.2.4 Procedure. Test the fibre as described in C.1.1.5, with the mask located or used in one of the ways described in C.1.2.3.7.

C.2 Length measurement of optical fibres

C.2.1 Pulse delay measurement

C.2.1.1 Principle. This test establishes the length of an optical fibre by measuring the propagation time of an optical pulse along the fibre.

C.2.1.2 Preparation of test specimen. Cut the fibre ends so that they are substantially clean, smooth and perpendicular to the fibre axis.

C.2.1.3 Apparatus

C.2.1.3.1 General. Suitable test arrangements are shown in figure 5. Figure 5(a) shows an arrangement for measuring the propagation time (Δ_t) of an optical pulse transmitted from one end of an optical fibre to the other end. Figure 5(b) shows an arrangement for measuring the propagation time ($2 \Delta_t$) of an optical pulse travelling from one end of the fibre to the other and reflected back to the input end.

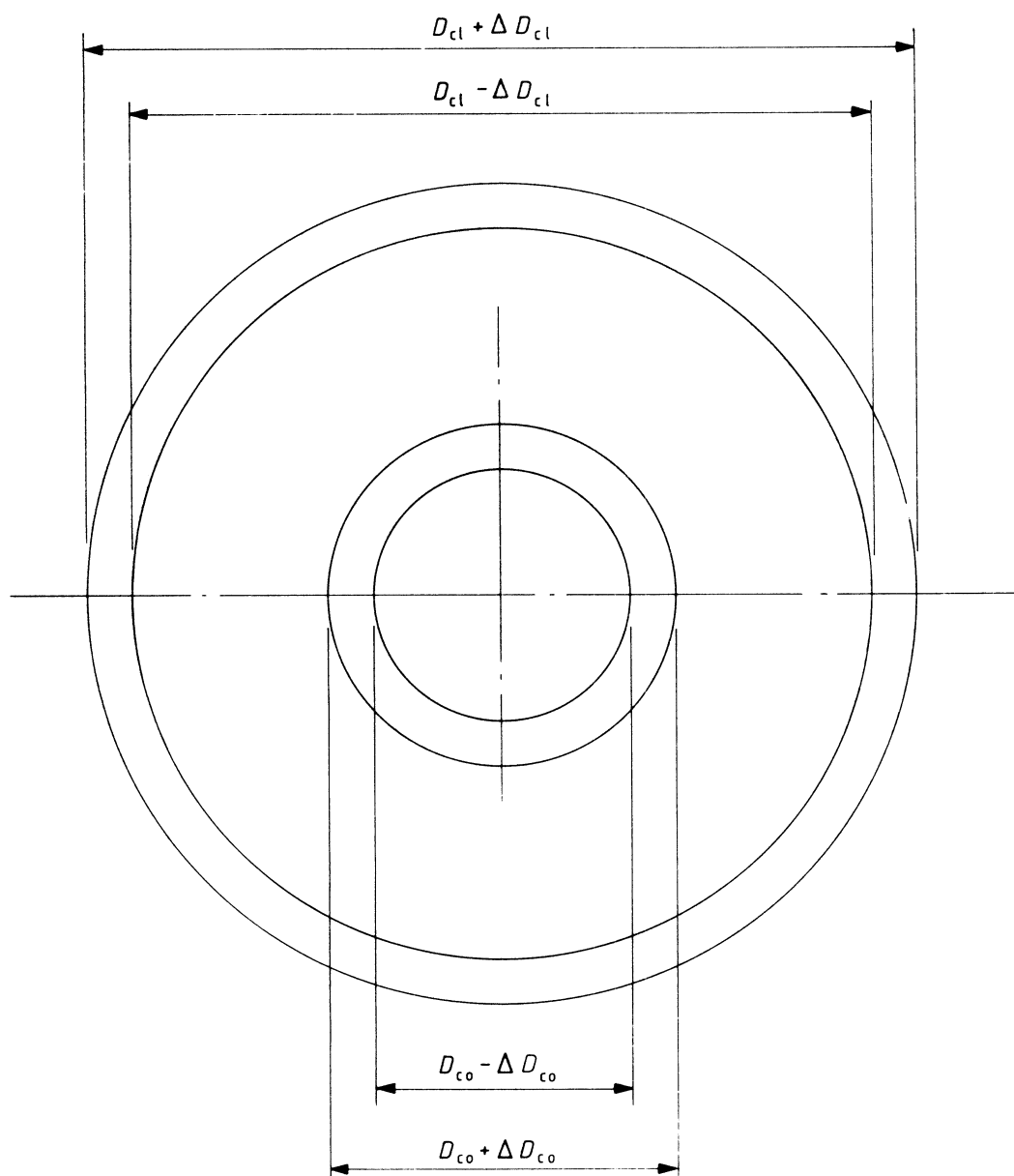
The measurement accuracy can be made independent of the fibre length by using a dual channel oscilloscope and adjusting the frequency of the emitted pulses on the first channel so that they coincide with the received pulses on the second channel.

C.2.1.3.2 Optical pulse generator, excited by an electrical pulse train generator tunable in frequency and width.

NOTE. A laser diode is preferred.

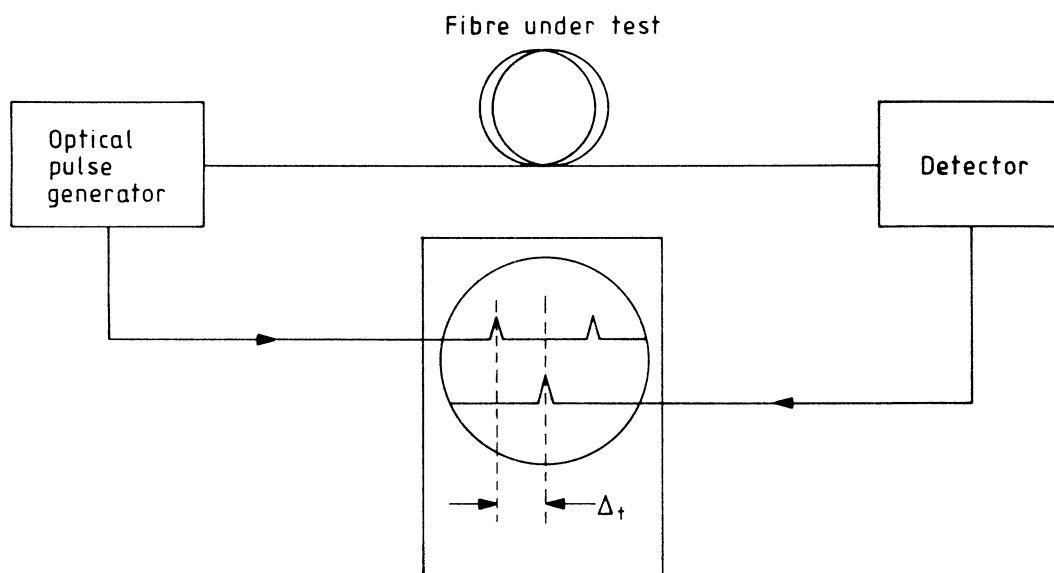
C.2.1.3.3 Detector, with a bandwidth large enough to avoid influencing the shape of the pulse.

NOTE. A high speed avalanche photodiode is preferred.

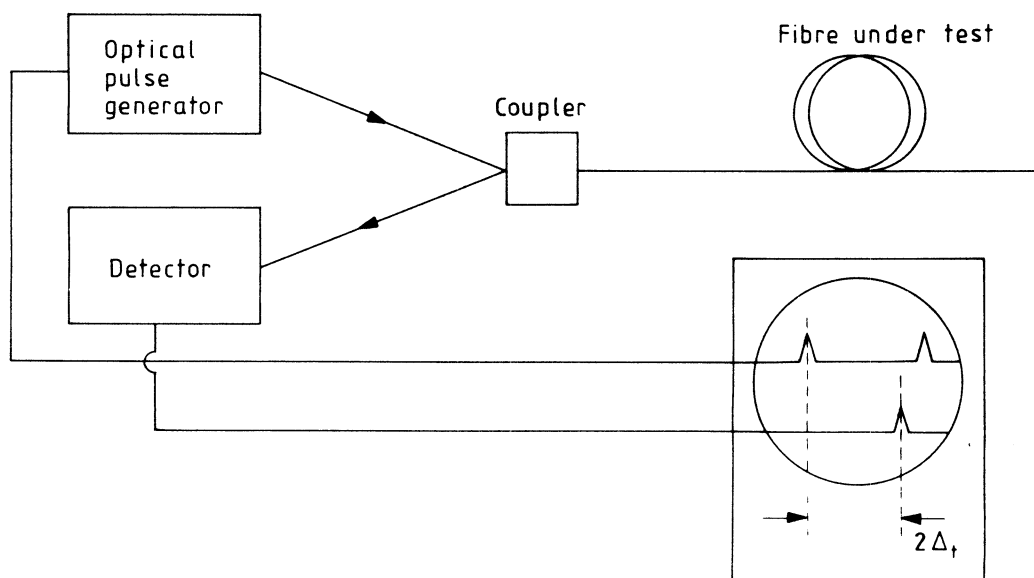


D_{co} is the nominal core diameter;
 ΔD_{co} is the core diameter tolerance;
 D_{cl} is the nominal cladding diameter;
 ΔD_{cl} is the cladding diameter tolerance.

Figure 4. Mask for four concentric circles test



(a) Transmitted pulse



(b) Reflected pulse

Figure 5. Test arrangement for measurement of fibre length by propagation time of optical pulses

C.2.1.3.4 *Dual channel oscilloscope.*

C.2.1.4 Procedure. To calibrate, measure the delay time from the source to the detector, without any specimen being inserted in the apparatus.

After calibration, insert the specimen in the test arrangement and measure the propagation time.

C.2.1.5 Expression of results. The fibre length shall be calculated from the following equation:

$$L = \frac{\Delta_t C}{N}$$

where

- L is the fibre length (in m);
- Δ_t is the propagation time over length L (in ns);
- C is the velocity of light in vacuum (in m/ns);
- N is the group index derived from propagation time measurements on a known length of fibre of the same type under the same conditions.

NOTE. The propagation time measured with a test arrangement as in figure 5(a) is Δ_t , with a test arrangement as in figure 5(b) it is $2\Delta_t$.

C.3 Length measurement of optical fibre cables

For some designs of optical cables, length can be determined from fibre length measurements by the pulse delay method described in C.2.1.

NOTE. In general, the length of an optical fibre can be measured using the same mechanical techniques as those applied to electrical cables.

Appendix D. Optical tests

D.1 Attenuation

D.1.1 Cut-back test

D.1.1.1 Principle. This test determines the attenuation coefficient or measures the attenuation of optical fibres and cables using the cut-back method. The test uses either of the following methods.

- (a) *Spot wavelength measurements*, made at one or more discrete wavelengths as specified in the relevant Part of this standard.
- (b) *Spectral measurements*, made over a range of wavelengths between the limits specified in the relevant Part of this standard. The results are presented as a plot of attenuation against wavelength.

D.1.1.2 Launch techniques

D.1.1.2.1 General. To measure attenuation coefficient, equilibrium launch techniques shall be used. To measure

attenuation, either equilibrium or full launch techniques shall be used.

D.1.1.2.2 Equilibrium launch techniques. Launch conditions shall approximate the equilibrium mode distribution encountered in fibre of sufficient length when the power distribution at the output of a fibre is substantially independent of the length of the fibre.

Approximate equilibrium mode distribution shall be obtained by the use of one of the following launch systems:

- (a) an equilibrium mode simulator (see 1.2.15);
- (b) beam optics;
- (c) launch fibres.

Regardless of the system chosen, it shall be established that approximate equilibrium mode distribution exists.

NOTE. It has been verified that at a wavelength of 850 nm, equilibrium mode conditions are created in class A1 fibre with a typical maximum theoretical numerical aperture of 0.2 and a nominal core diameter of 50 μm , when a launch system is used which gives, after the light has travelled over a distance of 2 m in the fibre under test, both of the following:

- (1) full width half maximum intensity value of the light spot measured from the near field, of $26 \pm 2 \mu\text{m}$;
- (2) full width half maximum value of the numerical aperture measured from the far field of 0.11 ± 0.02 .

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

D.1.1.2.3 Full launch techniques. In the full launch technique all modes are excited and the light shall be incident on the launch end of the fibre in the form of a spot, centrally located on the fibre core and of diameter at the 10 % intensity points greater than that of the fibre core diameter. In addition the NA of the launch beam shall be greater than the maximum theoretical NA of the fibre.

D.1.1.3 Preparation of test specimen. Cut the fibre ends so that they are substantially clean, smooth and perpendicular to the fibre axis.

NOTE. In some cases the fibre packaging, e.g. cross-winding and winding under tension, may lead to externally induced losses and optical irregularities.

D.1.1.4 Apparatus

D.1.1.4.1 General. Examples of suitable test arrangements are shown in figures 6 and 7.

D.1.1.4.2 Optical source, such as a lamp, laser or LED (light emitting diode). The choice of source shall depend upon the type of measurement (see D.1.1.1). The source shall be stable in position and intensity over a time period sufficiently long to complete the measurement procedure. The spectral line-width shall not exceed the value specified in the relevant Part of BS 6558 and shall be such that the line-width is narrow compared with any features of the fibre spectral attenuation.

NOTE. The optical signal can with advantage be modulated such that the receiver can distinguish between the signal and any stray light.

D.1.1.4.3 Optical detector, of large area so that all of the radiation in the output cone is intercepted. The detector