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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

British Standards Institution

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

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, α (λ), 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 (ω) is the power spectrum of the modulation signal at cross section 1 (normally at the input);

P_2 (ω) 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 axis.

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;

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

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	$1 \leqslant \alpha < 3$
A2.1	Quasi-step	Glass	Glass	$3 < \alpha < 10$
A2.2	Step	Glass	Glass	$10 \leqslant \alpha < \infty$
A3	Step	Glass	Plastics	$10 \leqslant \alpha < \infty$
A4	Step	Plastics	Plastics	—

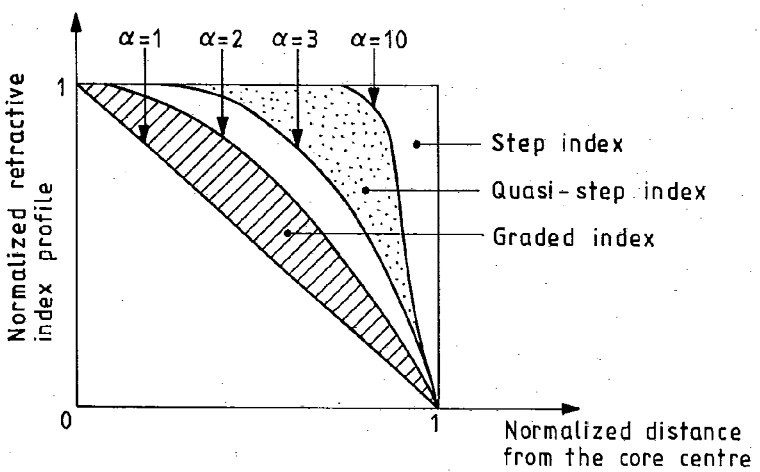


Figure 1. Classes of multimode fibre

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

Where other electrical characteristics are specified, e.g. capacitance or capacitance imbalance, the test method shall be in accordance with the relevant British Standard.

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

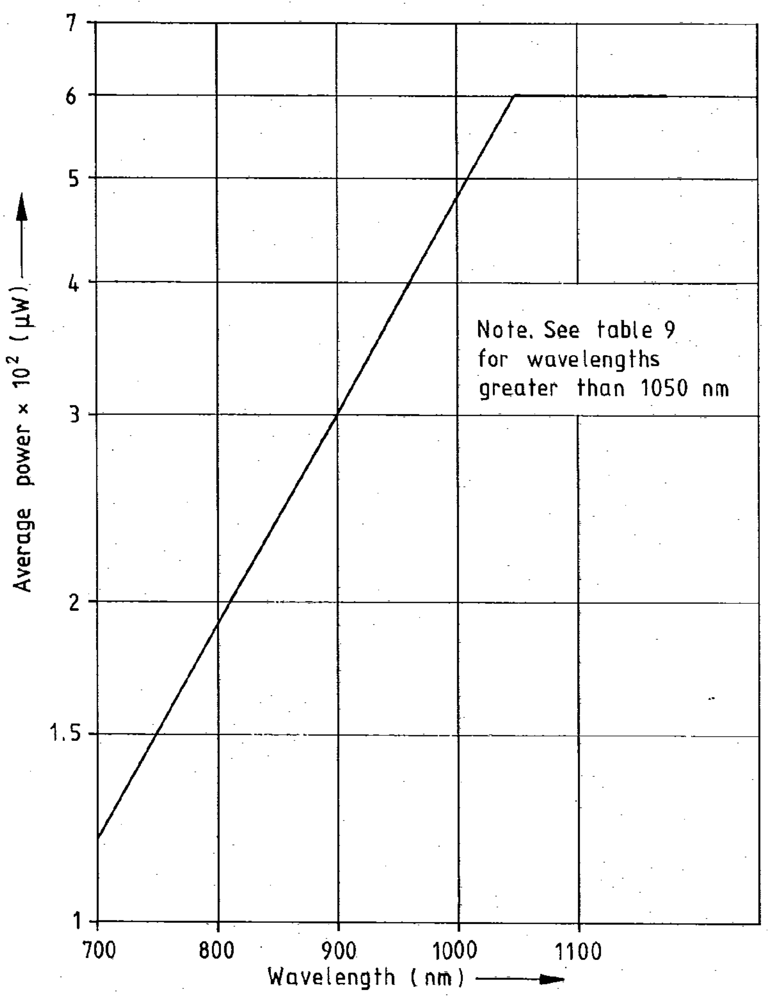


Figure 2. Maximum permissible average power emitted by class 1 products for continuous viewing (i.e. 1000 s)

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 θ = 0.13	sin θ = 0.2	sin θ = 0.3	sin θ = 0.4	sin θ = 0.13	sin θ = 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

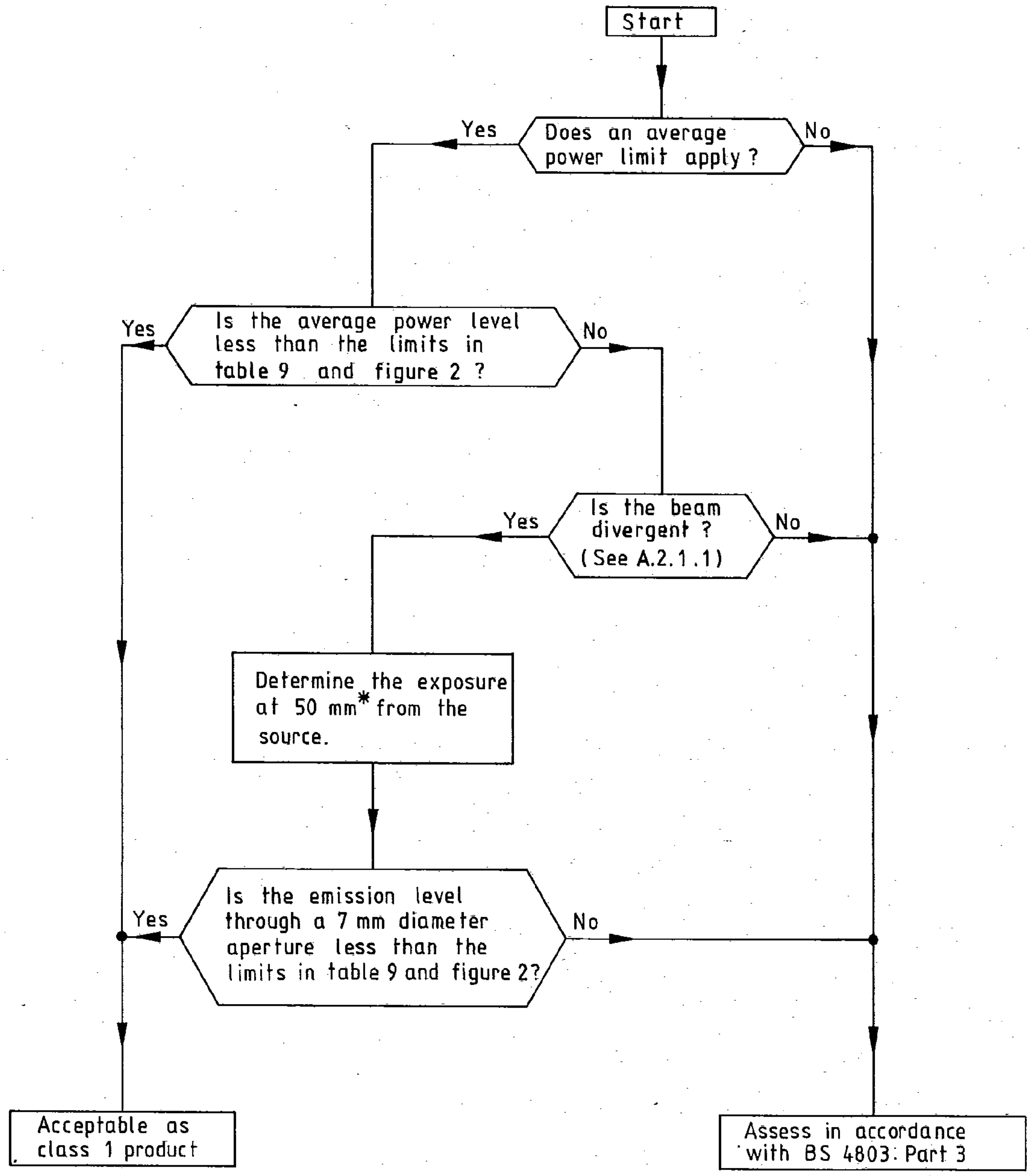
NOTE 1. The eye is virtually opaque to radiation at wavelengths greater than 1400 nm. Risk is limited to corneal damage.

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.



*50 mm is less than the minimum distance at which a person with normal eyesight can focus and assumes no viewing aids.

Figure 3. Flow chart for hazard evaluation

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	
	µm	µm	µm
A1	50	125	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 ×100 to ×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 × 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 x 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.

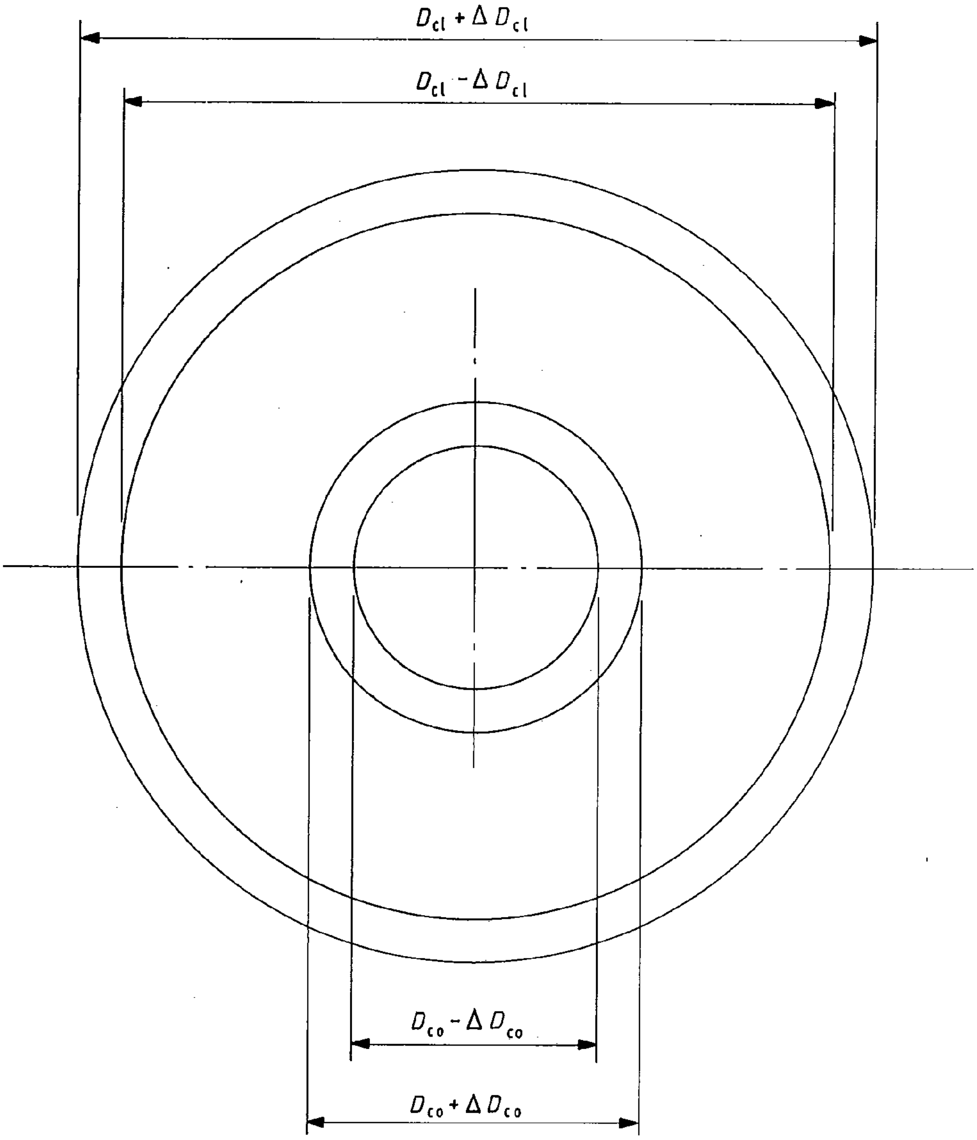
The measurement accuracy can be made independent of the fibre length by using a dual channel oscilloscope and adjusting the frequency of the emitted pulses on the first channel so that they coincide with the received pulses on the second channel.

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.

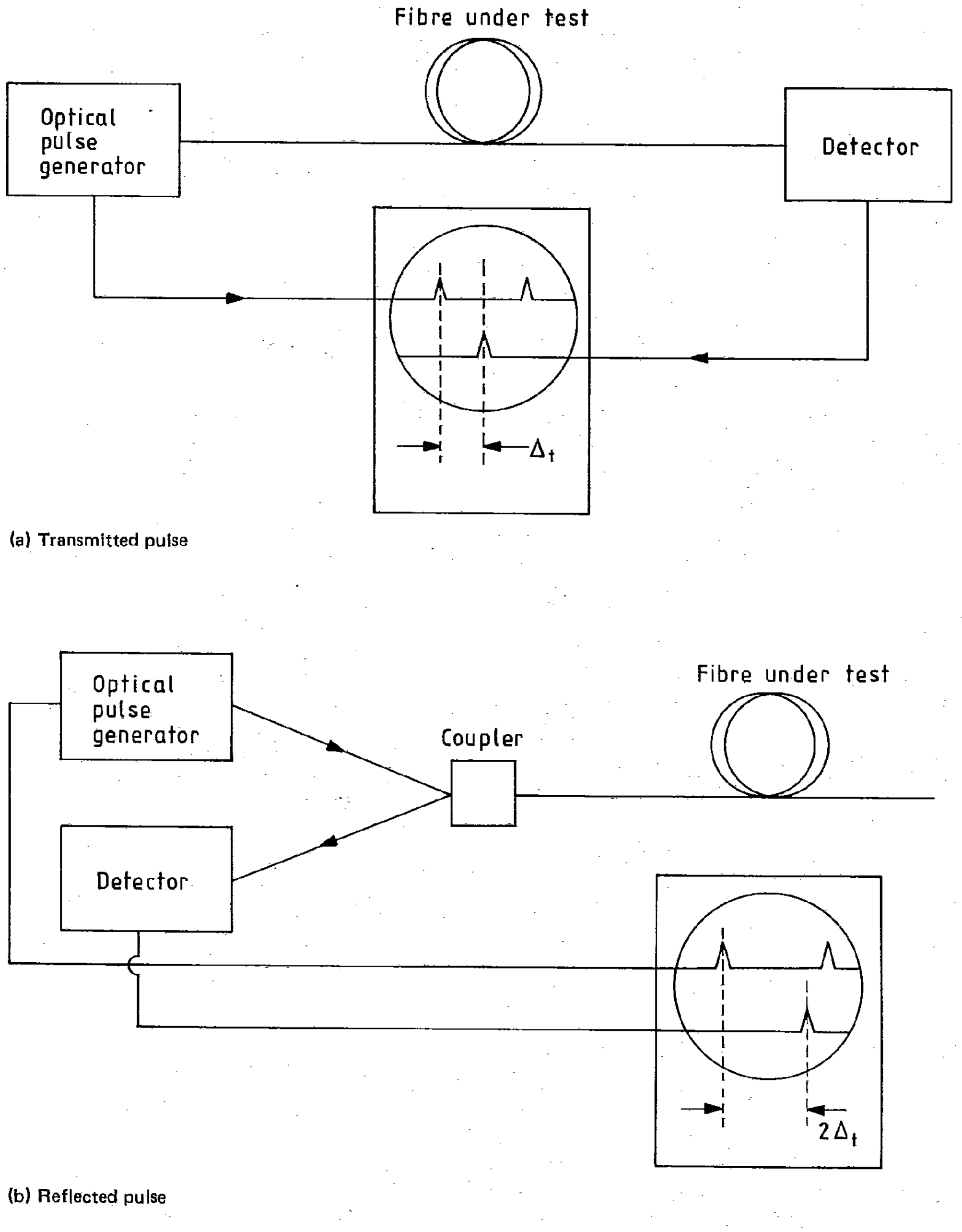
C.2.1.3.3 *Detector,* with a bandwidth large enough to avoid influencing the shape of the pulse.

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 ± 2 µm;

(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

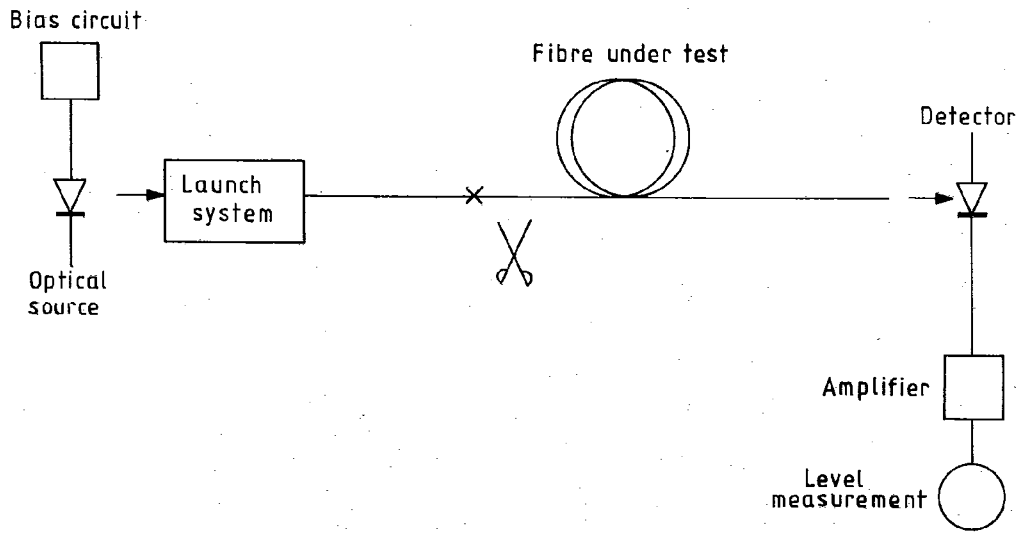


Figure 6. Test arrangement for spot wavelength attenuation measurements using the cut-back method

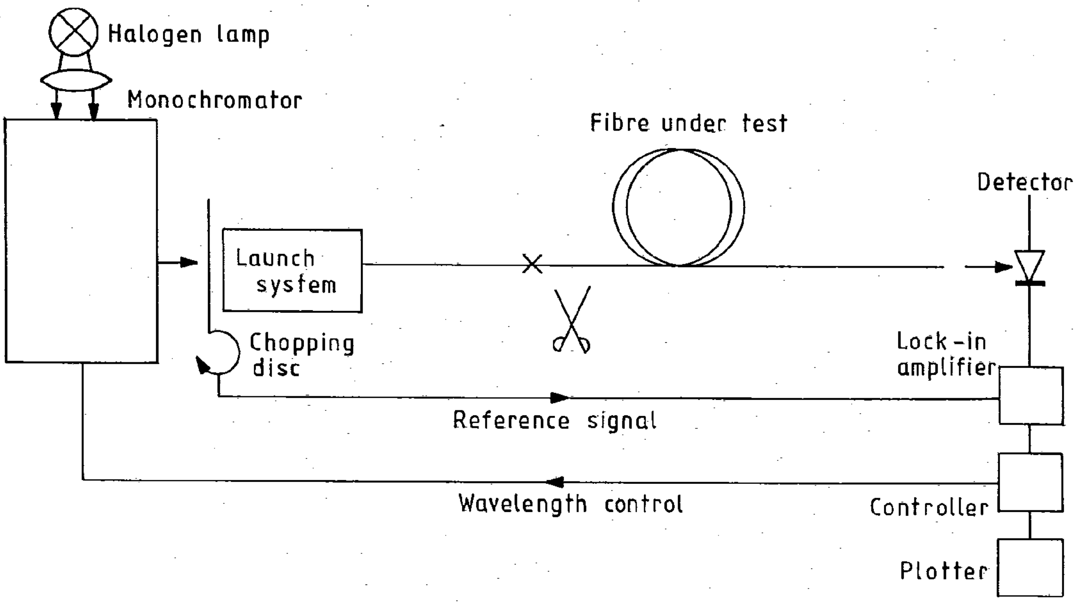


Figure 7. Test arrangement for spectral attenuation measurements using the cut-back method

shall have a sufficiently uniform response over the active area and range of incidence angle at the measurement wavelengths to ensure that movement of the output cone in position or angle relative to the detector, within the limits determined by the mechanical design of the test equipment, does not significantly affect the test results.

The spectral response of the detector shall be compatible with the source used. The detector system response shall be linear with respect to input power over the measured limits or shall be calibrated in units of optical power.

D.1.1.4.4 *Signal processor,* suitable to modulate the optical source in order to improve the signal-to-noise ratio at the receiver and to make the equipment less sensitive to room lighting. The detector shall be linked to a signal processing system synchronous to the souce modulation frequency.

D.1.1.4.5 *Cladding mode stripper,* using suitable index matching techniques to remove power propagating in the optical cladding where this would significantly perturb the received signal. The cladding mode stripper shall be placed on the section of the fibre immediately before the detector.

NOTE. Some launch systems may also include a cladding mode stripper.

D.1.1.4.6 *Equilibrium mode simulator,* e.g. a length of fibre wound five times round an appropriate sized mandrel.

D.1.1.4.7 *Beam optics.*

D.1.1.4.8 *Launch fibres,* of adequate length, e.g. 1 km of suitable fibre.

D.1.1.5 *Procedure.* Couple the detector system (**D.1.1.4.3**) to the launch system (**D.1.1.4.6, D.1.1.4.7** or **D.1.1.4.8**). Measure the output optical power (P_2) from the full length of the test specimen and, without changing the launch conditions, cut back the specimen to a point between 2 m and 3 m from the launching end. If used, refit the cladding mode stripper (**D.1.1.4.5**) and measure the output power (P_1) from the cut-back length.

D.1.1.6 *Expression of results.* The attenuation or attenuation coefficient shall be calculated from the equations given in **1.2.2** and **1.2.3** respectively. The results of spectral measurements shall be presented as a plot of attenuation against wavelength.

D.1.2 Insertion loss test

D.1.2.1 *Principle.* This test determines the attenuation coefficient or measures the attenuation of optical fibres and cables by the insertion loss method.

D.1.2.2 *Launch techniques.* The launch techniques shall be in accordance with **D.1.1.2.**

D.1.2.3 *Preparation of test specimen.* Prepare the test specimens as described in **D.1.1.3.**

D.1.2.4 *Apparatus*

D.1.2.4.1 *General.* Examples of suitable test arrangements are shown in figures 8(a) and 8(b).

D.1.2.4.2 *Optical source,* in accordance with **D.1.1.4.2.**

D.1.2.4.3 *Optical detector,* in accordance with **D.1.1.4.3.**

D.1.2.4.4 *Signal processor,* in accordance with **D.1.1.4.4.**

D.1.2.4.5 *Cladding mode stripper,* in accordance with **D.1.1.4.5.**

D.1.2.4.6 *Equilibrium mode simulator,* in accordance with **D.1.1.4.6.**

D.1.2.4.7 *Beam optics.*

D.1.2.4.8 *Launch fibres,* in accordance with **D.1.1.4.8.**

D.1.2.5 *Procedure.* Carry out initial calibration by coupling the detection system (**D.1.2.4.3**) to the launch system (**D.1.2.4.6, D.1.2.4.7** or **D.1.2.4.8**) through 2 m or 3 m of similar fibre in order to obtain the input reference level P_1 (see figure 8(a)).

Then insert the fibre or cable under test between the detection and launch systems (see figure 8(b)) and adjust the coupling to give a maximum level measurement P_2.

D.1.2.6 *Expression of results.* The attenuation or attenuation coefficient shall be determined from the equations given in **1.2.2** and **1.2.3** respectively and corrected for the various connection losses.

D.2 Backscattering test

D.2.1 *Principle.* This test evaluates optical continuity, mechanical defects, optical irregularities and backscattered light in optical fibres and, under certain conditions, determines the attenuation and attenuation coefficient.

D.2.2 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.2.3 Apparatus

D.2.3.1 *General.* An example of a suitable test arrangement is shown in figure 9(a). The signal level of the reflected 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 optical source in connection with signal processing of the detected signal. Further, for more accurate spatial resolution, adjustment of pulse width is required in order to obtain a compromise between resolution and pulse energy.

Devices such as a polarizer or index matching materials may be used to minimize the influence of Fresnel reflections. Optical non-linear effects should be avoided in the part of the fibre under test.

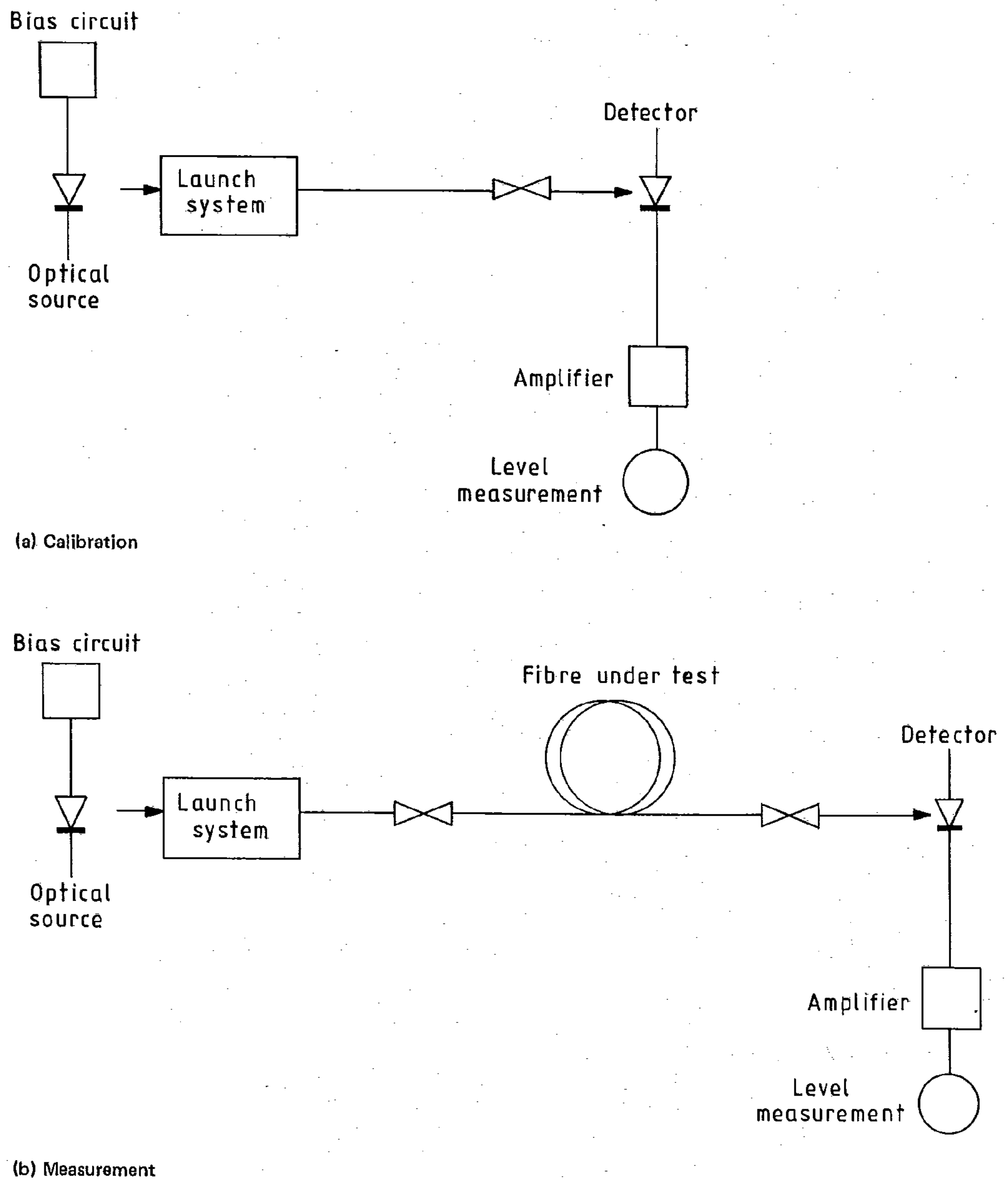
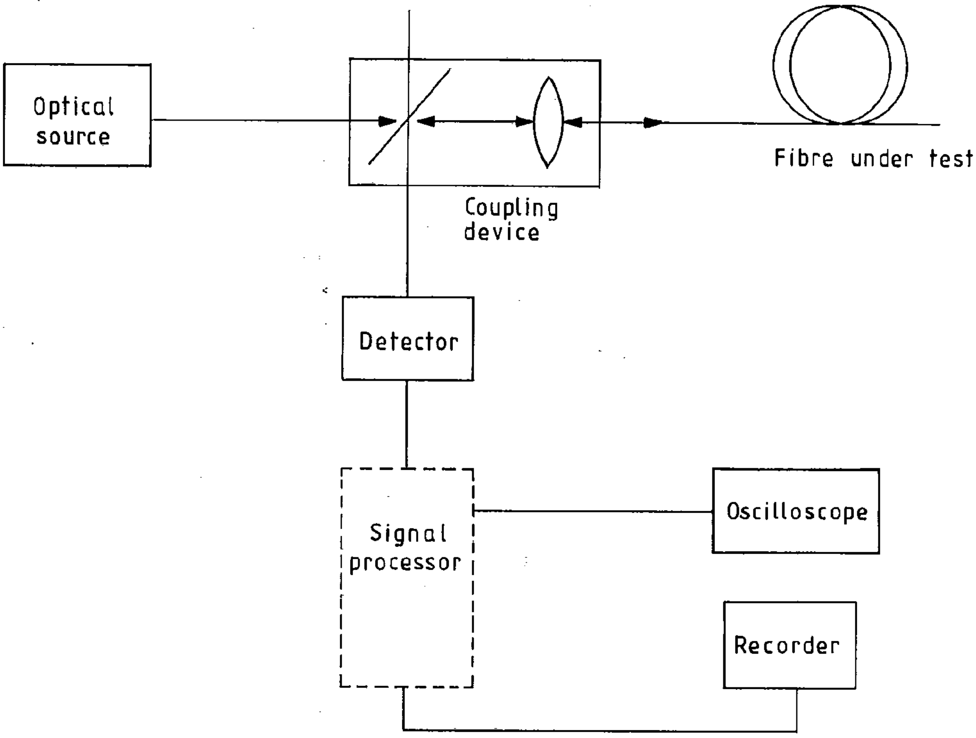
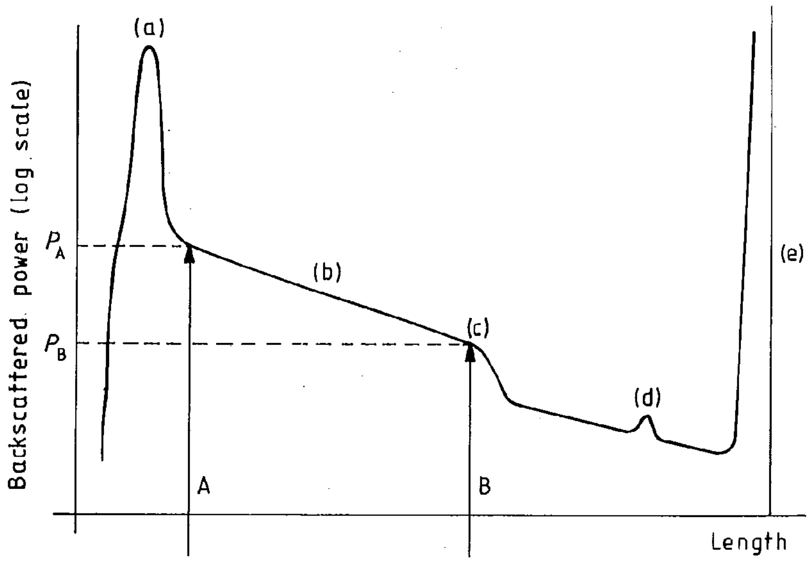


Figure 8. Test arrangements for insertion loss measurements



(a) Test arrangement for backscattering measurements



(b) Typical recorded curve

Figure 9. Backscattering measurements

D.2.3.2 *Optical source,* stable, high power and of an appropriate wavelength, e.g. a semi-conductor laser. The wavelength of the source shall be registered and the pulse width and repetition shall be consistent with the desired resolution and the length of the fibre.

D.2.3.3 *Coupling device,* adequate to prevent saturation of the detector and amplifier circuits due to Fresnel reflections, whilst simultaneously minimizing the insertion loss.

D.2.3.4 *Detector,* suitable to intercept all the reflected power. The detector response shall be compatible with the levels, wavelengths and pulse widths of the detected signal. For attenuation measurements, the detector response shall be substantially linear.

D.2.3.5 *Signal processor,* suitable to modulate optical source to improve the signal-to-noise ratio and to make the equipment less sensitive to room lighting.

NOTE. It is desirable for the detecting system to have a logarithmic response.

D.2.4 Procedure

Align the fibre under test to the coupling device (**D.2.3.3**). Record the backscattered power as analysed by the signal processor (**D.2.3.5**). If specified in the relevant Part of this standard, make bi-directional measurements.

NOTE. Launch techniques for this test are under consideration.

D.2.5 Expression of results

When logarithmic amplifiers are used, the recorded curve is typically as shown in figure 9(b).

The following typical zones can be distinguished on such a curve.

(a) Reflection originated by the coupling device, the input end of the fibre and mode mixing.

(b) A typical backscattering curve during the propagation of a pulse along the fibre.

(c) Loss due to local irregularity, splice or coupling.

(d) Reflection due to local irregularity, splice or coupling.

(e) Reflection at the end of the fibre.

When the curve does not show phenomena like (c) and significant points like (d) and when the zone (b) has a constant slope, the value of that slope gives the approximate attenuation, $A(\lambda)$, in dB and the attenuation coefficient, $\alpha(\lambda)$, in dB per unit length, of the fibre by the following equations:

$$A(\lambda)_{A-B} = \tfrac{1}{2}(P_A - P_B)$$

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

where

$A(\lambda)_{A-B}$ is the attenuation between points A and B at wavelength λ;

P_A is the power at point A;

P_B is the power at point B;

λ is the wavelength;

L is the total length between points A and B;

$\alpha(\lambda)$ is the attenuation coefficient.

D.3 Bandwidth test

D.3.1 Principle

This test determines the bandwidth of optical fibres and cables. The bandwidth can be derived from measurements made in either the time domain or the frequency domain. Time domain measurements determine the impulse response $g(t)$ of a fibre (see **1.2.21**). Frequency domain measurements determine the frequency response $G(\omega)$ of a fibre (see **1.2.5**). For a linear system, the impulse and frequency responses are related by:

$$G(\omega) = \int_{-\infty}^{+\infty} g(t) \exp(-j\omega t)\, dt$$

Measurements in the time domain and frequency domain should produce the same result.

D.3.2 Launch techniques

One of the following launch conditions shall be used.

(a) *Confined launch techniques,* in which the spot size and cone angle of the launch beam are chosen to simulate the behaviour of fibres in long spliced links.

(b) *Full launch techniques,* in which the maximum theoretical NA of the fibre is exceeded by the launch cone and in which the launch spot diameter is greater than the fibre core diameter.

D.3.3 Preparation of test specimen

Cut the fibre ends so that they are substantially flat across the whole cross section and normal to the axis of the fibre.

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.3.4 Apparatus

D.3.4.1 *General.* Figure 10 shows schematically a test arrangement for time domain measurements of impulse response.

Figure 11 shows a test arrangement for directly determining the frequency response of the test fibre using the same basic procedures.

NOTE. To provide sufficient data to compute the impulse response a separate phase measurement is required. The method of phase measurement is under consideration.

D.3.4.2 *Optical source,* of a known centre wavelength and spectral width determined from the 20 % optical intensity power points for the same modulation conditions as are to be used for fibre testing. The response of the source to modulation shall be at least comparable to the dispersion of the sample under test. The centre wavelength and spectral

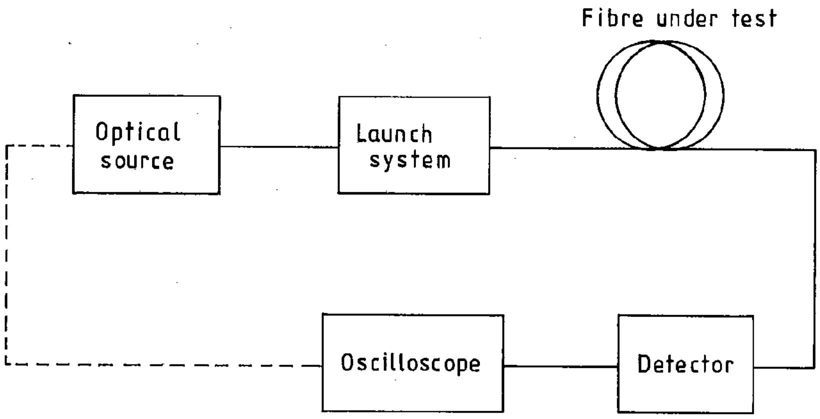


Figure 10. Test arrangement for impulse response measurements

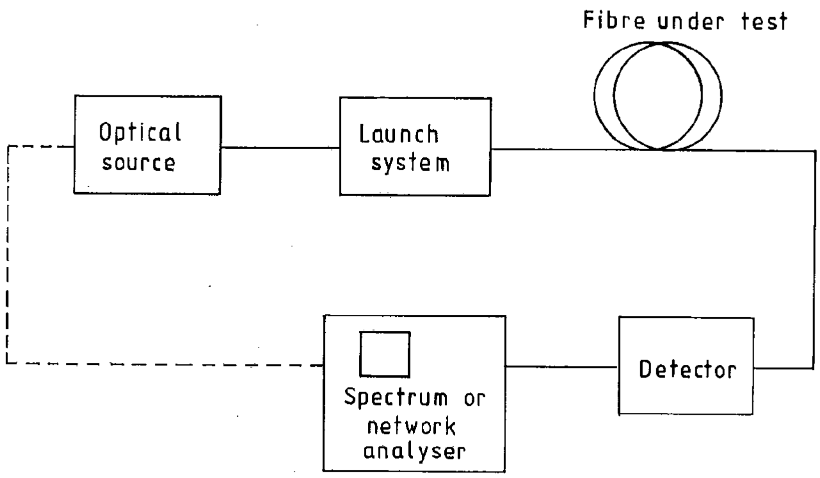


Figure 11. Test arrangement for frequency response measurements

width shall be as specified in the relevant Part of BS 6558.

NOTE. Without a separate knowledge of the material dispersion of a fibre it will not be possible to simply relate, for example, the measured values using an LED to the projected performance with a laser. For this reason, it is often preferable when measuring graded index fibres to use a narrow line-width source, i.e. about 2 nm to 3 nm and thereby minimize material dispersion effects.

D.3.4.3 *Optical detector,* with a bandwidth that exceeds that of the optical fibre under test. The range of linearity of the device shall be known.

D.3.4.4 *Cladding mode stripper,* using suitable index matching techniques to remove power propagating in the optical cladding where this would significantly perturb the received signal. The cladding mode stripper shall be placed on the section immediately before the detector.

NOTE. Some launch techniques may include a cladding mode stripper.

D.3.4.5 *Ancillary equipment,* depending on the type of measurement, e.g. pulse train generator, sampling oscilloscope, beamsplitter, XY recorder, sine wave source and spectrum or network analyser.

D.3.5 Procedure

D.3.5.1 *General.* Align the fibre normal to the axis of the launch cone and position it symmetrically in relation to the launch spot.

Position the output end of the fibre parallel to the detector surface so that all of the emitted radiation is received by the detector (**D.3.4.3**). Ensure that the area illuminated in each case is the same.

D.3.5.2 *Time domain measurements.* Adjust the input power to the source (**D.3.4.2**) to give a signal in the linear range of the detector (**D.3.4.3**). Take a permanent record of the launched pulse received and of the output pulse from the test length.

NOTE. The computed bandwidth for the length of specimen tested is the −6 dB electrical point of the amplitude *v* frequency characteristic, −3 dB optical.

D.3.5.3 *Frequency domain measurements.* Where frequency response measurements are obtained, take a record of the input spectrum and display the output spectrum on the spectrum analyser.

NOTE 1. For complete information, a measurement of the phase *v* frequency characteristic is also needed. Methods are still under investigation.

NOTE 2. The bandwidth for the length of specimen tested is the lowest frequency at which amplitude has fallen by 6 dB electrical, 3 dB optical.

D.3.6 Expression of results

Where specified in the relevant Part of BS 6558 the full amplitude *v* frequency characteristic shall be provided. The results of measurements made in the time domain are often quoted (in ns/km) as follows, but this method of presentation is only valid where both the input and output pulses are near Gaussian in shape:

$$\text{Pulse broadening } \tau = \frac{(\tau_2{}^2 - \tau_1{}^2)^{1/2}}{L}$$

where

L is the length of the test specimen (in km);

τ_1 is the full width half height of the input pulse (in ns);

τ_2 is the full width half height of the output pulse (in ns).

As the assumption of an inverse length dependence to power is also liable to error, the input and output pulse shall be in full. Where a single figure is to be quoted, this shall be the bandwidth corresponding to the first intersection with the −6 dB electrical (−3 dB optical) level in the amplitude *v* frequency characteristic.

NOTE. This value may be determined by Fourier transform from a knowledge of the full input and output pulse shapes.

As the accuracy of the measurements is limited by the resolvable difference between input and output pulses for a time domain measurement and by the frequency range of the equipment in frequency domain measurements, in situations where a fibre length is too short to allow such resolution, the performance of the test fibre shall be given as the defined resolution of the apparatus.

D.4 Radiation angle test

D.4.1 Principle

This test obtains the radiation angle of a multimode optical fibre by plotting the detected power transmitted through the fibre against the linear position of the detector.

D.4.2 Relationship between fibre acceptance angle and radiation angle

Fibre acceptance angle may be measured by a technique similar to this method for the measurement of radiation angle, except that the variable aperture is located in the launch optics rather than in the detector arrangement.

Acceptance and radiation angle measurements yield identical results as they are in effect an inverse of each other. Figure 12 shows a comparison of acceptance and radiation angle results for a 100 µm type A2.1 fibre. For overfilled launch spot diameter conditions there is complete agreement between results.

However, if with the acceptance angle technique both spot size and aperture are controlled at the input end, then for the radiation angle technique to yield identical results, both spot size and aperture have to be controlled at the output end. This, however, is not convenient in practice, it being much easier to control the spot size at the input end and the aperture at the output.

Figure 12 shows that for reduced launch spot diameters, the radiation angle technique will in general produce incorrect results, particularly at low apertures, the acceptance angle curve being the correct one. As the aperture is increased, the reduced spot curves converge. They merge together as the aperture approaches the fibre numerical aperture. Thus the reduced spot radiation angle measurement of sinθ (99 %) is correct in spite of the rest of the curve being invalid.

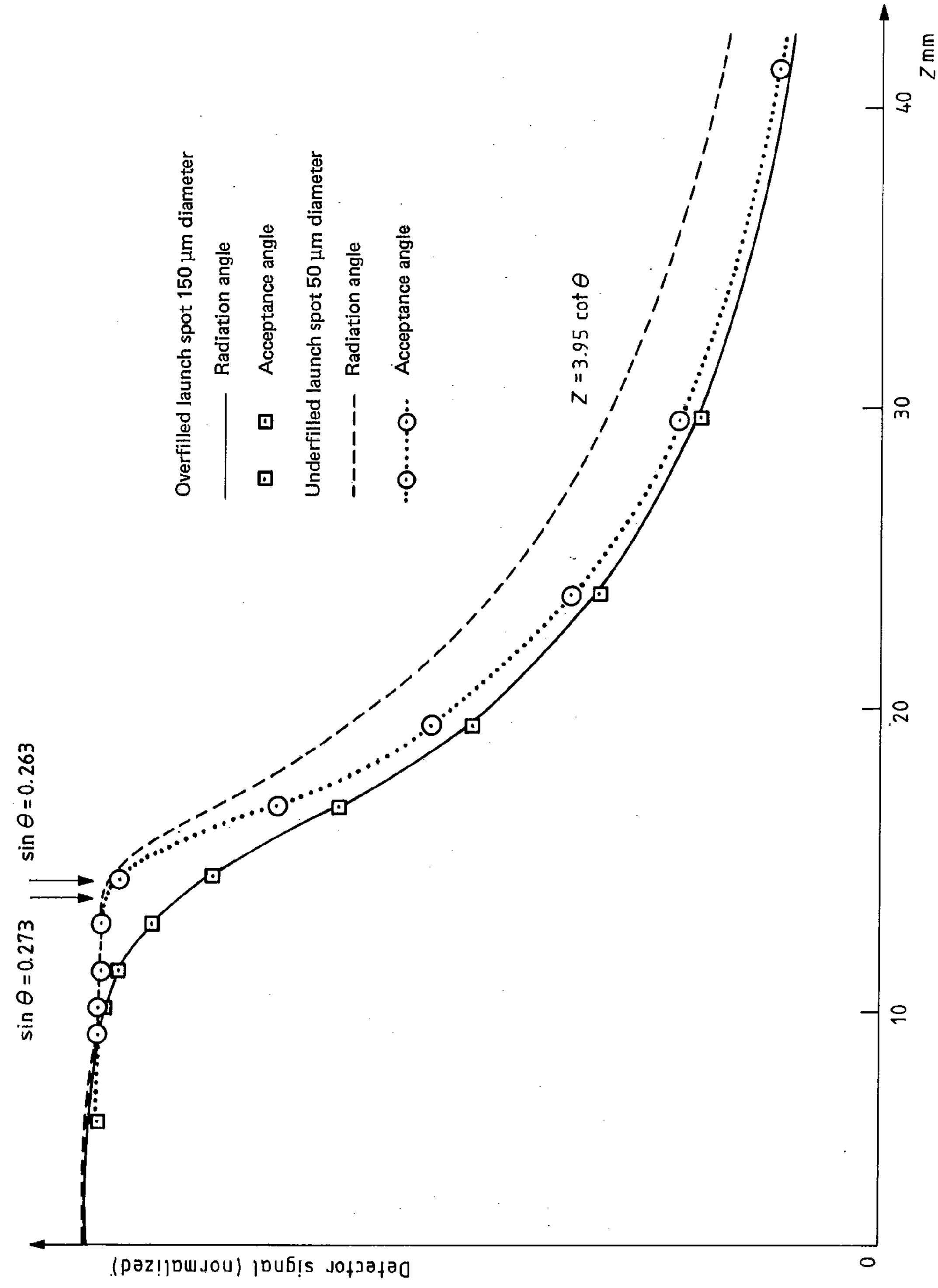


Figure 12. Typical acceptance and radiation angle results for 100 μm A2.1 fibre

The difference between the reduced spot radiation and acceptance angle measurements depends upon the refractive index profile grading at the core/cladding boundary. For type A1 fibres it would be enormous while for type A3 fibres it has been found to be negligibly small.

Since the acceptance angle technique does not readily lend itself to the production of continuous curves of results, the radiation angle technique is in general superior, particularly for the accurate measurement of sin θ (99 %) and where overfilled launch conditions are used.

D.4.3 Preparation of test specimen

Prepare a test specimen that is 2.0 ± 0.5 m long. Ensure that any bends are of a sufficiently large radius that their effect on the results is negligible.

Cut the fibre ends so that they are substantially flat across the whole cross section and normal to the axis of the fibre.

D.4.4 Apparatus

D.4.4.1 *Optical source,* either an LED or a broadband white light source, with a filtering device to restrict the wavelength spread to a known spectral width about a centre wavelength. The filtering device shall be either a monochromator or an interference filter.

The spectral width between the 10 % optical intensity power points of the light launched into the test fibre shall not exceed the value specified in the relevant Part of BS 6558.

The source shall be stable, both mechanically and in light output, over a time period sufficiently long to complete the measurement procedure.

D.4.4.2 *Optical launch optics,* similar to that shown in figure 13.

If lenses are used in the launch arrangement, they shall be used under the optical conditions for which they were designed.

NOTE. For example, plano-convex lenses may be used to collimate light from a source or bring collimated light to a focus. In each case the plane side of such a lens should be nearest to the source or focus.

If a microscope objective is used to launch the light into the fibre under test, then it shall be used under the correct tube length condition for which it was designed so as to produce minimum spherical aberration. Unless the input fibre holder (see **D.4.4.4**) is of the type shown in figure 14(b), such a lens shall be corrected for use without a cover glass.

If an optical arrangement of lenses and components is used, then an accurate alignment shall be carried out so that they all lie on a common optical axis. The input end of the test fibre shall be positioned in the focus of the final lens in such an arrangement. The fibre shall be supported near its end so that its axis is common with that of the optical components used.

NOTE 1. The optical launch conditions refer to the launch spot and are not dependent on the presence of a test fibre.

NOTE 2. The maximum theoretical numerical aperture of a multimode fibre is defined in **1.2.22**. Numerical aperture can also be defined as sin θ where θ is the half-angle of the cone containing essentially 100 % of the transmitted light from a short length of fibre when the input launch is overfilled, i.e. the numerical aperture is equal to sin θ (100 %). In practice, the value of sin θ (99 %) on the radiation angle plot may be taken as the numerical aperture.

NOTE 3. The far field power drop-off with angle, at constant radial distance from the launch spot, should be an approximately cosine relationship over an angular range of not less than $\sin^{-1} \theta_R$ (99 %), where θ_R (99 %) is the radiation angle of the fibre under test for 99 % of the output power. The power drop-off should be symmetrical about the optical axis. A technique for measuring power drop-off with angle is described in **D.4.7**.

D.4.4.3 *Optical detector,* suitable to intercept all the radiation in the output cone by its active area with the end of the fibre under test a few millimetres from the detector window. In order to avoid the possibility of damage to the detector surface during the measurement procedure, the detector shall be of the type fitted with a glass window. The window shall be flat.

The detector shall have a measured uniformity of response at the test wavelength(s) across the active surface area, together with a measured angular response variation at these wavelengths. Any non-uniformities shall not appreciably affect the test results.

The spectral response of the detector shall be compatible with the source used and the operating wavelength(s).

NOTE. The detector system response should be linear with respect to input power over the measured limits, as then the detector system calibration need not be in absolute units.

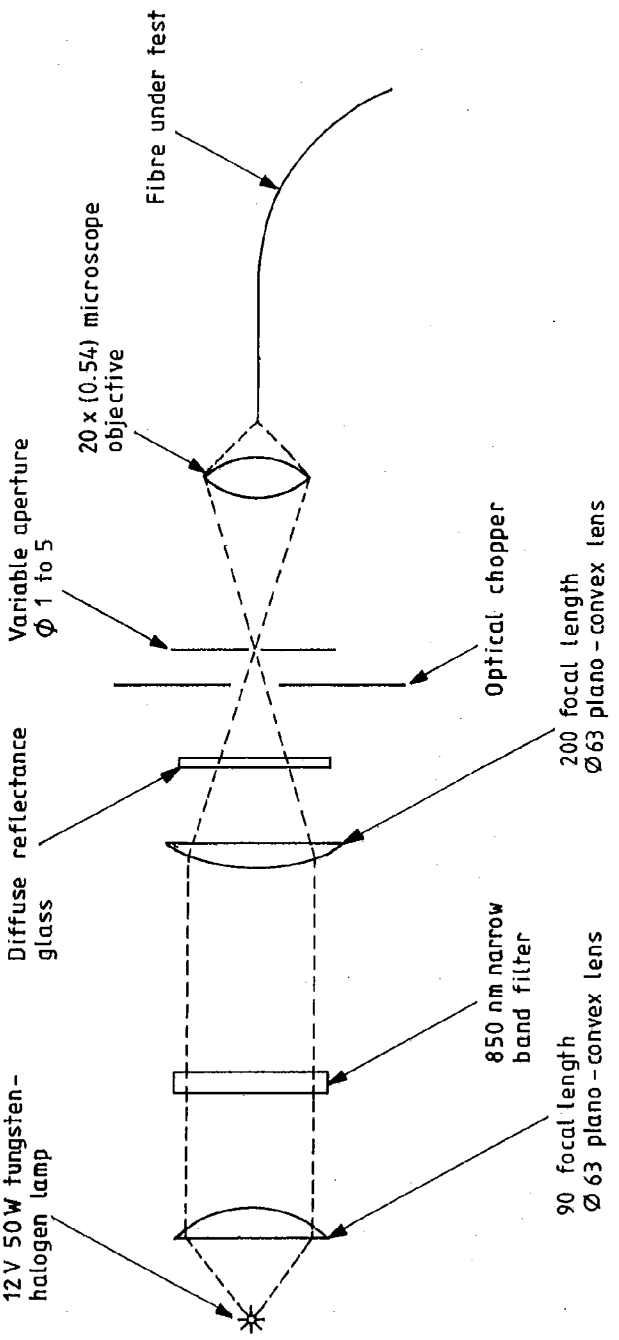
D.4.4.4 *Fibre holders,* similar to those shown in figure 14. Either type may be used for the launch end but care should be taken when using the vee-groove type to ensure that the clamping force applied, if any, is sufficiently light that the effect on the results is negligible. A fibre holder of the liquid-cell type shown in figure 14(b) shall be used for interfacing the fibre and detector.

D.4.4.5 *Linear translation stage,* to enable the separation between the fibre end and the detector to be varied. The axis of the fibre holder shall be common with that of the stage. Alternatively, it shall be permitted to use apparatus which transversely scans the far field pattern and computes the radiation angle, provided that it complies with the optical requirements. The linear translation stage shall be either manually or motor driven and shall have a scale so that the relative position of the detector is capable of being measured.

NOTE. A scale resolution of 0.01 mm is desirable.

A suitable linear transducer, e.g. a rectilinear potentiometer, shall be mounted on the linear translation stage so that an electrical output proportional to the separation of fibre end and detector is capable of being obtained or, alternatively, a stepping motor drive or similar system shall be used and the detector position obtained from the control electronics.

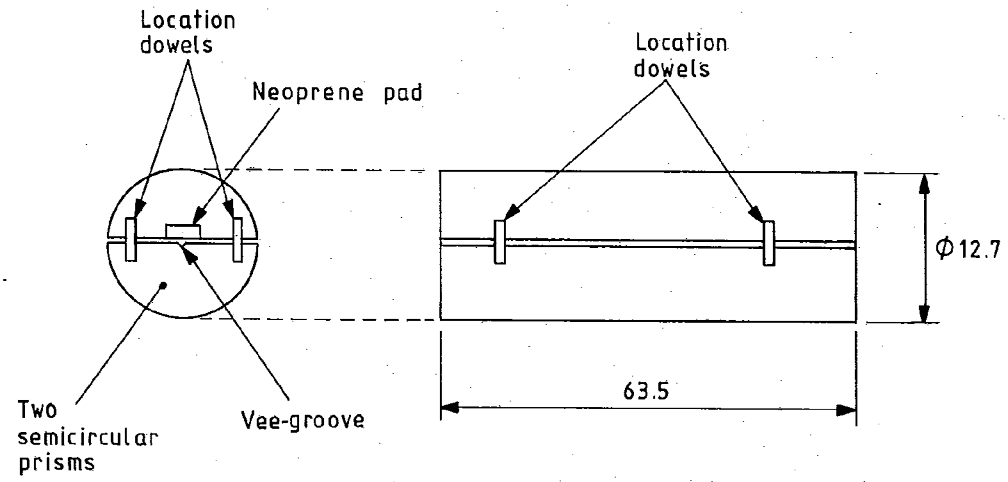
D.4.4.6 *Fixed aperture,* located immediately in front of the detector window so that the cone angle of the light accepted by the detector can be defined by the internal diameter of the aperture and the spacing between the fibre end and the detector window. The centre of the aperture shall lie on the optical axis of the fibre holder. The maximum



All dimensions are in millimetres unless otherwise stated.

Figure 13. Example of suitable launch optics for radiation angle measurements

Finish front surface matt black

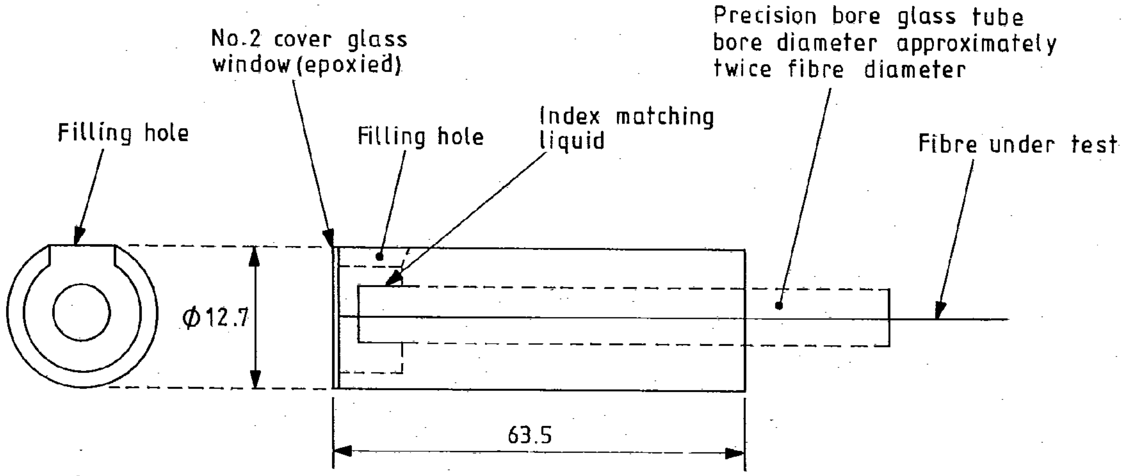


Dimensions are in millimetres.

NOTE. Vee-groove depth = 60 % of fibre diameter (fibre not shown).

(a) Vee-groove fibre holder

Finish front surface matt black



Dimensions are in millimetres.

(b) Liquid-cell fibre holder

Figure 14. Examples of suitable fibre holders for radiation angle measurements

diameter of the aperture shall be determined by the condition that if all the light in the output cone from the test fibre just passes through the aperture then it shall all fall upon the active area of the detector.

The most suitable value of aperture internal diameter will be somewhat less than this value and shall be determined by the minimum radiation angle required to be measured together with considerations of measurement accuracy of θ_R (99 %).

NOTE 1. A value of 70 % of the detector diameter may be found to be acceptable for large diameter detectors. Preferably, the translation stage length and the aperture internal diameter should be such that a minimum radiation angle of $\sin^{-1}$ (0.05) can be measured. An example is shown in figure 15.

The internal diameter of the aperture should be measured, preferably to an accuracy of 0.02 mm or better.

NOTE 2. Precautions should be taken to ensure that fibre output light reflected from the detector during a measurement cannot be re-reflected back on to the detector from metal or other surfaces.

In practice, this may mean coating some reflecting surfaces with matt black paint or other anti-reflecting material (see figure 14(b)).

NOTE 3. In order to attenuate the room light received by the detector, it is customary to shield it with blackened metal screens. Care should be taken to ensure that fibre output light at such angles is not accepted by the detector. Reflected light near grazing incidence is most likely to cause problems and should be avoided.

The thickness of the cover glass window on the liquid cell holding the output end of the fibre should be measured.

NOTE 4. A measurement accuracy of 0.01 mm is desirable.

D.4.4.7 *Cladding mode stripper,* using a suitable index power matching medium to the test sample in order to remove power propagated in the optical cladding where this would significantly perturb the received signal. The refractive index of the liquid at the measurement wavelength shall be equal to or slightly larger than the fibre cladding refractive index. The length of fibre immersed shall be at least 100 mm.

D.4.4.8 *Signal processor,* suitable to modulate the optical source in order to improve signal-to-noise ratio at the receiver and to make the equipment less sensitive to room lighting. Where modulation is used, the detector shall be linked to a signal processing system synchronous to the source modulation frequency. The detecting system shall be substantially linear. If a mechanical chopper is used, it shall be placed in such a position that the beam diameter passing through it is less than the blade spacing.

D.4.4.9 *XY recorder*

D.4.5 Procedure

Position the prepared input fibre end in the focus of the launch beam using a suitable fibre holder (**D.4.4.4**). Insert the prepared fibre output end into the liquid cell of the cladding mode stripper (**D.4.4.7**) and push until it is hard up against the cover glass window.

Measure the scale reading on the linear translation stage (**D.4.4.5**) for a known separation of liquid cell and detector by inserting between them a piece of material of known length. Use a material that does not scratch the glass surfaces. Position the detector (**D.4.4.3**) so that all of the output radiation from the fibre under test passes through the aperture (**D.4.4.6**) in front of it.

Control the diameter of the launch spot so that when it is measured at the 50 % optical intensity power points, it is greater than the fibre core diameter, except in the case of the measurement of the bound mode numerical aperture, i.e. $\sin_R$ (99 %) of step index fibres, when a reduced launch spot diameter of approximately 50 % of the fibre core diameter is required. Ensure that the shape of the intensity profile approximates to a square wave shape and keep any variations in intensity as small as possible, preferably less than 10 %. A technique for measuring the near field intensity of the launch spot is described in **D.4.8**.

Maximize the output signal at the particular wavelength of interest, by accurately adjusting the position of the input fibre end in three orthogonal directions, one of which is coaxial with the fibre axis.

Connect the optical signal and the signal from the transducer mounted on the linear translation stage to the Y and X axes respectively of the XY recorder (**D.4.4.9**). Increase the separation between the fibre end and detector window and obtain a plot of output power against a function of radiation angle (see figure 16).

NOTE 1. The near field distribution of leaky rays in step index fibres is such that the majority of their power is to be found near the core/cladding interface. The amount of power launched into these rays may thus be reduced by reducing the diameter of the launch spot below that of the fibre core diameter. A launch spot diameter of approximately 50 % of the fibre core diameter has been found to launch negligible power into the leaky rays and to enable the results for the bound modes alone to be obtained. For this to be effective, centre the reduced spot with respect to the fibre core.

NOTE 2. This is best done by observing the unfiltered white light radiation distribution on a screen spaced 50 mm to 100 mm from the end of the liquid cell. The leaky and bound mode regions can be observed and quite easily discriminated by adjusting the diameter or position of the launch spot. With reduced launch spot conditions, the power in the leaky mode region can be made to disappear by suitable adjustments to the linear translation stage.

Calibrate the X axis of the recorder trace by adjusting the linear translation stage to obtain the calibration factor K, given by:

$$K = \frac{\text{Movement on X axis of recorder (in mm)}}{\text{Movement of linear stage holding detector (in mm)}}$$

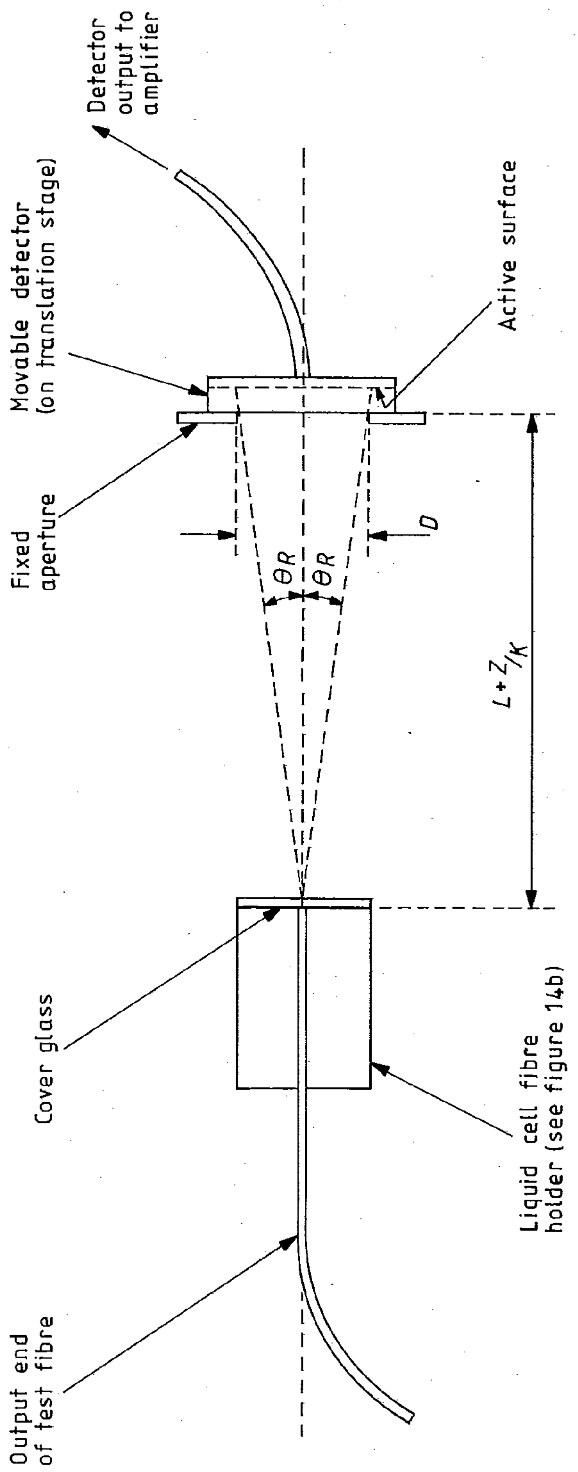
D.4.6 Expression of results

The radiation angle θ_R for a particular percentage of total light radiated from a fibre shall be calculated from the following:

$$\tan \theta_R = D/2(L+Z/K)$$

where

- D is the internal diameter of the fixed aperture in front of the detector (in mm);
- Z is the position on the graph with respect to the position of zero separation between liquid cell and detector (in mm);
- L is the thickness of the cover glass (in mm);
- K is the calibration factor (see **D.4.5**).



NOTE. *Z*, *K*, *L*, *D* and θ_R are defined in D.4.6.

Figure 15. Layout of radiation angle test apparatus at output end of fibre

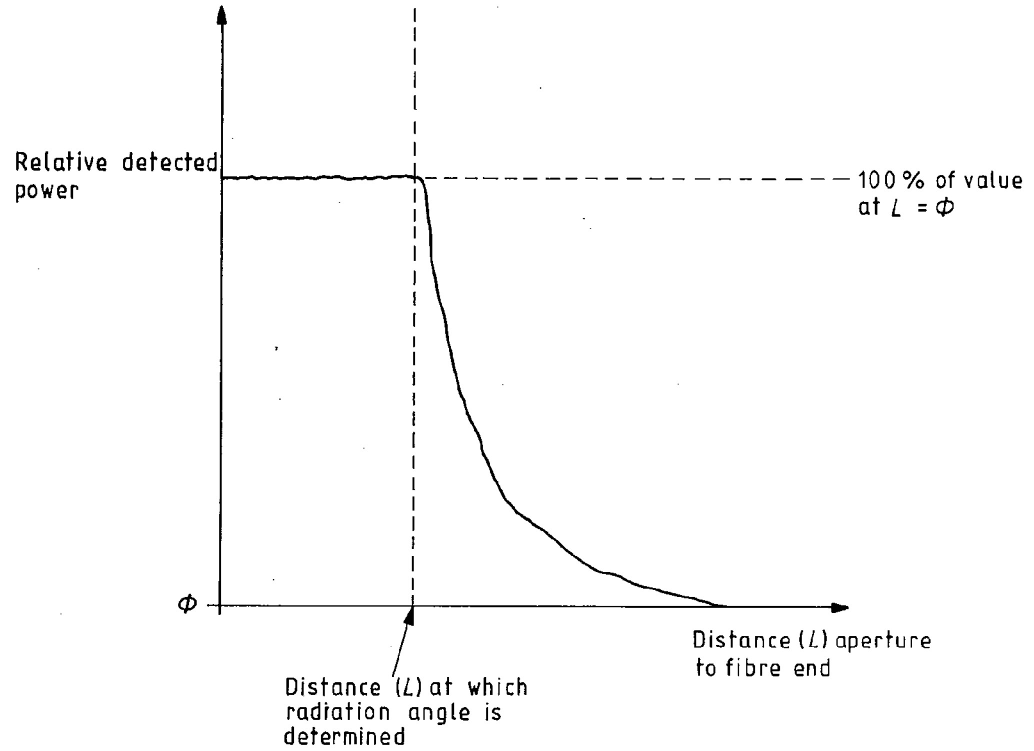


Figure 16. Example of XY plotter output for radiation angle test

In deriving this equation, refraction within the cover glass window on the liquid-cell fibre holder was ignored. Use of this equation will therefore result in a slight under-estimation of tan θ.

This error has been calculated using practical values of the parameters and the values given in table 12 are a typical result, assuming that the refractive index of the cover glass window is 1.522, L is 0.20 mm and D is 8.0 mm.

Table 12. Error caused by refraction within cover glass window

tan θ (true)	tan θ (calculated)	Error
		%
0.2	0.19930	0.35
0.25	0.24890	0.44
0.3	0.29839	0.54

The results can, if required, be corrected, but in general the error involved in using the equation is small compared to experimental errors.

Figure 12 shows radiation angle results obtained for a 100 µm quasi step index fibre under two different launch conditions. The reduced spot radiation angle curve should only be used to measure the value of sin θ (99 %); at lower apertures it yields incorrect results (see **D.4.2**).

The presence of leaky or skew rays complicates the interpretation of the results obtained by radiation angle measurements.

For graded index fibres the angular region of leaky rays in the output pattern lies within that containing the bound rays. Thus the value of radiation angle should be the same as that obtained from the equation given in **1.2.30**.

However, for step index fibres the angular region of the leaky rays in the output pattern lies outside that containing the bound rays. Their presence will lead to an increase in the power detected at high angles and the power v cot θ curve may never become horizontal. Thus it may not be possible to define θ (99 %) with any accuracy. In general, leaky modes attenuate fairly rapidly and it is the bound mode contribution which is significant and requires to be measured.

D.4.7 Method for measuring the angular dependence of the far field power from the launch spot

D.4.7.1 *Apparatus*

D.4.7.1.1 *Small diameter detector,* typically 0.5 mm diameter.

D.4.7.1.2 *Rotary translation stage,* with a minimum rotation of approximately 25 ° on each side of the optical axis.

NOTE. The rotary translation stage may be manually or motor driven and may have a transducer, e.g. a rotary potentiometer, so that an electrical output signal proportional to the angular rotation is available for connecting to the X-axis of an XY plotter.

D.4.7.2 *Procedure.* Adjust the position of the stage (**D.4.7.1.2**) so that the launch spot is located on the axis of rotation of the stage and this axis is at right angles to the optical axis of source, lenses, etc. Mount the detector (**D.4.7.1.1**) radially on the stage so that a normal from the centre of its active surface passes through the launch spot and is at right angles to the axis of rotation of the stage.

NOTE 1. The angular resolution required is typically 0.005 radians to 0.01 radians (half cone angle). Thus for a 0.5 mm diameter detector the distance of the detector surface from the stage centre would need to be 25 mm to 50 mm.

Vary the angle of the stage and measure the power.

NOTE 2. Figure 17 is an example of a typical result. Here the far field power drop-off from the launch spot is 7.5 % down at an angle of $\sin^{-1}$ (0.3).

NOTE 3. Precautions concerning the attenuation of room light reaching the detector should be observed as given in **D.4.5** and **D.4.6.**

D.4.8 Method for measuring the near field intensity profile of the launch spot

D.4.8.1 *Apparatus*

D.4.8.1.1 *Microscope objective,* with ×20 magnification.

D.4.8.1.2 *Probe,* consisting of a short length of fibre of approximately 50 µm diameter.

D.4.8.1.3 *Linear translation stage,* incorporating a displacement measuring transducer with an electrical output.

D.4.8.1.4 *Cladding mode stripper,* using a suitable matching medium to remove energy being propagated in the cladding mode.

D.4.8.1.5 *Large area detector*

D.4.8.2 *Procedure.* Carefully align the microscope (**D.4.8.1.1**) with the optical axis to form a magnified image of the launch spot. Then use the probe (**D.4.8.1.2**) to measure the intensity profile across a diameter of this magnified image.

Hold the input end of the probe fibre in the linear translation stage (**D.4.8.1.3**). Pass the fibre through the cladding mode stripper (**D.4.8.1.4**) and measure the total signal from the output end with the detector (**D.4.8.1.5**).

NOTE. Figure 18 is an example of a near field scan of the launch.

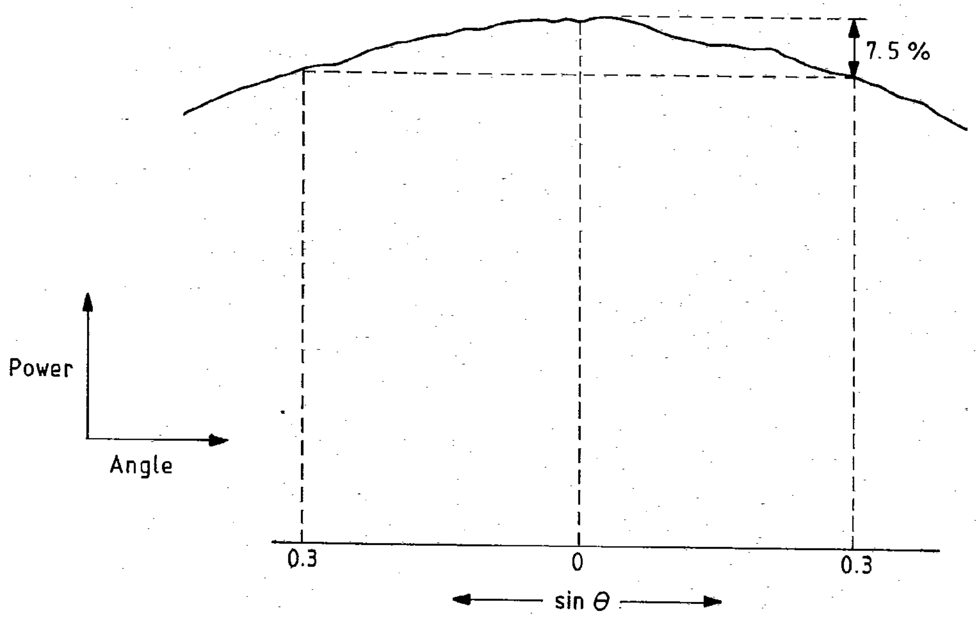


Figure 17. Radiation angle test: example of angular dependence of far field power from launch spot

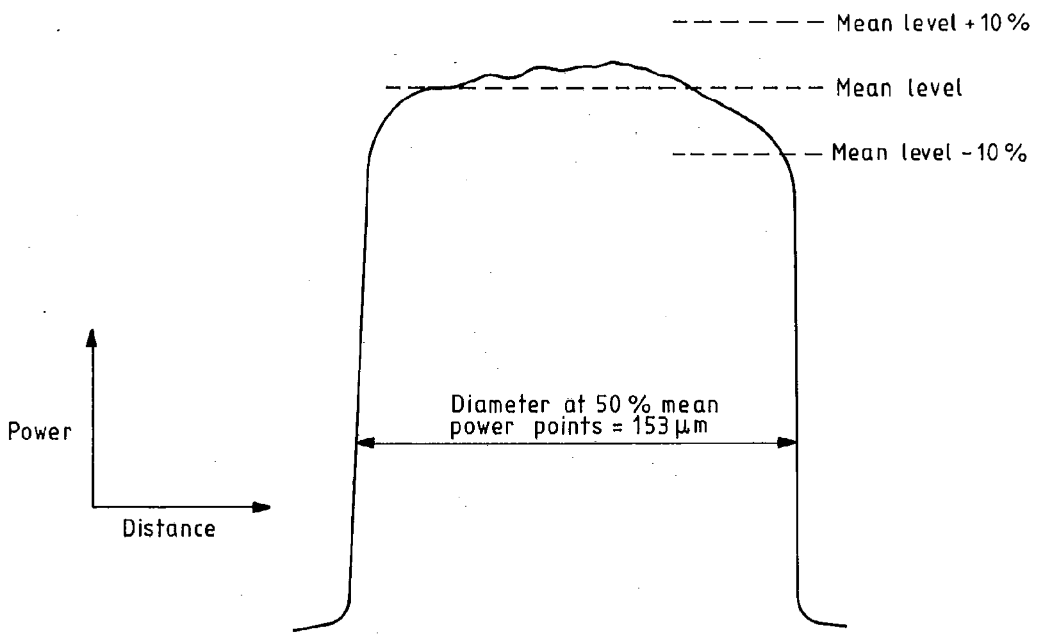


Figure 18. Radiation angle test: example of near field scan of launch spot

D.5 Refractive index profile test

D.5.1 Principle

This test determines the refractive index profile of any all-glass optical fibre by the refracted ray near field technique. The method can also be used to measure maximum theoretical NA and core and cladding diameters and, if combined with a raster rather than linear scan, fibre cross-sectional dimensions, core concentricity and circularity can be determined.

The refracted ray near field technique involves scanning a focused spot of light across the end of a fibre. As shown in figure 19 the launch optics are arranged to overfill the NA of the fibre. The fibre end is immersed in a liquid of slightly higher refractive index than the cladding. Part of the light is guided down the fibre and the rest appears as a hollow cone of refracted rays outside the fibre. The inner part of this cone contains leaky rays, whose contribution is difficult to assess. The outer part of the cone contains only refracted light. Light due to leaky rays can be prevented from reaching the detector by placing a disc on the axis of the cone. The higher-angle rays in the outer part of the cone are collected in a lens and focused on to the detector.

D.5.2 Preparation of test specimen

Prepare a test specimen that is approximately 2 m in length. Cut the fibre ends at the launch end of the specimen so that they are substantially flat across the whole cross section and normal to the axis of the fibre.

NOTE. The preparation of the output end is not so critical.

D.5.3 Apparatus

D.5.3.1 *General.* Figure 20 is an example of a typical optical arrangement. Light from the laser is rendered circularly polarized by a quarter wave plate. It then passes through a spatial filter, the pinhole of which also acts as a screen. This screen is used to observe and line up the magnified image of the fibre core obtained by white light back illumination. The magnification of this image is obtained from a combination of the x5 and x20 lenses. When the white light image is centred and in focus on the pinhole/screen then, by reciprocity, the laser spot is centred and in focus on the fibre end.

D.5.3.2 *Optical source,* such as a helium-neon laser or other source capable of providing a diffraction limited spot.

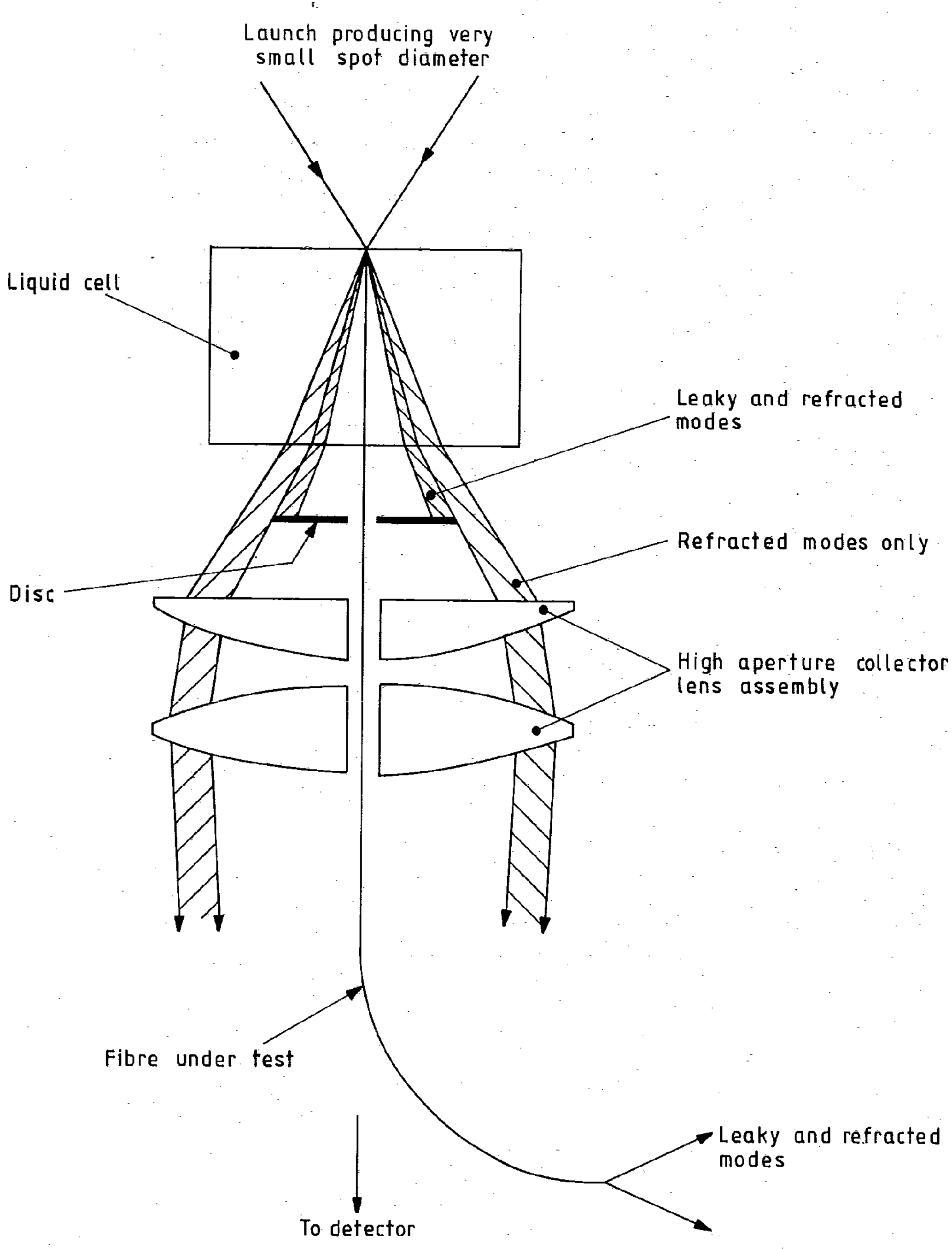
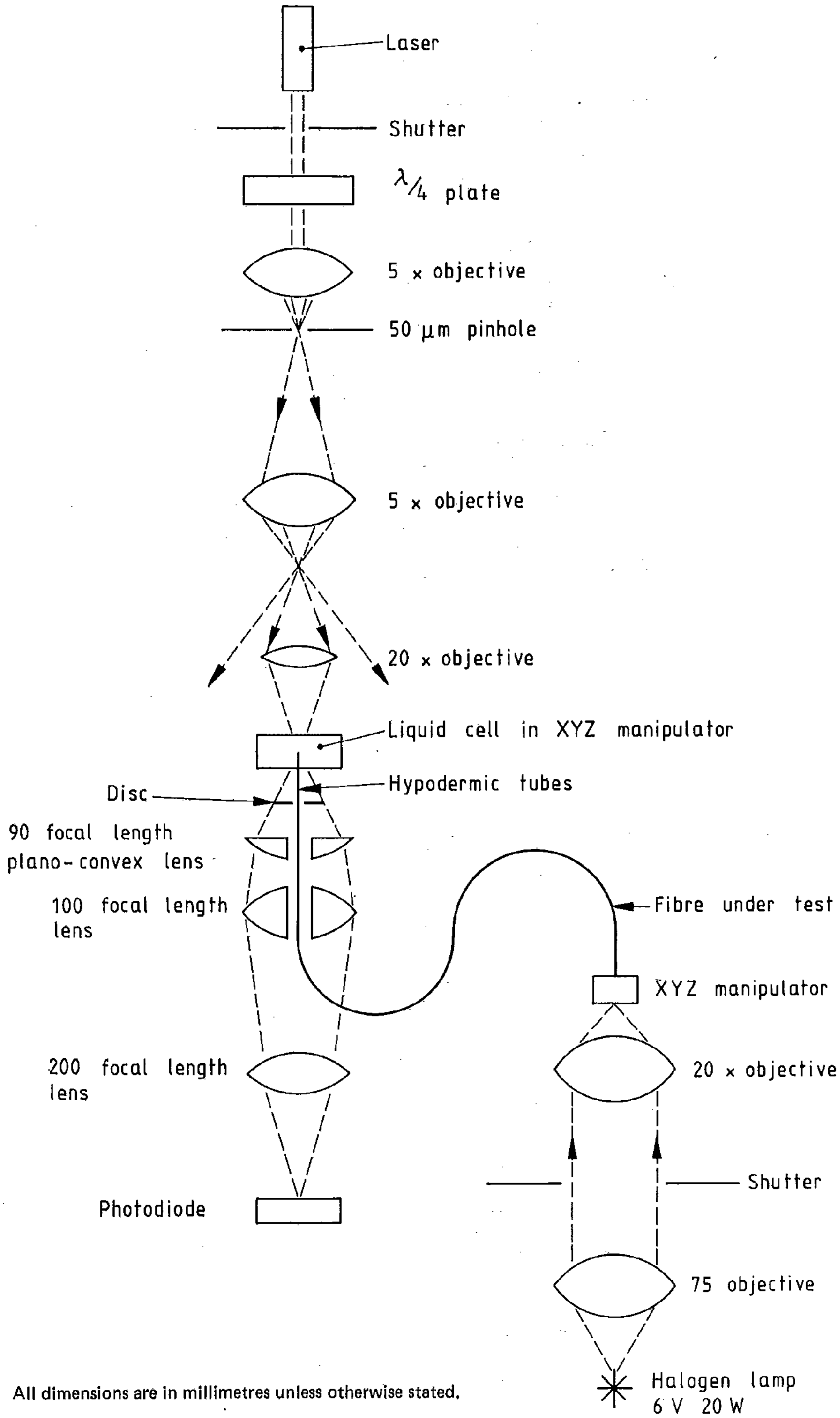


Figure 19. Schematic diagram of refractive index profile test method



All dimensions are in millimetres unless otherwise stated.

Figure 20. Typical optical arrangement for refractive index profile measurements

D.5.3.3 *High aperture collector lens assembly,* with a central hole to enable the fibre under test to be easily threaded into the liquid cell via hypodermic tubes (see figure 19).

D.5.3.4 *Electronic equipment for analogue reading of results,* using an electronic probe to measure positional displacements of the liquid cell caused by the manipulator (see figure 20). The d.c. offset supply is used to back off the unwanted d.c. component of the signal before recording on the XY plotter (see figure 21).

D.5.3.5 *Scanning systems,* capable of taking data as a line scan along a diameter of the fibre, by use of a single manipulator movement. Other diameters may be scanned by rotation of the sample. Alternatively, a raster scan may be obtained by use of orthogonal manipulators linked to stepping motor drives. In this case a series of chords are scanned across the fibre surface to produce a composite profile of the full end face. This may be displayed graphically and linked to a computing interface for direct calculation of geometrical parameters.

D.5.3.6 *XY plotter.*

D.5.4 Procedure

Mount the sample in the liquid cell and align it with the source (D.5.3.2) using the back illumination technique. Then perform the line scan or raster scan to give a reading of profile *v* position on the end face.

D.5.5 Calibration

Where values of refractive index on the profile plot are required, record the detected power level at two points on the plot. Then ascribe a relative scale of index to the plot. Make this scale absolute by assuming the index of one particular level, e.g. silica cladding level or liquid level.

D.5.6 Expression of results

The results may be presented as a graphical display of refractive index *v* position along a diameter.

The core diameter, cladding diameter and maximum theoretical numerical aperture may be directly derived by use of the appropriate definitions and the following theory.

Consider ray propagation as shown in figure 22. It can be seen that the wave-vector ratio B/k_0 is given by:

$$B/k_0 = n(r) \cos \phi_4 \text{ (on entry to the fibre)}$$
$$= n_L \cos \phi_3 \text{ (in the liquid)}$$

where

B is the z component of the wave-vector;

k_0 is the total wave-vector = $2\pi/\lambda$;

λ is the wavelength of light in vacuum;

$n(r)$ is the refractive index of the fibre at distance r from the core centre;

n_L is the refractive index of the liquid;

ϕ is the angle between the fibre axis and the ray direction.

By applying Snell's law at the entry to and exit from the liquid cell, an angle of incidence, ϕ_1, in the input cone of light can be uniquely related to a corresponding angle, ϕ_2, in the output cone by:

$$n^2(r) = \sin^2\phi_1 + n_L{}^2 - \sin^2\phi_2$$

The values of $n_L{}^2$ and $\sin^2\phi_2$ are fixed during each measurement, thus a change in $n^2(r)$ produces an equal change in $\sin^2\phi_1$. The detector measures all the power in the output beam at angles greater than the value of ϕ_2 defined by the disc. This is equivalent to the total power, $P(\phi_1)$, in the input beam above a corresponding angle ϕ_1 defined through the equation.

In the practical measurement set up by a suitable choice of optics $P(\phi_1)$ is chosen to be linearly dependent on $\sin^2\phi_1$ over the range of ϕ_1 used. $P(\phi_1)$ is therefore linearly dependent on $n^2(r)$ and hence $n(r)$, since the index difference is small. Thus as the focused spot is scanned across the fibre diameter the detected power gives the fibre profile directly.

Concentricity and non-circularity may be derived with sufficient knowledge of several diameters or the full raster.

D.6 Optical continuity

D.6.1 Backscattering test

Test the specimen using the method described in **D.2**

D.6.2 Transmitted light power

If specified in the relevant Part of BS 6558, the transmitted light power of optical fibres shall be tested.

NOTE. A method of test is under consideration.

D.7 Chromatic dispersion

If specified in the relevant Part of BS 6558, the chromatic dispersion of optical fibres shall be tested.

NOTE. LED and laser-based test methods are under consideration.

D.8 Change in optical transmittance

D.8.1 Principle

This test is used to monitor and measure the change in optical transmittance of optical fibres and cables undergoing mechanical or environmental tests. It provides an attenuation monitor of high resolution with good stability over prolonged times and temperature changes.

D.8.2 Preparation of test specimen

Prepare the test specimens as described in the appropriate mechanical, environmental or other test being carried out.

D.8.3 Apparatus

D.8.3.1 *General.* Figure 23 is an example of a typical test arrangement. This example shows an attenuation monitor with optical feedback stabilized LED.

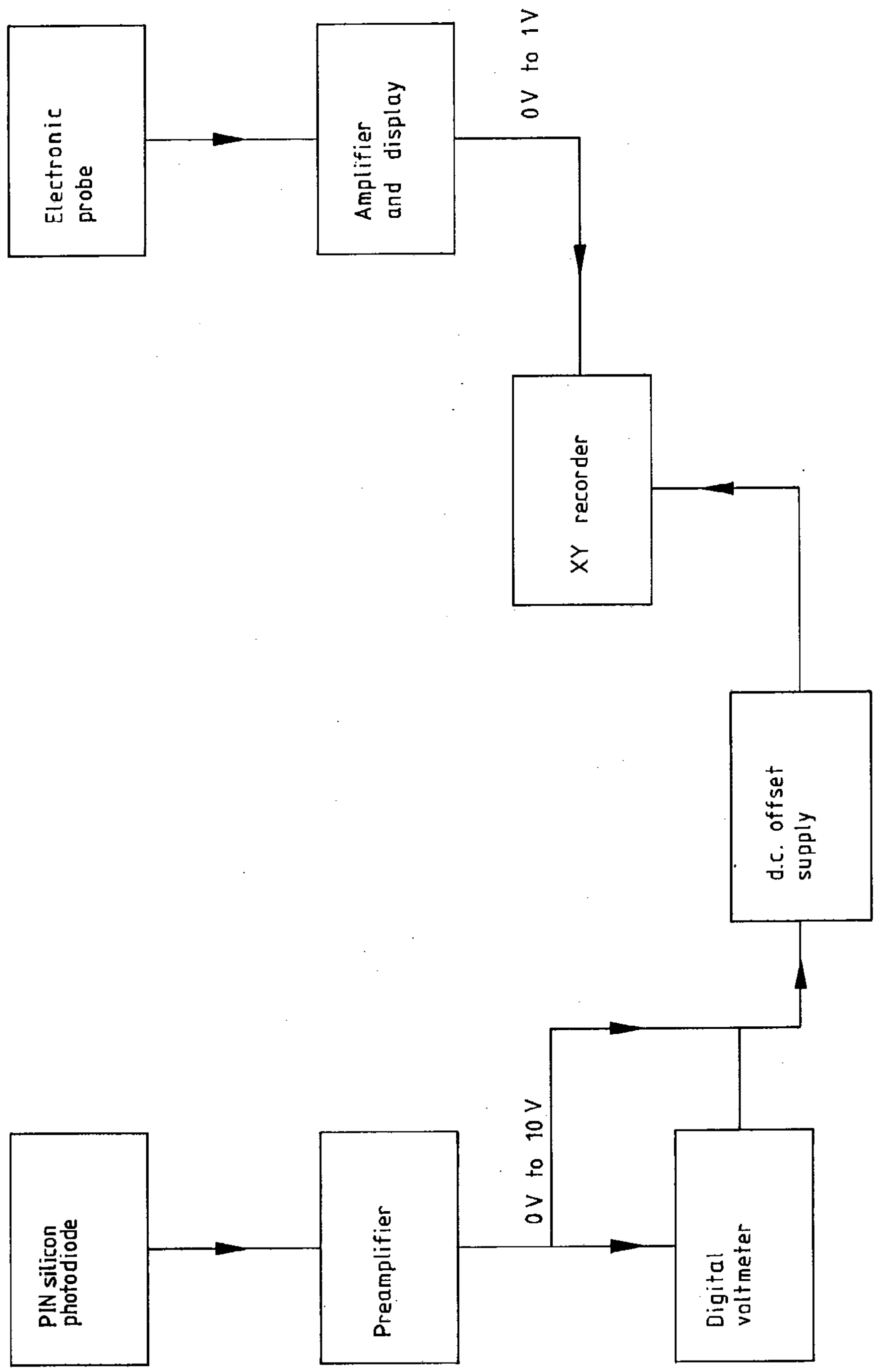


Figure 21. Block diagram of electronic arrangement for refractive index profile measurements

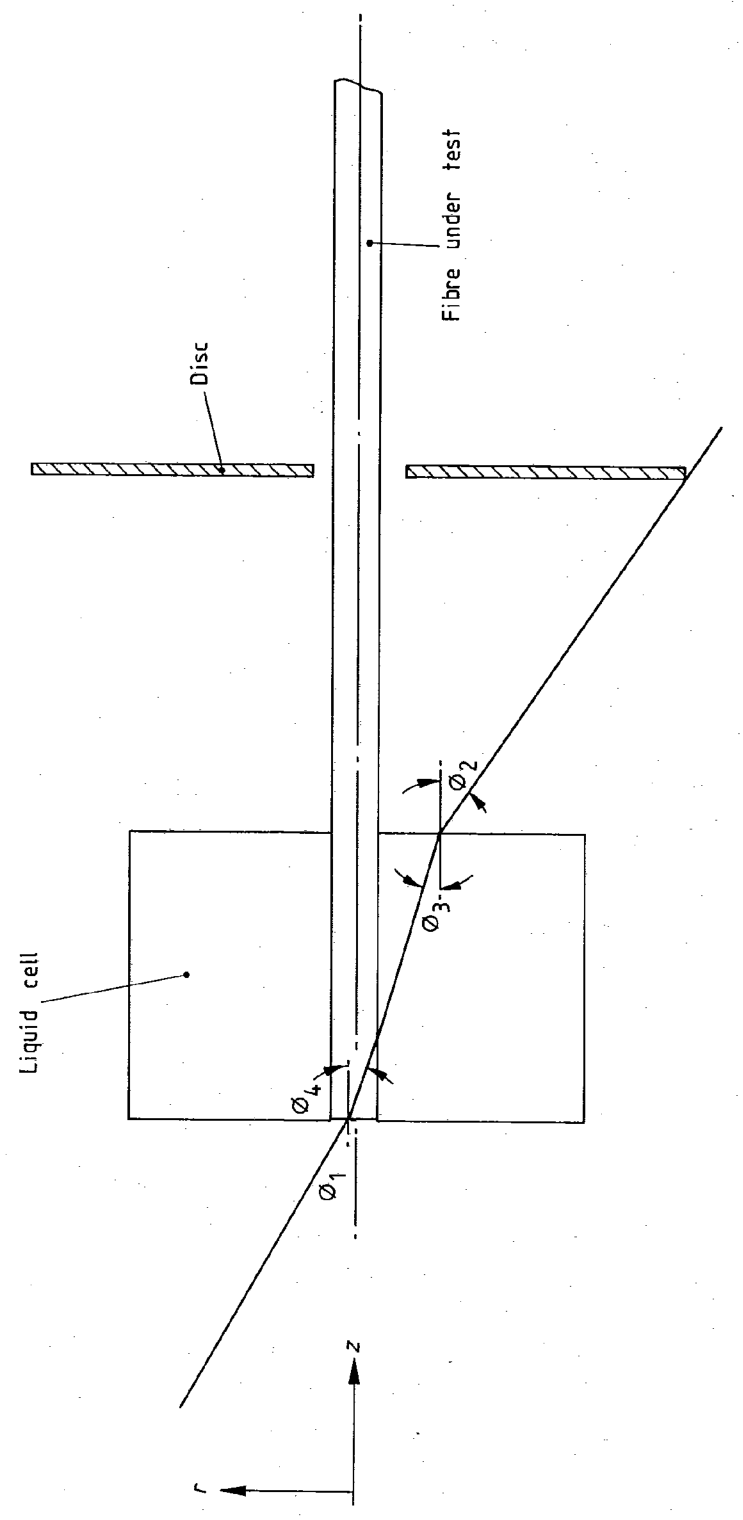
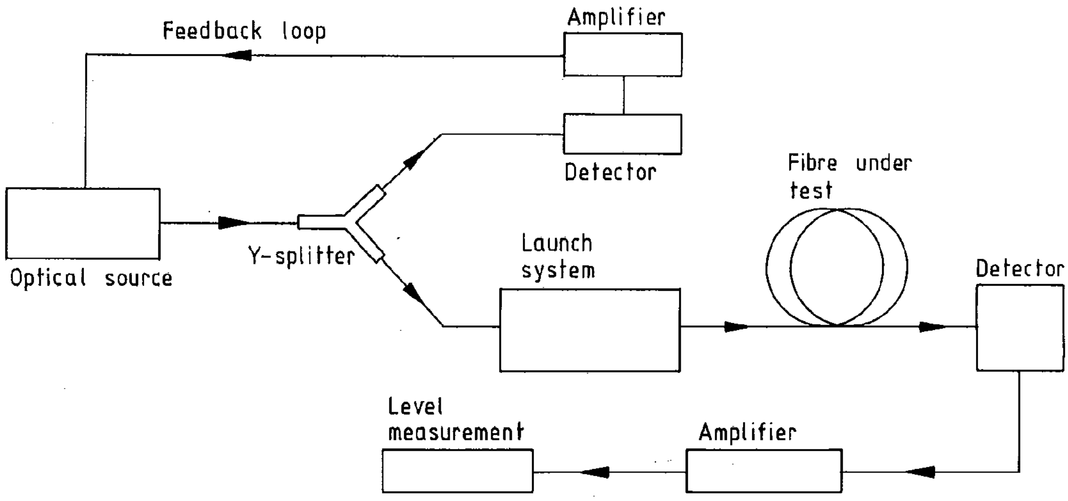
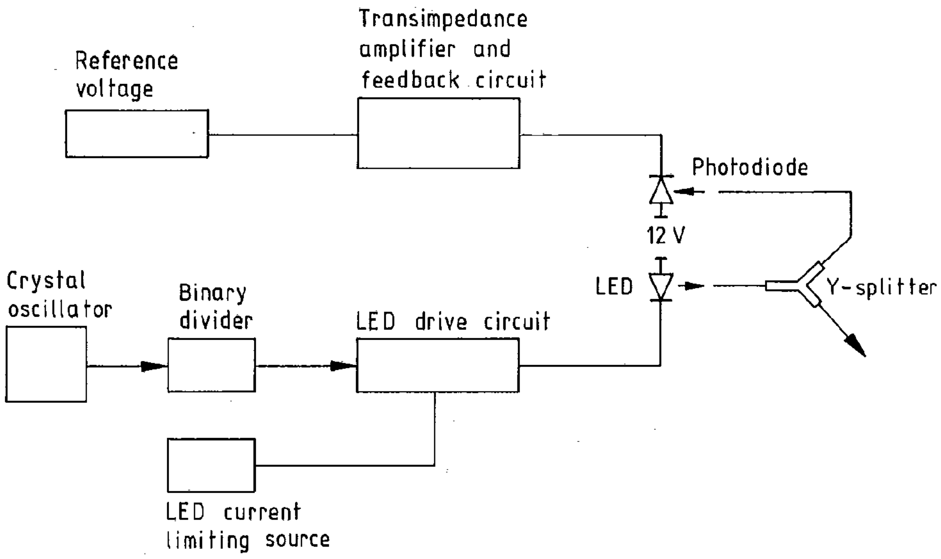


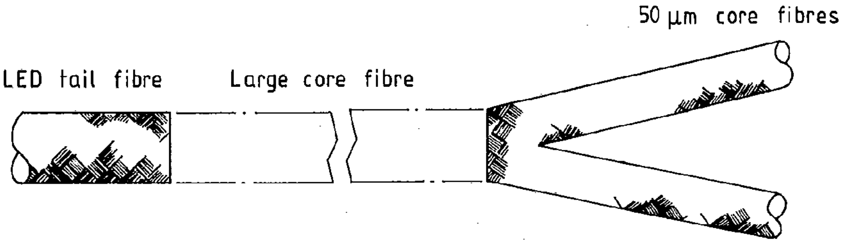
Figure 22. Propagation geometry for refractive index profile test



(a) Attenuation monitor with optical-feedback stabilized source



(b) Stabilized source



(c) Y-splitter

Figure 23. Test arrangement for measurement of change in optical transmittance

D.8.3.2 *Optical source,* such as an LED with a fibre tail whose output passes into a Y splitter, one branch of which provides the optical feedback via a photodetector and the LED drive current compensation circuit, the other launches light into the test specimen.

D.8.3.3 *Y splitter,* comprising a large core fibre with two smaller core fibres fusion-spliced to one end. Typically the LED fibre tail is fusion-spliced on to a 2 m long 90/125 µm step index fibre. Two 1 m long 50/125 µm graded index fibres are fusion-spliced on to the other end. The stability of the light output of the test branch is critically dependent on the ratio of the light outputs from the two branches. The splitting ratio shall be 1 ± 0.2 with a temperature stability better than 0.004 dB/°C. A fused fibre Y-splitter preceded by a mode scrambler is preferred to minimize variations in the branching ratio due to mechanical effects brought about by temperature changes or vibration, or by modal pattern changes at the LED due to temperature or injection current changes.

D.8.3.4 *Optical detector,* of large area so that all of the radiation in the output cone is intercepted. The detector shall have a sufficiently uniform response over the active area and range of incidence angle at the measurement wavelengths to ensure that movement of the output cone in position or angle relative to the detector, within the limits determined by the mechanical design of the test equipment, does not significantly affect the test results.

D.8.4 Launch techniques

Launch techniques shall be as described in **D.1.1.2**, and shall include a cladding mode stripper at the source and detector ends of the test specimen.

D.8.5 Procedure

Measure the output optical power from the test specimen before, at intervals during, and after the test sequence as specified in the appropriate mechanical, environmental or other test being carried out.

Appendix E. Mechanical tests

E.1 Optical fibre proof test

E.1.1 Principle

The proof test uses one of the following methods as specified in the relevant Part of BS 6558.

(a) constant stress;

(b) constant longitudinal strain;

(c) constant bending strain.

The tests at constant stress and constant longitudinal strain are appropriate for fibres with protective coatings and buffers of elastic modulus and thickness adequate to withstand the longitudinal and radial forces imposed and to protect the surface of the fibre from deleterious radial stresses. Where primary coatings and buffers are not adequate to withstand these forces, the test at constant bending strain may be appropriate.

E.1.1.1 *General.* In this test the entire length of an optical fibre is subjected to a constant stress or constant strain with the object of ensuring that a continuous length of fibre includes no flaws which will give rise to fracture if an instantaneous stress or strain less than the minimum strength determined by the proof test is applied.

E.1.1.2 *Flaw distribution.* In the course of manufacture, local stress and local damage result in the distribution of large numbers of cracks along the surface of the fibre. The size of the flaws will vary from a few large processing cracks to a large number of small inherent flaws. A crack of a specific size imposes a characteristic fracture strength on the fibre (see figure 24) and if a stress corresponding to this value is applied the fibre will fracture instantaneously.

E.1.1.3 *Flaw growth.* If a low value of stress is applied to a length of fibre containing a flaw, the following two mechanisms contribute to the fracture of the fibre.

(a) The flaw increases in size at a rate dependent upon the applied stress.

(b) When the size of the flaw has a fracture strength equal to the applied stress, the crack propagates radially from its tip in a plane perpendicular to the stress and at the velocity of sound, resulting in rupture of the fibre.

While it is possible to predict the lifetime to failure of a fibre under a known stress if the size of the largest flaw is established, no certain method exists of actually identifying the one or two large flaws which determine the overall strength of a long length of fibre.

E.1.1.4 *Fibre proof testing.* Proof testing is a technique to establish a limit on the maximum crack size or minimum strength of the complete length of fibre. The fibre is stressed or strained to a predetermined limit and fracture will occur if a flaw of fracture strength corresponding to the test value occurs within the gauge length during the period of the test. This can arise in the following two ways.

(a) A flaw of fracture strength equal to or less than the test value already existed before the test and fracture occurred as it came within the gauge length.

(b) A smaller, i.e. higher fracture strength, flaw existed in the fibre and, during the finite time of the test, it increased in size under the applied stress so that it fractured before it left the gauge length.

Since crack growth is finite with time and the aim of the test is to establish a limit for the surviving flaws, it is desirable that the period under stress should be short and that the time to remove the stress should be short. It is generally accepted that static fatigue is additive and so all flaws will have been reduced in fracture strength by the test even if they have not fractured. At the conclusion of the test, the value of strength of the weakest surviving flaw cannot be defined, only that it is greater than the proof stress. It is important that in use, subsequent stress placed on the fibre by manufacturing and installation processes remains well below the proof test level.

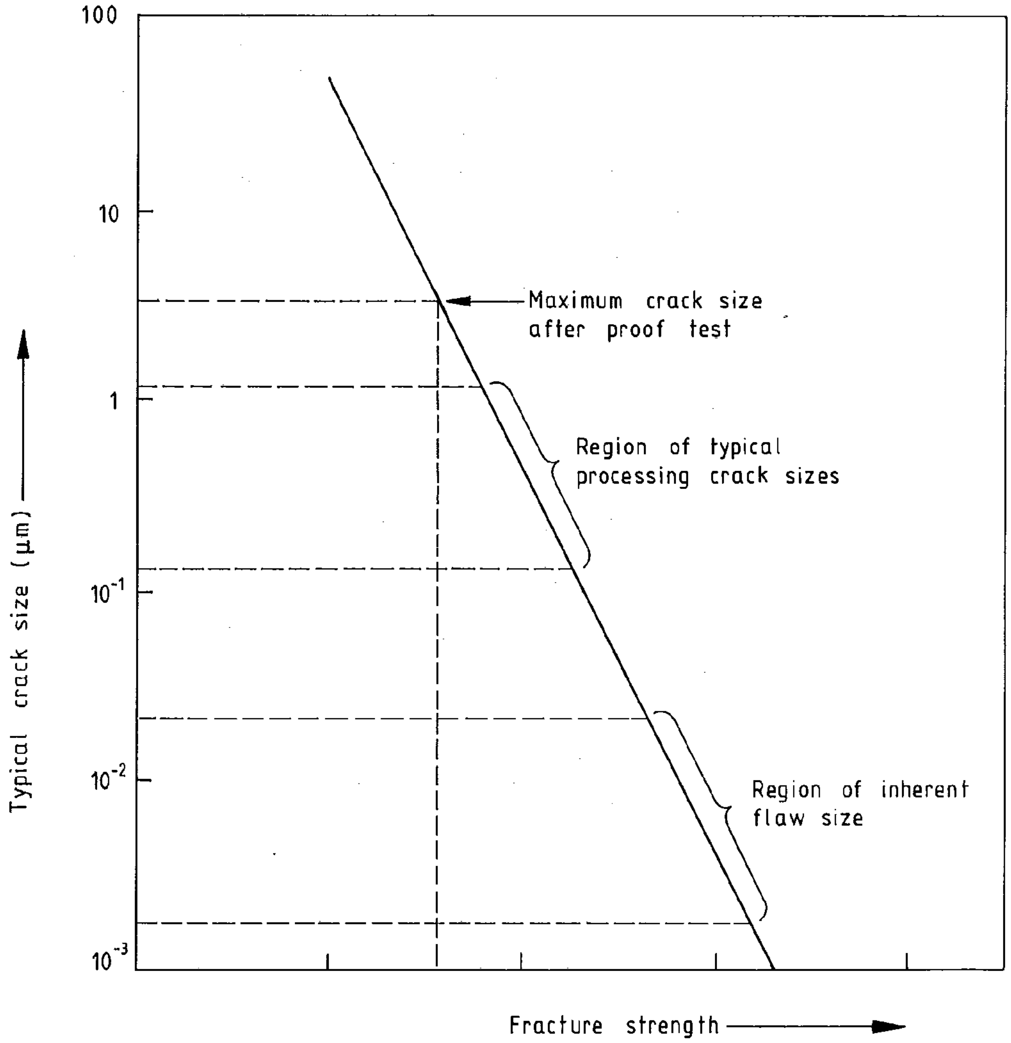


Figure 24. Optical fibre fracture strength and crack size

Where strain is deduced from the constant stress or bending strain test, care has to be taken to allow for the effects of protective coatings or fibre buffers.

E.1.2 Environmental test conditions

The test shall be carried out at standard atmospheric conditions for testing in accordance with 5.3 of BS 2011 : Part 1.1 : 1983.

E.1.3 Constant stress proof test

E.1.3.1 *Apparatus*

E.1.3.1.1 *Constant stress proof test rig,* similar to that shown in figure 25. A and C are driven wheels or pulleys and B is a free-running wheel or pulley, coplanar with the other two, which has free spatial movement restricted to a vertical line through its axis. A weight W applied to B provides the stress-related tension T. The coefficient of static friction between the optical fibre and wheels A and C shall be high, and a means such as pressure belts, may be provided to ensure that slippage is minimized. One of the wheels shall be driven at constant angular velocity and a means shall be provided to maintain a constant vertical position for wheel B by varying the angular velocity of wheel C. The feed tension T_l shall not exceed one-tenth of the test tension T. The diameter of the wheels shall be such that the stress due to bending at any point of the optically transmitting element shall not exceed one-tenth of the test value and the absolute strain due to bending at any point of any associated plastics material shall not exceed 1 %. Means shall be provided to apply the weight W to the free-running wheel or pulley B, the mass being as specified in the relevant Part of this standard.

E.1.3.1.2 *Optical time domain reflectometer*, or other means to test the optical fibre for breaks.

E.1.3.2 *Procedure.* Pass the optical fibre through the apparatus as shown in figure 25 at a velocity corresponding to the proof test time specified in the relevant Part of BS 6558.

E.1.4 Constant longitudinal strain proof stress test

E.1.4.1 *Apparatus*

E.1.4.1.1 *Constant strain proof test rig*, similar to that shown in figure 26. A and B are wheels or pulleys which are arranged to rotate with a peripheral velocity difference to give the required strain.

The velocity difference may be achieved by arranging that the wheels have the same nominal diameter but rotate with an angular velocity difference corresponding with the required strain level or by fixing the diameters of the wheels in a fixed ratio corresponding to the required strain level but with the wheels coupled to rotate at the same angular velocity. The coefficient of static friction between the optical fibre and the wheels shall be high to minimize slippage and pressure belts or similar devices may be used. The strain corresponding to the feed tension T_1 shall not exceed one-tenth of the test value. The diameter of the wheels shall be such that the strain due to bending at any point of the optically transmitting element shall not exceed one-tenth of the test value and the absolute strain due to bending at any point of any associated plastics material shall not exceed 1 %.

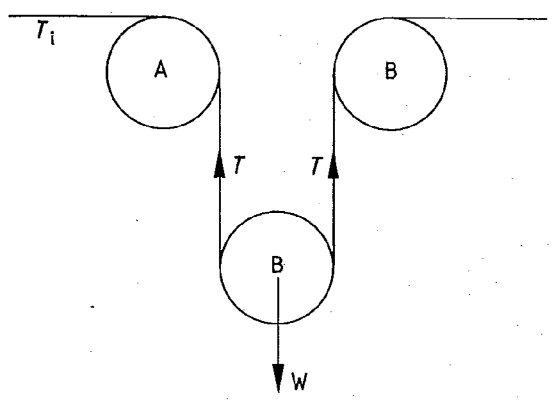


Figure 25. Apparatus for constant stress proof test

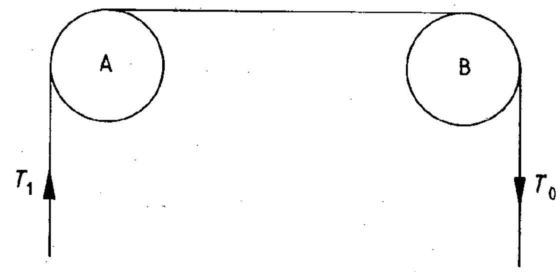


Figure 26. Apparatus for constant strain proof test

E.1.4.1.2 *Optical time domain reflectometer*, or other means to test the optical fibre for breaks.

E.1.4.2 *Procedure.* Set the strain applied to the value specified in the relevant Part of BS 6558, either by adjusting the speed controls to the wheels to give the required rotational difference or by fitting wheels with the required diameter difference.

Pass the optical fibre through the constant strain proof test apparatus (**E.1.4.1.1**) at a velocity corresponding to the test time specified in the relevant Part of BS 6558.

E.1.5 Constant bending strain proof test

E.1.5.1 *Apparatus*

E.1.5.1.1 *Bending strain test rig*, similar to that shown in figure 27(a). A, B and C are three rollers that are free to rotate about parallel axes. The fibre is drawn along a path in which it is bent over the freely rotating rollers under sufficient tension to make it conform to the roller geometry. The roller diameters are chosen so that the maximum strain induced by bending in the surface of the fibre is equal to the required strain, after allowing for the thickness of any protective coatings or buffers.

In order to ensure a near constant maximum strain to all parts of the fibre surface, a number of sets of rollers are used arranged at angles to the first. Typically four sets of rollers at 45 ° to each other may be used (see figure 27(b)).

The fibre feed and winding arrangement are arranged to avoid twisting of the fibre as it passes through the machine.

E.1.5.1.2 *Optical time domain reflectometer*, or other means to test the optical fibre for breaks.

E.1.5.2 *Procedure.* Set the strain to the value specified in the relevant Part of this standard by the choice of roller diameter. Pass the optical fibre through the constant strain test apparatus (**E.1.5.1.1**) at a velocity corresponding to the test time specified in the relevant Part of BS 6558.

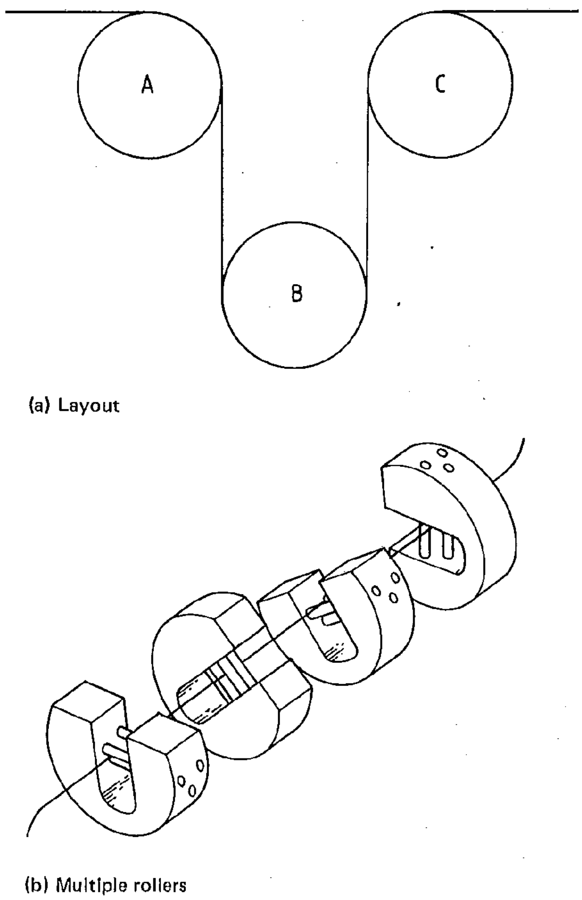


Figure 27. Apparatus for bending strain proof test

E.2 Cable abrasion test

E.2.1 Principle

This test determines the ability of an optical fibre cable to withstand abrasion. The test specimen is heated and then abraded by a scraping device. Four tests are made in different positions and directions.

E.2.2 Apparatus

A typical abrasion test rig is shown in figure 28. The test rig shall be provided with a counter for recording the number of cycles.

NOTE. One cycle is defined as the excursion of the scraping device and its return to the starting position.

The scraping device shall be a blade or a polished piano wire as specified in the relevant Part of BS 6558. For the blade, the dimensions shall be as shown in figure 28 and the blade material shall be hardened tungsten carbide. The diameter of the piano wire shall be as specified in the relevant Part of BS 6558.

Provision shall be made for heating the specimen by enclosing the cable specimen and abrasion device within an oven fitted with suitable temperature control and monitoring equipment.

E.2.3 Procedure

Firmly clamp the cable specimen to the anvil and then heat it to the temperature specified in the relevant Part of BS 6558.

Load the scraping device with the weight specified in the relevant Part of BS 6558.

Make four tests, each comprising the number of cycles specified in the relevant Part of BS 6558, on each specimen, moving the specimen forward 100 mm and rotating it through 90 ° in one direction between tests.

This test shall be conducted at room temperature or at the temperature specified in the relevant Part of BS 6558.

E.3 Cable tensile test

E.3.1 Principle

This test determines the ability of an optical fibre cable to withstand tensile loading or to monitor optical performance under tensile loading by one of the methods listed in E.3.4.

E.3.2 Environmental test conditions

The test shall be carried out at standard atmospheric conditions for testing in accordance with **5.3** of BS 2011 : Part 1.1 : 1983.

E.3.3 Preparation of test specimen

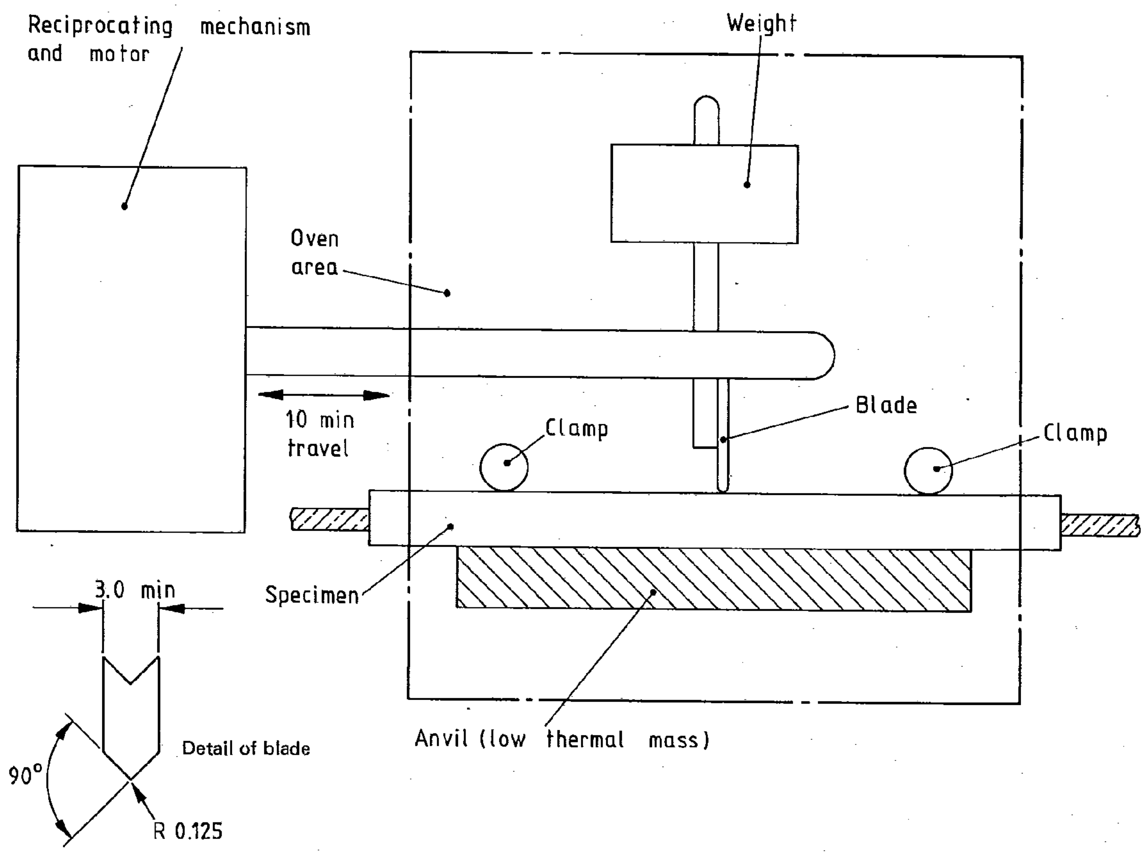
Prepare a test specimen of the length specified in the relevant Part of BS 6558. Terminate the specimen at each end in a connector or in a manner appropriate to the cable construction and nature of use and installation. If attenuation is being monitored, ensure that the test specimen is sufficiently long to achieve the required accuracy of measurement of change in attenuation.

E.3.4 Apparatus

The apparatus shall enable a measured and controlled axial force to be applied to a cable specimen, using one of the following methods.

(a) *Method 1.* Linear clamps shall be attached to the outer surface of the cable. The pressure applied to the clamps shall be sufficient to prevent slippage during the test. Depending on the cable construction, this method can cause an increase in attenuation which can be measured before the tensile load is applied.

(b) *Method 2.* The cable shall be wound around a mandrel, pulley or drum such as shown in figure 29.



All dimensions are in millimetres unless otherwise stated.

Figure 28. Apparatus for cable abrasion test

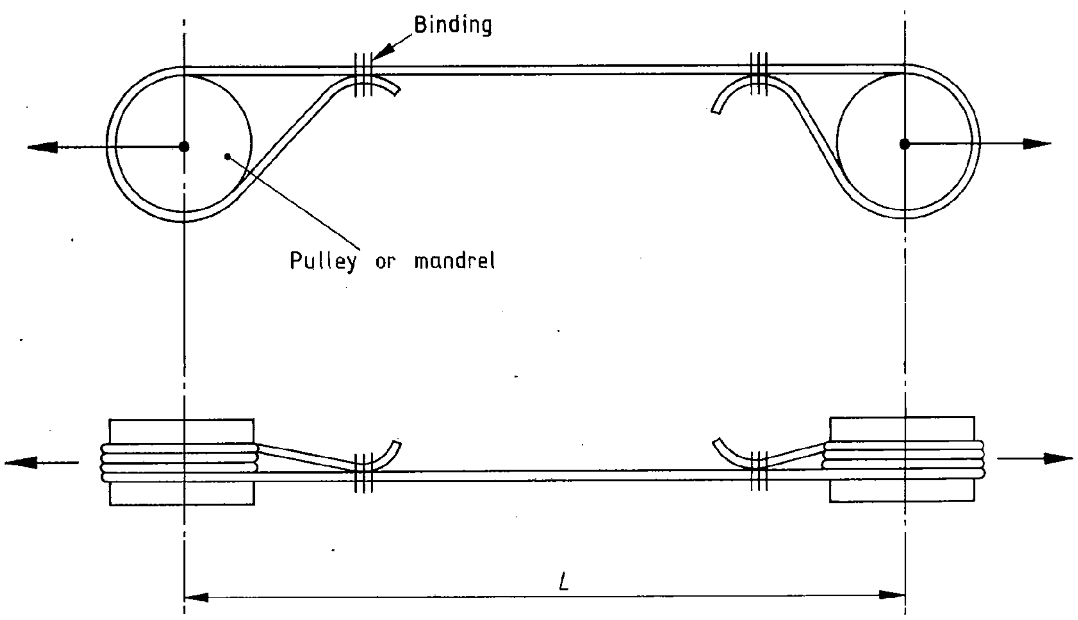


Figure 29. Apparatus for cable tensile test

If the free end is secured to the cable under test, at least three close turns are required. Otherwise, at least six close turns are required to prevent slippage during the test. The diameter of the mandrel shall be not less than 15 times the diameter of the cable under test. This method can cause an increase in attenuation during the test, which is indistinguishable from that of part of the cable under test.

(c) *Method 3.* The cable shall be attached by clamping selected cable components, e.g. strength members. This method does not cause an increase in attenuation, but does not stress the complete cable construction.

(d) *Method 4.* A system of multiple pulleys shall be used for non-destructive tests to measure strain margin on long lengths of cable.

NOTE. Optical fibre cables have to operate in many different environments and withstand different methods of installation, e.g. direct burial, being pulled into ducts and aerial suspension, and the clamping method used in this test should be appropriate to the cable construction and nature of use and installation.

E.3.5 Procedure

Increase the tensile load until the minimum value specified in the relevant Part of BS 6558 is achieved. Maintain the load for a sufficient period to demonstrate that the specimen is not yielding.

E.4 Cable bend test

E.4.1 Cable bend test at room temperature

E.4.1.1 *Principle.* This test determines the ability of an optical fibre cable to withstand bending. The specimen is wrapped in a close helix about a mandrel and then unwrapped and wrapped again for a specified number of cycles.

E.4.1.2 *Environmental test conditions.* The test shall be carried out at standard atmospheric conditions for testing in accordance with **5.3** of BS 2011 : Part 1.1 : 1983.

E.4.1.3 *Preparation of test specimen.* The specimen shall be terminated at each end in a connector, or in a manner such that the fibres, sheathings and any strain members are clamped together representative of a connector.

E.4.1.4 *Apparatus.* A single mandrel apparatus shall enable the specimen to be wrapped tangentially in a close helix around a test mandrel. The diameter of the mandrel shall be as specified in the relevant Part of BS 6558. A suitable apparatus is shown in BS 6469 and figure 30 but other substantially equivalent apparatus may also be used.

E.4.1.5 *Procedure.* Wrap the specimen in a close helix around the mandrel at a uniform rate of one revolution in

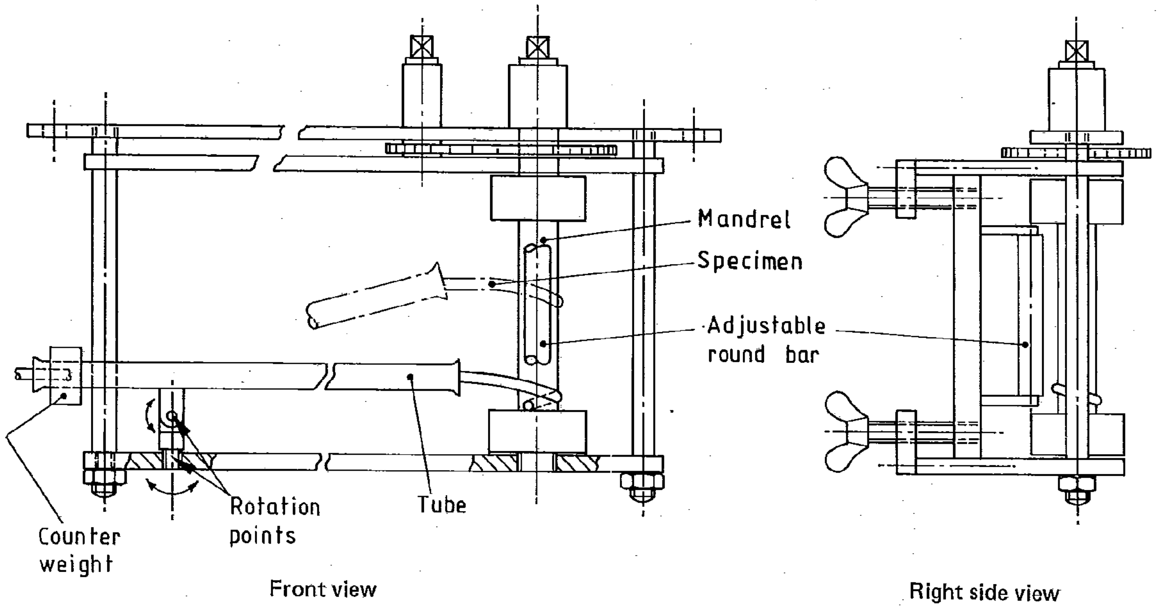


Figure 30. Apparatus for cable bend test

about 5 s, the number of turns being as specified in the relevant Part of BS 6558. Apply a tension sufficient to ensure that the specimen contours the mandrel. Then unwrap the specimen.

Repeat for the number of cycles specified in the relevant Part of BS 6558, a cycle consisting of one wrapping and unwrapping.

E.4.2 Cable bend test at low temperature

The cable shall be tested in accordance with **4.3.2** of BS 6469 : 1984 at the temperature specified in the relevant Part of BS 6558.

E.5 Cable cyclic bend test

E.5.1 Principle

This test determines the ability of an optical fibre cable or cable/connector assembly to withstand repeated bending. The test specimen is subjected to a tensile load and then bent through 180 ° for a specified number of cycles.

E.5.2 Environmental test conditions

The test shall be carried out at standard atmospheric conditions for testing in accordance with **5.3** of BS 2011 : Part 1.1 : 1983.

E.5.3 Preparation of test specimen

Terminate the specimen at each end in a connector or in a manner such that when the fibres, sheathings and any strain members are clamped together, they are representative of a connector.

E.5.4 Apparatus

For testing cable, a suitable apparatus is shown in BS 6500 and figure 31. For testing cable/connector assemblies, a suitable apparatus is shown in figure 32. The mass of the weight, bending radius *R* and dimensions *L* and *b* shall be as specified in the relevant Part of BS 6558.

The apparatus shall enable the specimen to be bent backwards and forwards through 180 °, the two extreme positions making an angle of 90 ° on both sides of the vertical, whilst being subjected to a tensile load.

E.5.5 Procedure

Fix the specimen to the apparatus as shown in figures 31 and 32 and load it with the weight.

Bend the specimen backwards and forwards, the two extreme positions making an angle of 90 ° on both sides of the vertical at the bending rate specified in the relevant Part of BS 6558 as appropriate to the cable size. Repeat for the number of cycles specified in the relevant Part of BS 6558, a cycle constituting an oscillation from the vertical to the extreme right position then to the extreme left position and returning to the central vertical position.

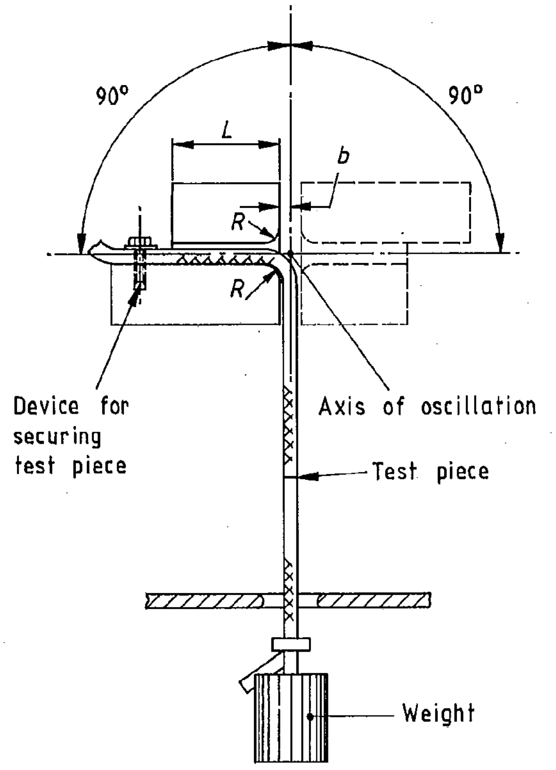


Figure 31. Apparatus for cable cyclic bend test

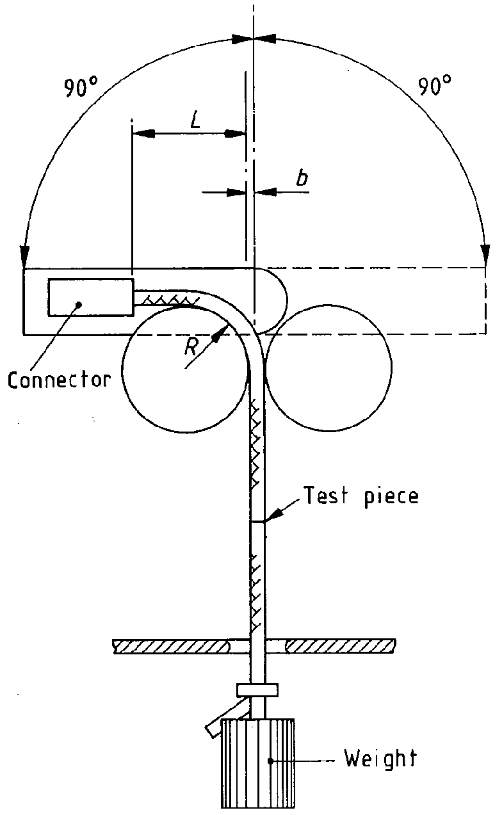


Figure 32. Apparatus for cyclic bend test for cable assembly with connector

E.6 Cable flexing test

E.6.1 Principle

This test determines the ability of an optical fibre cable to withstand repeated flexing. The test specimen is subjected to a load and then flexed by a system of pulleys for a specified number of cycles.

E.6.2 Environmental test conditions

The test shall be carried out at standard atmospheric conditions for testing in accordance with **5.3** of BS 2011 : Part 1.1 : 1983.

E.6.3 Preparation of test specimen

Terminate the specimen at each end in a connector or in a manner such that when the fibres, sheathings and any strain members are clamped together, they are representative of a connector.

E.6.4 Apparatus

A suitable apparatus is shown in BS 6500 and figure 33. This apparatus has a carrier C supporting two pulleys A and B arranged so that the cable is horizontal between the pulleys. The carrier makes a backward and forward movement over a distance of 1 m at an approximately constant speed of 0.33 m/s unless otherwise specified in the relevant Part of BS 6558.

NOTE. A cycle comprises a complete backward and forward movement of the carrier.

The pulleys shall have a semi-circular shaped groove for circular cables and a flat groove for flat cables. The restraining clamps D shall be fixed so that the pull is always applied by the weight from which the carrier is moving away.

The mass of the loading weight and the diameter of pulleys A, B and E shall be as specified in the relevant Part of BS 6558.

E.6.5 Procedure

Stretch the specimen over the pulleys as shown in figure 33, each end being loaded with a weight.

Flex the specimen for the number of cycles specified in the relevant Part of BS 6558.

E.7 Cable torque test

E.7.1 Principle

This test determines the ability of an optical fibre cable or cable/connector assembly to withstand twisting. The test specimen is subjected to a load and then rotated both clockwise and anticlockwise for a specified number of cycles.

E.7.2 Preparation of test specimen

Terminate the specimen in a connector or in a manner such that when the fibres, sheathings and any strain members are clamped together, they are representative of a connector.

E.7.3 Environmental test conditions

The test shall be carried out at standard atmospheric conditions for testing in accordance with **5.3** of BS 2011 : Part 1.1 : 1983.

E.7.4 Apparatus

The test shall be carried out by means of an apparatus consisting of a fixed clamp and a rotating clamp. Provision shall be made to monitor cable attenuation and for the application of a tensile load to the specimen during test. Suitable apparatus is shown in figures 34(a) and 34(b) but other substantially equivalent apparatus may also be used. The length of cable *L* and the mass shall be as specified in the relevant Part of BS 6558.

E.7.5 Procedure

Mount the specimen in the test apparatus with the cable clamped in the fixed clamp sufficiently tightly to prevent movement of the cable sheath during the test. Fix the connector or termination to the rotating clamp and rotate it in a clockwise direction for the numbers of turns specified in the relevant Part of BS 6558, a turn being a 360 ° rotation. Then return the specimen to the starting position and rotate it in an anticlockwise direction for the same number of turns and return it to the starting position, this complete movement constituting one cycle.

E.8 Cable impact test

E.8.1 Impact test at room temperature

E.8.1.1 *Principle.* This test determines the ability of an optical fibre cable to withstand impact. A weight is dropped vertically on to an intermediate piece resting on the test specimen.

E.8.1.2 *Environmental test conditions.* The test shall be carried out at standard atmospheric conditions for testing in accordance with **5.3** of BS 2011 : Part 1.1 : 1983.

E.8.1.3 *Apparatus.* A suitable apparatus is shown in BS 6469 and figure 35 but other equivalent apparatus may also be used.

E.8.1.4 *Procedure.* Adjust the mass of the weight and the height from which the weight falls to give the value of starting energy specified in the relevant Part of BS 6558.

Drop the weight on to the intermediate piece for the number of impacts specified in the relevant Part of BS 6558.

E.8.2 Impact test at low temperature

The test specimen shall be tested in accordance with **4.3.6** of BS 6469 : 1984 at the temperature specified in the relevant Part of BS 6558.

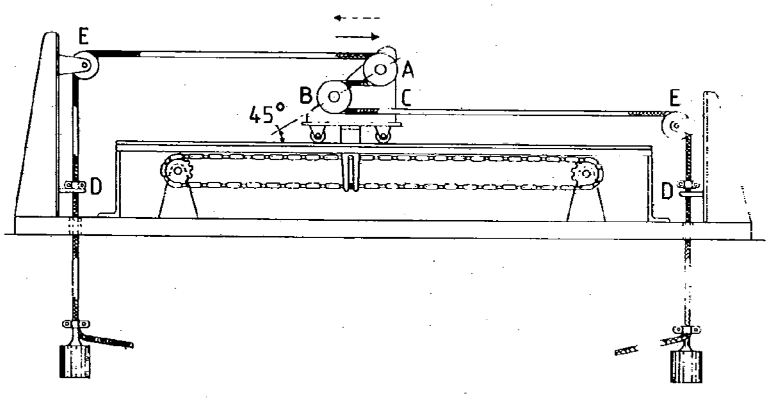


Figure 33. Apparatus for cable flexing test

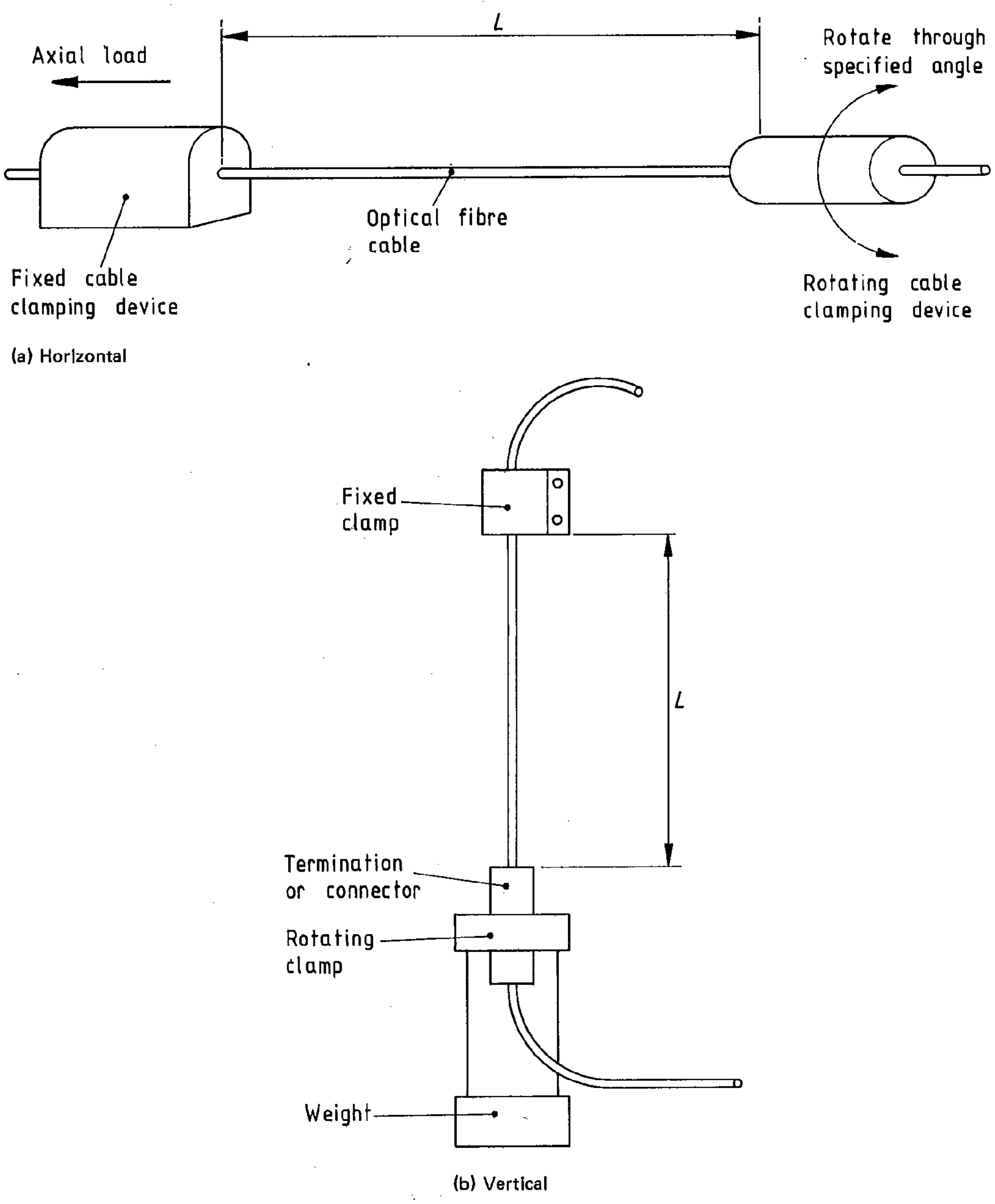


Figure 34. Apparatus for cable torque test

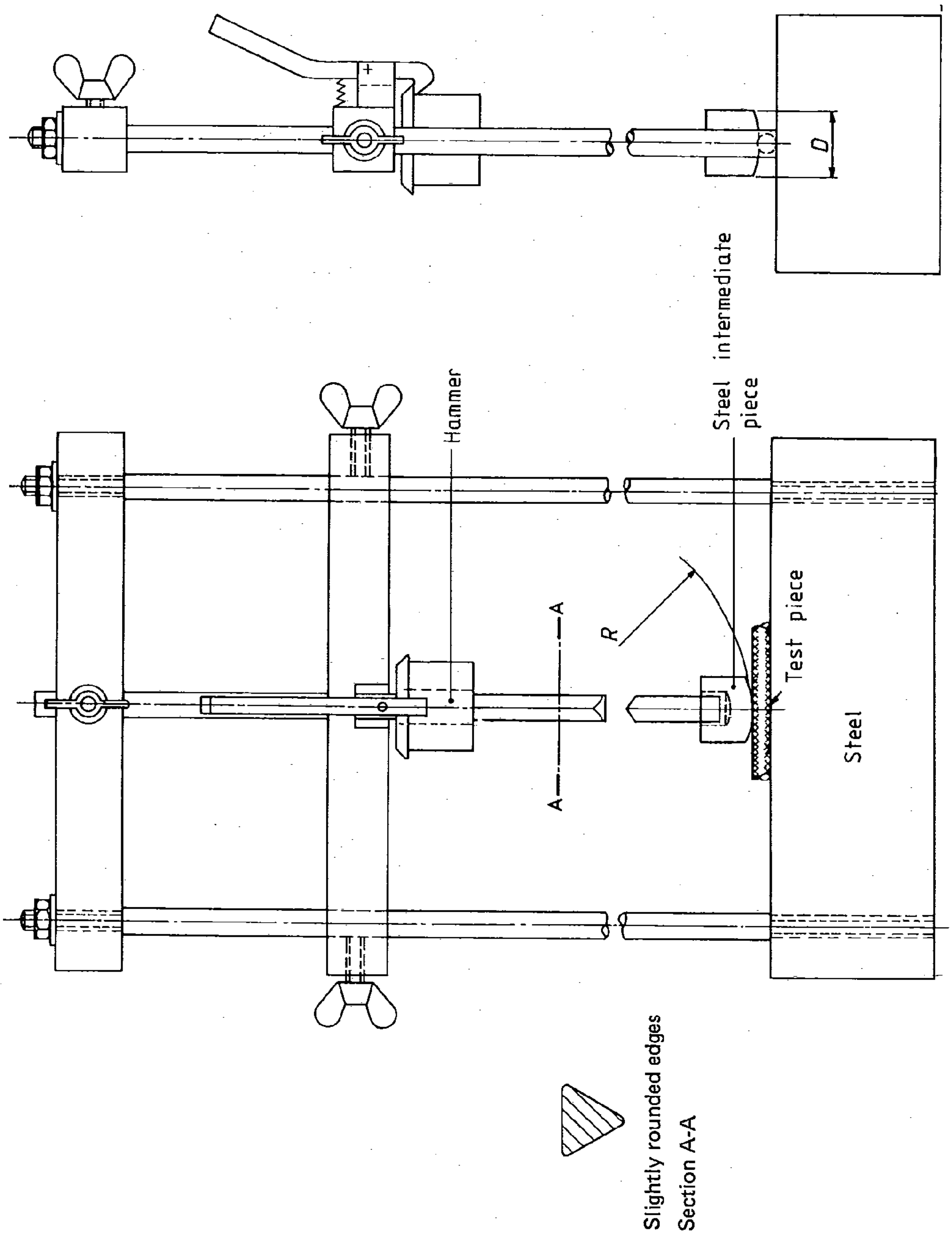


Figure 35. Apparatus for cable impact test

E.9 Cable crush test

E.9.1 Principle

This test determines the ability of an optical fibre cable to withstand crushing. The test specimen is crushed between a flat base plate and a movable plate or cylindrical mandrel.

E.9.2 Environmental test conditions

The test shall be carried out at standard atmospheric conditions for testing in accordance with **5.3** of BS 2011 : Part 1.1 : 1983.

E.9.3 Apparatus

Suitable apparatus is shown in figure 36. The apparatus shall allow a specimen of cable to be crushed between a flat steel base plate and a flat steel movable plate or a steel cylindrical mandrel which applies the crushing force. A plate or mandrel shall be used as specified in the relevant Part of BS 6558. The movable plate shall apply the crushing force uniformly over a 100 mm length of the specimen.

The total load and the radius r to which the edges of the movable plate shall be rounded, or the radius R of the mandrel, shall be as specified in the relevant Part of BS 6558.

E.9.4 Procedure

Mount the cable specimen so that lateral movement is prevented, and only apply the load gradually without any abrupt change. If incremental loading is used, ensure that the steps do not exceed a ratio of 1.5:1.

Apply the load for the duration specified in the relevant Part of BS 6558.

E.10 Cable snatch test

E.10.1 Principle

This test determines the ability of an optical fibre cable to withstand a sudden snatch load. A hook bearing a load is dropped so that it catches the cable and imposes the snatch load.

E.10.2 Environmental test conditions

The test shall be carried out at standard atmospheric conditions for testing in accordance with **5.3** of BS 2011 : Part 1.1 : 1983.

E.10.3 Preparation of test specimen

Terminate the test specimen in a connector, or in a manner such that when the fibres, sheathings and any strain members are clamped together, they are representative of a connector.

E.10.4 Apparatus

E.10.4.1 *Hook*, of dimensions as shown in figure 37 and having a shaft capable of bearing variable loads secured to it. The mass attached to the hook shall be as specified in the relevant Part of BS 6558. The radius of that part of the hook coming into contact with the cable shall be greater than the radius of the cable. In addition, the hook shall be so constructed that it does not distort during the test. The diameter D of the hook and the radius r of the cross section of the hook material shall be as specified in the relevant Part of BS 6558.

E.10.4.2 *Clamping device,* in accordance with **E.3.4**.

E.10.5 Procedure

Clamp the cable (**E.10.4.2**) firmly between two rigid supports forming a catenary with a span of 4.5 m and a sag of 300 mm. After assembling the catenary, measure the attenuation.

Hold the hook with the mass attached over the cable, so that the crown of the hook is centred over the lowest point of the cable at a height of 100 mm. Release the hook so as to catch the cable.

Remove the mass from the cable.

This constitutes one cycle. Apply the number of cycles specified in the relevant Part of BS 6558.

E.11 Cable vibration test

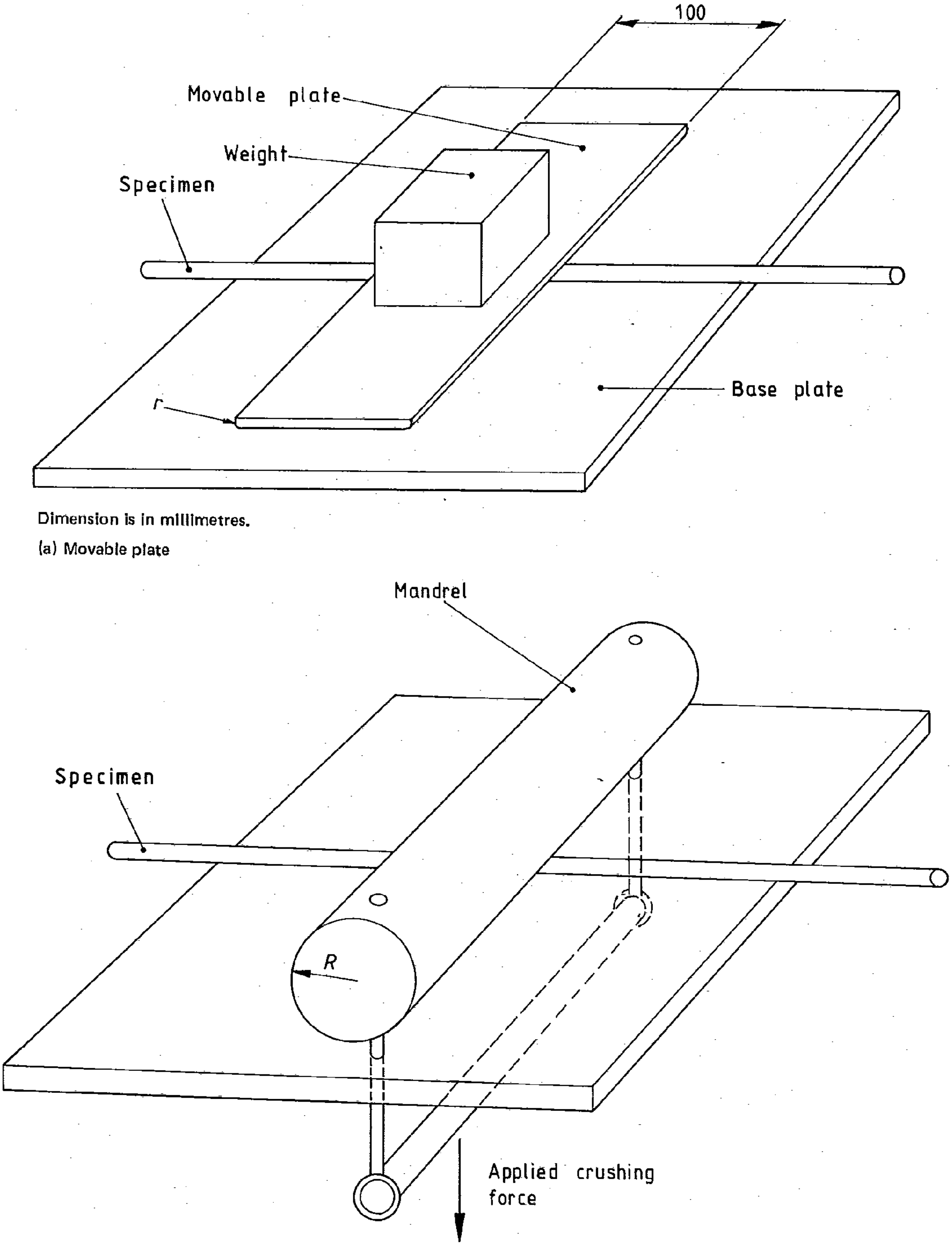
If specified in the relevant Part of BS 6558, the cable vibration shall be tested.

NOTE. A method of test is under consideration.

E.12 Cable isostatic pressure test

If specified in the relevant Part of BS 6558, the cable isostatic pressure shall be tested.

NOTE. A method of test is under consideration.



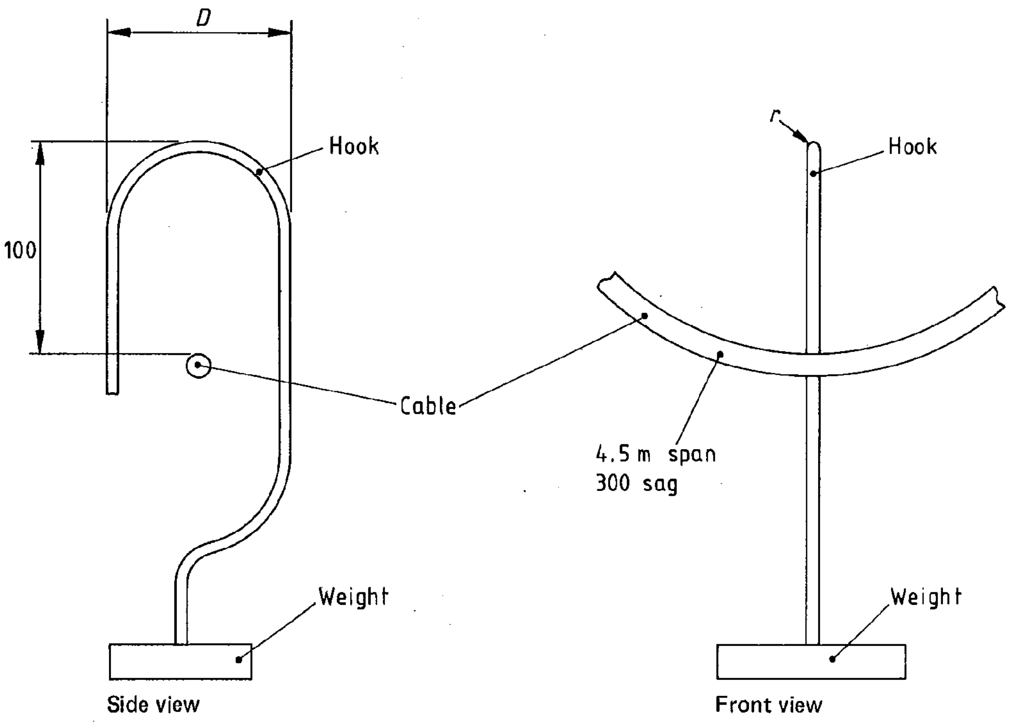
Dimension is in millimetres.

(a) Movable plate

Dimensions are in millimetres unless otherwise stated.

(b) Cylindrical mandrel

Figure 36. Apparatus for cable crush test



All dimensions are in millimetres unless otherwise stated.

Figure 37. Apparatus for cable snatch test

Appendix F. Environmental tests

F.1 Tests on optical fibres

The ability of an optical fibre to comply with environmental requirements without deterioration of its mechanical or optical properties shall be verified by subjecting samples to a temperature cycling test and to a test for resistance to contaminating fluids. The relevant temperatures and conditions, the number of samples and the acceptance criteria shall be as specified in the relevant Part of BS 6558.

NOTE. Methods of test for temperature cycling and for resistance to contaminating fluids are under consideration.

F.2 Tests on optical fibre cables

F.2.1 General

If specified in the relevant Part of BS 6558, optical fibre cables shall be tested in accordance with **F.2.2** to **F.2.7**.

NOTE. Methods of test for **F.2.2** to **F.2.7** are under consideration.

F.2.2 Temperature cycling.

F.2.3 Climatic cycling.

F.2.4 Resistance to contaminating fluids.

F.2.5 Fire resistance.

F.2.6 Acid evolution.

F.2.7 Smoke emission.

F.2.8 Flame retardance

Test the specimen in accordance with BS 4066 : Part 1. Calculate the time for which the flame is applied in accordance with BS 4066 : Part 1, if not otherwise specified in the relevant Part of BS 6558.

Index to methods of test

Dimensional tests (optical fibres only)

Optical tests (optical fibres and cables)

Mechanical tests (optical fibres and cables)

Environmental tests (optical fibres and cables)

Publications referred to

BS 2011 Basic environmental testing procedures
Part 1.1 General and guidance
Part 2.1J. Test J. Mould growth
Part 2.1Sa. Test Sa. Simulated solar radiation at ground level
BS 3573 Polyethylene-insulated copper-conductor telecommunication distribution cables
BS 4066 Tests on electric cables under fire conditions
Part 1 Method of test on a single vertical insulated wire or cable
BS 4109 Copper for electrical purposes. Wire for general electrical purposes and for insulated cables and flexible cords
BS 4803 Radiation safety of laser products and systems
Part 1 General
Part 2 Specification for manufacturing requirements for laser products
Part 3 Guidance for users
BS 4808 L.F. cables and wires with PVC insulation and PVC sheath for telecommunication
Part 1 General requirements and tests
Part 2 Equipment wires with solid or stranded conductors, unscreened, single
Part 3 Cables and equipment wires, with solid or stranded conductors, screened, single
Part 4 Equipment wires with solid or stranded conductors, unscreened, in pairs, triples, quads and quintuples
Part 5 Cables with solid or stranded conductors, screened and sheathed, one pair
BS 6004 PVC-insulated cables (non-armoured) for electric power and lighting
BS 6360 Specification for conductors in insulated cables and cords
BS 6469 Methods of test for insulation and sheaths of electric cables
BS 6500 Insulated flexible cords

Timmerman C.C. Handling optical cables: safety aspects. *Applied Optics,* 1977, 16, (9), 2380–2382

World Health Organisation. Environmental Health Criteria 23, *Lasers and optical radiation,* 1982

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BS 6558 : Part 1 : 1985

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