BSI BS*7718 96 ■ 1624669 0556356 2T7 ■

Code of Practice for

Installation of fibre optic cabling

ICS 33.180.10

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Electrotechnical Sector Board to Technical Committee EPL/86, Fibre optics, upon which the following bodies were represented:

BECCAMA (BEAMA Electrical Cable Connector and Accessories Manufacturer's Association)
BCMC (Telecommunications Cables Group)
British Approvals Service for Cables
British Cable Makers Confederation
British Telecommunications
Department of Trade and Industry (National Physical Laboratory)
ERA Technology Ltd.
FEI (Federation of the Electronics Industry)
Fibre Optic Industry Association (FIA)
Ministry of Defence
National Supervising Inspectorate (BSI PC)
Society of Cable Television Engineers

This British Standard, having been prepared under the direction of the Electrotechnical Sector Board, was published under the authority of the Standards Board and comes into effect on 15 September 1996

BS 7718 First published November 1994
Second edition September 1996

The following BSI references relate to the work on this standard:
Committee reference EPL/86
Special announcement *BSI News* February 1996

ISBN 0 580 25785 1

Amendments issued since publication

Amd. No.	Date	Text affected

Contents

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Foreword

This British Standard has been prepared by Technical Committee EPL/86 and supersedes BS 7718 : 1994 which is withdrawn. It was first circulated as a Draft for Public Comment in 1990 and was then considered by the CENELEC Committee CECC/WG 28, during which time the Standstill Agreement was applied and no national standard could be published.

However, the Fibre Optic Industry Association (FIA) was able to issue an interim document during 1991 which satisfied the urgent need to provide guidance and give recommended practices for the installation of fibre optic cabling.

After due consideration the CENELEC Committee CECC/WG 28 agreed that the Standstill Agreement should be waived and that each national standards organization should be free to issue its own publication on the subject.

BS 7718 : 1994 took into consideration the original British Standard draft and the interim FIA document as modified in the light of experience gained.

The revision incorporates a number of essential amendments which have been found necessary as a result of comments received from users of the Code of Practice since the original publication in 1994.

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

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

Code of practice

Introduction

Fibre optic cabling either separate from or combined with other media provides a high performance communications pathway. However, poor design and workmanship may incur severe penalties during both installation and operation. This code of practice is intended to allow the user and the installer to establish a specification for installation and defines recommended practices to ensure compliance with that specification.

This code of practice covers all applications of optical fibre as a communications medium and provides guidance to the user and installer with regard to the general aspects of fibre optic cabling design.

It also makes recommendations for the following:

- safe installation and operation of fibre optic cabling;
- design criteria of cabling components and accessories;
- the definition of a specification covering the installation of fibre optic cabling;
- working practices during installation;
- levels of quality assurance ensuring that the agreed specification is attained for the cabling components, accessories and the completed installation;
- levels of documentation;
- the performance verification of existing fibre optic cabling;
- repair and maintenance philosophies.

Installation practices are treated sequentially beginning with the installation specification and culminating with repair and maintenance.

Annex A details the recommended methods to be used to demonstrate that both cabling components and the installed cabling meet the requirements of the installation specification.

The need for guidance during the design phase, prior to the generation of an installation specification, is addressed in annex B.

A number of alternative communications media are available to the user, and the consideration of technical merit and cost, together with installation and operational aspects will promote the adoption of either copper, optical fibre or unguided transmission as the communications medium. Cabling systems may comprise a mixture of technologies, each being chosen as the most appropriate for the relevant application. The code of practice does not promote the sole or dominant use of optical fibre but supports its use within a communication system.

1 Scope

This British Standard provides recommendations for design, workmanship and quality assurance requirements for the installation of fibre optic cabling used to provide a communications path between two or more points.

This British Standard covers the use of glass and silica based optical fibres designed for transmission of electromagnetic radiation in the near-infra-red region between 750 nm and 1600 nm.

Optical fibre may be installed using either conventional cables or 'blown fibre' techniques. Unless otherwise stated the requirements for conventional cable designs are applicable to blown fibre ducts throughout the cabling design and installation process.

The information communicated covers the full range of communications services including voice, data, image and video. Applications are categorized as follows:

- *Equipment independent cabling*:

  cabling designed and installed in accordance with overall attenuation and/or bandwidth envelopes laid down by communications standards (e.g. FOIRL, IEEE 802.3 10baseF, FDDI);
- *Equipment based cabling*:

  cabling designed and installed to enable communication not covered by nationally and internationally agreed attenuation and bandwidth envelopes (e.g. video);
- *System based cabling*:

  cabling designed and installed as an integral component within a fixed proprietary communications system (e.g. command and control systems within a fighting vehicle).

A given installation can comprise cabling to service one or more of these applications.

Cabling installed in accordance with the recommendations of this code of practice is intended to have an operational lifetime consistent with or in excess of that exhibited by the terminal communications equipment.

This code of practice in no way supersedes the additional relevant standards and requirements applicable to certain hazardous environments, e.g. electricity supply and railway authorities.

2 References

2.1 Normative references

This British Standard incorporates, by dated or undated reference, provisions from other publications. These normative references are made at the appropriate places in the text and the cited publications are listed on the inside back cover. For dated references, only the edition cited applies; any subsequent amendments to or revisions of the cited publication apply to this British Standard only when incorporated in the reference by amendment or revision. For undated references, the latest edition of the cited publication applies, together with any amendments.

2.2 Informative references

This British Standard refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

3 Definitions and symbols

3.1 Definitions

For the purposes of this British Standard, the following definitions apply.

3.1.1 adaptor (adapter)

A female-type part of an optical fibre connector in which one or two connector plugs are inserted and aligned.

3.1.2 attenuation

A decrease of electromagnetic power between two points and the quantitive expression of power decrease which may be expressed by the ratio of the values at two points of a quantity related to power in a well defined manner.

NOTE 1. The loss of optical power through a fibre optic component is measured in dB units.

NOTE 2. Attenuation is generally expressed in logarithmic units, such as the decibel (dB).

3.1.3 attenuation coefficient

The limit of the quotient of attenuation between two points on the axis of a transmission line or waveguide by the distance between the points when this distance tends to zero.

NOTE. Attenuation per kilometre of an optical fibre is measured in dB/km.

3.1.4 bandwidth

a) That value numerically equal to the lowest modulation frequency at which the magnitude of the baseband transfer function of an optical fibre decreases to a specified fraction, generally to one half, of the zero frequency value.

b) A measure of the capacity of an optical fibre to transmit high speed data.

NOTE. The bandwidth is limited by several mechanisms:

a) in multimode fibres, mainly modal distortion and material dispersion;

b) in singlemode fibres, mainly material and waveguide dispersion.

3.1.5 basic fibre optic subsystem

The serial combination of an optical transmitter, optical receiver and the interconnecting fibre optic span.

3.1.6 cable assembly

An optical cable that is terminated with optical fibre connectors.

3.1.7 chip defect

Material broken away from the fibre following the generation of crack defects.

3.1.8 cladding

That dielectric material of an optical fibre surrounding the core.

3.1.9 cladding diameter

The diameter of the circle defining the cladding centre.

3.1.10 connector

See optical fibre connector (**3.1.32**).

3.1.11 connector plug

A male-type part of an optical fibre connector.

3.1.12 core

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

3.1.13 core diameter

The diameter of the circle defining the core centre.

3.1.14 crack defect

A stress fracture either wholly within the fibre or intersecting the fibre surface.

3.1.15 fibre optic cabling

All of the installed optical fibre components and all accessories including closures.

3.1.16 fibre optic span

A series of one or more terminated optical fibre elements which may contain complex passive components.

3.1.17 Fresnel reflection

The reflection of a portion of the light incident on a planar interface between two homogeneous dielectric media having different refractive indices.

3.1.18 fusion splice

A splice accomplished by the application of localized heat sufficient to fuse or melt the ends of two lengths of optical fibre, to produce a single continuous optical fibre.

3.1.19 index matching material

A material, often a liquid or cement whose refractive index is nearly equal to the core refractive index, used to reduce Fresnel reflections from an optical end-face.

3.1.20 insertion loss

The extra optical attenuation caused by the insertion of an extra optical component into an optical system.

3.1.21 joint

An assembly designed to permit connection between two or more optical fibres.

3.1.22 jumper

A cable assembly, permanently assembled at both ends with connector components principally for connection to transmission equipment.

3.1.23 material dispersion

That dispersion attributable to the wavelength dependence of the refractive index of material used to form the fibre.

3.1.24 mechanical splice

A fibre splice accomplished by fixtures or materials rather than thermal fusion.

3.1.25 modal distortion

In a multimode optical fibre, that distortion resulting from the propagation of different modes having different properties.

3.1.26 mode field diameter

For Gaussian distributions in singlemode fibres, the diameter at the 1/e points of the optical field amplitude distribution equivalent to the $1/e^2$ points of the optical power distribution.

3.1.27 multimode optical fibre

An optical fibre in the core of which the radiation of two or more bound modes can propagate at the wavelength of interest.

3.1.28 node

A point of flexibility and/or interconnection within the fibre optic cabling.

3.1.29 numerical aperture (N.A.)

a) A measure of the capacity of the following:

1) an optical fibre to accept light;

2) an optical transmitter to inject light into an optical fibre;

3) an optical receiver to accept light from an optical fibre.

b) The sine of the vertex half-angle of the largest cone of meridional rays that enter or leave the core of an optical system or element multiplied by the refractive index of the medium in which the vertex of the core is located.

3.1.30 optical cable

An assembly comprising one or more optical fibres or fibre bundles inside a common covering designed to protect them against mechanical stresses and other environmental influences while retaining the transmission quality of the fibres.

NOTE. It may also contain metallic conductors.

3.1.31 optical fibre

A filament shaped optical waveguide made of dielectric materials.

3.1.32 optical fibre connector

An optical fibre component normally attached to a cable or piece of apparatus, for the purpose of providing interconnection/disconnection of optical cables.

3.1.33 optical fibre coupler

A passive device whose purpose is to transfer optical power between two or more ports in a predetermined manner.

NOTE. The ports may be connected to waveguides, sources, detectors, etc.

3.1.34 optical fibre element

An unterminated optical fibre which may contain splices and other complex optical components.

3.1.35 optical fibre pigtail

A short length of optical fibre usually attached to a component and intended to facilitate jointing between that component and another optical fibre or component.

3.1.36 optical loss

See attenuation (**3.1.2**).

3.1.37 optical receiver

See receive FO terminal device (**3.1.45**).

3.1.38 optical time domain reflectometer (OTDR)

An instrument capable of characterizing optical fibre and joints using optical time domain reflectometry.

3.1.39 optical time domain reflectometry

A technique for characterizing an optical fibre whereby an optical pulse is transmitted through the optical fibre and the optical power of the resulting light scattered and reflected back to the input is measured as a function of time.

3.1.40 optical transmitter

See transmit FO terminal device (**3.1.53**).

3.1.41 patchcord

A cable assembly, permanently assembled at both ends with connector components principally for cross-connection within a patching facility.

3.1.42 pigtail

See optical fibre pigtail (**3.1.35**).

3.1.43 pit defect

A localized surface mark.

3.1.44 primary coating

A thin coating applied directly to the cladding to preserve the integrity of the cladding surface.

3.1.45 receive FO terminal device

A fibre optic terminal device including one or more optical detectors and having one or more optical inputs.

3.1.46 refractive index

At a point in a medium and in a given direction, the ratio of the velocity of light in vacuum to the phase velocity of a sinusoidal phase wave propagating in that given direction.

3.1.47 scratch defect

A linear extended surface mark.

3.1.48 secondary coating

A coating applied directly to the primary coating to reinforce the protection of the optical fibre during handling and cabling.

3.1.49 singlemode optical fibre

An optical fibre in which the radiation of only one bound mode can propagate at the wavelength of interest.

3.1.50 splice

A permanent joint whose purpose is to couple optical power between two optical fibres.

3.1.51 spectral window

A wavelength region in an optical waveguide over which the transmission loss is acceptably low such that system operation can be readily achieved.

3.1.52 transmission window

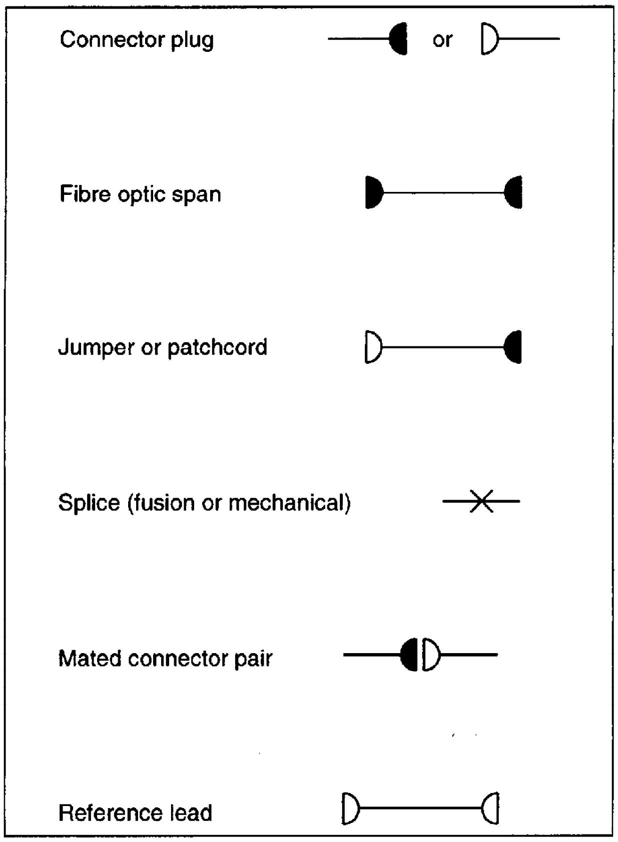
See spectral window (**3.1.51**).

3.1.53 transmit FO terminal device

A fibre optic terminal device including one or more optical sources and having one or more optical outputs.

3.2 Symbols

The following symbols are used in figures throughout the text.



4 Optical fibre safety

4.1 General

The primary safety issues relating to optical fibre are as follows:

- risks of inhaling fumes from, or allergic reactions to, chemicals used to prepare and process optical fibres for the subsequent application of connectors or jointing mechanisms;
- risks of optical fibre fragments piercing the skin (and the eyes) which can lead to infection and complications because of the difficulty of removing them;
- risks from exposure of the skin (and the eyes) to optical power either direct from sources (laser or LED) or from free interfaces (connectors, fractured optical fibres or joints).

WARNING. It is essential that the installer should have documented procedures for substances that are hazardous to health. In particular attention is drawn to the Control of Substances Hazardous to Health Regulations : 1988 [1].

Working areas should provide sufficient space for safe operation, supervision and maintenance of all installation practices. The following working practices should be adopted throughout the installation and operation of fibre optic cabling.

4.2 Chemical hazard

4.2.1 Certain chemicals used to prepare and clean optical fibres may be considered hazardous when inhaled or ingested by mouth. Others such as the epoxide resins used in the production of joints may cause allergic reactions.

The practices described in **4.2.2** to **4.2.7** should be adopted. Failure to do so may endanger the health of those involved.

4.2.2 Work should be carried out in well ventilated areas or forced ventilation should be provided. Prolonged and repeated breathing of vapour or fumes should be avoided.

4.2.3 Precautions should be taken to avoid contact with eyes or skin or clothing.

4.2.4 Eating and smoking should not be permitted in the vicinity of processing chemicals used since this may represent an enhanced hazard due to potential ingestion or explosion.

4.2.5 In case of contamination a basic first aid kit should be available together with a ready supply of water.

4.2.6 All chemicals should be stored in clearly and correctly marked containers and should be securely stoppered when not in use.

All chemicals should be safely disposed of following use and upon reaching relevant expiry dates.

4.2.7 Fire extinguishing equipment of the relevant type should be available where required.

Where a gaseous flooding system is used for extinction of fire in a working area:

- safety information should be clearly displayed;
- a manual disable function should be available and its use clearly explained to those persons working in the area;
- all escape routes should be clearly marked.

4.3 Optical fibre hazard

4.3.1 Good housekeeping should be adopted to minimize the quantity of optical fibre waste. It is essential that exposed optical fibre ends should be kept away from the skin and eyes.

4.3.2 Waste fragments should be treated with care and collected (not with bare or unprotected hands) together with other waste materials and disposed of in suitable containers via an approved agency.

4.4 Optical power hazard

4.4.1 The installer and user are often unable to determine the nature or level of the incident power. For this reason the issue of optical safety is particularly critical and the practices described in **4.4.2** to **4.4.5** should be adopted.

4.4.2 Under no circumstances should a connector end-face, prepared optical fibre or fractured optical fibre be viewed directly unless the power emitted from the optical fibre is known to be safe (as defined in BS EN 60825) and under local control.

This allows inspection of components using locally injected visible light but prevents the inspection of components using light injection from a remote non-controlled location.

4.4.3 The provision of the correct safety labelling is a mandatory requirement on all products where transmission equipment features an optical hazard as defined in BS EN 60825. It is essential that all potential hazard areas are similarly marked.

4.4.4 Adaptors within patch panel closures and free connectors should be permanently capped to prevent accidental eye or skin contact which might result in injury.

4.4.5 The user should ensure that all authorized personnel are aware of the relevant safety issues and should obtain training where appropriate.

5 Installation specification

5.1 General

Following due consideration of the design issues discussed in annex B, it is recommended that an installation specification be produced by or on behalf of the user. The installation specification should comprise the following:

- operational requirement;
- technical specification;
- scope of work;
- contractual terms and conditions.

The production of an installation specification allows effective comparison of technical and commercial submissions by potential installers and should be agreed between the user and the installer prior to the commencement of the installation.

5.2 Operational requirement

5.2.1 Infrastructure

It is recommended that a clear description of the proposed infrastructure should be produced including the following.

a) *Topology*, detailing the locations (each containing one or more nodes) to be interconnected by the cabling infrastructure.

Requirements for the extension of the cabling into existing or new locations should be detailed.

b) *Application*, detailing the application(s), highlighting, where relevant, current and future requirements for compliance with national and international communications standards.

The number of communications routes between each node should be specified, with suitable allowance for service expansion where relevant.

c) *Lifetime*, detailing the requirements for the physical and operational lifetime of the installed cabling infrastructure.

d) *Routeing*, detailing the routes into which cabling is to be installed.

e) *Hazards*, identifying and classifying hazardous areas within the proposed routes and working areas. The user should provide relevant information and drawings clearly identifying the boundaries of hazardous, or potentially hazardous, areas together with the classification of those areas.

f) *Environment*, defining the installation environment within the routes and stating any conditions which may assist in the choice of cabling components or may affect the fibre optic cabling both during and following installation.

Common factors affecting component choice and installation methods include the following:

- temperature, humidity, vibration;
- exposure to UV, chemical attack or physical damage;
- presence of hazards as detailed above (in particular the presence, or potential presence, of contaminating, toxic or explosive materials).

NOTE. Certain environments may place restrictions on the use of fusion splicing (which generally use an open electric arc).

Levels of toxic emission from the installed cabling (particularly during combustion) should be detailed.

5.2.2 Operational capability

It is recommended that the desired operational capability should be defined to include the following:

- optical power budgets of transmission equipment to be used;
- bandwidth requirements of transmission equipment to be used;
- tranmission windows of transmission equipment to be used.

5.3 Technical specification

The technical specification forms a basis against which all components and techniques used within the installation are assessed. It should be based upon the information provided in the guidance notes (see annex B) and should include the following.

a) *Identification scheme:*
   1) nodes;
   2) routes;
   3) optical cables and optical fibre elements;
   4) closures.

b) *Optical fibre(s)*:
   1) physical parameters;
   2) optical parameters.

c) *Optical cable(s)*:
   1) physical parameters;
   2) environmental parameters.

NOTE. Additional information may be found in annex A of IEC 794-1 : 1993.

d) *Blown fibre duct*:
   1) physical parameters;
   2) environmental parameters.

e) *Connectors*:
   1) physical parameters;
   2) random mated, worst case, insertion loss, return;
   3) loss (where relevant).

f) *Joints*:
   1) random mated, worst case, insertion loss, return;
   2) loss (where relevant).

g) *Closures*:
   physical parameters.

5.4 Scope of work

5.4.1 *Pre-installation*

5.4.1.1 *Civil works*

Any building work required on each route should be detailed, together with a clear statement of responsibility for the identification, design and completion of the works involved.

The responsibility for obtaining all necessary clearances and permits should also be defined.

5.4.1.2 *Route preparation*

All known route information should be detailed, and requirements for the installation of drawpits, ductwork, traywork, trunking and other cable installation accessories should be stated.

A clear statement of responsibility for the identification, design and completion of the works should be included. The responsibility for obtaining all necessary clearances and permits should also be defined.

5.4.1.3 *Bill of materials*

Exact quantities of all cabling components and installation accessories should be detailed, and those areas requiring evaluation and/or verification should be stated clearly.

5.4.1.4 *Survey status*

The need for a survey by the installer should be defined and, where relevant, the areas to be assessed during such a survey should also be detailed.

5.4.2 *Installation*

5.4.2.1 *Contract interfaces*

Contractual interfaces for the installation should be detailed including responsibilities for the following:

a) documentation of existing cabling;

b) proving compatibility of existing cabling components and items to be issued to the installer by, or on behalf of, the user;

c) storage of materials;

d) installation of optical cable by a third party.

5.4.2.2 *Programme*

The required programme of installation should be detailed and any access and/or site limitations should be stated clearly. Implications of other works should be made known to the installer where they may affect the programme.

Any limitations to access in terms of time and personnel together with restrictions on personnel movement, vetting and clearance levels should be clearly stated.

Requirements for progress meetings should be detailed.

5.4.2.3 *Cable installation*

Requirements for warning signs, marking and labelling to be applied to the optical cables and closures should be detailed.

5.4.2.4 *Earthing*

Requirements for the protective and functional earthing of cabling components and closures should be detailed. It is essential that the relevant national standards should be complied with.

5.4.2.5 *Connectivity*

Requirements for jointing and termination of optical fibre elements at each node should be detailed.

5.4.2.6 *Testing*

Requirements for final cabling acceptance should be detailed.

5.4.2.7 *Documentation*

Levels of documentation to be supplied both during and following installation should be detailed.

5.4.3 *Post-installation*

5.4.3.1 *Reinstatement*

Requirements for the reinstatement of all routes should be detailed.

A clear statement of responsibility for the identification, design and completion of the works should be included. The responsibility for obtaining all necessary clearances and permits should also be defined.

5.4.3.2 *Spares*

A list should be prepared of recommended spare materials and components to be supplied including optical cable, cable assemblies, closures, test equipment and test leads.

5.4.3.3 *Ancillary services*

Ancillary services should include repair and maintenance contracts, optical safety training, analysis training, user-based maintenance training.

5.4.4 *Regulatory issues*

Applicable legislation and regulations should be clearly stated and should include the following:

- building regulations relating to the installation;
- specific site regulations;
- relevant national legislation, regulations and requirements relating to safe working practices;
- relevant national regulatory requirements for telecommunications network apparatus.

5.4.5 *Site contacts*

The user should provide details of the site contacts with responsibilities for the following:

- operational requirements;
- site information (including knowledge of all hazardous areas);
- technical requirements.

5.5 Contractual terms and conditions

Contract terms and conditions should be defined prior to submission and the installation specification should refer to any specific operational limitation which may alter the contract. It is essential that contract terms should be agreed by all parties prior to commencement of work.

5.6 Changes and variations to installation specification

It is common for the initial specification to be modified prior to the commencement of the installation. Further modifications may be agreed during the course of the installation.

All modifications, changes and variations should be clearly documented in an agreed manner to provide adequate traceability.

6 Quality plan

6.1 General

It is essential that the methods, techniques and processes to be adopted during installation should be in accordance with the installation specification.

Clauses **7** to **12** detail the recommendations which relate to the installation of fibre optic cabling including the following:

- acceptance test methods and inspection criteria for cabling components;
- cable installation;
- acceptance test methods and inspection criteria for installed cabling;
- documentation of installed fibre optic cabling;
- repair and maintenance of installed cabling.

It is recognized that organizations operating a quality assurance system in accordance with BS EN ISO 9000 may have a standard approach to all installation projects. However, installations may vary with regard to the contractual interfaces present. It is recommended that a quality plan should be submitted to the user prior to the installation of each fibre optic cabling infrastructure which is relevant to that installation.

The purpose of the quality plan is to provide the user and installer with a detailed proposal which indicates the procedures to be implemented to ensure that the installation proceeds according to the agreed programme and technical specification.

The quality plan should reflect the contractual interfaces which relate to the task defined within the installation specification and should clearly identify the measures to be adopted to facilitate straightforward transfer of responsibilities at these interfaces.

6.2 Cabling component acceptance tests

6.2.1 ***Optical cable and blown fibre components*** (see **7.2** and **7.3**)

The proposed test procedures should be detailed including the following:

a) test schedule (at contractual interfaces);

b) operating wavelength;

c) test method;

d) limitations of measurement;

e) acceptance criteria (and requirements for correlation with other results);

f) sampling level;

g) provision of test results and certificate of conformance.

6.2.2 ***Connectors*** (see **7.5**)

The proposed inspection procedures should be detailed to include the sampling level and provision of certificate of conformance.

6.2.3 ***Cable assemblies*** (see **7.6**)

The proposed test and inspection procedures should be detailed including the following.

a) *Optical performance testing*

1) operating wavelength;

2) test method;

3) limitations of measurement;

4) acceptance criteria;

5) sampling level;

6) provision of results;

7) provision of certificates of conformance.

b) *Visual inspection*

1) definition of connector end-face zones;

2) acceptance criteria;

3) sampling level;

4) provision of certificate of conformance.

6.2.4 ***Cabling component compatibility***

Where existing cabling components are to be provided by, or on behalf of, the user the installer should define the procedures to be adopted to ensure compatibility between those components and any others to be used during the installation.

6.3 Laid cable acceptance (stage I) tests (see clause 8)

The proposed test procedures should be detailed including the following:

a) test schedule;

b) operating wavelength;

c) test method;

d) limitations of measurement;

e) acceptance criteria (and requirements for correlation with other results);

f) sampling level;

g) provision of test results.

6.4 Final cabling acceptance (stage II) tests (see clause 10)

The proposed test procedures should be detailed in accordance with **6.3** and in addition wavelength correction should be applied where relevant.

6.5 Details of test equipment and test leads

All items of inspection and test equipment to be used should be defined and information provided.

Also the test leads to be used should be defined stating the methods used to achieve the desired launch conditions.

6.6 Test equipment calibration

All items of test equipment should be covered by a calibration system meeting the requirements of the relevant standard. Information regarding the calibration status of the test equipment should be provided within the quality plan.

6.7 Documentation

The proposed level of documentation to be provided both during and following the installation should be detailed and agreed between the installer and user.

7 Cabling component acceptance

7.1 General

This clause defines the recommended practices to be undertaken by the installer following receipt of the following cabling components:

a) optical cable (**7.2**);

b) blown fibre components (**7.3**);

1) blown fibre;

2) blown fibre duct.

c) closures (**7.4**);

d) connectors (**7.5**);

e) cable assemblies (**7.6**) comprising the following;

1) pigtails;

2) jumpers;

3) patchcords.

f) free-issue components (**7.7**).

The installer's responsibility with regard to establishing cabling component compatibility is given in **7.8**.

The installer's responsibility with regard to establishing the validity of the documentation covering existing fibre optic cabling is given in **7.9**.

7.2 Optical cable

7.2.1 ***General***

Optical cables frequently undergo a great number of stages during the installation of fibre optic cabling. Early diagnosis of faults is essential and is in the interest of both user and installer alike.

With reference to **B.7**, optical cable should be procured against a specification containing physical and optical requirements. This subclause defines the recommended practices for the inspection of optical cable prior to installation.

7.2.2 *Physical acceptance criteria*

The optical cable should be inspected for conformance against its physical specification in so far as is practicable without its removal from its means of transport, generally a drum or reel. The inspection should include the following.

a) *Internal construction*

The quantity and identification of optical fibre elements, presence of moisture barrier, strength member etc.

b) *External construction*

Cable diameter, condition of external sheath, marking, identification.

A certificate of conformance against the specification should be obtained from the manufacturer.

7.2.3 *Optical acceptance criteria*

7.2.3.1 *General*

The optical cable should be tested for conformance with its optical specification.

Using an optical time domain reflectometer (OTDR) operating at the relevant wavelength (and in accordance with manufacturer's instructions and specification) the optical cable should be tested in accordance with the method detailed in **A.4.1**.

Details of measurement procedure should be provided together with the type, serial number and proof of calibration of the measurement equipment.

Each optical fibre element (or a sample as defined within the quality plan) should be tested and a permanent record retained. The optical cable should be assessed against the criteria of **7.2.3.2** and **7.2.3.3**.

7.2.3.2 *Length*

For OTDR measurements, the relevant refractive index, provided by the manufacturer, should be used. Alternatively, a suitable value should be used such that any errors introduced are understood and agreed between the installer and the user.

It should be noted that the length measured relates to the length of optical fibre within the cable and this may differ from the actual length of the cable. Within complex constructions the optical fibres may be of different lengths within a given length of optical cable. Where relevant, information should be sought from the manufacturer.

Following clarification of the above factors, where relevant, it should be established that the optical fibres measured are of a length equal to or longer than that of the optical cable as supplied (consistent with design factors and subject to the resolution of the measurement).

7.2.3.3 *Attenuation coefficient*

The attenuation coefficient of optical fibre elements should be measured to ensure compliance with the specification. Measurements made are subject to the restrictions detailed in **A.2.2**.

Any non-compliance should be reported to the manufacturer. Typical issues are as follows:

- localized loss events;
- attenuation coefficient in excess of specification;
- variations in attenuation coefficient.

Optical fibre specifications may allow minor discontinuities in the attenuation profile. The cable manufacturer should produce test records for the optical cable and also the optical fibre used within the cable. If the cabling processes can be shown not to have produced or exaggerated such discontinuities and providing that the uncabled optical fibre can be shown to have met its specification then the optical cable should be accepted.

7.2.3.4 *Optical fibre design parameters*

A certificate of conformance against the specification should be obtained from the cable manufacturer.

7.3 Blown fibre components

7.3.1 *Blown fibre*

Blown fibre should be inspected for conformance with its physical and optical specifications in so far as is practicable without its removal from its means of transport, generally a spool. The inspection should include the following:

- spool label information, including optical fibre design, colour, length, attenuation coefficient and bandwidth;
- condition of external covering.

A certificate of conformance should be obtained from the manufacturer.

7.3.2 *Blown fibre duct*

Blown fibre should be inspected for conformance with its physical specification in so far as is practicable without its removal from its means of transport, generally a drum. The inspection should include the following:

- internal construction: number of tubes (in multiway duct);
- external construction: outer diameter, condition of sheath, marking, identification, seals.

7.4 Closures

7.4.1 *External physical features*

The closure should be inspected against the design requirements of the specification. The inspection should include the following:

- mechanical construction: dimensions, material, mounting facilities, environmental sealing;
- entry points for optical cable: quantity and dimensions
- entry points for adaptors: quantity and dimensions
- glands: material, quantity and fitting;
- adaptors: manufacturer, quantity and fitting;.
- temporary seals: quantity and fitting;
- labelling and identification.

7.4.2 *Internal physical features*

The closure should be inspected against the design requirements of the specification.

The inspection should include the following:

- optical cable strain relief fittings;
- internal optical fibre management system: protection, strain relief, routeing (and maintenance of minimum bend radii);
- earthing fittings (where appropriate).

7.5 Connectors

With reference to **B.9**, connectors (plugs and adaptors) should be procured against a specification containing physical and optical requirements. The optical specification is relevant only when the connectors are applied to the optical cable (see **7.6** and clause **9**). This clause defines the recommended practices for the inspection and acceptance of connectors prior to installation.

The connectors should be inspected for conformance against the physical specification. The inspection should include the following:

- type of connector;
- manufacturer;
- mechanical compatibility with the optical cables to be terminated.

A certificate of conformance against the specification should be obtained from the supplier.

7.6 Pigtail, jumper and patchcord cable assemblies

7.6.1 *General*

It is essential that all preterminated components should exhibit optical performance as defined within the installation specification. Where the preterminated components are produced by the installer the following practices are recommended to ensure satisfactory performance. Where the preterminated components are procured by the installer a certificate of conformance should be obtained from the supplier.

Subclauses **7.6.2** and **7.6.3** detail the recommended practices to assess the optical performance of the products.

Subclauses **7.6.4** and **7.6.5** detail the recommended practices to assess the mechanical aspects of the connector end-faces which are responsible for extended operational life.

7.6.2 *Insertion loss*

For short cable assemblies the most relevant optical parameter is the insertion loss of the connector applied to the cable. The insertion loss of each termination (or a sample as defined within the quality plan) should be measured and its performance recorded for analysis. (See for example IEC 874-1 (method 7)).

Details of measurement procedures should be provided with the components and the type, serial number and proof of calibration of measurement equipment should be recorded. (See for example IEC 874-1).

7.6.3 *Return loss*

Where relevant, return loss should be measured (see **B.9.1**). The return loss of each termination (or a sample as defined within the quality plan) should be measured and its performance recorded for analysis. The method of measurement should be defined within the quality plan.

Details of measurement procedures should be provided with the components and the type, serial number and proof of calibration of the measurement equipment should be recorded.

7.6.4 *Connector end-face: visual acceptance*

The condition of each terminated optical fibre end-face (or a sample as defined within the quality plan) should be inspected in accordance with the method and acceptance criteria defined in **A.7.1** and **A.7.2**.

7.6.5 *Optical fibre–connector bond: visual acceptance*

The condition of each terminated optical fibre end-face (or a sample as defined within the quality plan) should be inspected in accordance with the method and acceptance criteria defined in **A.7.4**.

7.6.6 *Connector end-face protection*

All exposed connector end-faces should be fitted with protective caps.

7.7 Free-issue components

Subclauses **7.2** to **7.6** detailed the recommended practices for the acceptance testing and inspection of cabling components manufactured, or procured, by the installer. Other components to be incorporated into a fibre optic cabling infrastructure may be supplied to the installer by, or on behalf of, the user. These include the following:

- uninstalled optical cables;
- installed optical cables;
- pigtail, jumper or patchcord cable assemblies.

The installation specification defines performance criteria for these components and their interconnections. It is the responsibility of the installer to ensure that the component acceptance procedures detailed in **7.2** to **7.6** should be implemented prior to the acceptance of these components. Where doubt exists as to the compatibility of the components supplied it is essential that the resulting non-compliances should be agreed with the user prior to installation.

7.8 Cabling component compatibility

7.8.1 *General*

The performance of a joint is dependent upon the parameters of the optical fibres producing the joint together with the potential of the connection mechanism used to create the joint. Incompatibility between optical fibres may result in poor joint performance and it is recommended that the installer should establish the compatibility of all optical fibres used.

7.8.2 *Parametric mismatch*

A given optical fibre design exhibits tolerances for core diameter (or mode field diameter), cladding diameter, core-cladding concentricity and numerical aperture. These tolerances contribute to the distribution of measured power losses at joints.

Parameters outside the accepted specifications will result in measured losses which may exceed those defined within the installation specification. It is recommended that the installer should establish the compatibility of the cabling components to be used.

7.8.3 *Processing mismatch*

Optical fibres manufactured using different techniques or materials, whilst complying with the accepted specifications, may be difficult to joint using fusion splicing techniques.

It is recommended that the installer should establish that acceptable performance can be achieved and that the techniques adopted can meet the jointing requirements of all cabling components.

7.8.4 *Joint component mismatch*

In order to achieve optimum performance it is recommended that all the joint components should be provided by a single manufacturer or produced to meet a single specification. Where this is not possible it is recommended that the installer should establish the compliance of resulting joints with the specification.

7.9 Documentation for existing cabling

Where documentation showing pre-installed cabling exists it is generally the responsibility of the user to ensure that all information is accurate.

If doubt exists this should be made clear to the installer who may choose to resurvey and verify the existing installation.

8 Optical cable and closure installation

NOTE. This clause details the recommended practices for the installation of optical cable, blown fibre duct and closures.

8.1 General precautions

8.1.1 The delivery of optical cable should be monitored to ensure that no mechanical damage occurs during off-loading from vehicles.

Documentation supplied with the optical cable should be checked for compliance with the procurement specification and retained.

8.1.2 The optical cable should be stored in a suitable place until required. Consideration should be given to security and environmental conditions.

8.1.3 The optical cable should not be unpacked until required.

8.1.4 Suitable protective caps should be fitted to the exposed ends of the optical cable. These should not be removed until required and should be replaced or renewed after the relevant acceptance testing has been undertaken (see clause **7**).

8.2 Pre-installation procedures

8.2.1 The installer should establish that the routes defined in the installation specification are accessible and available in accordance with the installation programme. The installer should advise the user of all proposed deviations.

8.2.2 The installer should establish that the environmental conditions within the routes and the installation methods to be used are suitable for the design of optical cable to be installed.

The open routeing within buildings of optical cables sheathed in flammable materials is not recommended. Where external environment cables, incorporating such materials, enter buildings then a transition to suitable internal cables is recommended. Alternatively, the external cable should be housed, along the internal route, in fire resistant trunking or conduit.

8.2.3 Where direct burial of optical cable is to be undertaken, ground conditions should be given careful consideration. It is recommended that a depth of cover in excess of 350 mm (450 mm in cultivated ground) should be provided and the optical cable should be suitably protected, for example by armouring.

Where the optical cable is to be laid beneath roadways or railway lines then ducts should be used and laid with a depth in excess of 600 mm.

Where aerial or catenary mounted optical cables are to be used, fittings and accessories should be provided which allow installation in accordance with the cable manufacturer's instructions.

8.2.4 The installer should determine any measures necessary to prevent the optical fibre within the optical cable experiencing direct stress following installation. Where long vertical runs are proposed, optical cables may need to deviate from the vertical at intervals as recommended by the manufacturer (by the inclusion of short horizontal runs or loops).

8.2.5 The installer should determine the proposed locations at which drums (or reels) are to be positioned during the installation programme and should establish the accessibility and availability of those locations.

8.2.6 The installer should identify proposed locations of service loops and should establish their accessibility and availability in accordance with the installation programme.

8.2.7 The installer should ensure that all necessary installation accessories are available.

8.2.8 The installer should identify proposed locations of closures and should establish their accessibility and availability in accordance with the installation programme.

The closures should be positioned such that subsequent repair, expansion or extension of the installed cabling may be undertaken with minimal disruption and in safety.

8.3 Optical cable acceptance tests

Where appropriate, and as defined within the quality plan, the installer should undertake optical cable acceptance testing (as detailed in **7.2**) prior to its installation.

8.4 Preparation of cable route

8.4.1 Where optical cable is to be installed in shared routes, reasonable precautions should be taken to prevent damage to existing cables or fragile structures within those routes.

8.4.2 Catenary wires should be installed where necessary. Any existing wires should be checked for satisfactory function.

8.4.3 Cable ducts, sub-ducts, tray and trunking should be installed as required.

All underground ducts should be of a non-porous material and should have smooth internal walls. Sections should be jointed to prevent ingress of foreign materials. Building entry ducts should be sealed to prevent the ingress of gases or water.

The design of duct, conduit and trunking should allow installation and removal of the optical cable without risk of damage.

8.4.4 Cleats or temporary structures (to assist cabling installation) should be fitted where necessary.

8.4.5 Routes should be pre-roped as required. Under no circumstances should draw ropes be installed concurrently with the optical cable.

8.4.6 Existing draw ropes should be checked for satisfactory function.

8.4.7 Where necessary, the minimum quantity of ceiling tiles, floor covers or duct covers should be removed.

8.4.8 Ducts, fire-ducts and gas seals should be opened as required.

8.4.9 Any enclosed environments within the routes should be tested for asphyxiating and explosive gases (see clause **4**). Such environments include ducts, manholes, drawpits, cable chambers and any other enclosed, unventilated structures.

Should a gas hazard be detected the installer should contact the site contact nominated by the user (see **5.4.5**) and appropriate action should be agreed and undertaken.

8.4.10 The installer should ensure that all necessary guards, protective structures and warning signs are used to protect both the optical cable and third parties. It is essential that relevant national legislation for safe working practices should be complied with. Attention is drawn to the Health and Safety at Work etc. Act 1974 [2].

8.5 Optical cable installation procedures

8.5.1 Drums (or reels) should be positioned in accordance with **8.2.5**. During cable installation one operative should remain with the drum (or reel) and should be in communication at all times with the installation team.

8.5.2 Reasonable steps should be taken to avoid damaging existing fragile cabling or structures, particularly if working under raised floors.

8.5.3 When pulling-in optical cables, mechanical fuses (or equivalent protection) should be used to ensure that the manufacturer's recommended tensile loads are not exceeded. The cable end should remain sealed at all times during its installation to prevent the ingress of water and other contaminants.

8.5.4 Optical cable should be removed from the drum (or reel) with the drum (or reel) in a vertical position without the optical cable being drawn across the drum (or reel) flange. Precautions should be taken to prevent cable kinking, ravelling or twisting and to prevent excessive abrasion, crushing, bending or tensile loads.

8.5.5 The manufacturer's recommended minimum bend radii (for both installation and for subsequent fixing) should be complied with. Where this is not possible, any non-compliance should be agreed between the installer and the user.

8.5.6 A minimum agreed length of optical cable should be allowed at each closure position. This is to enable subsequent access to the closure and to ensure sufficient length for cable management, acceptance testing and also to reduce the impact of damage to the end of the optical cable.

8.5.7 All relevant safety precautions should be observed. In particular the presence of asphyxiating gases should be monitored and suitable rescue equipment and trained personnel should be available at all relevant locations.

8.6 Protection of installed optical cable

8.6.1 Where appropriate, restraining clips should be fitted and closed at separations of not greater than 2 m.

8.6.2 Warning signs and labels should be fitted in accordance with the installation specification.

8.6.3 Exposed optical cable ends should be fitted with suitable protective caps.

8.6.4 Optical cables should be labelled and numbered in accordance with the installation specification.

8.6.5 Where relevant, external metallic cable elements (armouring) should be accessed and glanded external to the closure. Relevant earthing requirements should be complied with as defined within the installation specification.

8.7 Post-installation procedures

8.7.1 Previously removed ceiling tiles, floor tiles and duct covers should be replaced and checked for damage.

8.7.2 Fire-ducts, gas seals, floor passages and building entry ducts installed or opened during the installation should be sealed in an approved manner in order to prevent ingress of foreign materials or gases. The integrity of all barriers should be retained.

8.7.3 Drums (or reels), installation accessories and temporary structures used to aid installation should be removed.

8.8 Installation of closures

8.8.1 Closures should be located as previously defined.

8.8.2 Closures should be fixed or mounted in position using the recommended fittings. It is recommended that patch panel closures are fixed to prevent the ingress of foreign material into unprotected adaptors. All adaptors should be fitted with suitable protective caps.

8.8.3 Closures should be labelled and identified in accordance with the installation specification.

8.8.4 Any electrical equipment provided within closures should be installed in accordance with the relevant national standards.

8.8.5 Where relevant, earthing requirements should conform to the installation specification.

8.8.6 Documentation which provides the information necessary to allow subsequent installation of the optical cable into the closures should be collated.

8.9 Laid optical cable acceptance (stage I) tests

8.9.1 ***General***

If required within the quality plan the installed optical cable should be tested for compliance with its specification prior to further handling, jointing and commissioning. It is recommended that installed (laid) optical cable acceptance tests (see **7.2**) should be undertaken to avoid contractual disputes. These may be described as stage I tests.

8.9.2 ***Acceptance tests***

The physical parameters of the optical cable should not be affected during cable installation provided that the recommended practices in this section are complied with. Subsequent testing is at the optical parameter level.

Using an OTDR operating at the relevant wavelength (and in accordance with the manufacturer's instructions and specification) the optical cable should be tested in accordance with the method detailed in **A.4.1**.

Details of measurement procedures should be provided together with the type, serial number and proof of calibration of the measurement equipment.

Each optical fibre element (or a sample as defined within the quality plan) should be tested and a permanent record retained. The optical cable should be assessed against the criteria given in **8.9.3** and **8.9.4**.

8.9.3 ***Length***

The relevant refractive index (see **7.2**) should be used. Alternatively, a suitable value should be used such that any errors introduced are understood and agreed between the installer and the user.

It should be noted that the length measured relates to the length of optical fibre within the cable and this may differ from the actual length of the cable. Within complex constructions the optical fibres may be of different lengths within a given length of optical cable. Where relevant, information should be sought from the manufacturer.

Following clarification of the above factors, where relevant, it should be established that the optical fibres measured are of a length equal to or longer than that of the optical cable as laid (consistent with design factors and subject to the resolution of the measurement).

It is recommended that measurements should be made from both ends of the installed cable. The lengths recorded for a given optical fibre should be identical, independent of measurement direction (subject to the resolution of the equipment).

8.9.4 ***Attenuation coefficient***

The attenuation coefficient of optical fibre elements should be measured to ensure compliance with the specification. Measurements made are subject to the restrictions detailed in **A.2.2** to assess:

- compliance with specification;
- comparison with pre-laid performance.

Particular regard should be given to localized loss events and/or variations in attenuation coefficient not apparent in the records of the initial optical cable acceptance tests (see **7.2**). The presence of localized losses following installation is generally the result of induced stress within the optical fibre. Induced stress may result in optical fibre failure at some indeterminate time during the operational life of the cabling. The causes of the induced stress should be identified and removed.

9 Jointing and termination

NOTE. This clause details the recommended practices which should be adopted by the installer during the jointing and termination of the installed optical cable.

9.1 Installation of optical cable within closures

9.1.1 The optical cable should enter the closure through suitable glands. The gland should perform the following functions:

- maintain the environmental performance of the closure;
- provide the necessary cable support and prevent kinking at the point of entry into the closure;
- provide strain relief for the optical cable. Alternatively, strain relief may be provided by separate fixtures within the closure.

9.1.2 Where the optical cable contains metallic elements (strength members, moisture barriers) the relevant earthing and interconnection requirements should be complied with as defined within the installation specification.

9.2 Jointing of optical fibres

9.2.1 ***General***

The use of either fusion or mechanical splicing during the installation of cabling represents a stable, low attenuation technique for the permanent connection of optical fibres.

The performance of a splice is dependent upon the capability of the technique, the workmanship applied to achieve the splice and the subsequent workmanship applied to protect the splice to ensure satisfactory operational lifetime.

9.2.2 ***Mechanical spliced joints***

Mechanical spliced joints are achieved by the alignment of the two optical fibre ends within a protective sleeve. The manufacturer's recommended instructions for protection and retention of the optical fibres should be observed.

The mechanical splice is generally retained by either friction or adhesive bonds to the optical fibre. It may be necessary to provide further strain relief for the completed joint.

9.2.3 ***Fusion spliced joints***

Fusion spliced joints are achieved by welding the core and cladding regions of the two optical fibre ends. The fusion splice should be protected by a suitable sleeve or splint.

The fusion splice is generally retained within the protective sleeve by either friction or adhesive bonds to the optical fibre. It may be necessary to provide further strain relief for the completed joint.

9.2.4 ***Optical fibre management***

All splice joints and their strain relief mechanisms should be fixed within the optical fibre management system of the closure.

Under no circumstances should splices be left unsupported where risk of damage could limit operational lifetime.

9.3 Termination of optical cables

9.3.1 Optical fibre elements may be terminated using one of the following methods:

- direct application of connectors to the installed optical fibre element or cable construction;
- jointing of a premanufactured pigtail to the installed optical cable.

9.3.2 During the direct application of connectors to the installed optical fibre elements, the recommended installation procedures should be followed.

9.3.3 Connectors applied to optical fibres should be subjected to visual inspection as defined in **A.7.2** and **A.7.4**.

9.3.4 All exposed connector end-faces should be fitted with suitable protective caps.

9.4 Storage of optical fibres within closures

9.4.1 Primary coated optical fibre not contained within a management system should be protected from physical damage by use of appropriate sleeving.

9.4.2 Each optical fibre should be uniquely identifiable using one or more of the following methods:

- colour coding;
- labelling;
- physical position routeing.

9.4.3 Following jointing or termination, the optical fibre elements should be arranged within the closure in a manner which allows access to individual connectors, joints and elements with minimal disruption to neighbouring components during subsequent repair, expansion or extension of the installed cabling.

9.4.4 Where closures are configured as patch panels the following should be observed:

- adaptors should be inspected for contamination;
- terminated optical cables should be connected into the adaptors in accordance with the connectivity defined within the installation specification;
- exposed adaptor ports should be fitted with protective caps.

Final acceptance testing (clause **10**) should be undertaken following final assembly of the closure into the desired location. Subsequent disconnection of internally mounted connectors or the use of other adaptors during testing may affect the measured results and may render such testing invalid.

9.4.5 When fitted into the closure, the routeing of the optical fibre elements should comply with the relevant minimum bend radii.

9.5 Final assembly of closures

9.5.1 Labels in accordance with BS EN 60825 should be applied adjacent to all accessible optical interfaces (see **4.4.3**).

9.5.2 The installation specification may require each closure to be externally labelled with a unique identifier.

10 Final cabling acceptance (stage II) tests

10.1 General

Once the fibre optic cabling has been installed, jointed and fitted into closures it is recommended that final cabling acceptance testing should be undertaken.

Acceptance can be treated both at the physical level (to ensure compliance with clauses **8** and **9**) and at the optical performance level. The latter should be defined within the quality plan and may be described as stage II tests.

The installed fibre optic cabling may take the form of fibre optic spans, configured as shown in figure A.2 and/or as unterminated optical fibre elements.

Final cabling acceptance (stage II) tests applied to fibre optic spans are detailed in **10.2** to **10.5**.

Final cabling acceptance (stage II) tests applied to unterminated optical fibre elements are detailed in **10.6**. These tests are identical to the stage I tests detailed in **8.9**. As such they are only required when further jointing has taken place following installation.

10.2 Fibre optic span test conditions

It is recommended that acceptance tests of completed fibre optic spans should proceed following final marking, labelling and fitting of all cabling components.

Acceptance testing of installed fibre optic spans may take the following forms:

- optical loss measurement (**10.3**);
- assessment of component compliance (**10.4**);
- continuity testing (**10.5**);
- a combination of the above.

To ensure full compliance it is necessary to undertake final cabling acceptance testing on all installed fibre optic spans. However, sample levels of testing may be undertaken.

The quality plan should define the form and sample level of acceptance tests to be undertaken.

10.3 Optical loss measurement of fibre optic spans

Each fibre optic span (or a sample as defined within the quality plan) should be measured using a light source and power meter (in accordance with **A.2.3**), operating at the relevant wavelength, and suitable test leads (in accordance with **A.2.4.2**).

Details of measurement procedures should be provided together with the type, serial number and proof of calibration of the measurement equipment. The fibre optic spans should be tested in accordance with the methods detailed in **A.4.4**. The test method used should be appropriate for the configuration of the fibre optic span. Except where required and defined within the quality plan, measurement should be made in a single direction only.

The results obtained should be recorded together with the following:

- identification of the fibre optic span;
- location of light source during test;
- location of power meter during test;
- the optical loss budget for the fibre optic span (for comparison with the measured result).

Where measured results do not comply with the relevant optical loss budget it is recommended that the fibre optic span should be investigated using an OTDR (as detailed in **10.4**) in order to identify the non-compliant component(s).

10.4 Assessment of component compliance within fibre optic spans

10.4.1 ***General***

Using an OTDR operating at the relevant wavelength (and in accordance with the manufacturer's instructions and specification) and a suitable launch lead (in accordance with **A.2.4.1**) the fibre optic span should be tested in accordance with the method detailed in **A.4.3**.

Details of measurement procedures should be provided together with the type, serial number and proof of calibration of the measurement equipment.

Each fibre optic span (or a sample as defined within the quality plan) should be tested from both ends and permanent records retained. The following information should also be recorded:

- fibre optic span identification;
- location of the OTDR during testing.

The measurements described in **10.4.2** to **10.4.5** should be made and recorded directly or indirectly (using the permanent record produced by the OTDR).

10.4.2 ***Fibre optic span length***

The relevant refractive index (see **7.2**) should be used. Alternatively, a suitable value should be used such that any errors introduced are understood and agreed between the installer and the user.

The lengths recorded for a given optical fibre should be identical independent of measurement direction (subject to the resolution of the equipment). Any other result requires investigation.

It should be noted that the length measured relates to the length of optical fibre within the cable. This may differ from the actual length of the cable dependent upon the cable construction. Where relevant, information should be sought from the manufacturer.

10.4.3 ***Attenuation coefficient***

The attenuation coefficient of optical fibre elements should be measured to ensure compliance with the specification. Measurements made are subject to the restrictions detailed in **A.2.2** to assess:

- compliance with specification;
- comparison with pre-laid performance.

Particular regard should be given to localized loss events and/or variations of attenuation coefficient not apparent in the records of the initial optical cable acceptance tests (see **7.2**). The presence of localized losses following installation is generally the result of induced stress within the optical fibre. Induced stress may result in optical fibre failure during the operational life of the cabling. The causes of the induced stress should be identified and removed.

10.4.4 ***Connector insertion loss***

The local (launch) connector insertion loss should be measured and recorded. Where the result does not comply with the installation specification, investigation should be undertaken to identify the cause. Resolution of the non-compliance with the installation specification may be achieved by either:

- rework of connector;
- replacement of connector;
- agreement of non-compliance (see **7.8**).

10.4.5 ***Joint insertion loss***

Joint insertion loss measurements should be made as detailed in figure A.1.

10.5 Continuity tests of fibre optic spans

Optical loss measurement techniques as detailed in **10.3** act as continuity tests. Where such tests are not defined within the quality plan the installation should be proven to have been installed with the connectivity defined within the installation specification.

OTDR measurements as detailed in **10.4** do not act as a continuity test. A short tail lead may be added to the remote end of the fibre optic span to perform continuity measurements. However, this does not remove the need for bidirectional testing.

To perform simple continuity tests, equipment in accordance with **A.2.1** should be connected to the ends of each fibre optic span (or a sample as defined within the quality plan).

10.6 Final cabling acceptance tests of optical fibre elements

10.6.1 ***General***

Using an OTDR operating at the relevant wavelength (and in accordance with the manufacturer's instructions and specification) the optical fibre elements should be tested in accordance with the method detailed in **A.4.1**.

Details of measurement procedures should be provided together with the type, serial number and proof of calibration of the measurement equipment.

Each optical fibre element (or a sample as defined within the quality plan) should be tested and permanent records retained. The following information should also be recorded:

- fibre optic span identification;
- location of the OTDR during testing.

The measurements described in **10.6.2** and **10.6.3** should be made and recorded directly or indirectly (using the permanent record produced by the OTDR).

10.6.2 ***Optical fibre element length***

The relevant refractive index (see **7.2**) should be used. Alternatively, a suitable value should be used such that any errors introduced are understood and agreed between the installer and the user.

It should be noted that the length measured relates to the length of optical fibre within the cable and this may differ from the actual length of the cable. Within complex constructions the optical fibres may be of different lengths within a given length of optical cable. Where relevant, information should be sought from the manufacturer.

It should be established that the optical fibres measured are of a length equal to or larger than that of the optical cabling as installed (consistent with design factors and subject to the resolution of the measurement).

It is recommended that measurements should be made from both ends of the installed cable. The lengths recorded for a given optical fibre should be identical independent of measurement direction (subject to the resolution of the equipment). Any other result should be investigated.

10.6.3 ***Attenuation coefficient***

The attenuation coefficient of optical fibre elements should be measured to ensure compliance with specification. Measurements made are subject to the restrictions detailed in **A.2.2** in order to assess the following:

- compliance with specification;
- comparison with pre-laid performance.

It is essential that particular regard should be given to localized loss events and/or variations in attenuation coefficient not apparent in the records of the initial optical cable acceptance tests (see **7.2**). The presence of localized losses following installation are generally the result of induced stress within the optical fibre. Induced stress may result in optical fibre failure time during the operational life of the cabling. The causes of the induced stress should be identified and removed.

10.6.4 ***Joint insertion loss***

Joint insertion loss measurements should be made as detailed in **A.4.3**.

11 Documentation

11.1 General

This clause details the recommended level of documentation throughout the design and installation stages. Commercial documentation is also necessary but is not considered here.

The documentation should cover all technical and contractual issues relating to the user requirements and the installation undertaken and should include the following.

a) Installation specification (see clause **5**).

b) Quality plan (see clause **6**).

c) Component acceptance test documentation.

It is recommended that this should include the following:

1) certificates of conformance for optical cable, connectors, cable assemblies etc.;

2) optical cable acceptance test records and other information (see **7.2**);

3) cable assembly acceptance test records and other information (see **7.6**).

d) Laid cabling acceptance (stage I) test documentation (see **8.9**).

e) Final cabling documentation.

It is recommended that this should include the following:

1) route drawings;

2) closure location drawings;

3) as-built drawings including:

i) cabling schematics;

ii) closure schematics;

iii) connectivity.

f) Final cabling acceptance (stage II) test records and other information (see clause **10**).

g) Certificates of conformance (from installer).

h) Handover certification.

11.2 Documentation format

The documentation formats should facilitate changes to be made to the installed cabling throughout its intended operational life.

A formal change control procedure should be established and agreed between the user and installer.

12 Maintenance and repair

12.1 General

Once installed and fully commissioned, tested and documented the fibre optic cabling has fulfilled its basic requirement. Regular and simple maintenance is necessary to ensure optimum performance.

As discussed in annex B the design of the cabling network should reflect repairability and redundancy which are intended to reduce the cost of disruption.

It is essential that the importance of the transmitted data, in terms of its security, value or convenience, is assessed, and consideration should be given to ongoing support in the form of formal maintenance and repair contracts.

12.2 Maintenance

12.2.1 ***General***

There are two forms of maintenance as follows:

- regular maintenance of accessible components such as connector plugs and adaptors;
- formal preventive maintenance which may include periodic re-testing of the installed cabling to enable reassessment against original performance.

12.2.2 ***User based maintenance***

The user should receive full training in simple cleaning procedures to be adopted during cabling disconnection, reconnection or reconfiguration.

Potential damage may result due to misuse of the connector plugs and connector adaptors. Interference with these components may cause system failure. Correctly installed cabling should limit unauthorized access to closures and cable assemblies.

12.2.3 ***Preventive maintenance contracts***

Consideration should be given to the establishment of a preventive maintenance contract.

The terms of such a contract should provide for periodic checks to be undertaken on the installed cabling to ensure that the performance continues to comply with the original specification.

This may include the following:

- connector end-face inspection (see **A.7**);
- assessment of cabling component compliance (see **10.4**);
- optical loss measurement of fibre optic spans (see **10.3**).

Particular regard should be paid to retesting following further installations.

Full retesting may be expensive and may disrupt transmission. Consideration should be given at the design stage with regard to the inclusion of excess optical fibres elements to allow such testing without disruption.

12.3 Repair

12.3.1 ***General***

Correctly installed cabling will have addressed the issue of repairability by providing patching facilities and spare capacity.

Independent of the configuration of installed cabling there should be a repair philosophy, a fault analysis path and where relevant a formal repair contract for work not covered by the installer's warranty.

12.3.2 ***User based fault analysis***

In the event of a failure in communication it is important for a rapid assessment to be undertaken to identify whether the fault lies within the transmission equipment or the cabling.

During or immediately following the installation of a fibre optic cabling infrastructure, the customer should consider the aspects of training (from the installer and the supplier of transmission equipment) relating to the analysis of faults and their resolution.

12.4 Repair contracts

Consideration should be given to the establishment of a formal repair contract covering the installed cabling.

The terms of this contract may include rapid response and spares holding including closures, cable assemblies and additional lengths of optical cable. Where relevant, specific items of emergency repair equipment may be retained by the user.

The existence of a repair contract does not remove the need for comprehensive training as defined in **12.2.2** and **12.3.2**.

Annexes

Annex A (normative)

Acceptance test and inspection methods

A.1 Introduction

Satisfactory performance of fibre optic cabling is dependent upon installation and operation according to the relevant specifications.

Testing should be undertaken, as defined within the quality plan, to ensure that the optical performance of the components is in accordance with their specifications. This annex defines the types of test equipment to be used and the recommended methods of testing to be undertaken using each type of equipment.

Stable performance over extended periods requires compliance with the optomechanical aspects of installation including the termination of optical fibres. This annex defines recommended acceptance criteria for terminated optical fibres and recommends inspection methods to be applied for both factory and field terminations.

A.2 Optical performance test equipment

A.2.1 *Continuity testing*

Continuity testing may be undertaken using either visible or infra-red radiation.

The wavelength dependence of attenuation coefficient values may render continuity testing of extended lengths of optical fibre impractical using visible radiation. In such cases infra-red sources and suitable detectors (including light sensitive papers) may be used.

Under no circumstances should the sources used for optical continuity testing contravene safety standards as defined in BS EN 60825.

A.2.2 *Optical time domain reflectometry*

The optical time domain reflectometer (OTDR) is an instrument capable of characterizing and assessing the optical performance of optical fibre elements and fibre optic spans from one end only.

The OTDR operates by sampling the backscattered light produced by the injection of a laser pulse. The sampled information is normally displayed graphically allowing the assessment of the following:

- optical fibre attenuation and attenuation coefficient;
- optical fibre length;
- features symptomatic of stress or damage at the core-cladding interface;
- connector or joint loss;
- continuity.

The technique produces geographic information with regard to localized loss events thereby providing a pictorial and permanent record which may be used as a performance baseline.

Tests should be undertaken using an OTDR operating at the wavelength(s) specified within the quality plan. The measurements made are not absolute. The OTDR can only assess cabling components for compliance with individual component specifications (subject to the restrictions detailed in **A.4.2**) and does not provide overall optical loss measurement for fibre optic spans.

There are limitations to the effectiveness of an OTDR which are summarized as follows. These limitations should be considered during the development of the quality plan for the installation.

a) Separate assessment of loss events in close proximity is limited by the achievable resolution of the equipment used. In such circumstances assessment may be made against the combined optical loss specification of the two events.

b) Short lengths of optical fibre may not appear linear due to saturation and noise effects within the equipment. This defines a minimum length limit above which attenuation coefficient may be assessed. The value of this limit should be established for the equipment used and measurement of optical fibre losses below this limit should not be attempted.

A.2.3 *Attenuation measurement*

A combination of light source and power meter may be used to provide a single valued measurement for optical loss within a fibre optic span.

Tests should be undertaken using a light source and power meter operating at the wavelength(s) specified within the quality plan.

Measurements made are subject to the restrictions detailed in **A.4.2** and **A.4.4** and can only prove compliance with the optical loss budget specification for a fibre optic span. Measurements made do not provide an absolute value of the optical loss of the fibre optic span.

A.2.4 *Requirements for optical fibre test leads*

A.2.4.1 *OTDR launch leads*

It is recommended that launch leads intended for connection to OTDR equipment should be as follows.

- The geometry and overall specification of the optical fibre within the launch lead should be compatible with that of the optical fibre to be tested.
- Launch leads should be of a length which produces an equilibrium modal distribution at the point of connection to the optical fibre under test.

This requires the possible transmission modes within the optical fibre to be fully populated and all the optical power initially transmitted within the cladding to be removed.

The distance along the optical fibre at which this condition is achieved is dependent both upon the optical fibre geometry and the type of equipment used. When connected to laser based OTDR equipment the equilibrium length may exceed several hundred metres in multimode optical fibre. An alternative is to use specially manufactured launch leads which have been processed to achieve the required launch conditions. Such core mode scrambled and cladding mode stripped launch leads enable shorter lengths to be used.

Equilibrium lengths for single mode optical fibres may be regarded as negligible.

It is recommended that the quality plan defines the design of OTDR launch lead to be used and that it should be as follows:

a) of a length suitable to give unambiguous readings of the optical fibre and cabling components under test;

b) terminated at one end with a connector of the same design, style and manufacture as used on the fibre optic span to be tested.

A.2.4.2 *Light source and power meter test leads*

Test leads for use with light source and power meter equipment are manufactured as launch, reference and tail leads. It is recommended that all test leads intended for connection to light source and power meter equipment should be as follows.

a) The geometry and overall specification of the optical fibre within launch leads should be compatible with that of the optical fibre to be tested.

b) The lead should be of a length which produces an equilibrium modal distribution at the point of connection to the optical fibre under test.

This requires the possible transmission modes within the optical fibre to be fully populated and all the optical power initially transmitted within the cladding to be removed.

The distance along the optical fibre at which this condition is achieved is dependent both upon the optical fibre geometry and the type of equipment used.

When testing multimode systems using LED based equipment then the equilibrium lengths may be less than 10 m. If laser based equipment is used to test multimode optical fibre then the launch lead design should reflect the criteria detailed in **A.2.4.1**.

Equilibrium lengths for single mode optical fibres may be regarded as negligible.

It is recommended that the quality plan defines the design of test leads to be used and these should be sufficiently short to minimize the additional loss generated by the optical fibre within the leads. Test leads should also be terminated with connectors of the same design, style and manufacture as used upon the fibre optic span to be tested.

A.2.4.3 *Index matching materials*

The use of index matching materials in mated connector pairs or joints under test is not recommended because the introduction of such materials invalidates any measurement or test result for the modified joint and because contamination of the terminated optical fibre ends may result.

A.3 Inspection equipment

A.3.1 ***Microscope***

Microscopes used for the inspection of connector end-faces should be capable of $\times$ 200 magnification.

The microscope should be fitted with suitable fixtures to retain the connector in a stable manner to allow careful inspection.

The microscope should be fitted with suitable infra-red filter mechanisms to prevent accidental eye damage. This is particularly important during the inspection of connector end-faces once installed where the remote end is not under the control of the inspector (when the safety precautions of **4.4.1** should be followed).

A.3.2 ***Illumination***

A.3.2.1 *Factory terminated optical fibre*

Inspection allows the illumination of the connector end-face from both the front and the rear using visible radiation.

A.3.2.2 *Field terminated optical fibre*

Inspection requires the illumination of the connector end-face from the front only, using visible radiation.

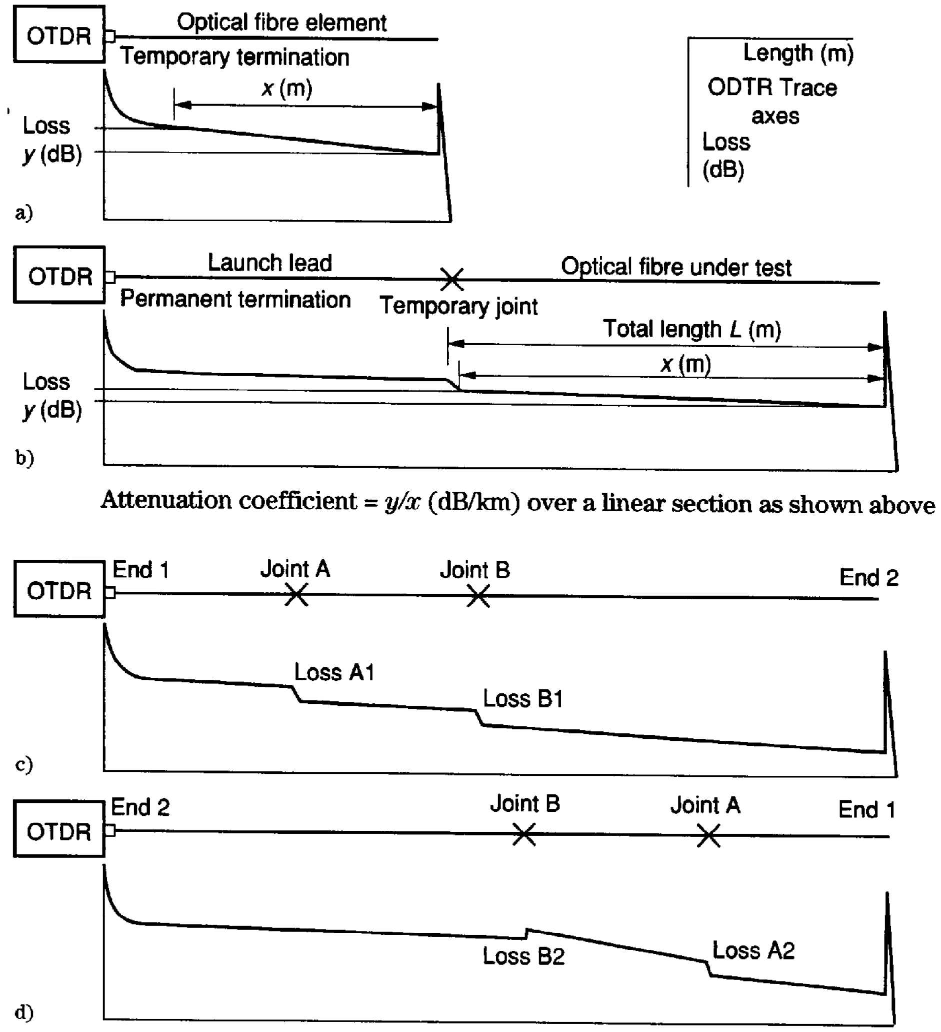
A.4 Optical performance test methods

A.4.1 ***Optical fibre elements***

An OTDR operating at the wavelength defined within the quality plan should be connected to the optical fibre element using either a temporary termination or a temporary joint connecting the optical fibre element under test to a launch lead (see **A.2.4.1**).

The measurement may include the following:

- attenuation and attenuation coefficient, for suitable lengths of optical fibre (see **A.2.2**);
- length: the length measured relates to the length of the optical fibre;
- splice loss measurement, bidirectional measurement is required for accurate results;
- interjoint distances.



True loss (A) = 0.5 [loss(A1+A2)] True loss (B) = 0.5 [loss(B1+B2)]

Apparent amplifications, due to optical fibres with differing scattering properties, are treated as negative losses

Figure A.1 OTDR testing of optical fibre elements

A.4.2 *Fibre optic spans*

A.4.2.1 *General*

Figure B.4 identifies the relevant optical loss budget boundaries XY for the equipment connection formats shown in figures B.2 and B.3. For each of these formats the installed fibre optic spans may be configured as shown in figure A.2.

Configuration A includes closures at both ends of the installed cabling configured as patch panels.

Configuration B includes pigtailed closures at both ends of the installed cabling or direct connection at both ends.

Configuration C includes a closure at one end of the installed cabling configured as a patch panel and a pigtailed closure or a direct connection at the other end.

The installed fibre optic spans may be tested in order to either assess components against individual component specifications or assess the fibre optic span for compliance with the optical loss budget.

Testing shall be undertaken at the specific wavelengths defined in the quality plan.

A.4.2.2 *Measurement relevance*

A fibre optic span contains a quantity of fixed attenuation components and may also include a quantity of variable attenuation components defined as follows:

– fixed components: cable, permanent joints;

– variable components: mated connectors.

Any measurement of the optical loss of the fibre optic span will therefore comprise a fixed plus a variable content.

The variable content, due to the attenuation variations within mated connector pairs, renders any absolute measurement impossible.

The results of any tests undertaken by connection to these variable elements are:

- valid only for those components under the measurement conditions applied;
- a basis for assessing compliance against the original specification;
- unable to be used for any further calculations. For instance, the performance of concatenated fibre optic spans can only be assessed in terms of the optical loss budget of the overall concatenated span.

A.4.2.3 *Individual component compliance*

It is essential that the optical loss of a given fibre optic span should comply with its optical loss budget as defined in **B.2**.

If the individual components are assessed to be compliant with the individual specifications (see **A.4.3**) then the optical loss of the fibre optic span should also be compliant.

A.4.2.4 *Overall loss measurement*

A single valued measurement of the optical loss of a fibre optic span represents a simple means of assessment against the relevant optical loss budget.

However, it is possible for non-compliant components to be disguised within an apparently compliant overall measurement and it is essential that results should be treated with caution. Where doubt exists the compliance of the cabling components should be assessed using OTDR techniques.

A.4.3 ***Assessment of component compliance within fibre optic spans***

An OTDR operating at the wavelength defined within the quality plan may be used to assess the performance of components within the fibre optic span in the configuration shown in figure A.2.

Using a launch lead meeting the requirements of **A.2.4.1** the OTDR should be connected to each end of the fibre optic span as shown in figure A.3.

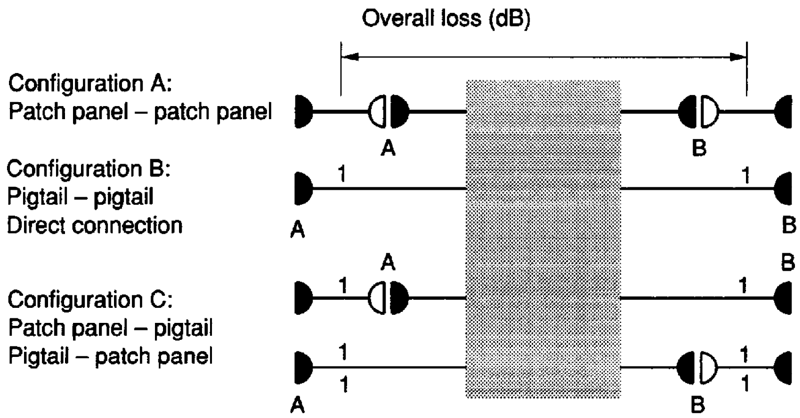
Using this technique the connectors at each end of the fibre optic span may be assessed for compliance with the relevant specification (subject to the restrictions detailed in **A.4.2.2**). The optical loss values should be recorded.

However other optical losses within the fibre optic span may be measured using the mean value of the readings taken from each end (see figure A.1).

A.4.4 ***Loss measurement of fibre optic spans***

A.4.4.1 *General*

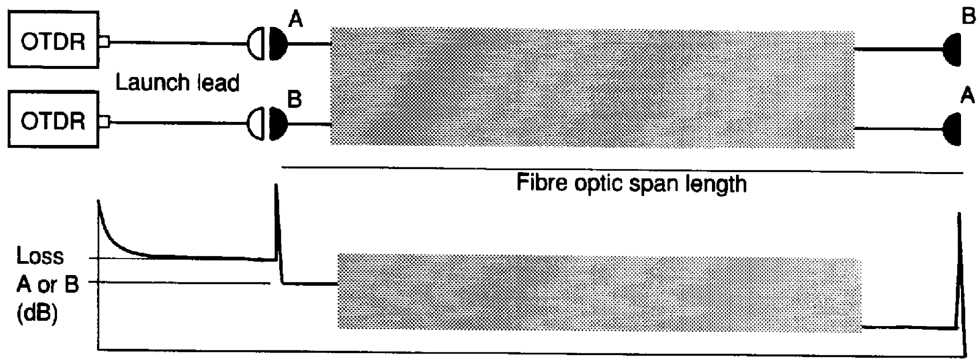
To undertake measurement of the optical loss of fibre optic spans it is necessary to use light source–power meter combinations together with launch and tail leads meeting the requirements of **A.2.4.2**.



NOTE 1. Equipment connections are excluded from loss measurement.

NOTE 2. Shaded area may contain optical cable, connectors, splices and other complex passive components.

Figure A.2 Fibre optic span configurations



NOTE 1. Event losses within the shaded area may be measured from both ends. The mean value may be assessed for compliance with specification.

NOTE 2. All tests should be undertaken in the as-built configuration.

Figure A.3 OTDR tests on fibre optic spans

A.4.4.2 *Testing of fibre optic spans — configuration A*

A power measurement should be made with a launch lead connected directly between the light source and the power meter. This power (P_0) represents the reference measurement and should be recorded.

The launch lead should be disconnected from the power meter. A tail lead should then be connected into the power meter.

The launch lead should not be disconnected from the light source until measurements have been completed. To do so necessitates reestablishment of the reference measurement.

The free ends of the launch lead and the tail lead should be connected to the adaptors fitted to the patch panels at either end of the fibre optic span and the power measurement recorded (P_1). This method is shown in figure A.4.

The difference between the two power measurements ($P_1 - P_0$) represents the optical loss between points X and Y in figure A.4 which relates directly to the optical loss budget of the fibre optic span as defined in figure A.2. The result should be assessed against the optical loss budget defined for the fibre optic span.

A.4.4.3 *Testing of fibre optic spans — configuration B*

A power measurement should be made with a launch lead, a reference lead and a tail lead connected between the light source and the power meter. This power (P_0) represents the reference measurement and should be recorded. The reference lead should then be removed.

The launch lead and tail lead should not be disconnected from the light source and power meter respectively until measurements have been completed. To do so necessitates the reestablishment of the reference measurement.

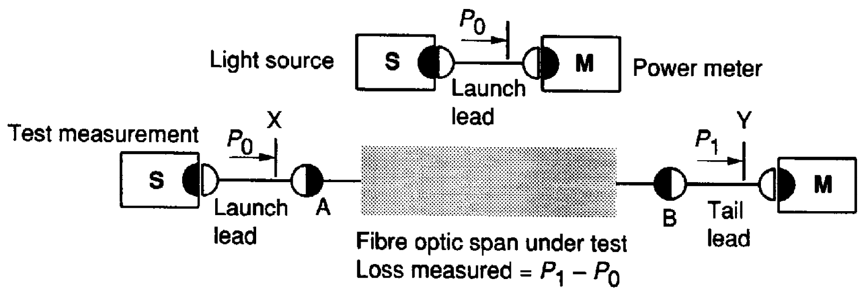


Figure A.4 Configuration A: optical loss measurement

The free ends of the launch lead and the tail lead should be connected to the adaptors fitted to the terminating connectors of the fibre optic span and the power measurement recorded (P_1). This method is shown in figure A.5.

The difference between the two power measurements ($P_1 - P_0$) represents the optical loss between points X and Y in the figure A.5 which relates directly to the optical loss budget XY of the fibre optic span as defined in figures B.4 and A.2 configuration B. The result should be assessed against the optical loss budget of the fibre optic span.

A.4.4.4 *Testing of fibre optic spans — configuration C*

A power measurement should be made with a launch lead and tail lead connected directly between the light source and the power meter. This power (P_0) represents the reference measurement and should be recorded. The launch lead should be disconnected from the tail lead.

The launch lead and tail lead should not be disconnected from the light source and power meter respectively until measurements have been completed. To do so necessitates the reestablishment of the reference measurement.

The free ends of the launch lead and the tail lead should be connected to the adaptors fitted to the terminating connectors of the fibre optic span and the power measurement recorded (P_1). This method is shown in figure A.6. The difference between the two power measurements ($P_1 - P_0$) represents the optical loss between points X and Y in the figure A.6 which relates directly to the optical loss budget of the fibre optic span as defined in figure A.2 configuration C. The result should be assessed against the optical loss budget of the fibre optic span.

A.4.4.5 *Testing of alternative configurations*

Subclauses **A.4.4.2** to **A.4.4.4** define test methods for basic fibre optic span configurations which constitute the vast majority of applications. However, alternative configurations may be tested using methods based upon those detailed earlier.

The following guidance may be useful.

- Method **A.4.4.2** is used to measure the loss of fibre optic spans including the terminating connectors.
- Method **A.4.4.3** is used to measure the loss of fibre optic spans excluding the terminating connectors.
- Method **A.4.4.4** is used to measure the loss of fibre optic spans including one of the terminating connectors.

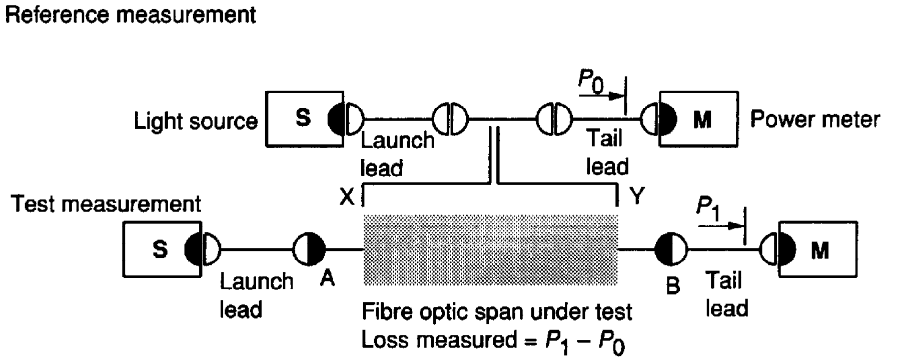


Figure A.5 Configuration B: optical loss measurement

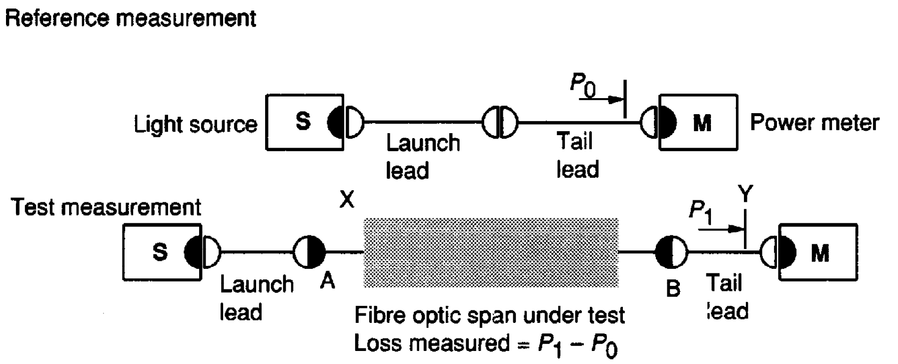


Figure A.6 Configuration C: optical loss measurement

A.4.5 ***Measurement reproducibility***

The variable content of any measurement containing proven mated connector pairs is due to core (or mode field) diameter, numerical aperture and core alignment mismatches within the joint. Therefore to reproduce a given measurement it is necessary to reproduce the measurement conditions at all points where variable elements exist. The connectors used may be either keyed or non-keyed.

Non-keyed connectors can be rotated against each other thereby exploring the full range of attenuation due to the above mismatches. Multiple measurements may be made to investigate the variations and to identify the worst case loss value. This value should be compared with the specification to prove compliance.

Keyed connectors cannot be rotated against each other and measurements are highly repeatable. The measured value should be compared with the specification to prove compliance.

The measurements made are not absolute and are only valid for the particular test leads used. If defined within the quality plan these leads may be retained by the customer.

A.5 Test equipment stability

With regard to optical loss measurement of fibre optic spans (as discussed in **A.4.4**) it is frequently necessary for the reference measurement (P_0) and test measurement (P_1) to be undertaken separated by considerable time periods. Full regard should be taken of the stability of the light source and power meter to prevent unacceptable variations in the measurement.

A.6 Wavelength correction

The light source–power meter combinations may operate at wavelengths different from 850 nm, 1310 nm or 1550 nm.

The attenuation of optical fibre varies with wavelength (see **B.2.2.2**) and it is essential that any measurement should be corrected to the central wavelength (850 nm, 1310 nm or 1550 nm). Alternatively the measurement may be normalized to the wavelength of the transmission equipment, where known, and the normalized wavelength should be clearly documented.

Correction is most relevant in the first window and table A.1 indicates typical correction factors. Where necessary, information should be sought from the manufacturer for second and third window designs.

Table A.1 Typical wavelength correction values

Test wavelength nm	**Correction to 850 nm** dB/km	**Test wavelength** nm	**Correction to 850 nm** dB/km
780	−1.5	920	1.5
790	−1.3	910	1.3
800	−1.0	900	1.0
810	−0.8	890	0.8
820	−0.6	880	0.6
830	−0.4	870	0.4
840	−0.2	860	0.2
850	0.0	850	0.0

NOTE. The following is a worked example: A 500 m long fibre optic span measured at 780 nm has a loss of 2.85 dB. The correction to 850 nm is achieved by applying the correction factor shown above:

i.e. Loss (850 nm) = 2.85 dB + [0.5 km × (−1.5) dB/km]
= 2.85 dB − 0.75 dB
= 2.1 dB

A.7 Terminated optical fibre inspection methods and criteria

A.7.1 ***Connector end-face definitions***

NOTE. The condition of the connector end-faces can be a significant factor in the long term operation of the network. This clause defines recommended requirements for the inspection of terminated optical fibres.

A.7.1.1 *End-face region definitions*

With reference to figure A.7 the connector end-face is subdivided into a core region and a cladding region.

For the purposes of inspection, the cladding region is further subdivided into notional inner and outer regions as shown in figure A.7 and as defined in table A.2.

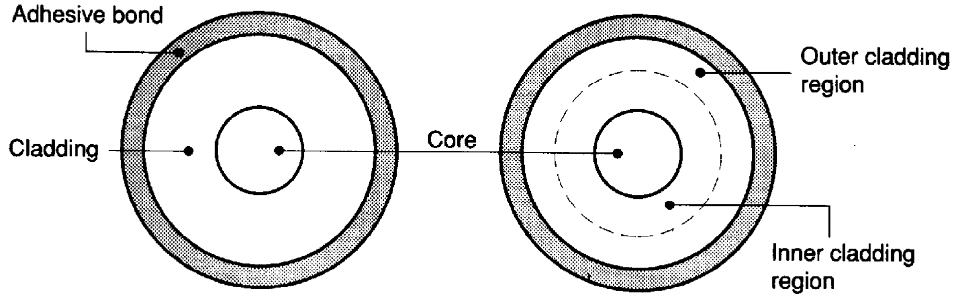


Figure A.7 Connector end-face region definitions

Table A.2 Connector end-face regions

Optical fibre design µm	Core diameter µm	Inner cladding diameter µm	Outer cladding diameter µm
8/125	8	67	125
50/125	50	88	125
62.5/125	62.5	94	125
85/125	85	105	125
100/140	100	120	140
200/250	200	225	250
200/280	200	240	280
200/300	200	250	300

A.7.1.2 *Modified inspection criteria*

The criteria defined in **A.7.2**, and **A.7.3** and the subdivision of cladding regions as given in table A.2 reflect a basic standard which has been proven to provide products of satisfactory operational lifetime.

Modified standards may be adopted following their definition within the installation specification and quality plan.

A.7.2 ***Inspection of factory terminated optical fibre***

A.7.2.1 *General*

The connector end-faces should be subjected to visual inspection using a microscope as defined in **A.3** and should meet the following visual standards providing a finished product capable of meeting the specified system lifetime and performance.

A.7.2.2 *Scratch and pit defects*

Inspection should be undertaken under front illumination conditions.

The core region should be free from blemishes which are not consistent with those produced by the surface finishing techniques recommended by the manufacturer of the connectors used.

A.7.2.3 *Chip defects*

Inspection for scratch and chip defects should be undertaken under front illumination conditions.

The core region and the inner cladding region should be free from defects (either as flaws within the fibre or cracks intersecting the surface).

The outer cladding region should be free from defects that extend for more than 25 % of the cladding circumference (either as flaws within the fibre or cracks intersecting the surface). See figure A.8.

A.7.2.4 *Crack defects*

Inspection should be undertaken using both front and rear illumination conditions.

Acceptance criteria are as in **A.7.2.3**. See figure A.9.

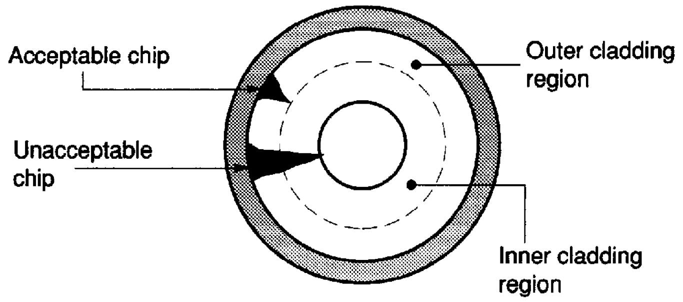


Figure A.8 Chip defects

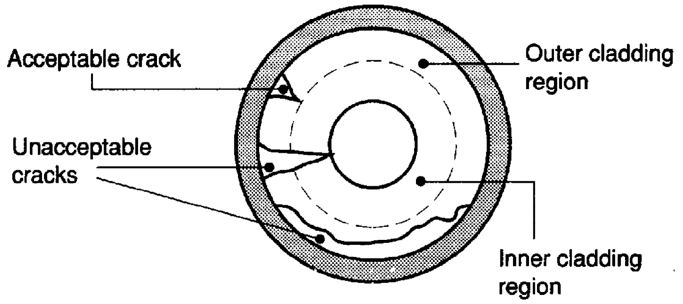


Figure A.9 Crack defects

A.7.3 ***Inspection of field terminated optical fibre***

A.7.3.1 *General*

The connector end-faces should be subjected to visual inspection using a microscope as defined in **A.3**.

The connector end-faces should meet the following visual standards providing a finished product capable of meeting the specified system lifetime and performance.

A.7.3.2 *Scratch and pit defects*

See **A.7.2.2**.

A.7.3.3 *Chip defects*

As **A.7.2.3**.

A.7.3.4 *Crack defects*

Inspection should be undertaken using front illumination conditions only. Acceptance criteria are as in **A.7.2.3**.

A.7.3.5 *Thermal cycling*

Thermal cycling may be undertaken to accelerate any [illegible] failure.

[illegible] ***echanical stability***

[illegible] *General*

To ensure extended operational lifetime and to prevent damage to mating connectors or devices it is necessary to prove that the bond between the optical fibre and the connector is stable and fixed.

Optical fibre–connector bonds can be categorized as adhesive or mechanical.

The bond should be inspected in accordance with **A.7.4.2** to **A.7.4.4**.

A.7.4.2 *Adhesive based bonds*

The adhesive bond between the connector and the optical fibre should be inspected to ensure that the adhesive is fully cured in accordance with the manufacturer's instructions and that the optical fibre is supported for more than 75 % of its circumference and any air-bubbles in the adhesive should not extend in total for more than 25 % of the circumference.

Where adhesive covers an extended area of the connector end-face (by design) then small air bubbles are acceptable provided that they do not fall outside the above criteria.

A.7.4.3 *Mechanical based bonds*

The strength of bond should be established ensuring that optical fibre movement within the connector cannot occur due to tensile load applied to the cable at a level below that defined as the appropriate pull-out strength of the connector/cable assembly (see **B.9.3**).

A.7.4.4 *Pistoning effects (grow-out and pull-in)*

If bond failure occurs unsupported optical fibre may protrude from the face of the connector. This is commonly termed grow-out. Alternatively the optical fibre may draw back within the connector (an effect termed pull-in or grow-in). These phenomena are described as pistoning effects.

Such effects are unacceptable and the termination should be inspected to ensure that the fibre end face profile is consistent within that of the connector ferrule tip. Thermal cycling may be undertaken to accelerate any potential failure.

Annex B (informative)

Guidance notes

B.1 Introduction

The choice of optical fibre represents just one option for the transmission medium within any communications cabling system. The benefits of communications using optical fibre may be summarized as follows:

- bandwidth, i.e. optical fibre enables the transmission of high speed signals over extended distances with minimal distortion;
- attenuation, i.e. optical fibres can exhibit extremely low levels of optical signal loss over extended distances;
- dielectric, i.e. optical fibres are manufactured from a variety of materials which can be considered to be non-conducting;
- lightweight cable construction;
- low cable cross-sectional areas;
- non-radiating transmission medium (electromagnetic compatibility);
- freedom from electromagnetic interference;
- freedom from inter-element crosstalk;
- isolation providing protection from transmitted electrical faults;
- open circuit failure resulting from cable damage;
- signal security.

These benefits may be combined in a variety of ways to suit the specific communications requirement and physical environment but the combination offered by optical technology presents the opportunity for enormous growth in transmission capacity to be achieved without the necessity for reinstallation of the cabling system. This potential for extended lifetime places significantly more emphasis upon the design of the cabling system and the specification to which it is installed.

A fibre optic cabling infrastructure comprises two or more nodes, or access points, between which fibre optic cabling is installed. The nodes may be located at suitable points relevant to the specific application or environment. Nodes are categorized as follows:

a) active, which allow direct access to the fibre optic cabling plant (e.g. at a patching facility);

b) passive, within the fibre optic cabling housing permanent joints or simply to enable future direct access (e.g. within an in-line joint);

c) mixed, which allow direct access to a limited number of fibre optic spans within the fibre optic cabling in addition to housing permanent joints for others;

d) sub-, which allow direct access but are normally included to ease installation or as a means of rapid repair of specialist fibre optic cabling (e.g. between bulkheads in fighting vehicles).

It is essential that the design of fibre optic spans within fibre optic cabling infrastructures should be carefully considered. The criteria to be addressed at the design stage of a fibre optic cabling infrastructure are detailed in **B.2 to B.9**.

Clauses should be read in conjunction with clause **3** to enable the reader to progress through the following design concepts:

- optical power (and loss) budget;
- bandwidth;
- operational lifetime;
- repairability and redundancy;
- nodal design;
- optical cables;
- closures;
- connectors.

The design may be an iterative process leading to the definition of an overall technical and operating specification which should be agreed prior to commencement of the installation.

B.2 Optical power and loss budget

B.2.1 *General*

Optical power budget is a measure of the performance of the transmission equipment and is defined as the range of optical power loss ratios, expressed in dB (decibels), which can be tolerated between the point of transmission and the point or points of reception whilst still maintaining communication integrity as defined by the equipment manufacturer.

An optical power budget is bounded by a maximum and minimum value.

The maximum value, b_{max}, is the difference in dB of the minimum optical power launched into a fibre optic span L_{min} (by the optical transmitter) and the minimum which may be received from that fibre optic span R_{min} (by the optical receiver) whilst still maintaining communication integrity as defined by the equipment manufacturer (see figure B.1).

$$b_{max} = L_{min} - R_{min}$$

where

b_{max} is the maximum optical power budget in dB;

L_{min} is the minimum optical power launched into the fibre optic span in dBm;

R_{min} is the minimum optical power received from the fibre optic span in dBm.

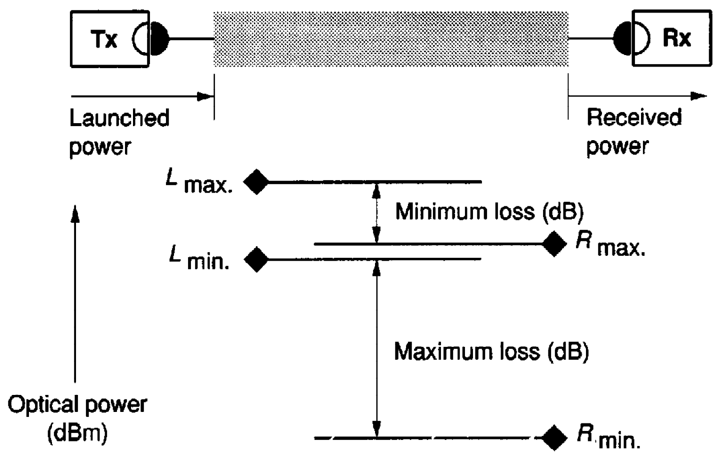


Figure B.1 Optical power budget

The minimum value, b_{min}, is the difference in dB of the maximum optical power launched into a fibre optic span L_{max} (by the optical transmitter) and the maximum which may be received from that fibre optic span R_{max} (by the optical receiver) whilst still maintaining communication integrity as defined by the equipment manufacturer (see figure B.1).

$b_{min} = L_{max} - R_{max}$

where

b_{min} is the minimum optical power budget, in dB;

L_{max} is the maximum optical power launched into the fibre optic span, in dBm;

R_{max} is the maximum optical power received from the fibre optic span, in dBm.

It is essential that the optical loss or attenuation of the fibre optic span should be within these limits.

An optical loss budget has a maximum and minimum value.

The maximum value is the sum of the maximum specified values of each of the components within the fibre optic span.

The minimum value is the sum of the minimum specified values of each of the components within the fibre optic span.

It is suggested that the topics covered in **B.2.2** to **B.2.7** should be considered during the calculation of the optical power and optical loss budgets.

B.2.2 *Optical power budget*

B.2.2.1 *Launched power*

For the purposes of the installation specification it is essential that the launched power should be that measured into an optical fibre of a defined design at point X in figure B.2. The measurement should be made using a launch lead meeting the recommendations of **A.2.4.2**.

NOTE. Where system based cabling involves fibre optic span designs which are shorter than the equilibrium length of the optical fibre used then different measurement conditions may be required (see **B.2.7**).

B.2.2.2 *Received power*

For the purposes of the installation specification it is essential that the received power should be that measured from an optical fibre of a defined design at point Y in figure B.3.

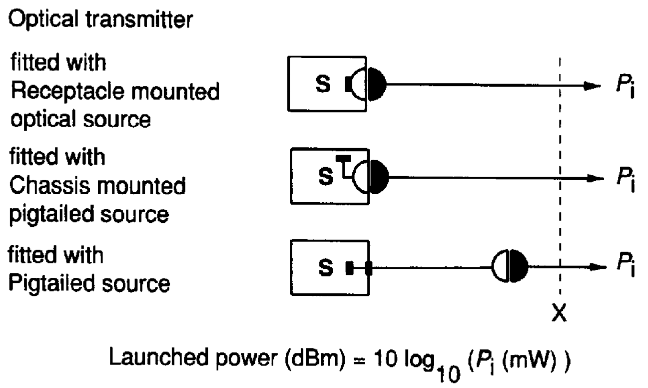


Figure B.2 Launched power

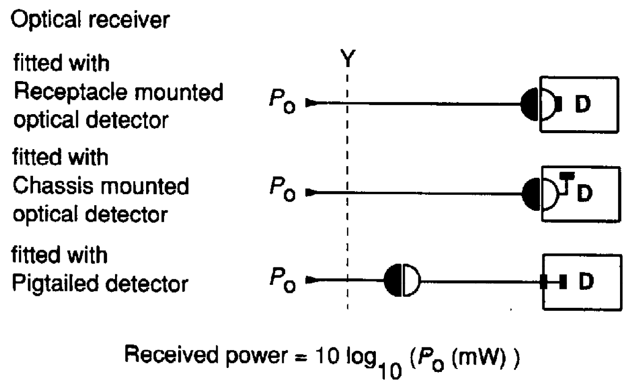


Figure B.3 Received power

B.2.2.3 *Related issues*

B.2.2.3.1 *General*

These optical power levels, expressed in dBm (1 mW = 0 dBm), are subject to the factors detailed in **B.2.2.3.2** to **B.2.2.3.4** which should be considered when assessing the optical power budget for a specific set of transmission equipment.

B.2.2.3.2 *Component ageing*

Optical power output may fall during extended operation. The degree of ageing varies dependent upon the type of optical transmitting device. Where relevant, 'end-of-life' parameters should be used in the calculation of optical power budgets.

Manufacturers should be consulted where information supplied is not specific.

B.2.2.3.3 *Thermal effects*

Optical power output may vary with operating temperature. The worst case values should be established for the specific application.

Optical receivers may be subject to variations in performance with operating temperature.

Manufacturers should be consulted where information supplied is not specific.

B.2.2.3.4 *Optical fibre design*

Transmission equipment manufacturers may specify an optical power budget for a single optical fibre design only. Table B.1 shows correction factors for a range of optical fibre designs. It should be noted that these values are based upon theoretical calculation and manufacturers should be consulted where information supplied is not specific.

B.2.3 *Optical loss budget*

B.2.3.1 *General*

It is necessary to establish the method and points of measurement prior to calculating optical loss budgets.

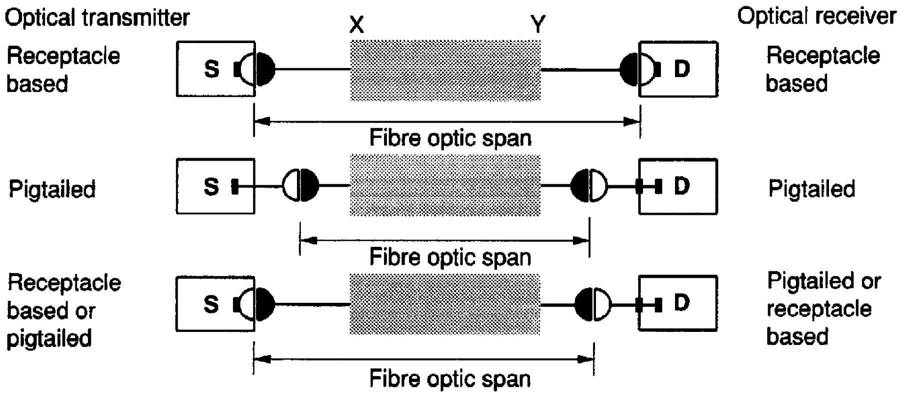
For the purposes of the installation specification the relevant optical loss of the fibre optic span should be as defined in figure B.4 for the equipment connection formats shown in figures B.2 and B.3.

It is essential that optical loss, expressed in dB, should comply with the optical power budget for the proposed transmission equipment.

Table B.1 Optical power budget correction factors

Core diameter μm	Numerical aperture	Relative launched power (dB)			
		Reference 100 μm 0.29 N.A.	Reference 85 μm 0.26 N.A.	Reference 62.5 μm 0.275 N.A.	Reference 50 μm 0.20 N.A.
8	0.11	−30.3	−28.0	−25.8	−21.1
50	0.20	−9.2	−6.9	−4.7	0
62.5	0.275	−4.5	−2.2	0	
85	0.26	−2.3	0		
100	0.29	0			
200	×				

NOTE. A cross (×) suggests a variable parameter and manufacturer's advice should be sought where relevant.



NOTE 1. Optical loss budget (OLB) is calculated between X and Y.

NOTE 2. Equipment connection is excluded from OLB calculations.

NOTE 3. Shaded area may contain optical cable, connectors, splices and other complex passive components.

Figure B.4 Optical loss within a fibre optic span

B.2.3.2 *Optical fibre*

The maximum optical loss produced by the optical fibre within a fibre optic span is obtained by multiplying the total length of optical fibre by the maximum value of the attenuation coefficient, expressed in dB/km, quoted by the manufacturer of the optical fibre.

Attenuation coefficient is dependent upon the optical fibre design and the wavelength of the optical radiation transmitted. Attenuation coefficient values are normally specified at defined wavelengths. These wavelengths lie within defined transmission windows as follows:

- first (1st) window of central wavelength 850 nm;
- second (2nd) window of central wavelength 1310 nm;
- third (3rd) window of central wavelength 1550 nm.

Attenuation coefficient varies continuously with wavelength and therefore equipment operating at wavelengths different from those specified will encounter modified losses (see **B.2.6** and figure B.5).

B.2.3.3 *Other components*

B.2.3.3.1 *General*

Optical loss may occur at joints and within complex optical components. When calculating the optical loss budget of a fibre optic span it is vital to include the specified losses of all components and joints.

Joint losses are incurred not only in initial configurations but also during reworking, reconfiguration or repair during the operational life of the fibre optic cabling. It is recommended that consideration should be given to future requirements and that suitable margins should be included within optical loss budgets.

Where necessary it is recommended that information should be sought from the manufacturer and installers with regard to relevant performance parameters. It is vital that all components and installation techniques used have defined optical loss specifications.

B.2.3.3.2 *Connectors*

Performance is dependent upon design of the connector, the optical fibre design and the method of application. It is vital to define an optical loss specification at the earliest stage of the design.

B.2.3.3.3 *Splices*

Performance is dependent upon the mechanism used. It is vital to define an optical loss specification at the earliest stage of the design.

B.2.3.3.4 *Passive components*

Optical fibre couplers, optical attenuators and optical switches may have complex optical loss characteristics.

B.2.3.4 *Ageing effects*

B.2.3.4.1 *Optical cable*

This is normally insignificant; however, a commitment may be sought from the installer and, where necessary, inspection may be carried out at defined intervals to establish the level of variation.

B.2.3.4.2 *Connectors*

The optical loss exhibited by mated connector pairs is dependent upon the relative alignment of the cores. The degree of deterioration is dependent upon the design of the connector and the materials used within the alignment mechanisms.

B.2.3.4.3

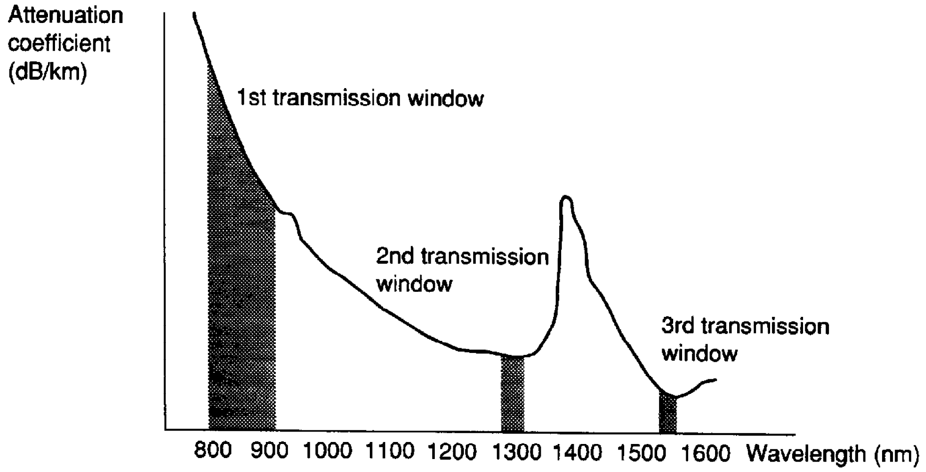


Figure B.5 Attenuation coefficient and wavelength

B.2.3.5 ***Thermal effects***

Where extreme operating conditions are predicted it is recommended that detailed analysis should be undertaken in conjunction with the installer and component manufacturers.

B.2.6 ***Geometry mismatch***

Optical losses occur at transition points between different optical fibre geometries and installations utilizing multiple geometries should only be adopted provided that accidental intermating of different designs cannot occur (see **B.7.3.3**).

B.2.7 ***Operational wavelength***

During the design phase the optical loss budget should be calculated at the central wavelength of the relevant transmission window. Transmission equipment may operate at wavelengths which differ from these central wavelengths and it is recommended that the optical loss budget be normalized to the transmission wavelength (where known) to ensure compliance. This is most relevant in the first window (see table A.1). However, where necessary, information should be sought from the manufacturer for second and third window designs.

B.2.8 ***Equipment independent cabling***

National and international standards have been developed for certain local area networking applications which have defined optical power budgets specified within defined transmission windows. These may be used in equipment independent cabling infrastructures without recourse to detailed analysis of the transmission equipment used.

B.2.9 ***Short range systems***

Equipment based or system based cabling may feature short fibre optic spans (typically 50 m) which may be less than the equilibrium length of the optical fibre used.

The equilibrium length is the length over which the transmitted power attains equilibrium, i.e. cladding modes have been removed and, for multimode applications, the possible modes are fully populated. This length varies with the optical fibre design and the coatings applied to the optical fibre.

If fibre optic spans below the equilibrium length are to be installed then the following should be considered:

- launched powers may exceed those measured using test leads meeting the requirements of **B.2.2**;
- optical fibre loss may differ from the calculated value as defined in **B.2.3.2**;
- the loss of connectors, joints and complex components may be variable dependent upon their position in the fibre optic span(s).

It is essential that short range cabling should be carefully investigated and testing methods should reflect the relevant conditions.

B.3 Bandwidth

B.3.1 ***General***

With reference to **B.2**, it is essential that the optical loss budget of the fibre optic span complies with the optical power budget of the transmission equipment. In many cases a given optical power budget may be supported by a range of optical fibre designs.

The bandwidth of the optical fibre is a vital aspect of the operational lifetime of the installed cabling. Optical fibre designs exhibiting the highest potential bandwidths generally exhibit lower launched optical power levels thereby producing lower optical power budgets (see table B.1) and it is impractical to select a high bandwidth optical fibre design which cannot support the satisfactory operation of the transmission equipment. It is recommended that optical fibre designs should be installed which offer the maximum bandwidth consistent with satisfactory operation of current transmission equipment. However, consideration should be given to the adoption of optical fibre designs in accordance with appropriate standards relevant to the communications application.

B.3.2 ***Optical fibre bandwidth***

B.3.2.1 *General*

The bandwidth of an optical fibre subsystem is a complex function of the fibre optic span and the transmission equipment.

The optical fibre can be viewed as a transmission medium with a defined potential bandwidth (see table B.2). The actual bandwidth is dependent upon the transmission equipment used and may approach the potential bandwidth when narrow spectral width optical transmitters are incorporated within the transmission equipment.

B.3.2.2 *Multimode optical fibre bandwidth*

The bandwidth of an optical fibre depends upon its length. For ease of calculation the potential bandwidth (B) of the optical fibre at the proposed operating wavelengths, expressed in MHz·km, may be treated as linear.

The potential bandwidth ($B(L)$) (in MHz) of an optical fibre of length L may be calculated as follows:

$$B(L) = \frac{B(\text{o})}{L}$$

where $B(\text{o})$ is the specified bandwidth (in MHz·km).

The majority of multimode optical fibre transmission systems are based upon LED optical sources. The actual bandwidth of such systems is dominated by the spectral width of those sources and can be significantly lower than the potential bandwidths quoted in table B.2.

Table B.2 Typical data for optical fibre designs

Mode	Core diameter	Cladding diameter	Numerical aperture	Potential bandwidth (MHz·km)			Chromatic dispersion coefficient (ps/nm·km)		Attenuation coefficient (dB/km)		
				850 nm	1310 nm	1550 nm	1310 nm	1550 nm	850 nm	1310 nm	1550 nm
Single	8	125	0.11	*	*	*	3.0	18.0	*	0.4	0.3
Multi	50	125	0.20	200 to 1000	400 to 1500	*	*	*	3.0	1.0	*
Multi	62.5	125	0.275	160 to 300	200 to 1000	*	*	*	3.75	1.75	*
Multi	85	125	0.26	100 to 200	200 to 400	*	*	*	4.0	2.0	*
Multi	100	140	0.29	100	100 to 200	*	*	*	5.0	2.0	*
Multi	200	×	×	10	×	×	×	×	>10.0	×	*

NOTE 1. The bandwidth ranges shown are those from which products may be purchased and do not denote flexibility within a given product. The manufacturer's guidance should be sought prior to the definition of a detailed specification.

NOTE 2. The asterisk (*) denotes a parameter not normally specified and for which guidance should be sought where relevant.

NOTE 3. A cross (×) suggests a variable parameter and the manufacturer's advice should be sought where relevant.

B.3.2.3 *Singlemode optical fibre bandwidth*

The dependence upon the spectral width of the optical transmitter is emphasized by the use of material dispersion rather than bandwidth parameters.

The bandwidth ($B(L)$) of an optical fibre of length L using an optical transmitter of spectral width s has the form:

$$B(L) = \frac{\text{constant}}{M(\lambda)Ls}$$

where $M(\lambda)$ is the specified material dispersion parameter.

B.3.2.4 *Concatenation of multimode fibre optic spans*

The conservative treatment of potential bandwidth for multimode optical fibre spans (see **B.3.2.2**) is not definitive. For extended distances involving multiple lengths of optical fibre a detailed analysis should be considered including the assessment of bandwidths for concatenated optical fibre elements and/or fibre optic spans. This is complicated and should only be undertaken following consultation with the installer and the manufacturer of the optical cable.

B.3.3 ***Equipment independent cabling***

National and international standards have been developed for certain local area networking applications which have a specification for actual bandwidth of fibre optic spans. This has been achieved by defining a minimum potential bandwidth for the optical fibre and a defined spectral width for the optical transmitter. This facilitates the design of equipment independent cabling infrastructures without recourse to detailed analysis of the transmission equipment used.

B.4 Operational lifetime

B.4.1 ***General***

The operational lifetime of a fibre optic cabling infrastructure is based upon its ability to accept expansion, extension and evolving communications standards and technology.

B.4.2 ***Service expansion and optical fibre count***

As the cost of optical fibre has tended to fall with increased usage, and higher bandwidth designs have been developed, the use of additional elements within the fibre optic cabling designs meeting both initial and future needs should be considered.

Spare optical fibres within optical cables can be used for repairability, redundancy and for monitoring purposes (during preventive maintenance testing). However, the incorporation of additional optical fibres should be considered to allow for service expansion or evolution of transmission technology.

B.4.3 ***Infrastructure extension and cabling topology***

It is recommended that the requirements should be assessed for future users to have access to the installed fibre optic cabling infrastructure.

The design of the installation should take account of locations not initially connected which may be activated in the future and of the spread of optical fibre within locations which may be desirable as communications requirements are modified.

B.4.4 ***Evolution of communications standards and transmission technology***

Equipment independent cabling, based upon envelope specifications for optical power budgets and actual bandwidths (within specified transmission windows) provides a basis upon which fibre optic spans may be designed. Deviation from these envelope specifications may limit the flexibility of the resulting fibre optic cabling infrastructure.

Also, consideration should be given to the evolution of technology and, where necessary, designs should assess the need for operation at multiple wavelengths (and measurement against specification at those wavelengths).

B.5 Repairability and redundancy

B.5.1 ***Costs of communications failure***

The user should consider the true costs of communications failure in terms of lost production, lost information or in any other manner relevant to the application of the data being transmitted.

These costs may then be balanced against the installation costs of repairable or self-healing designs (via transmission software or transmission hardware reconfiguration).

B.5.2 ***Failure mechanisms***

B.5.2.1 *Optical cable damage*

The likelihood of damage to the optical cable is dependent upon installed environment. The use of a suitable optical cable design will reduce the probability of failure but it should be recognized that any optical fibre breaks may result in total communications failure.

This can be repaired by either software or hardware reconfiguration or redundancy via the use of a separately routed optical fibre cable.

B.5.2.2 *Connector damage*

This results in selective disruption to communications since it affects only the optical fibre (or fibres) within the damaged connector.

Consideration should be given to additional optical fibre elements within the fibre optic cabling allowing reconfiguration at both ends following failure. Full repair may then be effected without further communications disruption.

B.5.2.3 *Other components*

The introduction of optical fibre couplers, optical attenuators and optical switches may modify levels of repairability.

Consideration should be given to appropriate reconfiguration contingencies and approaches to redundancy.

B.6 Nodal design

B.6.1 ***General***

The configuration of the nodes should be based upon consideration of the following criteria:

- the total number of optical fibres at the node;
- optical cable constructions at the node (see **B.7**);
- susceptibility to damage and ease of repair;
- service expansion (see **B.4.2**);
- infrastructure extension (see **B.4.3**);
- optical fibre and optical cable management;
- maintainability;
- health and safety (see clause **4**).

B.6.2 ***Direct connection***

The use of a single optical cable directly connected to the transmission equipment (as in figure B.6) is not recommended unless cable replacement is straightforward.

B.6.3 ***Closures***

B.6.3.1 *General*

Where it is not acceptable to directly connect a single optical cable between the transmission equipment then it is recommended that closures be used at the nodes. These provide the necessary safeguards with regard to strain relief and protection of both terminated and unterminated optical fibre elements.

If repairability is to be enhanced by the use of spare optical fibre elements then these may be housed within the closure.

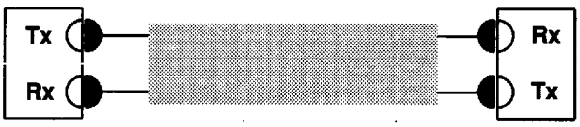


Figure B.6 Direct connection to transmission equipment

B.6.3.2 *Patch panel approach*

This allows the main optical cable to be terminated on, or within, the closure (see figure B.7). Connectors may be applied directly to the optical fibres within the main optical cable. Alternatively, premanufactured pigtails may be jointed (using fusion or mechanical splice techniques) to the optical fibre within the main optical cable.

Connection to the transmission equipment is made by premanufactured jumpers.

B.6.3.3 *Pigtailed approach*

An alternative approach may be used (as shown in figure B.8) where premanufactured pigtails are jointed to the optical fibre within the main optical cable.

B.6.4 ***Design criteria***

B.6.4.1 *Patch panel approach*

A patch panel approach offers the following benefits:

- closures act as flexibility points enabling the user to configure the installed fibre optic cabling plant via the use of patchcords;
- equipment upgrades can be facilitated by the purchase of jumpers removing the need for skilled technicians to reterminate the main optical cable;
- damage to a patchcord or jumper can be rectified by replacement;
- the fibre optic cabling plant terminates at the patch panel.

Reconfiguration using patchcords or jumpers may be undertaken without the revision of the documentation provided (see clause **11**). However, unrestricted patching by users can generate inoperable systems due to the increase in optical loss.

B.6.4.2 *Pigtailed approach*

A pigtailed approach offers the following benefits:

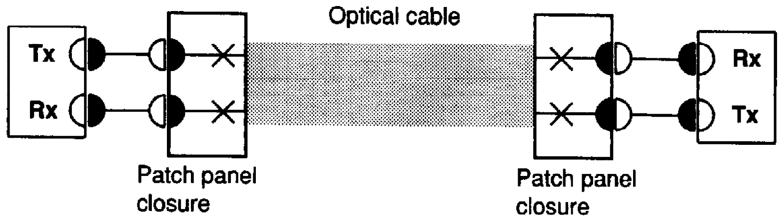
- a reduction in the number of connectors will result in lower optical loss budgets for the fibre optic cabling. This may allow increased transmission distances;
- a reduction in the number of connectors restricts the probability of contamination and handling related damage.

B.7 Optical cable design

B.7.1 ***General***

The choice of optical cables is one of the most important decisions to be made during the design phase. The choice is generally dictated by the installation and operating environments. The correct selection of a cable design suitable for its intended environment will minimize the risk of system failures and expensive replacement costs.

Design concepts are described in **B.7.1** to **B.7.6**.



NOTE. The splice within the patch panel closure is optional.

Figure B.7 Patch panel closure

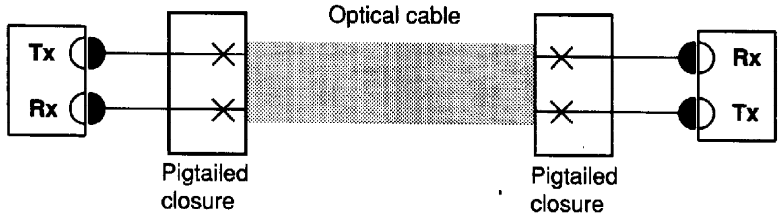


Figure B.8 Pigtailed closure

B.7.2 ***Optical fibre and optical cable specifications***

There are a number of standards and recommendations which relate to the design and performance of optical fibres. These include the following:

— IEC 793;

— CCITT Recommendations G652, G653 and G654 (single mode);

— CCITT Recommendation G651 (50/125 µm multimode).

Silica based optical fibres are generally manufactured with a thin primary protective coating of acrylate or similar material. The primary coating alone provides insufficient protection for the optical fibres to guarantee the service required for most applications. For greater protection optical fibres are cabled to suit a variety of requirements.

B.7.3 ***Basic cable design concepts***

B.7.3.1 *Loose tube construction*

This design allows primary coated optical fibre or bundles of primary coated optical fibres to lie loosely inside a polymer tube or former thus taking advantage of the minimum strain configuration within the tube or former whilst protecting them from abrasion and other external forces.

The tube or former may be filled with compounds to prevent ingress and propagation of moisture which may affect the optical fibres.

These cables are designed to withstand the mechanical stresses involved when cables are pulled through extensive duct systems and are particularly suitable for external use.

B.7.3.2 *Tight buffer construction*

This design features secondary coated (buffered) optical fibres within a flexible and durable construction. The cables are of generally low fibre count with aramid yarn protection layers and a polymer outer sheath. This design is particularly suited to internal applications.

The application of the above approach to a single fibre element can be described as a single ruggedized optical cable.

B.7.3.3 *Design variants*

Design variants are described as follows.

a) Ribbon fibre: optical cables containing primary coated optical fibres formed into multi-fibre ribbons.

b) Hybrid cables: optical cables containing two or more optical fibre designs.

Where mixed optical fibre designs are to be used it is necessary to ensure that the overall design considers measures to prevent accidental misconnection of the designs. Such measures include the following:

1) optical fibre connector selection (to prevent physical interconnection of different optical fibre designs);

2) jumper and patchcord colour coding.

c) Composite cables: cables containing optical fibre elements and metallic conductors.

d) Blown Fibre: cabling plant comprising a network of tubes into which optical fibres, or bundles of optical fibres, are subsequently installed using compressed air.

B.7.4 ***Optical fibre identification***

It is recommended that all optical fibres, independent of cable construction, should be uniquely and individually identifiable.

B.7.5 ***Tensile strength members***

Optical cables are produced with both metallic and non-metallic strength members. The strength member may be internal to, or embedded within, the cable sheath. Alternatively strength members may be located externally and bonded to the cable sheath.

If an optical cable is to be installed through duct or other conduit then a loose tube construction cable with a central or sheath embedded/bonded strength member is recommended. This strength member should be used as tensile load protection during cable installation.

Tight buffer constructions incorporating longitudinally laid aramid yarns acting as strength members may be installed through duct or other conduit using the strength member as tensile load protection provided that evidence supporting its use is obtained from the manufacturer.

Tight buffer constructions incorporating wrapped, braided or wound aramid yarns may be employed over shorter cabling routes. However, the use of aramid yarn as tensile load protection during cable installation should be avoided.

B.7.6 ***Environmental protection***

B.7.6.1 *Mechanical damage and rodent damage resistance*

Metal tapes, galvanized wires and non-metallic yarns can offer some resistance to external crushing and piercing forces and protection against rodent damage. These materials are generally applied directly under the outer sheath.

B.7.6.2 *UV exposure resistance*

A UV stabilized sheathing material should be used for outdoor applications in which the cable is to be subjected to UV radiation.

B.7.6.3 *Moisture resistance*

Polyethylene is generally used for external applications in conjunction with internal moisture barriers for improved performance. The moisture barriers which may be used include metallic and non-metallic materials to prevent radial ingress of moisture into the cable together with filling compounds in and between the tubes, formers and optical fibre elements to prevent axial migration of moisture along the cable.

NOTE. In a filled cable construction a metallic radial moisture barrier is principally used as a protection against heat during glanding processes.

B.7.6.4 *Fire resistance*

There are a variety of flame retardant and low toxicity materials which can be used to minimize the propagation of fire and the harmful effect of smoke and fumes. The materials are broadly classified as follows:

a) *Flame retardant*

These materials contain agents which make the material less flammable.

b) *Low smoke and low toxic gas emission sheath*

These materials are usually halogen free and may contain fire resistant agents. Consequently the toxicity levels of the gases which evolve when these materials are burnt are considerably lower than flame retardant materials.

Materials are available for both internal and external applications. However, the following issues should be considered:

1) hygroscopic absorption of moisture (which may create an electrically conductive discharge path);

2) abrasion resistance during installation.

It should be noted that the properties of a cable depend upon all the materials used within the construction including filling compounds. Information should be sought from the manufacturer where necessary.

B.7.6.5 *Hydrocarbon resistance*

The most effective barrier against hydrocarbon attack is a lead inner sheath with a polyethylene outer sheath. Other materials, e.g. nylon, provide a less effective but simpler alternative.

B.8 Closures

B.8.1 *Introduction*

The purpose of a closure is to provide safe storage and access to individual fibres allowing for the following:

— onward splicing, jointing (figure B.9a);

— change of optical cable type (figure B.9a);

— change of optical fibre capacity along route (figure B.9b);

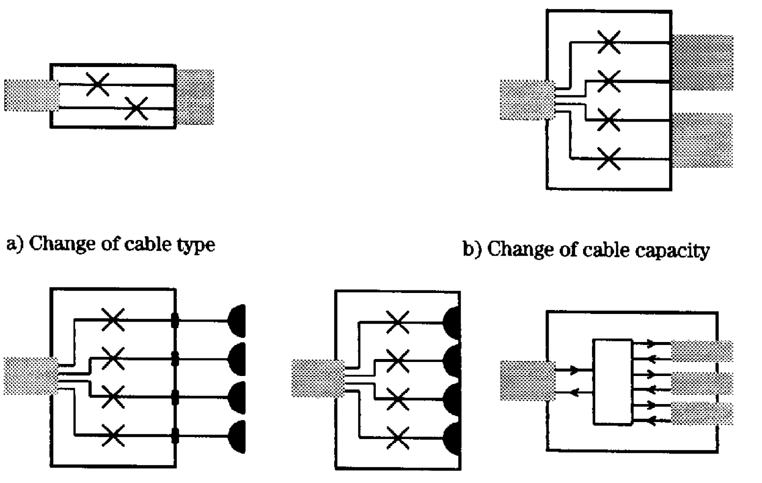
— termination of optical fibre to pigtails (figure B.9c);

— termination of optical fibre at patch panels (figure B.9d).

Under certain circumstances the closure may also house additional devices as shown in figure B.9e such as the following:

— passive components e.g. couplers, attenuators, switches;

— active devices.



a) Change of cable type

b) Change of cable capacity

c) Pigtailed closure

d) Patch panel closure

e) Housing of devices e.g. optical coupler

Figure B.9 Closure applications

The closure should offer strain relief to all entering cables whilst maintaining, as appropriate, the environmental features of the optical cable.

B.8.2 ***Physical features (external)***

B.8.2.1 *Material options*

Closures are constructed from a wide range of materials and their design should reflect the appropriate environmental conditions.

B.8.2.2 *Mounting options*

Closures are available for both internal and external applications. In all cases the mounting facilities provided with each closure should meet the requirements of the locations defined within the installation specification.

B.8.2.3 *Environmental considerations*

The design of each closure should comply with the environmental conditions at the site of deployment as defined within the installation specification. Environmental factors include:

- anticipated temperature range;
- climatic conditions;
- ambient light: the material of construction should eliminate external light being coupled to the optical fibres contained within the closure;
- moisture ingress: the sealing properties of each closure should be consistent with the requirements of its proposed location; all points of entry to the closures may affect the sealing properties and the choice of glands and seals should meet the overall requirement;
- wind;
- salt spray;
- mould growth;
- chemical attack.

B.8.2.4 *Physical protection*

Physical protection may be related to the following.

a) Cables entering the closure.

Strain relief should be provided for each cable entering the closure. This will be dependent upon the cable construction and may encompass one or more of the following:

1) compression gland;

2) entrapment of yarn based strength member;

3) securing of axial strength member;

4) heatshrink techniques;

5) movement of the closure.

The design of the closure and/or its immediate surroundings should allow for storage of service loops of optical cable. The loops should be sufficient to allow the removal of the closure from its specified location to a position which will allow access to the optical fibres contained for purposes of repair, rework or modification.

b) protection of the function of the closure from accidental or wilful damage by the provision of:

1) integral locks;

2) secure enclosures;

3) additional lockable enclosure;

4) rooms with controlled access.

The choice of protection should be made following consideration of the importance of the data transmitted as defined by the user.

B.8.2.5 *Earth bonding*

Suitable fittings should be provided to allow the closure or any metallic element of the cables contained therein to be bonded to an electrical earth for both safety and functional purposes as defined in the installation specification.

B.8.2.6 *Glanding*

The closure should have sufficient capacity for both the initial and proposed quantity of cable entries and the associated glands.

B.8.2.7 *Adaptors*

The closure should have sufficient capacity for both the initial and proposed quantity of connector entries and the associated adaptors.

B.8.2.8 *Labelling*

Optical safety labels in accordance with BS EN 60825 should be applied adjacent to all accessible optical interfaces (see **4.4.2**).

B.8.2.9 *Identification*

An identification scheme should be agreed between the user and the installer for all closures.

Space should be allocated on a visible surface of the closure to allow a label or marker to be affixed displaying the identification details of the closure.

Enclosed glands, adaptors and optical cables should also be labelled.

B.8.3 ***Physical features (internal)***

B.8.3.1 *General*

Internal features of the closure should provide optical fibre management ensuring the following:

- optical fibre protection;
- optical fibre identification;
- splice (fusion or mechanical) restraint, where used.

B.8.3.2 *Optical fibre protection*

This should be achieved by housing service loops of optical fibre within the following:

- integral pockets;
- cassettes;
- other fibre handling techniques.

These mechanisms should maintain the minimum bend radii as recommended by the optical cable manufacturers.

B.8.3.3 *Ambient light protection*

Ambient light should be kept to a minimum within the closure. Where transparent exterior panels are used the internal features should prevent coupling of the ambient light to the optical fibre elements.

B.8.3.4 *Optical fibre management*

Where relevant the closure should have the capability to house safely and in a controlled manner the required range of joint components.

The closure should facilitate access to individual fibres/splices to allow the following:

- initial termination or splicing;
- future expansion;
- repair;
- changes to cabling configuration;
- storage of unterminated or unspliced optical fibres.

B.8.4 ***Closure design***

The external design of the closure should where possible be compatible with its immediate surroundings.

B.9 Connectors

B.9.1 ***Optical performance criteria***

B.9.1.1 *General*

The optical performance of a mated connector pair is dependent on the tolerances of the mechanical components together with the tolerances within the optical fibre alignment. Careful consideration should be given to the worst case random mated optical performance figures.

Optical performance is generally defined for a joint containing components (plug connectors and adaptors) from a single manufacturer. Performance levels resulting from the use of components of different origin may vary significantly and, where relevant, guidance should be sought from the connector or cable assembly manufacturer.

B.9.1.2 *Insertion loss*

The principal measure of the optical peformance of an optical fibre connector is its insertion loss. Insertion loss is the loss of transmitted optical power expressed in dB, resulting from the insertion of a pair of mated connectors within a length of optical fibre cable. The lower the insertion loss value, the greater the optical coupling efficiency.

B.9.1.3 *Return loss*

When an optical signal passing through an optical fibre encounters a discontinuity in refractive index, Fresnel reflection occurs and a portion of the signal is reflected back towards the source. This back reflection or return loss can cause instability and noise problems in some laser based systems. Guidance should be sought from the transmission equipment manufacturer where relevant.

B.9.2 ***Plug construction***

B.9.2.1 *Ferrule*

To achieve stable optical performance, it is essential that the optical fibre should be secured in a ferrule. This is achieved by means of adhesive, crimps or collets which grip the optical fibre.

It is essential that the tip of the ferrule, called the mating surface, should be carefully prepared for optimum optical performance.

Processes adopted may create either non-contacting or contacting mating surfaces. The use of contacting mating services generally results in improved optical performance.

B.9.2.2 *Body*

The prime function of the body is to provide the means of coupling to mating components. The mechanisms used for the retention of plugs within sockets and adaptors include threaded coupling nuts, bayonet and snap-fit fittings.

The plug body may also provide the mechanical strain relief within the cable construction by means of a crimp sleeve, collet or adhesive (see **B.9.3** items d) and e)).

Connectors which incorporate a keying mechanism provide greater mating stability and repeatability. The key ensures the mating surface aligns in the same orientation each time a mating with another fibre plug or optical source is made.

Further improvements may be achieved with optimized keyed connectors, where the key locking position is chosen after rotating the ferrules relative to a master connector to give the optimum optical continuity.

Adequate bend limiting strain relief at the rear of the plug is generally provided by means of a cable boot or sleeve.

B.9.3 ***Choice of connector design***

The performance of fibre optic cabling plant is highly dependent on optical interfaces. The performance of these optical fibre to optical fibre interfaces and optical fibre to transmission equipment interfaces is dependent upon on the style of connector used.

The choice of connector design should take into account the following considerations.

a) *Insertion loss (dB)*:

The insertion loss that can be tolerated following an analysis of optical power and loss budgets (see **B.2**).

b) *Return loss (dB)*:

This is applicable only to high performance optical systems with laser based or wide dynamic range LED based transmission equipment or where cross-talk isolation in bi-directional transmission is required.

c) *Repeatability and durability*:

This is usually expressed as an incremental insertion loss or return loss change following a given number of matings. This is particularly relevant if the cabling is to endure frequent connections and disconnections.

d) *Ruggedness*:

A measure of the ability of the connector to withstand normal and abnormal handling.

e) *Pull-out and lateral pull strength*:

When connecting and disconnecting optical fibre cables tensile force may be applied. Excessive force may result in permanent loss of optical transmission.

f) *Environmental stability (climatic and mechanical)*:

Environmental conditions such as temperature, humidity and vibration may affect the performance of connectors.

g) *Field termination and repairability*:

Optical cables can be terminated at the site of installation. On-site termination conditions and facilities are generally inferior to purpose-designed factory conditions. When carrying out on-site termination work it is important to ensure that connectors can be fitted in a satisfactory manner.

B.9.4 ***Equipment and system connectors***

The transmission equipment chosen will determine the style of optical fibre connector required at the equipment (equipment connector). However, the choice of optical fibre connector for patch panels (system connector) is not so constrained and it is recommended that the choice made should reflect improvements in performance over the equipment connector and/or current standards.

B.10 Design summary

Subclauses **B.1** to **B.9** have provided basic guidance in relation to the criteria which may be addressed during the design of fibre optic cabling infrastructures. The principles are valid to all applications.

Following an analysis of the proposed design, and having selected an optical fibre and defined suitable optical cables and connectors (and any other passive components), each individual fibre optic span should be assessed.

It is essential that the optical loss budget for each fibre optic span should not exceed the optical power budget of the transmission equipment or communication standard utilizing that fibre optic span.

It is essential that the available bandwidth for each fibre optic span should be greater than the bandwidth requirement of the transmission equipment or communication standard utilizing that fibre optic span.

List of references (see clause 2)

Normative reference

BSI publication

BRITISH STANDARDS INSTITUTION, London

BS EN 60825 *Safety of laser products*
Part 1 : 1994 *Equipment classification, requirements and user's guide*
Part 2 : 1995 *Safety of optical fibre communication systems*

Informative references

BSI publications

BRITISH STANDARDS INSTITUTION, London

BS EN ISO 9000 *Quality management and quality assurance standards*

IEC publications

INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC), Geneva. (All publications are available from BSI Sales)

IEC 793 *Optical fibres*
IEC 794-1 *Optical fibre cables*
Part 1 : 1993 *Generic specification*
IEC 874-1 *Connectors for optical fibres and cables*
Part 1 : 1993 *Generic specification*

Other references

[1] GREAT BRITAIN. Control of Substances Hazardous to Health Regulations, 1988. London : HMSO
[2] GREAT BRITAIN. The Health and Safety at Work etc. Act 1974. London : HMSO

CCITT Standards

The following CCITT Standards and references have no related British Standards but have been considered by the Technical Committee and accepted for the purposes contained in this British Standard text.

[3] G652 : *Characteristics of a single mode optical fibre cable*
[4] G653 : *Characteristics of a dispersion shifted single mode optical fibre cable*
[5] G654 : *Characteristics of a 1550nm loss-minimised single mode optical fibre cable*
[6] G651 : *Characteristics of a 50/125μm multimode graded index optical fibre cable*

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ISBN 0 580 25785 1

EPL/86