TECHNICAL SUPPORT DOCUMENT

FIA-TSD-2000-1-1

OPTICAL FIBRE CABLING
-
LAN APPLICATION SUPPORT GUIDE

Price: £150 (free to FIA members)

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The Fibreoptic Industry Association
-
An introduction for the new millennium

The past decade has been a time in which there has been a vast increase in the use of optical fibre - primarily driven by the need to provide a quality, high-speed transmission media for digital trunk telephony services. The specifications for these systems have typically been produced by large national telecommunications service providers. This has resulted in clear standards and specifications exist to which all suppliers to the WAN telecommunications industry must adhere.

In parallel there has been a significant growth in optical fibre systems being installed in private data, entertainment and telecommunications networks which are separate from the national telephony and data carrier systems. This part of the industry is characterised by having a large number of relatively small company participants albeit supplying large corporate customers with products and services. The use of optical fibres in private, local area data and sensor networks has increased rapidly throughout the 1990's. In order to support this rate of growth, an organizational focus is required for both suppliers and users in the industry in order to ensure the quality and reliability of network design, installation practice and methods of training.

The **Fibreoptic Industry Association** provides such a focus as a Trade Association to which companies, organizations and individuals involved with, or planning an involvement with, fibre optics can subscribe. In addition, by means of seminars, publications, newsletters, press promotion and similar activities, the **Fibreoptic Industry Association** is dedicated to raising the profile of the industry and highlighting its many benefits in order to increase its growth and thus provide direct benefits for members.

Our overall aims can be summarised as follows:

- to promote an awareness of the benefits and applications of fibre optic technology as an adjunct to - or as a replacement for - conventional copper communications technology;
- to promote an awareness of the existence of a professional fibre optics industry fully capable of meeting the needs of users or, so benefiting both suppliers and their customers;
- to promote and adopt standards to which professional participants within the fibre optic industry should be expected to adhere;
- to provide a central source for information on wide ranging aspects of the fibre optic industry;
- to provide a single voice to promote and represent the interests of the industry obtained by consensus and debate amongst FIA members;
- to develop and promote codes of practice within the industry - both operational and ethical - to which members will be expected to adhere and thus offer an assurance that the highest quality of service will be provided.

FIA TECHNICAL SUPPORT DOCUMENTS

This document is one a series of FIA Technical Support Documents. During the year 2000 all the existing FIA documents will be re-written or re-published in the format used throughout this document.

More importantly, the way in which these Technical Support Documents is published has also changed.

These documents are now **free** to **FIA members** via downloads from the FIA web-site (www.fibreoptic.org.uk). Non-members are also able to purchase these documents either by contacting the Secretariat (address shown below) or by on-line purchase.

Members and non-members unable to benefit from this service may receive the documents in hard-copy or diskette/CD ROM by contacting the FIA Secretariat (contact details are shown at the bottom of each text page in this document). However, the rapidly changing nature of our technology means that web-based documents can be amended and revised easily and it is the responsibility of the reader to ensure that the latest issue of a document is used.

The FIA web-site will indicate the issue status of each document and will have links to previous issues in order that changes made will be clear to readers.

The complete list of FIA Technical Support Documents is shown in the Table below.

TOPIC	FIA-TSD-	TITLE
DESIGN	2000-1-1	OPTICAL FIBRE CABLING: LAN APPLICATION SUPPORT GUIDE
COMPONENT SELECTION	2000-2-1	OPTICAL FIBRE CABLING: CABLE SELECTION GUIDE
OPERATION	2000-3-3	OPTICAL FIBRE CABLING: POLARITY MAINTENANCE
INSTALLATION	2000-4-1-1	OPTICAL FIBRE CABLING: INSTALLATION PRACTICE: SPLICING
	2000-4-2-1	OPTICAL FIBRE CABLING: TESTING OF INSTALLED CABLING LSPM equipment
	2000-4-2-2	OPTICAL FIBRE CABLING: TESTING OF INSTALLED CABLING OTDR equipment
	2000-4-2-3	OPTICAL FIBRE CABLING: TESTING OF INSTALLED CABLING Specification, procurement and use of test cords
SAFETY	2000-5-1	OPTICAL POWER: SAFETY LEVELS
	2000-5-2	OPTICAL FIBRE: HANDLING OF PROCESSING CHEMICALS
	2000-5-3	OPTICAL FIBRE: DISPOSAL OF WASTE

FOREWORD

By Paul Bateson, Chairman of the FIA

There's never been a better time to be involved with fibre optics.

30 years ago, when the technology was radically new and had novelty, it was exciting for the few. Now, fibre optics is not only a mainstream technology that has been responsible for the creation of thousands of new jobs, it is once again going through a period of breathtaking change. New components are no sooner off the drawing board than they are being designed into new generations of system. Production capacity in start-up as well as established companies has had to be expanded at breakneck speed.

This situation is of course being driven by the insatiable demand for increased bandwidth in the Internet. While there may have been a slowdown recently in the rate of market growth, it still remains strong by any normal standards.

Recent large installations have been going into the long haul pan-European networks. The next phase, which has already started, is the installation of new systems and bandwidth into Metropolitan Area Networks.

What is the relevance of all this to the LAN Support Guide?

Bandwidth in the Wide Area Network is rapidly becoming a commodity, and will increasingly be sold as such. I believe we can look forward to a continuation and perhaps acceleration of the reduction in the cost of bandwidth we have been seeing. This commodity is one which will be very attractive to the large multi-site corporations, since will offer the prospect of services that require high bandwidth becoming progressively more cost-effective. These will include all kinds of video-based applications.

However, the LAN will also have to acquire the capacity to benefit from the cheap bandwidth in the WAN. The use of multi-gigabit technology in the LAN is the inescapable conclusion. This LAN Application Support Guide is the document that shows how this may be achieved.

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The Fibreoptic Industry Association www.fia-online.co.uk

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INTRODUCTION

The conventional way of designing optical fibre cabling has been to ensure that the optical loss budget of the cabling is conformant with the optical power budget of the equipment to be connected to it. The actual loss of the cabling, verified during post-installation testing, is required to be conformant with its optical loss budget. This approach to the design and implementation of optical fibre cabling was described in BS 7718 (1996), withdrawn from publication as a British Standard in September 2003 but available for download, for information only, from the FIA web-site.

Since that time the ways in which the capacity of optical fibres, both single mode and multimode, is used have changed radically.

For long-haul telecommunications the design of singlemode systems now has to consider new types of transmission using wavelength division multiplexing techniques together with optical input powers many thousands of times higher than those in the early 1990's. These changes have, in turn, required the development of a series of singlemode optical fibres with subtly different performance parameters that if intermixed can have dramatic affects on overall system performance. These issues are described in FIA-TSD-2000-4-1-1.

For local area network (LAN) telecommunications the data rates have increased dramatically and are still doing so. As part of that process we have moved from loss-limited, or attenuation-limited, applications such as Token Ring and FDDI to bandwidth-limited applications such as 1, 10, 40 and 100 Gigabit Ethernet. This evolution has brought with it new design rules and enhanced performance options for multimode optical fibre cabling together with an increased emphasis on singlemode technology.

The object of this LAN Application Support Guide is to provide the reader with an understanding of both the "old" and "new" design issues.

For new installations, the key issues addressed are:

- the specification of optical fibre performance;
- the selection of optical fibre type;
- the design of optical fibre cabling channels.

In support of this Technical Support Document the Fibreoptic Industry Association has produced a spreadsheet that allows calculation of application support in accordance with the overall design rules. This can be downloaded from the FIA web-site (www.fia-online co.uk).

1 SCOPE

This Technical Support Document covers the use of optical fibre cabling within premises that are intended to support local area network telecommunications.

It is intended to be used in association with the following standards:

- LAN application standards produced by IEEE and other organizations;
- generic cabling standards including the BS EN 50173 series, the range of premises-specific standards produced by ISO/IEC JTC1 SC25 WG3 including ISO/IEC 11801 Ed.2.2 and the ANSI/TIA-568-C series.

This Technical Support Document refers to FIA-CCP-1/91 (Code of Practice for the Installation of Fibre Optic Cabling) and its subsequent publication as BS 7718. However, the publication of the BS EN 50174 series of standards has resulted in the withdrawal of BS 7718 (1996). For this reason the relevant design guidance elements of BS 7718 (1996) have been incorporated in this Technical Support Document.

2 REFERENCES

ANSI/TIA/EIA-568-C (series)	Commercial building telecommunications cabling standard
ANSI/TIA-568-C.3	Optical Fiber Cabling Components Standard
BS EN 50173 (1995)	Information technology - Generic cabling systems
BS EN 50173-1 (2002)	Information technology - Generic cabling systems - Part 1: General requirements and office areas
BS EN 50173-1 (2007)	Information technology - Generic cabling systems - Part 1: General requirements
BS EN 50173-2 (2007)	Information technology - Generic cabling systems - Part 2: Office premises
BS EN 50173-3 (2007)	Information technology - Generic cabling systems - Part 3: Industrial premises
BS EN 50173-5 (2007)	Information technology - Generic cabling systems - Part 5: Data centres
BS EN 50174-1:2009	Information technology - Cabling installation - Part 1: Installation specification and Quality Assurance
BS EN 50174-2:2009	Information technology - Cabling installation - Part 2: Installation planning and practices inside buildings
BS EN 50174-3:2003	Information technology - Cabling installation - Part 2: Installation planning and practices outside buildings
IEC 60793-2-10	Optical fibres: Part 2-10: Product specifications - Sectional specification for category A1 multimode fibres
IEC 60793-2-50	Optical fibres: Part 2-50: Product specifications - Sectional specification for class B single-mode fibres
IEC 61280-1-1	Fibre optic communication subsystem basic test procedures - Part 1-1: Test procedures for general communication subsystems - Transmitter output optical power measurement for single-mode optical fibre cable.
IEC 61280-1-2	Fibre optic communication subsystem basic test procedures - Part 1-2: Test procedures for general communication subsystems - Transmitter output optical power measurement for multimode optical fibre cable.
IEC 61280-4-2	Fibre optic communication subsystem basic test procedures - Part 4-2: Fibre optic cable plant - Single-mode fibre optic cable plant attenuation.
ISO/IEC 11801	Information technology - Generic cabling for customer premises
FIA-CCP-1/91 (withdrawn)	Code of Practice for the installation of fibre optic cabling
BS 7718 (withdrawn)	Code of Practice for the installation of fibre optic cabling

3 DEFINITIONS AND ABBREVIATIONS

3.1 Definitions

For the purpose of this Technical Support Document the following definitions apply:
None

3.2 Abbreviations

For the purpose of this Technical Support Document the following definitions apply:

CD	Compact Disc
CWDM	Coarse Wavelength Division Multiplexing
FP (LASER)	Fabry-Perot
LASER	Light Amplification by the Stimulated Emission of Radiation (a device)
LED	Light Emitting Diode
VCSEL	Vertical Cavity Surface Emitting Laser

4 CONFORMANCE

This document provides guidance and does not seek to modify or replace the requirements of any of standards referred to in clause 2 above. There are no specific conformance requirements.

5 CONVENTIONS

5.1 Optical fibre

Optical fibre for use within telecommunications is manufactured to international standards for both physical and optical performance.

Within this Technical Support Document the terms optical fibre geometry, optical fibre construction and optical fibre performance are used. These are defined in the following sub-clauses.

5.1.1 Physical performance

At the physical level, optical fibres are clearly differentiated by the diameter or their core/cladding elements. Throughout this Technical Support Document the term "**optical fibre geometry**" refers only to this aspect of a optical fibre specification. For multimode optical fibres (or **MMF**) the terms "50/125" and "62.5/125" are different geometries referred to in IEC 60793-2-10 as category A1a and A1b optical fibres respectively. Within IEC 60793-2-10 these geometries are also associated with specified dimensional tolerances and numerical apertures (N.A) values as shown in Table 1.

	50/125 (category A1a)	**62.5/125 (category A1b)**
Core diameter	50 +/- 3 microns (μm)	62.5 +/- 3 microns (μm)
Cladding diameter	125 +/- 2 microns (μm)	125 +/- 2 microns (μm)
Numerical aperture (N.A.)	0.200 +/- 0.015	0.275 +/- 0.015

Table 1: Optical fibre geometries

NOTE: There are other MMF geometries that have been used in the past (such as 85/125 and 100/140) and there are larger core diameter products in use in specialist application such as avionics. However, their use for local area networks is not widespread and their performance tends to fall below the currently accepted minimum for high bit rate systems. As a result they are not considered in this Technical Support Document.

For single mode optical fibres (or **SMF**) there are many variants specified in IEC 60793-2-50, and which are described in FIA White Papers and other Technical Support Documents. To simplify discussion within this Technical Support Document, it will only use the terms "singlemode optical fibre" or "SMF".

It is important to realize that **geometry alone does not define optical performance - it is more akin to the impedance of balanced pair copper cable technology.**

There are different methods of manufacturing optical fibre that lead to differences such as refractive index profile and other basic elements of specification. Two optical fibres with the same geometry but from different manufacturers will be termed throughout this Technical Support Document as having different "**detailed construction**".

5.1.2 Optical performance

The optical performance of MMF is defined in terms of attenuation coefficient (optical power loss, expressed in $dBkm^{-1}$) and modal bandwidth (the ability to support high frequencies signals, expressed in MHz.km).

These parameters are specified in one or both of the operational transmission windows as follows:

- **First (1st) Window**: central wavelength **850 nm**;
- **Second (2nd) Window**: central wavelength **1300 nm**.

By reference to IEC 60793-2-10 it is seen that:

- a **wide variety** of performance options are available for both 50/125 μm and 62.5/125 μm MMF;
- in general, 50/125 μm MMF offers lower attenuation coefficients and higher modal bandwidths than 62.5/125 μm MMF although higher coupling losses into 50/125 μm MMF obviates this apparent benefit for many low data rate applications (see clause 12).

Geometry does not dictate the length over which applications can be supported, only the correct specification of the optical performance for a particular geometry allows the level of application support to be determined. **It should be noted that many of the MMF performance options listed in IEC 60793-2-10, and available for purchase by installers and users, fail to meet the requirements of application standards.**

The optical performance of SMF is also defined in terms of attenuation coefficient (optical power loss, expressed in $dBkm^{-1}$) but bandwidth capability is specified in more complex parameters. These parameters are specified in one or both of the operational transmission windows as follows:

- Second (2nd) Window: central wavelength 1300 nm;
- Third (3rd) Window: central wavelength 1550 nm.

5.2 Connecting hardware

There are three basic design concepts that are applied to optical fibre connecting hardware:

- three component;
- two component;
- hermaphroditic.

The “three component” concept is generally recognized as the “conventional” approach: each optical fibre is terminated with a connector comprising a body and ferrule. The two ferrules are aligned using the third component, the adaptor housing (sometimes called a bulkhead adaptor or coupling).

The "two component" concept makes use of physically different male and female connectors (often referred to as plug and jack, respectively). This approach has recently become more widespread since it is used for some "small form factor" (SFF) connectors.

The “hermaphroditic” concept uses two components but they are physically identical.

To simplify the presentation of information throughout this Technical Support Document the diagrammatic conventions shown in Figure 1 are used where a mated connection is shown by a black and white combo-box.

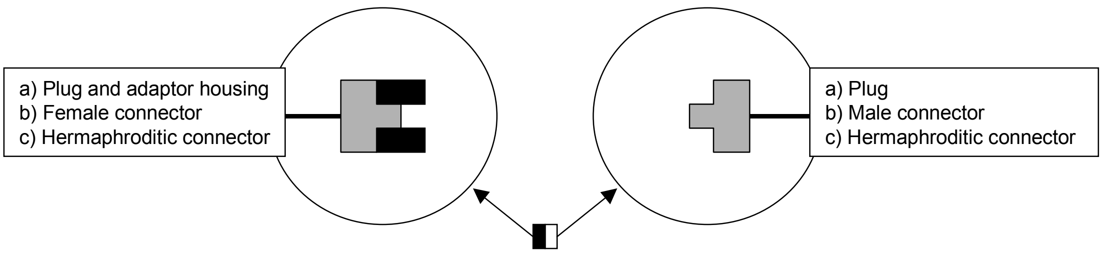


Figure 1: Connecting hardware convention

The black element of the combo-box represents one of the following:

- a plug with an adaptor housing;
- a female connector;
- a hermaphroditic connector.

The white element of the combo-box represents one of the following:

- a plug;
- a male connector;
- a hermaphroditic connector.

5.3 Transmission equipment

The interface to optical transmitter/receiver equipment is generally a chassis mounted device housing taking the form of an adaptor housing, female or hermaphroditic connector.

Within this Technical Support Document the transmitters (Tx) and receivers (Rx) are shown as in Figure 2.

Figure 2: Transmission equipment convention

In the majority of systems used for local area networks the transmitter and receiver equipment is housed on the same sub-assembly or equipment card and is presented as two separate chassis mounted ports. The introduction of duplex connectors has allowed the use of a single chassis mounted female connection containing both a source and detector. However, this Technical Support Document seeks to be generic and consideration is given to all options.

5.4 Applications

An application is the specific network protocol or telecommunications service being transmitted over the cabling.

Some applications are standardized at national or international level. This standardization is intended to allow interoperability between transceiver equipment from different suppliers. Examples of these are 10BASE-FL, 16Mb/s Token Ring, FDDI and 1000BASE-SX.

There are, in some cases, a number of physical layer applications to support a given network. For example, the term “Gigabit Ethernet” does not adequately specify an application since 1000BASE-SX, 1000BASE-LX (multimode) and 1000BASE-LX (singlemode) are all Gigabit Ethernet as far as the overall network is concerned but the requirements for cabling performance are dramatically different.

Application standards define the minimum requirements for the transceivers that all vendors shall meet. Individual manufacturers may exceed the minimum requirements as a means of product differentiation. Throughout this Technical Support Document the requirements of the application standards are used without modification.

The delivery of certain applications such as RS-232, RGB video, and others over optical fibre does is not currently standardized. The requirements of such applications are often manufacturer specific and interoperability between different manufacturers’ equipment should not be assumed.

6 CHANNELS AND LINKS

6.1 General

In all editions of the FIA-CCP-1/91 (Code of Practice for the Installation of Fibre Optic Cabling) and its subsequent publication as BS 7718 the term “**span**” was defined as “a series of one or more terminated optical fibre elements which may contain complex passive components”. In the generic cabling standards, including the BS EN 50173 series, ISO/IEC 11801 (and associated standards) and the ANSI/TIA-568-C series, the term “span” has been replaced by the two highly specific terms “**channel**” and “**link**”. This change not only unifies the treatment of balanced pair copper and optical fibre but also amends the way in which FIA-CCP-1/91 and BS 7718 should be interpreted.

6.2 Cabling channels

The channel is the complete transmission path between the transmitting and receiving equipment.

The simplest channel configuration contains a single length of optical fibre terminated at each end with the appropriate connection. However, in the most general sense, a channel can contain a number of individual links (see 6.3) together with other passive components such as splices, couplers/splitter and wavelength selective components.

The terminating connection at each end of the channel depends upon the design of the connections at the transmission equipment and may not be the same at both ends of the channel.

The application requirement defines the allowable performance boundaries of the channels (see clause 7). The performance of the channel is defined by its contents in terms of the length and specification of the optical fibre elements, the quantity and specification of the connections and the other passive components (see 7.3).

It is important to recognize the difference between:

- the physical nature of the channel;
- the reference points between which the channel performance are measured;
- the reference points at which application requirements are defined.

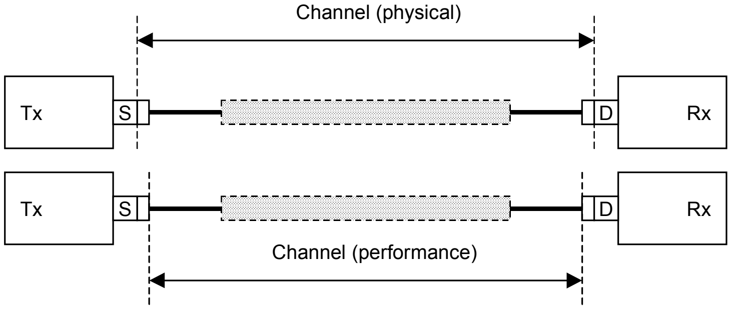


Figure 3: Optical fibre channel - physical and performance

Figure 3 shows the channel configuration for equipment with chassis mounted sources and detectors. In this example, the channel has to be terminated with a plug or a male or hermaphroditic connector as appropriate. These termination components are clearly part of the physical channel as they are attached to the interconnecting cable. **However, when referring to the requirements of the application or defining and measuring the performance of the channel the mated connection at either end of the channel is excluded.**

The definition of the equipment interface is the responsibility of the equipment manufacturer. While recognizing that the level of **intermateability** (i.e. mechanical compatibility) of optical fibre connecting hardware from different suppliers is high, it should also be realised that the **interoperability** (i.e. achievement of a given minimum performance) is not guaranteed for most types of connector.

This means that the application requirement for a channel may be based upon a specific manufacturer's product being used as the terminating connector of the channel. The use of a different supplier's product, albeit having the same overall design, may invalidate the basis of the application support from the equipment supplier.

6.3 Cabling links

In the generic cabling standards a link is defined as a transmission path between two interfaces but which excludes equipment cords. This definition suggests that a link may be fixed (i.e. installed) or temporary (i.e. patch cords). A link can contain a number of individual fixed and temporary links together with other passive components such as splices, couplers/splitters, attenuators, switches and other wavelength selective components.

As shown in Figure 4 links may be terminated in:

- a plug or male connector;
- a plug and an adaptor housing
- a female connector;
- a hermaphroditic connector.

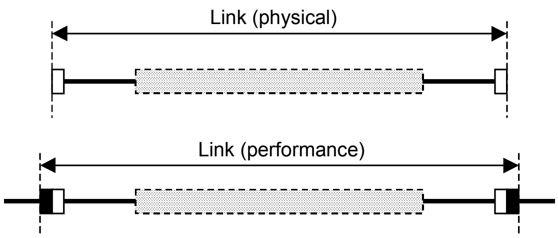


Figure 4: Optical fibre links - physical and performance

The performance of a link is defined by its contents in terms of the length, quantity and optical performance specifications of the components within the link (see 7.3).

It is important to recognize the difference between the physical nature of the link and the reference points between which the link performance are measured. **For the purposes of defining and measuring the performance of a link, the link includes the mated connectors at the ends of the cabling link under test**.

NOTE: This means that a logical discrepancy exists when the link under test is also a channel since the channel excludes the mated connections at each end whereas the link includes them. For this reason **channel tests should only be applied to channels** and **link tests should be applied to links which are sub-sections of channels only**.

7 OPTICAL POWER AND LOSS BUDGET

7.1 Optical power

7.1.1 Measurement and specification

The power launched into and received from a channel is measured in Watts (or fractions of Watts). For ease of further calculation, the power level in milliWatts (mW) is generally expressed in dBm where:

$$\textbf{Launched power (dBm)} = \textbf{10}\,\log_{10}\textbf{(Launched power (mW))}$$

Table 2 shows typical values converted from milliWatts to dBm.

Power (mW)	Power (dBm)
10	+10
1	0
0.5 (= 500 μW)	-3
0.1 (= 100 μW)	-10
0.05 (= 50 μW)	-13
0.01 (= 10 μW)	-20
0.005 (= 5 μW)	-23
0.001 (= 1 μW)	-30

Table 2: Conversions from mW to dBm

For the purposes of system design it is essential to be unambiguous regarding the reference points for both the transmission equipment and the cabling.

7.1.2 Launched power

7.1.2.1 General

The LAN application standards discussed in this Technical Support Document contain limits for launched power into specified optical fibre geometries. In all cases a minimum value $\mathbf{L}_{\mathbf{min}}$(dBm) is specified and in most cases a maximum value $\mathbf{L}_{\mathbf{max}}$(dBm) is also included. When taken in conjunction with specified values for received power this allows transceiver equipment to be interoperable.

7.1.2.2 MMF

Launched power is defined at the point shown in Figure 5 within a specified wavelength range.

The value specified shall define the design of optical fibre within the test system and the test lead shall meet specified requirements in IEC 61280-1-2.

Older MMF LAN application standards were based upon the use of light emitting diodes (LED) as the source of optical power. These devices had active surface areas and numerical apertures larger than the 62.5/125 μm (0.275 N.A.) optical fibre that was specified as the primary recommended optical fibre medium. As a result the launched power into smaller diameter optical fibres (such as 50/125 μm) was reduced.

The calculated reduction in launched power (termed coupling loss, see Table 4) into 50/125 μm (0.20 N.A.) compared with 62.5/125 μm (0.275 N.A.) is 4.7 dB (nominal). However, the actual difference depends upon the active surface area and numerical aperture of the LED used.

More recent MMF LAN application standards are based upon the use of CD LASER, VCSEL or conventional FP LASER technology. Such devices have active surface areas and numerical apertures smaller than either 50/125 μm (0.20 N.A.) or 62.5/125 μm (0.275 N.A.) optical fibres and there is little or no differential launch power between the two type of optical fibre.

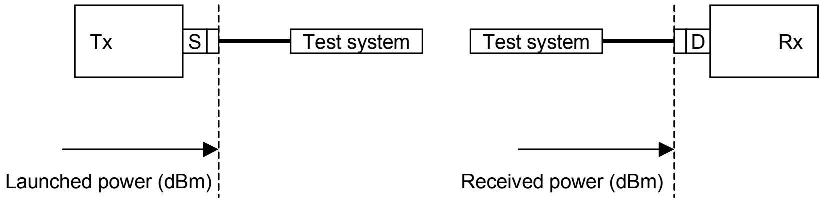


Figure 5: Launched and received power reference points

7.1.2.3 SMF

Launched power is defined at the point shown in Figure 5 within a specified wavelength range.

The value specified shall define the design of optical fibre within the test system and the test lead shall meet specified requirements in IEC 61280-1-1.

7.1.3 Received power

7.1.3.1 General

Received power is defined at the point shown in Figure 5 within a specified wavelength range.

The LAN application standards discussed in this Technical Support Document contain limits for received power from specified designs of optical fibre. In all cases a minimum value $\mathbf{R_{min}}$ (dBm) is specified and in most cases a maximum value $\mathbf{R_{max}}$ (dBm) is also included. When taken in conjunction with specified values for launched power this allows transceiver equipment to be interoperable.

7.1.3.2 MMF

Received power is defined at the point shown in Figure 5 within a specified wavelength range.

In general, for MMF LAN application standards the optical detector has an active surface area larger than that of 62.5/125 μm (0.275 N.A.) optical fibre that was specified as the primary recommended optical fibre medium. If this is not the case then the received power specified shall be defined for the design of optical fibre within the test system.

7.1.3.3 SMF

Received power is defined at the point shown in Figure 5 within a specified wavelength range.

7.2 Optical power budget

The optical power budget is a measure of the performance of the transmission equipment. It 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 maintaining a specified level of signal integrity.

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

The maximum value (**OPB$_{max}$**) is defined as the ratio of the minimum optical power launched into a channel **L$_{min}$** to the minimum which may be received from that channel **R$_{min}$** whilst maintaining a specified level of signal integrity (see Figure 6).

$$\mathbf{OPB_{max}}\ (\text{dB}) = \mathbf{L_{min}}\ (\text{dBm}) - \mathbf{R_{min}}\ (\text{dBm})$$

The minimum value (**OPB$_{min}$**) is defined as the ratio of the maximum optical power launched into a channel **L$_{max}$** to the maximum which may be received from that channel **R$_{max}$** whilst maintaining a specified level of signal integrity (see Figure 6).

$$\mathbf{OPB_{min}}\ (\text{dB}) = \mathbf{L_{max}}\ (\text{dBm}) - \mathbf{R_{max}}\ (\text{dBm})$$

An example of this process in operation for 10BASE-FL/FB is shown in Table 3.

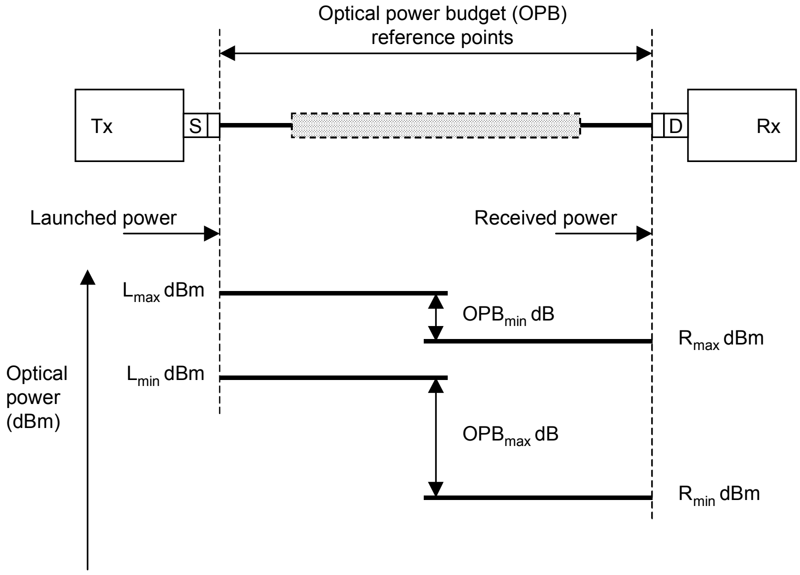


Figure 6: Optical power budget

		10BASE-FL/FB 850 nm
A	Optical Tx power **L$_{max}$** (dBm)	-12
B	Optical Tx power **L$_{min}$** (dBm)	-20
C	Optical Rx power **R$_{max}$** (dBm)	-12
D	Optical Rx power **R$_{min}$** (dBm)	-32.5
B-D	**OPB$_{max}$** (dB)	12.5
A-C	**OPB$_{min}$** (dB)	0

Table 3 Optical loss budget values for 10BASE-FL/FB

7.3 Optical power loss

7.3.1 Insertion loss and attenuation

The terms **insertion loss** and **attenuation** are both used to describe the optical power loss (expressed in dB's) through a component, link or channel.

However, the two terms are not quite the same (although to many the difference is irrelevant). The difference is that attenuation assumes that the refractive index values of all the components in the system are the same.

$$\textbf{Attenuation (dB)} = 10 \log_{10} (P_{out}\ (mW)/P_{in}\ (mW))$$

This is appropriate for data sheets and paper-based calculations. However, in reality, during a practical measurement of power loss through a component, link or channel, the refractive index of the test leads is unlikely to be exactly the same as that of the component under test. The result obtained is correctly termed “insertion loss”.

$$\textbf{Insertion loss (dB)} = 10 \log_{10} (P_{out}\ (mW)/P_{in}\ (mW)) + \text{refractive index mismatch in test system}$$

The difference is so small as to be insignificant and throughout this Technical Support Document the term attenuation is used.

7.4 Optical loss budget

7.4.1 Definition

An optical loss budget is a measure of the performance of a link or a channel. It is defined as the range of attenuation values that can be presented by the link or channel at a specified wavelength. The specified wavelengths are generally the central wavelength for each transmission window.

An optical power budget is bounded by a maximum and minimum value within a specified wavelength range.

The maximum value (**OLB_{max}**) is defined as the sum of all the maximum specified attenuation values for the individual components in the link or channel at the wavelength in question.

The minimum value (**OLB_{min}**) is defined as the sum of all the minimum specified attenuation values for the individual components in the link or channel at the wavelength in question.

7.4.2 Optical fibre cable attenuation

A link or channel may comprise a number of lengths of optical fibre within a variety of cable constructions. The calculated attenuation of each length of optical fibre is obtained by multiplying the length (in kilometres) by the attenuation coefficient of the optical fibre **cable** (the attenuation coefficient of the optical fibre may be modified during the cabling process).

The attenuation coefficient is that quoted by the manufacturer of the optical fibre cable or specified by the relevant cabling standards. It is not usual for either a cable manufacturer or cabling standard to provide minimum values for an attenuation coefficient. As a result it is normal to use the same value in the calculation of both **OLB_{max}** and **OLB_{min}**.

Although not recommended, links and channels may include optical fibres with different geometries. Attenuation will occur at interfaces between different optical fibre geometries. The nominal values of the losses are shown in Table 4 and are in addition to those caused by the connecting hardware or joints at the interfaces.

Coupling losses			
FROM			
62.5/125	**50/125**	**SMF**	**TO**
0.0 dB	-	-	62.5/125
4.7 dB	0.0 dB	-	50/125
26.6 dB	21.9 dB	0.0 dB	SMF

Table 4: Attenuation at interfaces between optical fibres with different geometries

7.4.3 Connecting hardware attenuation

The attenuation (insertion loss) of a mated connection is dependent upon the type of connecting hardware and the termination technique applied.

For the calculation of $\mathbf{OLB_{max}}$, the maximum specified attenuation, expressed in dB, for each mated connection in the link or channel shall used.

For the calculation of $\mathbf{OLB_{min}}$, it is recommended that a value of 0 dB should be used for each mated connection in the link or channel.

It is unusual for the attenuation specification of connecting hardware to vary with wavelength.

7.4.4 Splice attenuation

The attenuation of a splice is dependent upon the type of splice used.

The maximum specified attenuation, expressed in dB, for each splice in the link or channel shall be included in the calculation of $\mathbf{OLB_{max}}$. It is recommended that a value of 0 dB should be used for each splice in the link or channel during the calculation of $\mathbf{OLB_{min}}$.

It is unusual for the attenuation specification of splices to vary with wavelength.

7.4.5 Passive Components

Optical fibre couplers/splitters, attenuators, switches and other wavelength selective components may have complex attenuation characteristics. It is vital to determine an attenuation specification at the earliest stage of the design and the values obtained shall be included in the optical loss budget for the link or channel.

8 RETURN LOSS

All components reflect optical power back towards the transmitting source. Such reflections can be beneficial e.g. optical time domain reflectometry. However, reflections can, under certain circumstances, cause problems for transmission systems.

$$\textbf{Return loss (dB)} = 10 \log_{10} (P_{reflected}\ (mW)/P_{in}\ (mW))$$

Coherent and synchronous reflections into LASER devices can cause malfunction. For this reason strict return loss requirements may be applied to the connecting hardware into the channel (next to the optical source) rather to the entire channel. This is common in long-haul telecommunications and CaTV applications using SMF. In this technology area escalating return loss requirements have led to the development of physical contact (PC) terminations, super-PC, ultra-PC and angle-polish connecting hardware specifications.

Some LAN applications using SMF do include return loss requirements but have not yet demanded the same performance as adopted within the established technologies indicated above.
Some LAN applications using MMF do include return loss requirements but these are easily achieved and are rarely tested in installed conditions.

Duplex systems, where a single optical fibre carries both the transmit and receive signals and where either:
- optical splitters/couplers direct the two signals into a source and detector within the transmission equipment or
- integrated sources and detectors are used
- are not currently included in standardized LAN applications. In such systems the overall return loss of the channel, rather than the coherent and synchronous reflections from close to the transmission equipment described above, may be an issue.

9 PROPAGATION DELAY

The velocity of data transmission along an optical fibre core is defined by a parameter called group refractive index. It is closely related to the basic refractive index of the core material which, for most optical fibres, is within a few percentage points of 1.5. As an acceptable approximation the speed of light along a fibre is 2×10^8 ms^{-1} (equivalent to a propagation delay of 5 µs per 1000 metres of channel length).

10 MMF MODAL BANDWIDTH

10.1 General

Signals transmitted along multimode optical fibre suffer modal dispersion that ultimately limits the frequency of transmission and, therefore, the data rate that the optical fibre can support. The modal bandwidth (B) of the optical fibre at a given wavelength, expressed in MHz.km, is a measure of this aspect of optical performance. However, the actual bandwidth is also affected by the launch conditions introduced by the transmission equipment.

10.2 Over-filled launch (OFL) modal bandwidth

At present the international standards for optical fibre testing use a over-filled launch condition, similar to that produced by a LED, to measure modal bandwidth.

10.3 Restricted launch (LASER) modal bandwidth

It has been found that the launch conditions presented by LASER devices create anomalous bandwidth behaviour within certain constructions of optical fibre. To rectify this situation proposals have been made for the international standards for optical fibre testing to use a restricted launch condition (similar to that of a LASER launch) in addition to the original over-filled launch condition.

Cabled optical fibre Category	Optical fibre of BS EN/IEC 60793-2-10	Maximum attenuation (dB/km)		Minimum modal bandwidth MHz.km		
				Overfilled launch		"Laser" launch
	A1a or A1b	850 nm	1 300 nm	850 nm	1 300 nm	850 nm
OM1	A1a or A1b	3,5	1,5	200	500	not specified
OM2	A1a or A1b	3,5	1,5	500	500	not specified
OM3	A1a.2	3,5	1,5	1 500	500	2 000
OM4	A1a.3	3,5	1,5	3 500	500	4 700

Table 5: Cabled multimode optical fibre Category specifications from cabling design standards

Table 5 shows the specifications that result and which are now recognised in all the generic cabling standards.

10.4 Channel lengths and bandwidth

The actual bandwidth of a channel depends upon the modal bandwidth and length of the optical fibre(s) in the channel.

For ease of calculation the effective modal bandwidth B_L, expressed in MHz, of a length L km, should be treated as linear with reference to the base modal bandwidth of the optical fibre:

i.e. $B_L = B/L$ MHz

where B = modal bandwidth (MHz.km)

11 SMF BANDWIDTH

Bandwidth "per-se" is not specified for singlemode optical fibre. Clearly, in the absence of multiple transmission modes the term modal bandwidth (caused by differential dispersion between modes) has no meaning. However, there are other effects that limit the available bandwidth of singlemode transmission systems.

Two of the most important factors are chromatic dispersion (dispersion of between wavelengths from a given optical source) and polarization mode dispersion or PMD (dispersion between the x-axis and y-axis polarized modes within SMF). The first has been a recognized parameter for many years and the development of LASER devices with decreasing spectral widths has ensured that a given SMF is able to support higher data rates over greater distances. The second parameter, PMD, has not been an issue within LAN implementations of SMF. However, the 3rd window version of applications for 10 Gb/s and above tend to define limits for this parameter.

12 LAN APPLICATION STANDARDS

12.1 MMF LAN applications

MMF LAN applications can be divided into two groups: attenuation-limited and bandwidth-limited. The definitions of these terms, as used throughout this Technical Support Document are as follows:

- an **attenuation-limited application** is an application that is not restricted by the modal bandwidth of the specified optical fibre at the maximum channel lengths specified;
- a **bandwidth-limited application** is an application for which the maximum channel length is defined by the modal bandwidth of the optical fibre specified.

Some LAN application standards contain requirements for propagation delay which define the maximum channel length independent of optical fibre geometry or other channel performance parameters. For convenience these are included within the "attenuation-limited" group.

12.2 Attenuation-limited MMF LAN applications

To fully understand the definition of 12.1 it is helpful to consider the development of LAN applications over optical fibre. The following series of bullet points are taken from the Annex B of FIA-CCP-1/91 and BS 7718.
The bullet points introduce the benefits of optical fibre transmission as compared with its copper counterparts.

- *bandwidth*: optical fibre enables the transmission of high speed signals over extended distances with minimal distortion;
- *attenuation*: optical fibres can exhibit extremely low levels of optical signal loss over extended distances;
- *dielectric*: 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*;
- *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*.

For the early optical fibre LANs the principal aim was to provide an optical equivalent to an existing copper cabling LAN standard. The main objectives were to provide:

- longer channel lengths (*attenuation*);
- cabling between buildings (*dielectric, isolation, open circuit failure*);
- improved signal quality (*non-radiating transmission medium, freedom from electromagnetic interference, freedom from inter-element crosstalk, signal security*).

The use of optical fibre as a high bandwidth medium was not a significant consideration in the earliest LAN application standards as the data rates were low compared to those used by the long-haul telecommunications industry. It is entirely reasonable therefore to expect these MMF LAN applications to be designed on the basis of channel attenuation rather than bandwidth criteria.

The attenuation-limited LAN application standards are shown in Table 6 which includes important physical layer detail taken from the application standards and demonstrates a number of key features:

- lowest data rates tend to be supported in the 1st window, higher data rates being supported in the 2nd window;
- the data rates supported are low/medium when compared with those considered in balanced pair copper cabling applications
  - the maximum data rate in the 1st window (~850 nm) is 100 Mb/s with an intended channel length of 500 m;
  - the maximum data rate in the 2nd window (~1300 nm) is 155 Mb/s with an intended channel length of 2000 m;
- most of the maximum channel lengths are 2000 m;
- the difference in OPB_{max} between 62.5/125 and 50/125 is a minimum of 4.7dB.

λ (nm)	Mb/s	Application	Maximum channel length (m)	Optical power budget OPB_{max}(dB)		Difference in OPB (dB)
				62.5/125 μm	50/125 μm	
850	10	ISO/IEC 8802-3: FOIRL	1000	9.0	3.3	5.7
	10	ISO/IEC 8802-3:10BASE-FL & FB	2000	12.5	6.8	4.7
	4/16	ISO/IEC TR 11802-5 Token Ring	2000	13.0	8.0	5.0
	100	IEEE 802.12: Demand Priority	500	7.5	2.8	4.7
1300	52	ATM-52	2000	10.0	5.3	4.7
	100	CD 9314-9: FDDI LCF-PMD	2000	7.0	2.0	5.0
	100	ISO/IEC 9314-3: FDDI PMD	2000	11.0	6.0	5.0
	100	ISO/IEC 8802-3: 100BASE-FX	2000	11.0	6.0	5.0
	100	IEEE 802.12: Demand Priority	2000	7.0	2.3	4.7
	133	CD 14165-1: Fibre Channel (FC-PH)	1500	6.0	1.3	4.7
	155	ATM-155	2000	10.0	5.3	4.7

Table 6: Attenuation-limited MMF LAN applications standards

A number of conclusions can be drawn from the Table:

- optical power budget of the applications defines the length and quantity of channel components;
- there is no need to specify the bandwidth performance of the optical fibre used since virtually all of the modal bandwidth performance options for 62.5/125 and 50/125 MMF would support the desired channel lengths;
- the differential in launched power into the two optical fibre geometries and the low data rates indicate that LED sources are used;
- the additional optical power budget for 62.5/125 MMF supports longer channels or channels containing more connecting hardware or splices.

The MMF LAN application standards shown in Table 6 tend to justify the use of 62.5/125 MMF as the medium of first choice for the LAN applications listed. The "base" specification for this MMF became that shown in Table 7 and became known as "**FDDI fibre**".

	Wavelength (nm)	
	850	**1310**
Attenuation coefficient (dBkm-1 max.)	3.75	1.75
OFL modal bandwidth (MHz.km min.)	160	500

Table 7: Base specification 62.5/125 MMF cable

12.3 Attenuation-limited LAN cabling design rules

The design rules for attenuation-limited LAN cabling are as follows:

- the optical loss budget (maximum) of the channel shall not be greater than the optical power budget (maximum) of the LAN application standard;
- the optical loss budget (minimum) of the channel shall not be lower than the optical power budget (minimum) of the LAN application standard;
- the propagation delay of the channel shall not be greater than the value specified in the LAN application standard;
- the channel length shall not be greater than the maximum specified channel length of the LAN application standard.

These requirements are summarised in Table 8.

Channel	Requirement	LAN application standard
OLB_{max}	< or =	OPB_{max}
OLB_{min}	> or =	OPB_{min}
Return loss (near-end connecting hardware)	> or =	Return loss
Delay	< or =	Delay
Length	< or =	Length

Table 8: Attenuation-limited application design rules

NOTE: Individual manufacturers may exceed the minimum requirements of the application standard as a means of product differentiation. If it is known that only a specific type of equipment is to be used then the data sheets of the supplier may be used to define the application requirements.

12.4 Bandwidth-limited MMF LAN applications

12.4.1 Introduction to applications up to 1000 Mb/s

The development of LAN application standards that are bandwidth-limited was an inevitable consequence of rising demands for data throughput. The principal impact of this is that the maximum channel length supported by the LAN application standards becomes dependent upon the modal bandwidth of the optical fibre; with greater channel lengths being offered by optical fibres with higher modal bandwidths.

This was an entirely predictable outcome. As long ago as 1991, well in advance of the migration to higher data rates, FIA-CCP-1/91 and BS 7718 stated in their design guides that:

> "*It is recommended that optical fibre designs are installed which offer the maximum bandwidth consistent with satisfactory operation of current transmission equipment.*"

FDDI (Fibre Distributed Data Interface) and ATM-155, with aims of delivering a 2000 metre channel at 100 Mb/s (with a signalling rate of 125 Mb/s) and 155 Mb/s respectively, represented a "break-point" within the group of attenuation-limited MMF LAN application standards. "FDDI fibre" had not only a specified maximum attenuation coefficient but also a specified minimum OFL modal bandwidth as shown in Table 7.

As the LAN application standards data rates have risen up to, and beyond, 1000 Mb/s the supported channel lengths for MMF applications have entered the region 250-500 metres. The task of determining the capability of a channel to support a bandwidth-limited application becomes more of a challenge.

During the development of 1000BASE-SX it was found that the "FDDI fibre" specification for OFL modal bandwidth of 160 MHz.km @ 850 nm shown in Table 7 and specified in cabling standards such as ANSI/TIA/EIA-568-A, could only be guaranteed to support transmission up to 220 metres. For cabled optical fibre performance using 62.5/125 μm optical fibre, Table 9 adopts the international (ISO/IEC 11801) and UK (BS EN 50173-1) specification of 200 MHz.km @ 850 nm designated OM1 which supports transmission up to 275 metres.

It should be noted that these distances quoted for 1000BASE-LX applications assume the use of offset launch conditions (in which the LASER light is launched into the optical fibre channel “off-axis”). For 1000BASE-LX it is often found that the equipment supplier mandates the use of a “mode conditioning cord” as the equipment cord. Failure to use such a cord could limit the supported distances.

λ (nm)	Mb/s	Application	62.5/125μm OM1 OFL modal bandwidth 200/500 MHz.km		50/125 μm OM2 OFL modal bandwidth 500/500 MHz.km		Difference in OPB (dB)
			OPB (*CIL_{max})	Channel length	OPB (*CIL_{max})	Channel length	
850	155	ATM @ 155 Mb/s	7.2	1000	7.2	1000	0.0
	266	CD 14165-1: Fibre Channel (FC-PH)	12.0	700	12.0	2000	0.0
	531	CD 14165-1: Fibre Channel (FC-PH)	8.0	350	8.0	1000	0.0
	622	ATM @ 622 Mb/s	4.0	300	4.0	300	0.0
	1000	IEEE 802.3: 1000BASE-SX	2.6*	275	3.56*	550	-0.96
1300	266	CD 14165-1: Fibre Channel (FC-PH)	6.0	1500	5.5	2000	0.5
	622	ATM @ 622 Mb/s	6.0	330	2.0	500	4.0
	1000	IEEE 802.3: 1000BASE-LX	2.35*	550	2.35*	>550	0.0

Table 9: Bandwidth-limited MMF application standards up to 1000 Mb/s

The bandwidth-limited LAN application standards are shown in Table 9 which includes important physical layer detail taken from the application standards and demonstrates a number of key features:

- applications supporting a given protocol are present in both transmission windows;
- as the data rates increase the distances supported tend to reduce;
- the difference in OPB_{max}(dB) between 62.5/125 and 50/125 is typically 0 dB and in one particular case the differential is negative (therefore the parameter in the OPB columns may not be true OPB but the maximum channel insertion loss (CIL_{max}) as indicated for 1000BASE-SX/LX applications and described below.

A number of conclusions can be drawn from the Table:

- the optical power budget of the applications DOES NOT, in general, define the length or quantity of channel components;
- the supported channel lengths depend upon the OFL modal bandwidth (not the optical power budget);
- the differential in launched power into the two optical fibre geometries indicates that LASER sources are used;
- the additional optical power budget for 50/125 MMF, where applicable, supports longer channels or channels containing more connecting hardware or splices.

These conclusions are in many ways at variance with those in 12.2 and a new design approach has to be applied to make sense of the apparent conflict. As a starting point it should be pointed out that there is now a maximum channel length for each optical fibre geometry and modal bandwidth specification. This channel length is independent of the optical power budget of the equipment or the optical loss budget of the cabling.

This means that for a given MMF geometry and modal bandwidth performance, there is a maximum channel length that cannot be exceeded even if the resulting optical loss budget of the channel is below that of the available optical power budget

> As an example of this a simple reference to Table 9 shows that, at 850 nm, ATM @ 622 Mb/s is restricted a budget of 4.0 dB and a maximum length of 300 m (for both 50/125 and 62.5/125 μm OF).
>
> 300m of cable @ 3.5 $dBkm^{-1}$ is equivalent to 1.05 dB. This allows 2.95 dB of connecting hardware loss to produce the maximum loss of 4.0 dB. If a channel only has 1.5 dB of connecting hardware attenuation then an attenuation-limited calculation would allow a channel length of 2.5 dB/3.5 $dbkm^{-1}$ = 714 metres. This is not allowed because the maximum length is restricted to 300 metres.

For some applications, including the Gigabit Ethernet applications, a maximum channel insertion loss has been defined which replaces the optical power budget. To explain this it is necessary to start from the premise that the channel lengths supported have been determined experimentally for each optical fibre performance option.

As an example of this it is useful to refer to the optical power budgets included in the IEEE 802.3 specification as shown in Table 10.

Wavelength	850 nm				1300 nm		
Optical fibre geometry	**62.5/125**		**50/125**		**62.5/125**	**50/125**	
Cable Modal bandwidth (MHz.km)	160	200	400	500	500	400	500
Cable attenuation (dBkm^{-1})	3.75	3.75	3.5	3.5	1.5	1.5	1.5
Application	**1000BASE-SX**				**1000BASE-LX**		
Maximum channel length (m)	**220**	**275**	**500**	**550**	**550**	**550**	**550**
Cable attenuation allocation (dB)	0.88	1.1	1.87	2.06	0.85	0.85	0.85
Connecting hardware allocation (dB)	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Channel insertion loss (dB)	**2.38**	**2.60**	**3.37**	**3.56**	**2.35**	**2.35**	**2.35**
Equipment power budget (dB)	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Penalty (required for transmission) (dB)	**4.30**	**4.29**	**4.07**	**3.57**	**3.48**	**5.08**	**3.96**
Unallocated margin (dB)	**0.82**	**0.60**	**0.05**	**0.37**	**1.67**	**0.07**	**1.19**

Table 10: Power budget analysis for 1000BASE-SX and -LX for MMF

Table 10 shows data for seven modal bandwidth options, three for 62.5/125μm and four for 50/125μm OF. The maximum channel lengths shown are those that are the basic guaranteed minima set down in the application standard for the specific OF geometry/modal bandwidth option. The channel insertion loss is based upon an allocation of 1.5 dB for connecting hardware and a variable content related to the loss of the cable for the specified channel length. As a result the channel insertion loss values differ for each of the optical fibre options.

This process produces the strange situation in which smaller core optical fibres (or more correctly, ones with higher bandwidth) have higher optical power budgets.

It will also be noticed that the equipment power budget is 7.5 dB for both 1000BASE-SX and -LX but that this value is subject to a transmission penalty that, once again, differs for each of the optical fibre options. The available equipment budget (i.e. the true equipment budget minus the penalty) is not the same as the channel insertion loss - it differs by a value known as the “unallocated margin”.

IEEE do not support the use of the unallocated margin as part of the maximum allowed channel insertion loss. The view of the Fibreoptic Industry Association is that the use of the unallocated margin within channel power budget is only supportable under specific vendor guarantees and cannot be universally adopted.

The design rules for bandwidth-limited MMF LAN cabling are as follows:

- the optical loss budget (maximum) of the channel shall not be greater than the channel insertion loss (maximum) of the LAN application standard;
- the optical loss budget (minimum) of the channel shall not be lower than the optical power budget (minimum) of the LAN application standard;
- the propagation delay of the channel shall not be greater than the value specified in the LAN application standard;
- the channel length shall not be greater than the maximum specified channel length of the LAN application standard for the MMF geometry/performance option used.

These requirements are summarised in Table 11.

Channel	Requirement	LAN application standard (for the specific MMF geometry/performance option used).
OLB_{max}	< or =	CIL_{max}
OLB_{min}	> or =	OPB_{min}
Return loss (near-end connecting hardware)	> or =	Return loss
Delay	< or =	Delay
Length	< or =	Length

Table 11: Bandwidth-limited application design rules

NOTE: Individual manufacturers may exceed the minimum requirements of the application standard as a means of product differentiation. If it is known that only a specific type of equipment is to be used then the data sheets of the supplier may be used to define the application requirements.

This new design philosophy applies for all the applications described in the remaining subclauses of this clause.

12.4.2 Applications above 1000 Mb/s

During the development of 1000BASE-F applications it became evident that multimode optical fibre had serious bandwidth limitations. This became an even bigger issue with the development of 10GBASE-F applications. It became necessary to define a new Category of cabled optical fibre OM3, which was 50/125 MMF only, in order to achieve useful transmission distances. The reasons for this are all too apparent in Table 12.

λ (nm)	Gb/s	Application	62.5/125 µm OM1		50/125 µm OM2		50/125 µm OM3	
			CIL_{max} (dB)	Channel length	CIL_{max} (dB)	Channel length	Channel length	CIL_{max} (dB)
850	10	10GBASE-SR/SW	1.62	33	1.80	82	300	2.59
1270-1320	10	10GBASE-LX4	1.96	300	1.96	300	NA	NA

Table 12: MMF 10GBASE-S and -L channel parameters

Since the introduction of 10GBASE-LX4 solution listed in Table 12, an alternative, lower cost, solution (10GBASE-LRM) shown in Table 13 has been developed to achieve the same distances non-OM3 cabled optical fibre without the use of CWDM but this requires significant control of launch conditions using mode conditioning cords.

λ (nm)	Gb/s	Application	62.5/125 µm OM1		50/125 µm OM2	
			CIL_{max} (dB)	Channel length	CIL_{max} (dB)	CIL_{max} (dB)
1310	10	10GBASE-LRM	1.96	300	1.96	300

Table 13: 10GBASE-LRM channel parameters

It should be pointed out that OM3 may also give extended channel lengths for other bandwidth-limited applications such as 1000BASE-SX but the actual level of support has not been verified by IEEE and is not quoted here.

A number of other applications in the FibreChannel series have been developed with data rates between 1 and 10 Gigabit. As shown in Table 14.

λ (nm)	Gb/s	Application	62.5/125 μm OM1		50/125μm OM1		50/125 μm OM2		50/125 μm OM3	
			CIL_{max} (dB)	Channel length	CIL_{max} (dB)	Channel length	CIL_{max} (dB)	Channel length	Channel length	CIL_{max} (dB)
850	1062	CD 14165-1: Fibre Channel (FC-PH)	4.0	300	4.0	300	6.0	500	6.0	500
850	1	Fibre Channel (1,0625 GBd)					3.85	300	2.62	500
850	2	Fibre Channel (2.125 GBd)							3.31	300
850	4	Fibre Channel (4,25 GBd)	1.78	70			2.06	150	2.88	380
850	8	Fibre Channel (8,5 GBd)	1.62	21			1.77	50	2.19	150
NOTE: Any blanks in the table suggests that information is not available										

Table 14: MMF FibreChannel channel parameters

12.4.3 Applications above 10 Gb/s

It is clear from Table 14 that increasing data rates towards 10 Gb/s reduces the transmission distances to unusable levels even when Category OM3 cabled optical fibre is used. The opportunity to develop a higher bandwidth cabled optical fibre has been taken with the specification of Category OM4 cabled optical fibre as detailed in Table 5.

It should be pointed out that OM4 may give extended channel lengths for other bandwidth-limited applications such as 1000BASE-SX and 10GBASE-SR/SW but the actual level of support has not been verified by IEEE and is not quoted here. The same is true for the applications listed in Table 14.

FibreChannel applications were quick to adopt this new Category of cable optical fibre as detailed in Table 16.

λ (nm)	Gb/s	Application	50/125 μm OM3		50/125 μm OM4	
			CIL_{max} (dB)	Channel length	Channel length	CIL_{max} (dB)
850	1	Fibre Channel (1,0625 GBd)	2.62	500	as OM3	
850	2	Fibre Channel (2.125 GBd)	3.31	300		
850	4	Fibre Channel (4,25 GBd)	2.88	380	3,02	420
850	8	Fibre Channel (8,5 GBd)	2.19	150	2,22	190
850	16	Fibre Channel (14,025 GBd)	1,95	100	1,97	125

Table 15: MMF FibreChannel channel parameters for OM4

While the FibreChannel approach is to maintain a duplex transmission channel, IEEE were looking at even higher data transmission rates. It was clear that evolution to 40 Gb/s and 100 Gb/s suggested that, even if a higher bandwidth cabled optical fibre was introduced, a new approach would be necessary to deliver such services over multimode technology.

40 Gigabit Ethernet has adopted parallel optics, four optical fibres in each transmission direction, while 100 Gigabit Ethernet uses ten optical fibres in each transmission direction. These array solutions have been used in certain types of backbone-style installations but the idea of using the MPOI connections at path panels represents a substantial change in direction.

Table 16 contains the CIL_{max} and channel length limits for the 40GBASE-SR4 and 40GBASE-SR10 applications and shows that support is only provided for Category OM3 and Category OM4 cabled optical fibres.

λ (nm)	Gb/s	Application	50/125 µm OM3		50/125 µm OM4	
			CIL_{max} (dB)	Channel length	CIL_{max} (dB)	Channel length
850	40	40GBASE-SR4	1.90	100	1.50	150
850	100	100GBASE-SR10	1.90	100	1.50	150
NOTE: Any blanks in the table suggests that information is not available						

Table 16: MMF 40GBASE-F and 100GBASE-F channel parameters

It should be highlighted that the maximum channel insertion loss values and channel lengths are based on certain assumptions about the total connecting hardware loss in the channel. The applications listed in Table 12 to Table 16 are generally based on a total of 1,5 dB.

However the OM4 implementations of 40GBASE-SR4 and 100GBASE-SR10 assume only 1,0 dB. This restriction coupled with the use of MPO connections represents a challenge for many implementers.

12.5 Bandwidth-limited SMF LAN applications

There are singlemode variants of applications operating below 1000 Mb/s but these were largely provided as an option where SMF was already installed.

A significant change occurred when the achievable channel lengths using MMF became bandwidth-limited.

Table 17 shows the relevant values of OPB/CIL and maximum channel length for all relevant SMF LAN application variants of the applications discussed in 12.4.

It should be highlighted that the maximum channel insertion loss values and channel lengths are based on certain assumptions about the total connecting hardware loss in the channel. The applications listed in Table 17 are generally based on a total of 2,0 dB.

λ (nm)	Gb/s	Application	SMF	
			CIL_{max} (dB)	Channel length
1310	0.155	ATM @ 155 Mb/s	7.0	12500
1310	0.266	CD 14165-1: Fibre Channel (FC-PH)	6.0	10000
1310	0.531	CD 14165-1: Fibre Channel (FC-PH)	14.0	30000
1310	0.622	ATM @ 622 Mb/s	7.0	12500
1310	1	CD 14165-1: Fibre Channel (FC-PH) (1,0625 GBd)	6.0	10000
1310	1	IEEE 802.3: 1000BASE-LX	4.57	5000
1310	1	Fibre Channel (1.0625 GBd)	7.8	10000
1310	2	Fibre Channel (2.125 GBd)	7.8	10000
1310	4	Fibre Channel (4,25 GBd)	7.8	10000
1310	8	Fibre Channel (8,5 GBd)	6.4	10000
1310	16	Fibre Channel (14,025 GBd)	6.4	10000
1270-1320	10	10GBASE-LX4	6.20	10000
1310	10	10GBASE-LR/LW	6.20	10000
1550	10	10GBASE-ER/EW	10.9	40000
1310	40	40GBASE-LR4	6.7	10000
1310	100	100GBASE-LR4	8.3	10000
1550	100	100GBASE-ER4	18.0	16000

Table 17: SMF LAN application requirements

13 OVERALL DESIGN RULES

13.1 Aims and objectives

The obvious aim for any designer is to provide an optical fibre cabling infrastructure that is application-independent. However, as the requirements of applications have developed it has become more difficult to provide a single product solution that meets the need of every application for all possible channel lengths.

For channels with short lengths and few connections, it is possible to envisage a single two-fibre channel product solution to support all forecast applications (perhaps with an upper limit of 10 Gigabit Ethernet). However, if the channel length is 1.7 km then the singlemode optical fibre and transmission equipment necessary to deliver 1 Gigabit Ethernet will not be the most cost-effective method of delivering 10 Mb/s Ethernet. In such cases application-independence requires multiple product solutions. This is the reason that optical fibre is often judged to be not really generic within standards such as the BS EN 50173 series and ISO/IEC 11801 (and associated standards).

This clause attempts to provide and explain the basic rules necessary to map the application over the desired channel lengths and configurations.

13.2 The formulation of design rules

The overall design rules for MMF cabling in support of LAN application standards have changed dramatically since bandwidth became a key design factor.

The variety of cabling configurations that apply to optical fibre cabling renders simplistic rules useless.

Figure 7 shows some of the possible configurations of optical fibre cabling providing point-to-point communication. The number of connections at patch panels (PP) and splice panels (SP) can vary considerably. In addition, optical fibre cabling is used in backbone pathways that serve as both primary and secondary routes (for purposes of redundancy/resilience). The secondary routes can often contain more connections and the higher OLB values of these channels limit the delivery of applications.

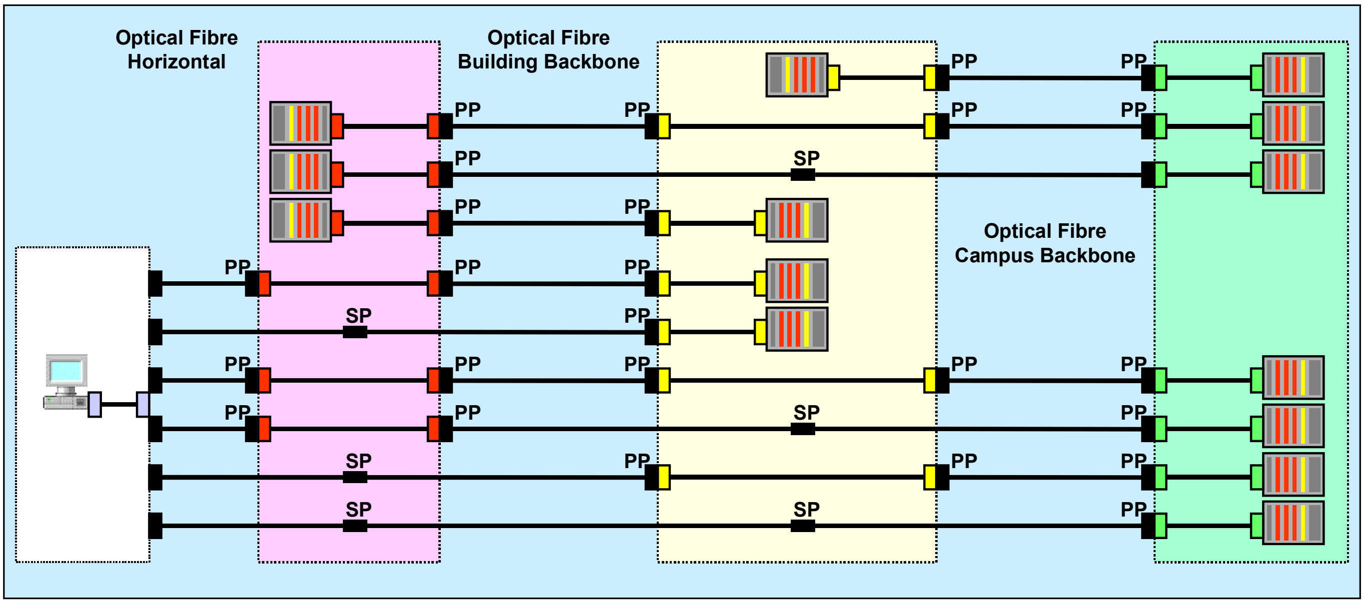


Figure 7: Typical configurations of optical fibre cabling within premises

Connections have an associated optical loss and are therefore equivalent to a reduction in supported distance. This did not matter very much when the optical power budgets of the OF LAN applications were high (i.e. 12.5 dB for 10BASE-F, 11 dB for 100BASE-FX) but now channel insertion loss limits have entered the region between 1 dB and 4 dB and the impact on design is much greater.

As an example of this Figure 8 shows the primary connection between a Comms Room and the two distributors (a.k.a. Satellite or Sub- Equipment Rooms) on a floor. If the connections are each specified to have a maximum loss of 0.75 dB then the maximum length of the channel in support of 1000BASE-SX is 275 metres using the 62.5/125 μm optical fibre defined in Table 9. However, if the secondary route shown in Figure 9 is used then the optical loss budget increases by 1.5dB and the supported length may drop to zero. In other words, using 62.5/125 μm the back-up route would be incapable of supporting 1000BASE-SX and a lower data rate system such as 100BASE-FX would have to be used. If the 50/125 μm optical fibre of Table 9 was used then the channel insertion loss would allow the secondary route to support 1000BASE-SX over channel lengths of up to 160 metres.

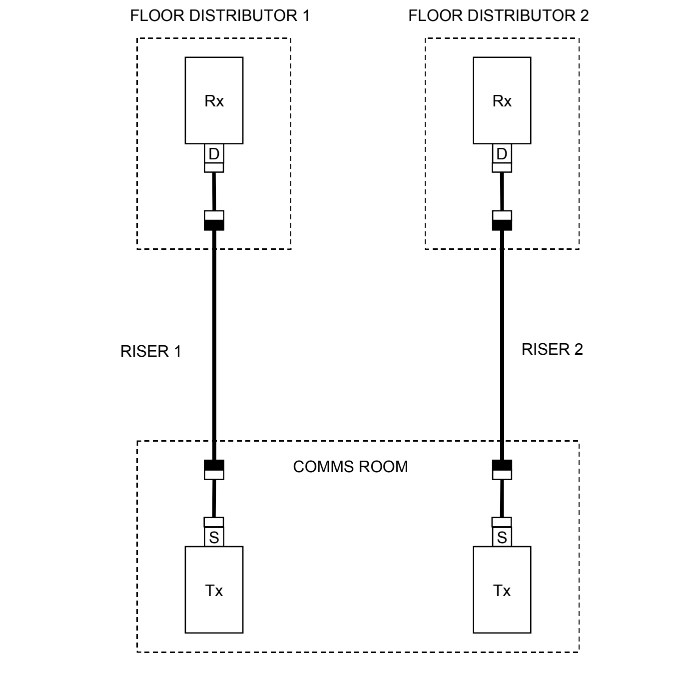


Figure 8: Primary channel

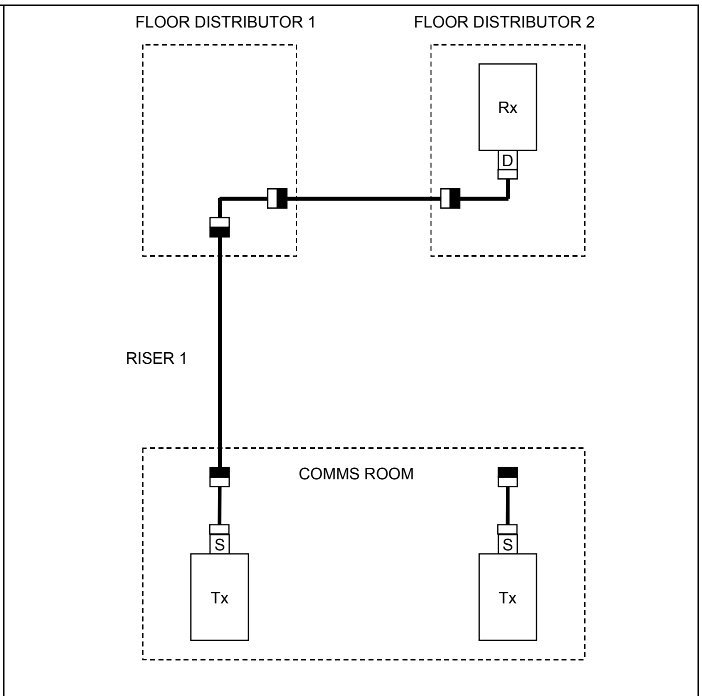


Figure 9: Secondary channel

13.3 Supported channel length equations

13.3.1 General

In order to accommodate differing quantities of mated connections and splices of the cables used within a channel the maximum channel length for a specific cabling configuration is calculated using the general formula:

$$L_{channel} = 1000*OPB/\alpha - (n_1c+n_2s) \text{ metres}$$

or

$$L_{channel} = 1000*CIL_{max}/\alpha - (n_1c+n_2s) \text{ metres}$$

subject to maximum value of L_{max})

where OPB = optical power budget of the application
α = attenuation coefficient of the cable at the relevant wavelength
c = length equivalent (metres) of a mated pair connection for the relevant cable and at the relevant wavelength
s = length equivalent (metres) of a spliced connection for the relevant cable and at the relevant wavelength
n_1 = number of mated pair connections in the channel
n_2 = number of spliced connections in the channel

and

L_{max} = maximum channel length for the relevant optical fibre geometry/OFL modal bandwidth cable (from the OF LAN application standard or equipment supplier)

13.3.2 MMF Cabling

Before using the channel length equation it is important to ensure that the basic information required is available. The information required is listed below:

- α_{850} = optical fibre cable attenuation coefficient @ 850 nm (dBkm^{-1} maximum)
- connection attenuation @ 850nm (dB maximum)
- splice attenuation @ 850nm (dB maximum)
- α_{1300} = optical fibre cable attenuation coefficient @ 1300 nm (dBkm^{-1} maximum)
- connection attenuation @ 1300nm (dB maximum)
- splice attenuation @ 1300nm (dB maximum)

Table 18 shows the relevant values for use in the channel length equation for one particular set of cable and connecting hardware specifications taken from the premises cabling standards ISO/IEC 11801 and the BS EN 50173 series (see 13.4). In these standards the worst case attenuation of an individual connection is specified to be 0.75 dB. However, 95% of randomly mated connections shall be below 0.5 dB. As any channel contains at least 2 connections the probability of the two connections having a total loss in excess of 1.0 dB is therefore 0.25%. For this reason a figure of 0.5 dB is used in Table 18.

The values for particular cables and connecting hardware solutions may be used as appropriate.

Parameter	Wavelength	Value	Units
Attenuation coefficient	850 nm	3.5	dBkm^{-1} max.
	1300 nm	1.5	dBkm^{-1} max.
Connection loss	850 nm	0.5	dB max.
	1300 nm	0.5	dB max.
Splice loss	850 nm	0.3	dB max.
	1300 nm	0.3	dB max.
c_{850} = 1000*0.5/3.5		143	metres
c_{1300} = 1000*0.5/1.5		333	metres
s_{850} = 1000*0.3/3.5		86	metres
s_{1300} = 1000*0.3/1.5		200	metres

Table 18: Example of length equivalence

An Excel spreadsheet showing the use of the formula shown in 13.3.1 using ISO/IEC 11801 and the BS EN 50173 series components is available from the FIA Technical Directorate via the FIA Secretariat.

13.3.3 SMF cabling

Before using the channel length equation it is important to ensure that the basic information required is available. The information required is listed below:

- α_{1310} = optical fibre cable attenuation coefficient @ 1310 nm (dBkm^{-1} maximum)
- connection attenuation @ 1310 nm (dB maximum)
- splice attenuation @ 1310 nm (dB maximum)
- α_{1550} = optical fibre cable attenuation coefficient @ 1550 nm (dBkm^{-1} maximum)
- connection attenuation @ 1550 nm (dB maximum)
- splice attenuation @ 1550 nm (dB maximum)

Table 19 shows the relevant values for use in the channel length equation for one particular set of cable and connecting hardware specifications taken from the premises cabling standards ISO/IEC 11801 and the BS EN 50173 series (see 13.4).

The values for particular cables and connecting hardware solutions may be used as appropriate.

An Excel spreadsheet showing the use of the formula shown in 13.3.1 using ISO/IEC 11801 and the BS EN 50173 series components is available from the FIA Technical Directorate via the FIA Secretariat.

Parameter	Wavelength	Value	Units
Attenuation coefficient	1310 nm	1.0	dBkm^{-1} max.
	1550 nm	1.0	dBkm^{-1} max.
Connection loss	1310 nm	0.5	dB max.
	1550 nm	0.5	dB max.
Splice loss	1310 nm	0.3	dB max.
	1550 nm	0.3	dB max.
$c_{1310} = c_{1550} =$ 1000*0.5/1.0		500	metres
$s_{1310} = s_{1550} =$ 1000*0.5/1.0		300	metres

Table 19: Example of length equivalence

13.4 Connecting hardware

There are two ways of adding the attenuation factors introduced by connecting hardware (both connections and splices) within the channel length equations.

The first is the “worst case” approach. This is used where the distribution of the performance of the connections and splices is not known. For example, if the only information regarding a particular connection is that 100% of mated connections shall be less than 0.75 dB then the use of two such connections shall not exceed 1.5 dB. This is the approach currently adopted by the North American cabling standards including ANSI/TIA-568-C.

However, the BS EN 50173 series and ISO/IEC 11801 (and associated standards) recognise that many IEC-specified connection types are specified in such a way that a statistical approach may be taken. For example, if the specification states that 100% shall be less than 0.75 dB and also that 95% shall be less than 0.5 dB then the probability of a two connection channel have a total connecting hardware loss of less than 1.0 dB is 99.75%.

Using a statistical approach should be carefully considered before it is adopted. A comprehensive analysis of statistical summation of connection loss is provided in a FIA OFE Thesis entitled “Multimode fibre bandwidth - its true value for high bit rate networks within plug-and-play data centre infrastructures" which is downloadable from the FIA web-site at www.fia-online.co.uk.

13.5 System and equipment connecting hardware

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.

13.6 Polarity maintenance

This should not be confused with “polarization” in singlemode transmission. Polarity maintenance relates to the requirement than systems be designed to ensure that accidental connection of Tx to Tx cannot occur. This subject is be covered in FIA-TSD-2000-3-3 (OPTICAL FIBRE CABLING: POLARITY MAINTENANCE).

14 PLANNING ISSUES

14.1 Optical fibre selection

There are many ways in which to develop planning guides for optical fibre selection based upon the information contained in clauses 12 and 13. One of the most straightforward systems that covers applications up to 100 Gb/s is shown in Table 20.

Channel length (L) m	OLB 850 nm (dB)	OLB 1300 nm (dB)	OM1 62.5	OM2 50/125	OM3	OM4	SMF
L<33	< 1.6	< 1.6	≤ 10 Gb/s	≤ 10 Gb/s	≤ 100 Gb/s [1]	≤ 100 Gb/s [1]	≤ 100 Gb/s
L<82	< 1.8	< 1.6	≤ 1 Gb/s	≤ 10 Gb/s	≤ 100 Gb/s [1]	≤ 100 Gb/s [1]	≤ 100 Gb/s
L<100	< 1.9	< 1.8	≤ 1 Gb/s	≤ 1 Gb/s	≤ 100 Gb/s [1]	≤ 100 Gb/s [1]	≤ 100 Gb/s
L<150	< 1.9	< 1.8	≤ 1 Gb/s	≤ 1 Gb/s	≤ 10 Gb/s	≤ 100 Gb/s [1]	≤ 100 Gb/s
L<300	< 2.5	< 2.0	≤ 1 Gb/s	≤ 1 Gb/s	≤ 10 Gb/s	≤ 10 Gb/s [3]	≤ 100 Gb/s
300<L< 500	< 3.3	< 2.3	≤ 155 Mb/s	≤ 1 Gb/s	≤ 1 Gb/s [2]	≤ 1 Gb/s [3]	≤ 100 Gb/s
500<L<2000	-	< 3.5	-	-	-	-	≤ 100 Gb/s
	< 8.5[4]	< 4.5[4]	≤ 155 Mb/s	≤ 155 Mb/s	≤ 155 Mb/s	≤ 155 Mb/s	≤ 100 Gb/s

Note 1: Implementation of 40 and 100 Gigabit Ethernet requires 8 and 20 MMF respectively - all of which are required to be of the same nominal length (i.e. within the same cable).

Note 2: OM3 is technically capable of delivering 1 Gb/s further than 500 m but the IEEE have not validated this implementation - although many vendors claim a variety of lengths in excess of 800 metres (with associated uplifts in channel insertion loss limits).

Note 3: OM4 is technically capable of delivering 1 Gb/s and 10 Gb/s further than 500 m and 300 m respectively but the IEEE are unlikely to validate this implementation - although many vendors may claim a variety of lengths in excess of the figures in the table (with associated uplifts in channel insertion loss limits).

Note 4: 62.5/125 MMF versions of OM1 and OM2 extend the OLB support to 12dB (@850nm) and 10dB (@1300nm)

Table 20: Optical fibre selection guide

There is little doubt that 62.5/125 MMF is obsolete as a technical solution for new in-building infrastructures that are intended to support network evolution beyond 1Gb/s. However, it may have some limited value as a product used to support specific applications and/or to extend existing infrastructures.

Cabling using 50/125 MMF is specified by the generic cabling standards in four Categories of cabled optical fibre performance. However, 50/125 OM1 should not really be considered to be a performance benchmark in terms of procurement. - the designation OM1 primarily exists to support any 50/125 MMF that has a lower performance than OM2. In reality, there are three procurement choices - OM2, OM3 and OM4 (with the proviso that, at the time Issue 4 of this Technical Support Document was published, OM4 had not completed its standardisation process).

The acceptance of 10Gb/s applications as an entry level requirement for most infrastructures suggests that OM3 is almost de-rigueur for in-building infrastructures. Its capability to support 40/100 Gigabit Ethernet up to 100 metres indicates a potentially strong position for some considerable time.

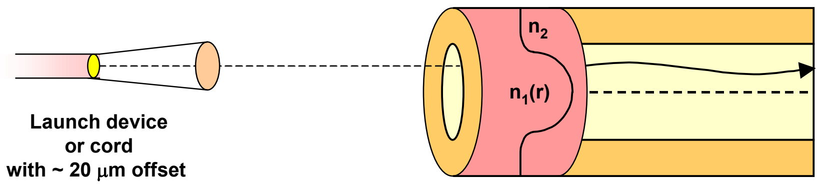
However, it cannot be ignored that OM3 (and OM4) are significantly more expensive cabling implementations than singlemode. Justifying the use of OM3 and OM4 on the basis of their potential support for extending channel lengths fails to recognise that the overall system break-even points for 1Gb/s and 10 Gb/s solutions (taking into account the cost of the equipment) have crossover points in the region of 200 metres (i.e. singlemode solutions may be cheaper beyond that distance).

The overall system cost analyses cannot be undertaken yet for 40 and 100 Gigabit Ethernet but the need for parallel optics, using considerable quantities of MMF, may still favour the established duplex communications solutions offered by SMF.

14.2 The use of mode conditioning cords

Mode conditioning cords are specially prepared equipment cords that are used with 1000BASE-LX and 10GBASE-LRM applications operating over multimode optical fibre of bandwidths lower than that specified for Category OM3 cabled optical fibre. They shall only be used as launch cords and great care shall be undertaken during their use as they are not symmetrical i.e. they can only be used "one-way round".

The mode conditioning cord contains length of singlemode optical fibre connected to a multimode optical fibre (either 50/125 μm or 62,5/125 μm to match the installed cabling). However, the connection is offset by approximately 20 μm in order to provide an offset launch into the installed cabling.



1000BASE				
-SX		-LX		
62.5/125	50/125	62.5/125	50/125	SMF
830nm		1270nm		1270nm
Internal to eqmt		Cord required		NA

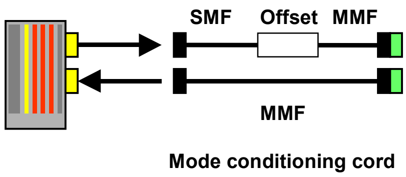


Figure 10: Mode conditioning

14.3 Risk analysis

14.3.1 Costs of telecommunications 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).

14.3.2 Failure mechanisms

14.3.2.1 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 recognised that any optical fibre breaks may result in total telecommunications failure. This can be repaired by software or hardware reconfiguration or redundancy via the use of a separately routed optical fibre cable.

14.3.2.2 Connector damage

This results in selective disruption to communications since it effects only the optical fibre (or fibres) within the damaged connector. Consideration should be given to additional optical fibre elements within the fibre optical cabling allowing reconfiguration at both ends following failure. Full repair may then be effected without further telecommunications disruption.

14.3.2.3 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.

14.4 Fault analysis

The failure of a transmission channel to support a specific transmission system can generally only result from seven issues:

- transmitter failure;
- launch connection failure;
- channel attenuation too high;
- channel attenuation too low;
- channel length too great;
- receive connection failure;
- receiver failure.

The first and last are electronics faults and lie outside the real definition of the channel fault. Nevertheless, they are included in the list as it is theoretically possible for a bad termination of the equipment cord plug to damage the source or detector devices.

A fault diagnosis profile is shown in Figure 11.

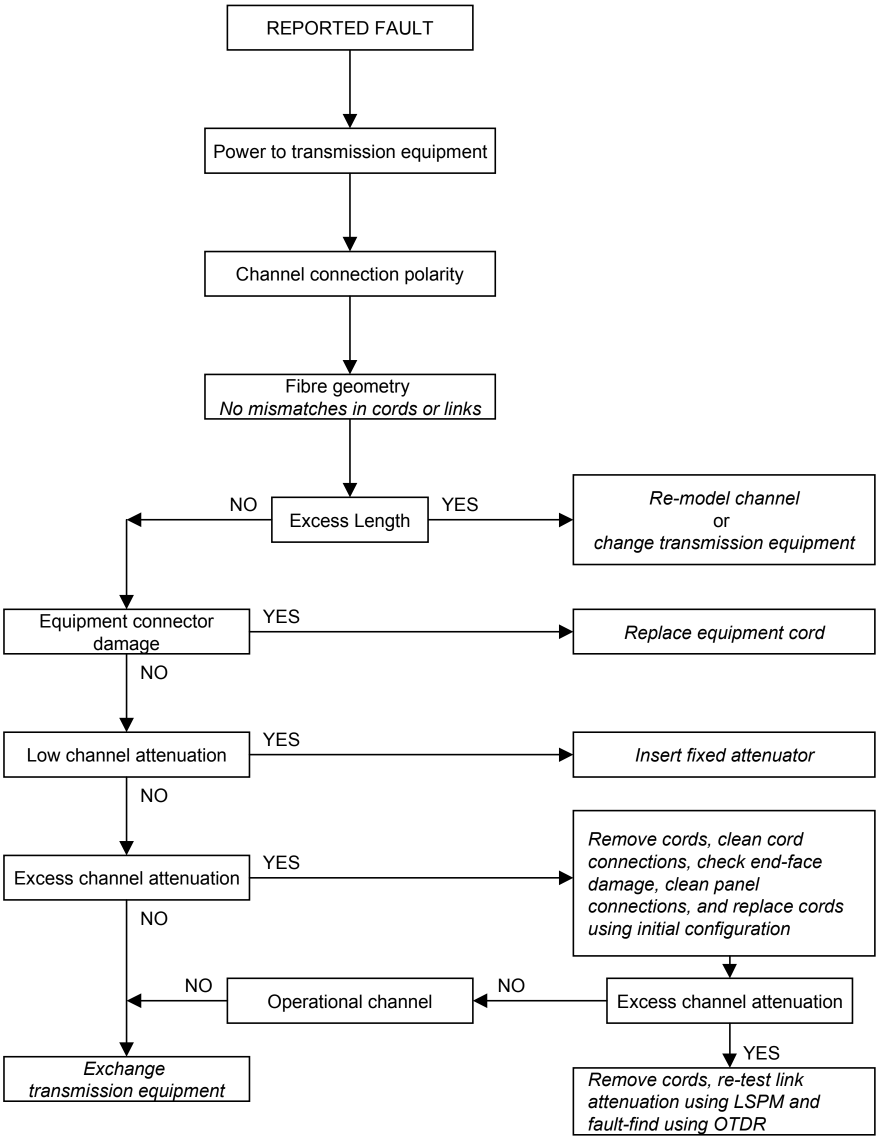


Figure 11: Fault diagnosis profile