MULTIMODE FIBRE BANDWIDTH - ITS TRUE VALUE FOR HIGH BIT RATE NETWORKS WITHIN PLUG-AND-PLAY DATA CENTRE INFRASTRUCTURES

This document was submitted as a thesis in support of an application for the status of

Certified (Optical) Fibre Expert (CFE)

under the FIA Qualifications Scheme

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Submitted: **16th February 2006**
Approved: **14th March 2006**
Final changes: **16th April 2006**

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1 INTRODUCTION

This paper introduces the general concept of attenuation- and bandwidth-limited applications as supported over multimode optical fibre. It then proceeds to explain the differences in cabling design approach that should be applied to the two groups of applications. The paper focuses on bandwidth-limited applications and specifically upon the 850 nm, multimode, optical fibre variants of 1 Gigabit per second Ethernet (1000BASE-SX) and 10 Gigabit per second Ethernet (10GBASE-SR/SW) protocols. The paper then provides a detailed analysis of the underpinning design rules for these applications that may be used to construct complex cabling solutions as might be used for the implementation of plug-and-play infrastructures within data centres. Finally, predictions are made which extend the design concepts to even higher bit rate applications and show how substantially future-proof solutions may be installed using current optical fibre cabling technologies.

This paper is not intended to be rigorous in its mathematical treatment of the subject and instead concentrates on explaining the general principles in such a way that can be understood by those with a basic understanding of optical fibre technology. Where useful references are available they will be highlighted - otherwise this paper is a stand-alone document intended to be read as a Technical White Paper published by the Fibreoptic Industry Association.

NOTE: The contents of this paper represent an extension to the information supplied in the FIA Technical Support Document TSD-2000-1-1 which should be updated by reference to this paper.

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2 BANDWIDTH-INSERTION LOSS RELATIONSHIPS FOR MULTIMODE OPTICAL FIBRE

2.1 General concepts

Until recently the concept of optical power budget (OPB) has been used, almost to the exclusion of other approaches, to design operational multimode optical fibre channels in support of specific applications. A useful example of this is the support of equipment that conforms to 100BASE-FX. Such equipment is required to have an OPB of 11dB if 62,5/125 μm optical fibre is used. The specified range of the application is 2000 metres. It is generally accepted that any 62,5/125 μm optical fibre cabling channel having an insertion loss (sometimes termed attenuation) of 11dB and shorter than 2000 metres will support the equipment - independent of the source of the attenuation (i.e. whether it arises from the length of the installed cables and cords or from the connecting hardware). This is because the assumed bandwidth of the installed cabling is much higher than the requiirements of the application. In this respect, the situation in which the maximum channel insertion loss is the same as the OPB is a special case - albeit a common one for many years and for many applications.

The question of what would happen if the bandwidth of the installed cabling channel was similar to that of the application was never considered for applications of up to 100 Mbits per second (Mbs^{-1}). Instead the maximum specified length of the channel coupled with the minimum bandwidth specification of the referenced optical fibre cables obviated the need for any complex design approaches.

Now that applications providing 1000 Mbs^{-1} and above are in common usage over multimode optical fibre, the idea that the maximum channel insertion loss is the same as the OPB no longer holds true. Instead we see that channel insertion loss limits and maximum channel lengths for a given application are no longer dependent upon the physical construction of the optical fibre but on its bandwidth. However, this paper introduces a more fundamental change to the design philosophy that lies hidden beneath the surface of this bandwidth-dependent regime.

2.2 Bandwidth-insertion loss characterisitics

The support for an application over optical fibre cabling is governed by a bandwidth-insertion loss characteristic. This is true for both multimode and singlemode applications but this paper focuses on the use of multimode applications.

The general case of a bandwidth-insertion loss characteristic is shown in Figure 1. The actual characteristic will be different for each application and the detail of the curved section (e.g. the gradients to the right of point “A”) will vary with the bandwidth of the channel. To the left of point “A” the characteristic represents the region in which the maximum channel insertion loss is not governed by the bandwidth of the channel and is, in effect, the OPB of the application. As the channel length increases, the channel insertion loss increases and the bandwidth falls. To the right of point “A” the maximum channel insertion loss is governed by the bandwidth of the channel - with the higher bandwidth channels providing higher maximum channel insertion loss values at a given channel length. The bandwidth-dependent curves beyond point “A” effectively limit the distance over which an application may be supported over a channel containing optical fibre cable of a given transmission performance specification.

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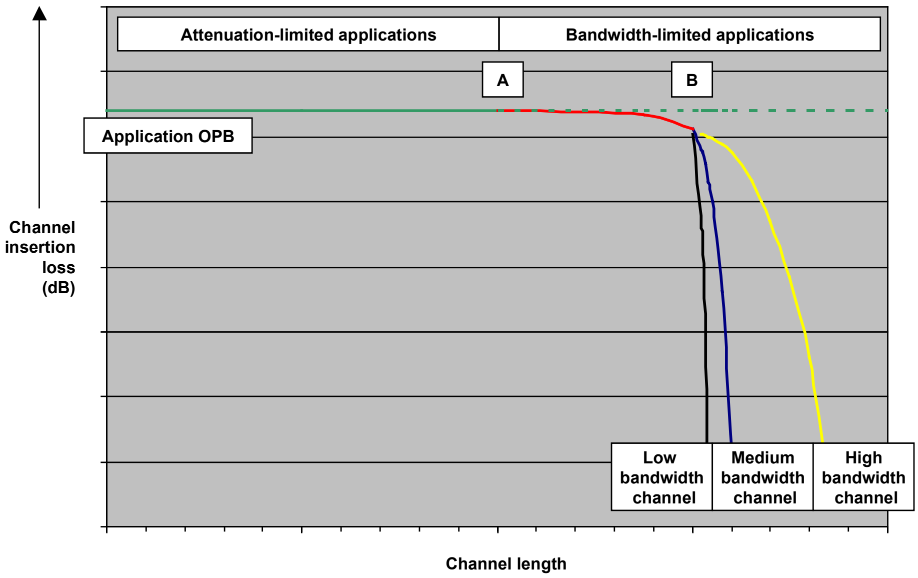

Figure 1 - General bandwidth-insertion loss characteristic

In order for an application to be attenuation-limited, the maximum channel length has to be specified to be lower than the point “A” on Figure 1 when using any of the optical fibres supported by the application. If, however, the application is so bandwidth-demanding that the maximum channel lengths are beyond point A on Figure 1 then the application is said to be bandwidth-limited. Up to certain point “B” in Figure 1, the variation of maximum channel insertion loss may be quite subtle but at some point the deviations between channel bandwidths will become more and more pronounced with the low bandwidth channels falling steeply in comparison to the higher bandwidth channels.

2.3 Attenuation-limited applications

There are a large number of low bit rate applications, generally operating at or below 100 Mbs^{-1}, that are clearly attenuation-limited. Their maximum channel lengths are stipulated in the application standards themselves as are the optical fibre performance specifications over which they are intended to operate up to those channel lengths.

They are typically LED-based applications and therefore have different OPB values for different optical fibre constructions but the channel lengths are unaffected by the resulting channel bandwidth. Two well-known applications, 10BASE-FL/FB and 100BASE-FX are detailed in Table 1. In both cases only the OPB values are quoted which differ for the 50/125 µm and 62.5/125 µm optical fibre constructions.

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Optical fibre construction (µm)		62.5/125		50/125	
Application	Wavelength (nm)	OPB (dB)	Maximum channel length (m)	OPB (dB)	Maximum channel length (m)
ISO/IEC 8802-3: 10BASE-FL, FP & FB	850	12,5	2000	6,8	1942
ISO/IEC 8802-3: 100BASE-FX	1300	11,0	2000	6,3	2000
The maximum channel length is the lower of: • the maximum channel length specified in the application standard; • a calculated length from the CIL with the cable attenuation coefficient = 3.5dBkm^{-1} and 0 dB allocated to connecting hardware.					

Table 1 - Cabling specifications for 10BASE-FL/FB and 100BASE-FX

The bandwidth-insertion loss characteristic of these applications only exhibits the behaviour to the left of point "A" in Figure 1, i.e. the insertion loss characteristic, but is different for each of the optical fibre constructions. This is shown in Figure 2 for 10BASE-FL/FB. The black diagonal line is the cable insertion loss as a function of channel length. The allowance for total insertion loss of all connecting hardware in the channel is given by the "gap" between the cable insertion loss at a given channel length and the OPB value.

A more complete list of optical fibre applications is provided in the "Supported Applications" Annex to BS EN 50173-1 and the FIA TSD-2000-1-1. FIA TSD-2000-1-1 indicates which applications fall into the attenuation-limited group.

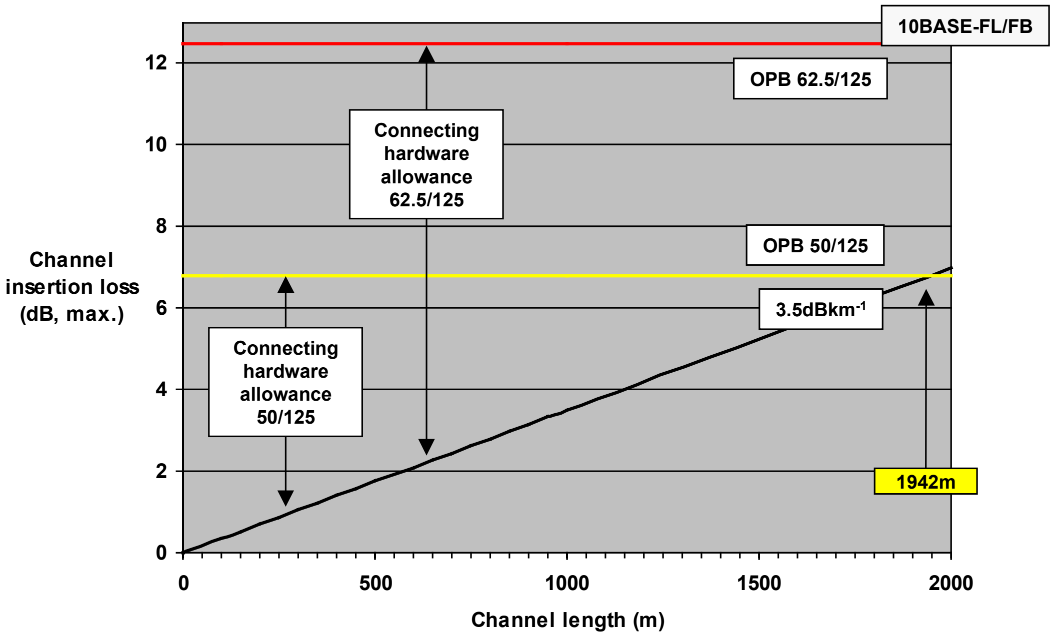

Figure 2 - 10BASE-FL/FB insertion loss characteristic

2.4 Bandwidth-limited applications

2.4.1 The myth of length-independent channel insertion loss

Bandwidth-limited applications generally feature the use of laser or laser-like devices. All the applications considered in this sub-clause use either VCSELs (for 850 nm transmission) or Fabry-Perot lasers (for 1300/1310 nm transmission). In both cases the light emitting areas of the devices are smaller than either of the core diameters in the referenced optical fibres (50 μm and 62.5 μm). As a result there is no difference in coupled power between the two optical fibre types.

However, the greatest difference between attenuation-limited and bandwidth-limited applications is that for the latter there is no single-valued maximum channel insertion loss. Instead there is a continuum of maximum channel insertion values as the channel length changes and the continuum is represent by a curve that depends upon the bandwidth of the channel i.e. the bandwidth of the optical fibre within the channel. This is a substantial move away from the relatively straightforward approach offered by attenuation-limited applications and is explained in 2.4.2.2 for 1000BASE-SX and in 2.4.3.2 for 10GBASE-SR/SW (generically called 10GBASE-S).

2.4.2 1000BASE-SX and 1000BASE-LX (MMF)

2.4.2.1 Introduction to 1000BASE-SX and –LX

The target of the application was to deliver 1000Mbs^{-1} over distances of up to 550 meters which was assumed to be a maximum length building backbone distribution cabling channel in standards such as ISO/IEC 11801:1995 and BS EN 50173:1995. A number of different optical fibre constructions and bandwidths are considered within the IEEE specification (IEEE 802.3:2002).

1000BASE-SX is considered to be a 850 nm application (“S” indicating “short” wavelength). 1000BASE-LX is considered to be a 1300 nm application (“L” indicating “long” wavelength) and is a dual multimode/single-mode application with the same equipment used in both cases.

NOTE: 1000BASE-SX is specified to operate at 830 nm but is delivered over cabling that is specified at a nominal wavelength of 850 nm. As a result small corrections have to be applied for certain calculations.

NOTE: 1000BASE-LX is specified to operate at 1270 nm but is delivered over cabling that is specified at a nominal wavelength of 1300 nm (MMF) and 1310 nm (SMF). As a result small corrections have to be applied for certain calculations.

Some of the optical fibre constructions and bandwidths failed to meet the 550 metres target length using 1000BASE-SX. 1000BASE-LX provides an alternative transmission system that does provide this target length. However, this application is only required if the installation contains optical fibre with a modal bandwidth (at 850 nm) lower than 500MHz.km (i.e. OM2, see clause 3) and this paper is focused on designing for the future rather than supporting old cabling technologies. As a result 1000BASE-LX is more fully analysed separately in a forthcoming document to be included as an FIA Technical White Paper and which should be read in conjunction with this paper.

It should be noted that in order to deliver the application over the full channel length specified on multimode optical fibre cabling, 1000BASE-LX requires a “mode conditioning cord” to be inserted between the transmitter and the cabling to be used.

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2.4.2.2 1000BASE-SX

The information shown in Table 38-5 of IEEE 802.3:2002 specification is presented here in Table 2. The information in Table 2 is often quoted without understanding its contents. As an example of this FIA TSD-2000-1-1 provides an introduction to the information in the Table but does not provide a full explanation.

Optical fibre construction (µm)	62.5/125	62.5/125	50/125	50/125
Optical fibre modal bandwidth @ 850nm (overfilled launch, MHz.km)	160	200	400	500
Channel length (m)	220	275	500	550
OPB (dB)	7.5	7.5	7.5	7.5
Link power penalty (dB)	4.27	4.29	4.07	3.57
Channel insertion loss (dB)	2.38	2.60	3.37	3.56
Unallocated margin (dB)	0.84	0.60	0.05	0.37

Table 2 - Channel length and insertion loss values for 1000BASE-SX

The maximum channel lengths vary with optical fibre construction and modal bandwidth. As a result we are clearly dealing with a bandwidth-limited application. However, Table 2 does not give any indication of the bandwidth-insertion loss characteristic of the type shown in Figure 1 and which is the primary focus of this thesis. For this information we have to go to the spreadsheets used to produce the information in Table 2 and also explained in IEC TR 61282-2. The resulting analysis produces a bandwidth-insertion loss characteristic as shown in Figure 3. All the characteristic curves shown in Figure 3 conform with the general principles of Figure 1 with points “A” and “B” co-located at 0 metres.

The link power penalty values referred to Table 2 are the difference between the OPB (7.5dB) and the maximum channel insertion loss at a given channel length. The link power penalty is the result of a complex calculation including the specified transmission parameters of both the transmitter and receiver in combination with the cabling. It is in effect an “unusable” part of the application OPB and simply reveals the maximum channel insertion loss at a given channel length.

However, by comparing the values shown in Figure 3 with those at the specified channel lengths of Table 2 a number of small discrepancies can be found. The value for 500MHz.km optical fibre cable at 550 metres is 3.56 dB in Table 2 but appears to be almost 4.0dB in Figure 3. This highlights a further common misunderstanding of the information in Table 2 because the channel insertion loss quoted is a calculated value based upon specific cable and connecting hardware performance rather than the true maximum channel insertion loss shown in Figure 3. This is explained in Table 3.

The IEEE 802.3:2002 specification calculates the channel insertion loss based upon the specified channel length as follows:

- for 62.5/125 µm optical fibre an attenuation coefficient of 3.75dBkm^{-1} @ 850 nm is used but is adjusted to 830 nm producing a value of 4.02 dBkm^{-1};
- for 50/125 µm optical fibre an attenuation coefficient of 3.5dBkm^{-1} @ 850 nm is used but is adjusted to 830 nm producing a value of 3.75 dBkm^{-1};
- 1.5dB is allocated to the total insertion loss of the connecting hardware in the channel (excluding, as usual, those to the transmission equipment).

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These assumptions produce the calculated values in rows A and B of Table 3 and when added together produce the channel insertion loss (calculated) shown in row C (the same as that shown in Table 2. However, the true maximum channel insertion loss is the difference between the OPB and the link power penalty (shown in row D of Table 3) and is as shown in Figure 3.

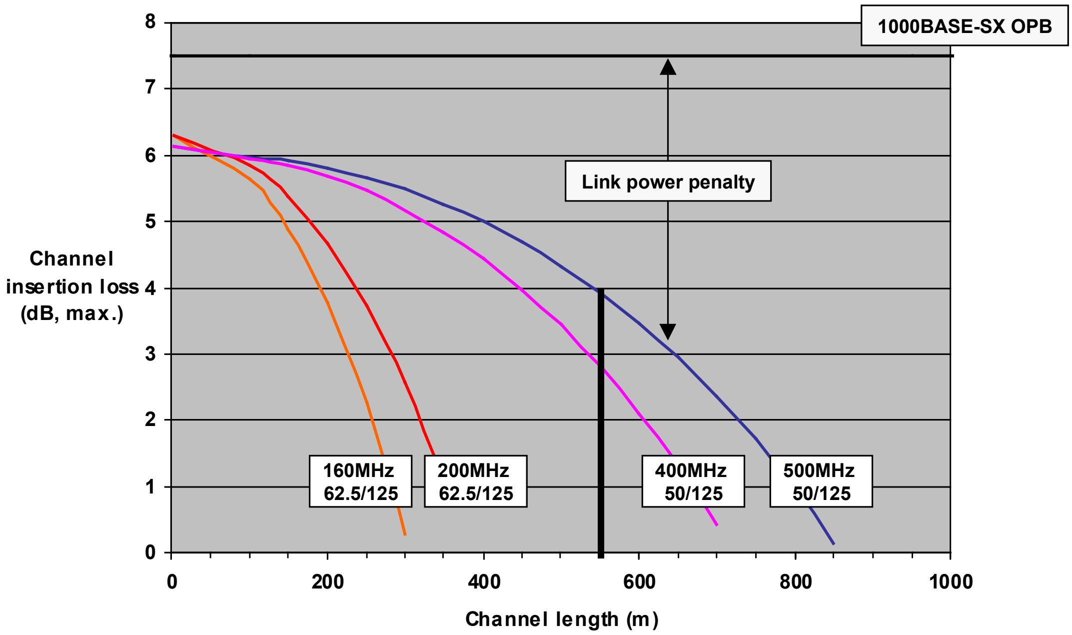

Figure 3 - 1000BASE-SX channel insertion loss

	Optical fibre construction (µm)	62.5/125	62.5/125	50/125	50/125
	Optical fibre modal bandwidth @ 850nm (overfilled launch, MHz.km)	160	200	400	500
	Channel length (m)	220	275	500	550
A	Cable insertion loss for channel length @830nm (calculated) (dB)	0.88	0.90	1.87	2.06
B	Connection insertion loss (assumed) (dB)	1.5	1.5	1.5	1.5
C	Channel insertion loss (calculated) = A+B (dB)	2.38	2.60	3.37	3.56
D	Channel insertion loss (true) = OPB-Link Power Penalty (dB)	3.23	3.21	3.43	3.93
	Unallocated margin (D-C) (dB) (any small differences are rounding errors in the original IEEE tables)	0.84	0.60	0.05	0.37

Table 3 - Explanation of the values in Table 2

The difference between true and calculated values for maximum channel insertion loss is the “unallocated margin”. In fact the unallocated margin is an artefact of the calculation process since a different set of cabling assumptions would have yielded a different value for the unallocated margin. Furthermore, the presence of an unallocated margin is, to some extent, due to the length granularity of the spreadsheet used.

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Based upon the analysis and explanation provided above, a number of important conclusions can be drawn:

- the channel lengths quoted in IEEE 802.3:2002 are in effect "sample values" and are aligned with original targets of the IEEE work;
- the maximum channel insertion at a given length is the difference between the application OPB and the link power penalty at that length
- the link power penalty is not single-valued for a given optical fibre construction and bandwidth;
- the true maximum channel length is reached when the channel insertion loss of the installed cabling exceeds the true maximum channel insertion loss;
- the maximum channel insertion loss increases rapidly as the channel length is reduced - enabling more complex channels to be created with the total insertion loss of the connecting hardware significantly in excess of 1.5dB;
- the unallocated margin is an artefact of the calculations undertaken and has no real impact on design.

A fuller picture is provided in Figure 4. This shows the maximum channel insertion loss curves of Figure 3 together with a line of calculated channel insertion loss (based on a common value for the cable attenuation coefficient of 3.5dBkm^{-1} @ 850 nm, adjusted to 830 nm producing a value of 3.75 dBkm^{-1}, plus an allocation of 1.5dB for the total insertion loss of connecting hardware).

Where the curves cross the line, the unallocated margin is zero. This shows that the channel lengths of Table 2 and Table 3 are only valid for a certain cabling configuration and that a lower attenuation coefficient can produce additional supported channel length.

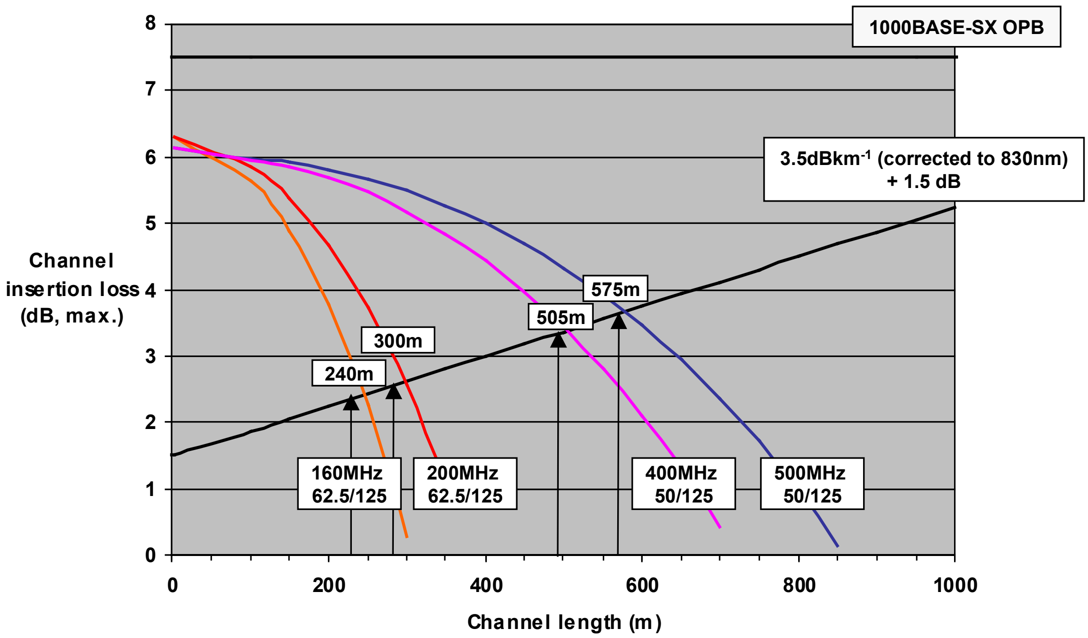

Figure 4 - 1000BASE-SX channel insertion loss and zero margin lengths

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2.4.3 10GBASE-F (MMF)

2.4.3.1 An introduction to 10GBASE-F (MMF)

The target of 10GBASE-F (the generic term applied to all optical fibre implementation of the 10Gbs^{-1} Ethernet applications) was to deliver the application over distances of at least 300 meters. A number of different optical fibre constructions and bandwidths are considered within the IEEE specification (IEEE 802.3ae:2002).

10GBASE-SR and 10GBASE-SW which are termed 10GBASE-S in this thesis are considered to be 850 nm applications ("S" indicating "short" wavelength). 10GBASE-LX4 uses four wavelength - or path - CWDM and is considered to be a 1300 nm applications. ("L" indicating "long" wavelength) and is a dual multimode/single-mode application with the same equipment used in both cases.

NOTE: 10GBASE-S is specified to operate at 840 nm but is delivered over cabling that is specified at a nominal wavelength of 850 nm. As a result small corrections have to be applied for certain calculations.

NOTE: 10GBASE-LX4 is specified to operate at 1270 nm but is delivered over cabling that is specified at a nominal wavelength of 1300 nm (MMF) and 1310 nm (SMF). As a result small corrections have to be applied for certain calculations.

Many of the optical fibre constructions and bandwidths failed to meet the 300 metres target length using 10GBASE-S applications. 10GBASE-LX4 provides an alternative transmission system that does provide this target length. As 10GBASE-LX4 is an expensive solution to deliver 10GbE over 300 metres, an alternative is in the final stages of development. IEEE will publish a variant called IEEE 802.3aq (or 10GBASE-LRM) in 2006. Further analysis of 10GBASE-LX4 is therefore not undertaken here.

2.4.3.2 10GBASE-S

The information shown in Table 52-10 of IEEE 802.3ae:2002 specification is presented here in Table 4.

Optical fibre construction (µm)	62.5/125	62.5/125	50/125	50/125	50/125
Optical fibre modal bandwidth @ 850nm (overfilled launch, MHz.km)	160	200	400	500	2000
Channel length (m)	26	33	66	82	300
OPB (dB)	7.3	7.3	7.3	7.3	7.3
Link power penalty (dB)	4.7	4.8	5.1	5.0	4.7 (4.69)
Channel insertion loss (dB)	1.6 (1.62)	1.6	1.7	1.8 (1.80)	2.6 (2.61)
Unallocated margin (dB)	1.0	0.8	0.5	0.5	0 (0.02)
NOTE: figure in brackets are the quoted values expressed to two decimal places					

Table 4 - Channel length and insertion loss values for 10GBASE-S

Table 4 differs in one significant aspect from Table 2 - it includes an optical fibre variant with a significantly higher modal bandwidth. This range of multimode optical fibre bandwidths resulted in the development of the OMx system of cabled optical fibre Categories in the major structured cabling standards (ISO/IEC 11801:2002 and BS EN 50173-1). Clause 3 discusses this in more detail.

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The information in Table 4 is often quoted without understanding its contents. As an example of this FIA TSD-2000-1-1 provides an introduction to the information in the Table but does not provide a full explanation.

The maximum channel lengths vary with optical fibre construction and modal bandwidth. As a result we are clearly dealing with a bandwidth-limited application. However, Table 4 does not give any indication of the bandwidth-insertion loss characteristic of the type shown in Figure 1 and which is the primary focus of this thesis. For this information we have to go to the spreadsheets used to produce the information in Table 4. The resulting analysis produces a bandwidth-insertion loss characteristic as shown in Figure 5. All the characteristic curves shown in Figure 5 conform with the general principles of Figure 1 with points “A” and “B” co-located at 0 metres.

The link power penalty values referred to Table 4 are the difference between the OPB (7.3dB) and the maximum channel insertion loss at a given channel length. The link power penalty is the result of a complex calculation including the specified transmission parameters of both the transmitter and receiver in combination with the cabling. It is in effect an “unusable” part of the application OPB and simply reveals the maximum channel insertion loss at a given channel length.

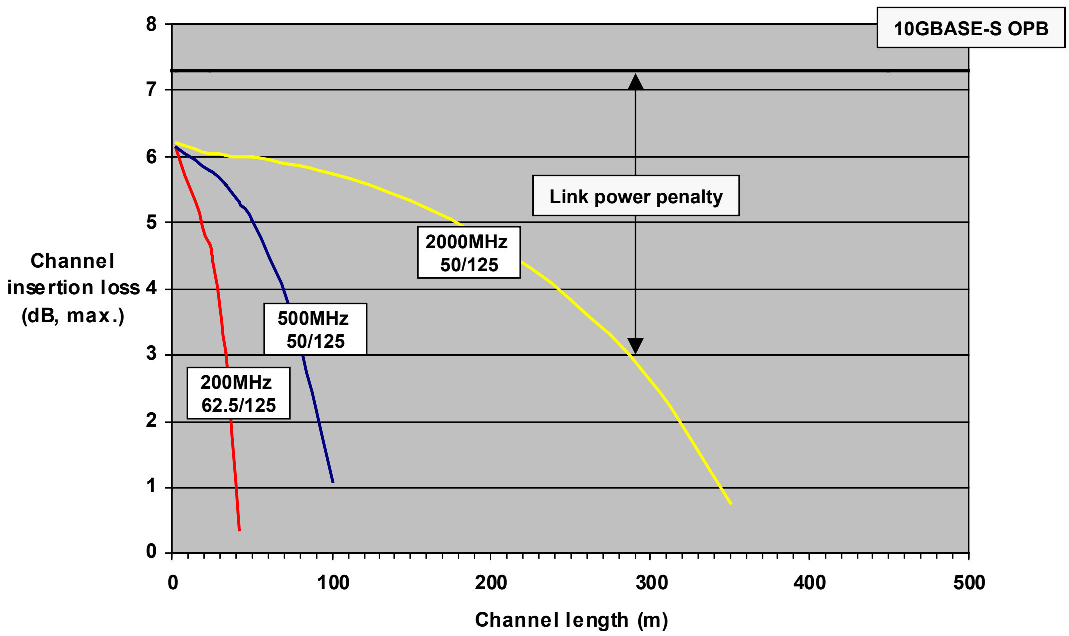

Figure 5 - 10GBASE-S channel insertion loss

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A similar analysis to that undertaken for 1000BASE-SX produces the same conclusions i.e.:

- the channel lengths quoted in IEEE 802.3:2002 are in effect "sample values" and are aligned with original targets of the IEEE work;
- the maximum channel insertion at a given length is the difference between the application OPB and the link power penalty at that length
- the link power penalty is not single-valued for a given optical fibre construction and bandwidth;
- the true maximum channel length is reached when the channel insertion loss of the installed cabling exceeds the true maximum channel insertion loss;
- the maximum channel insertion loss increases rapidly as the channel length is reduced - enabling more complex channels to be created with the total insertion loss of the connecting hardware significantly in excess of 1.5dB;
- the unallocated margin is an artefact of the calculations undertaken and has no real impact on design.

A fuller picture is provided in Figure 6 that shows the maximum channel insertion loss curves of Figure 5 together with a line of calculated channel insertion loss (based on a common value for the cable attenuation coefficient of 3.5dBkm^{-1} @ 850 nm, adjusted to 840 nm producing a value of 3.62 dBkm^{-1}, plus an allocation of 1.5dB for the total insertion loss of connecting hardware).

Where the curves cross the line, the unallocated margin is zero. This shows that the channel lengths of Table 4 are only valid for a certain cabling configuration.

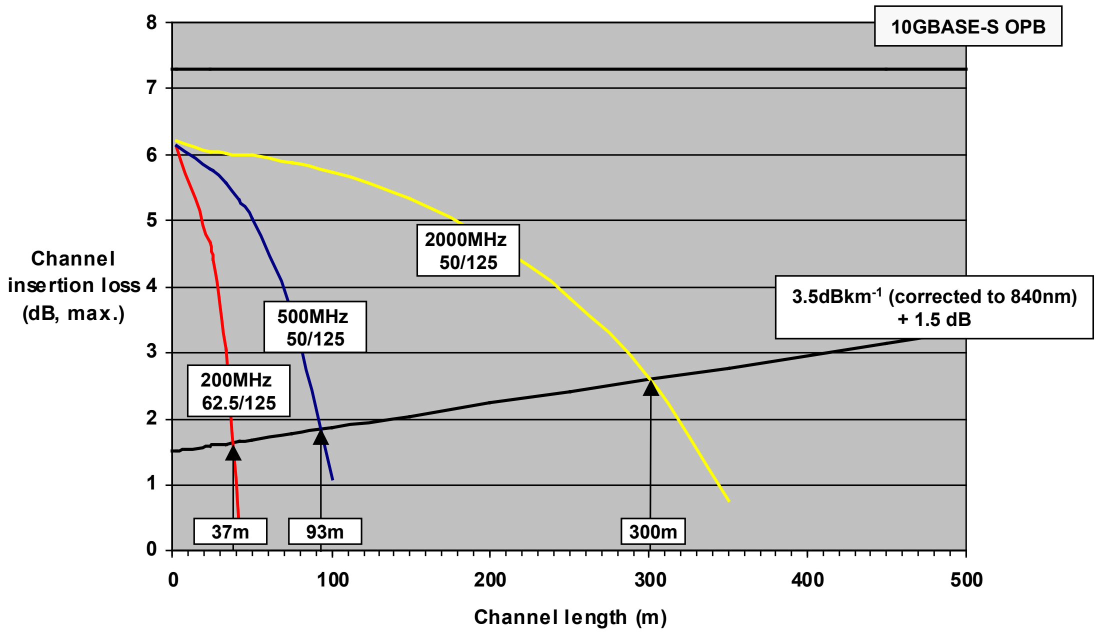

Figure 6 - 10GBASE-S channel insertion loss and zero margin lengths

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3 THE INTRODUCTION OF CABLED OPTICAL FIBRE CATEGORIES

The recognition of bandwidth-limited multimode applications by the European and international standards bodies involved in structured cabling has led to the development of performance Categories for cabled optical fibres.

These performance Categories are summarised in Figure 7. The three multimode all-silica Categories OM1, OM2 and OM3 are currently specified and no additions are planned. The only singlemode Category in a published standards is OS1 but OS2 will appear in ISO/IEC 24702 (covering industrial premises) and in a new European standard EN 50173-1:2006.

With reference to multimode cabling, it should be noticed that he attenuation coefficient of the cabled optical fibres is the same for all three Categories. The only differentiator is the modal bandwidth.

The remainder of this paper will concentrate on the design rules for the 1GbE and 10GbE applications using Categories OM1, OM2 and OM3.

		Multimode OF				Singlemode OF	
		50/125 or 62.5/125		50/125			
	Wavelength	OM1	OM2	OM3	Wavelength	OS1	OS2*
Attenuation coefficient (max)	850nm	3,5 dBkm^{-1}			1310nm	1,0	0,4
	1300nm	1,5 dBkm^{-1}			1550nm	1,0	0,4
Modal bandwidth OFL (MHz.km min)	850nm	200	500	1500			
	1300nm	500	500	500			
Modal bandwidth LL (MHz.km min)	850nm	-	-	2000			
	1300nm	-	-	-			
Propagation delay (ns.m^{-1} max)	850nm	5			1310nm	5	5
	1300nm				1550nm		

ISO/IEC 11801 Ed. 2 (2002)

EN 50173-1 (2002)

IT CABLING STANDARDS

Figure 7 - Cabled optical fibre Categories

Figure 4 and Figure 6 can be amended as shown in terms of these Categories as Figure 8 and Figure 9 respectively. Figure 8 contains information on the maximum channel insertion loss for 62.5/125 µm OM1, 50/125 µm OM2 and OM3. It should be pointed out that OM3 was not referenced in IEEE 802.3:2002 but relevant information for the OM3 product can be determined from the detailed spreadsheet used to create the graphs.

Figure 8 and Figure 9 also show a line for cable attenuation based on the three multimode Categories (corrected to 830 nm and 840 nm respectively). The gap between the line and curve provides information on the allowance for connecting hardware within the channel. It is this “gap” which is vital for the high connectivity pathways to be found in data centres.

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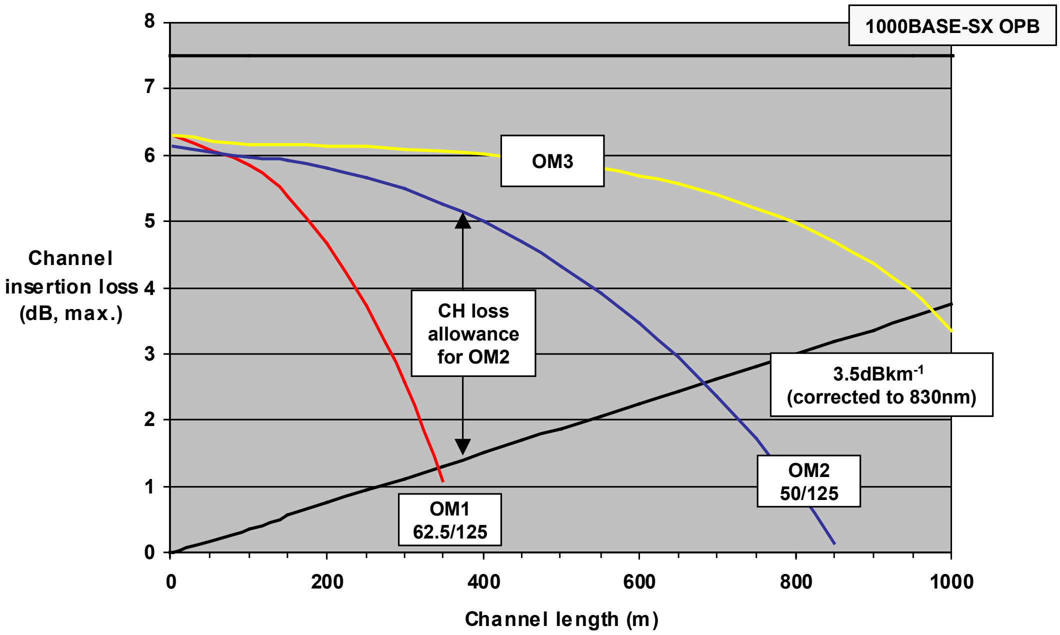

Figure 8 - Connecting hardware (CH) loss allowances for OM1, OM2 and OM3 cabled optical fibres for 1000BASE-SX

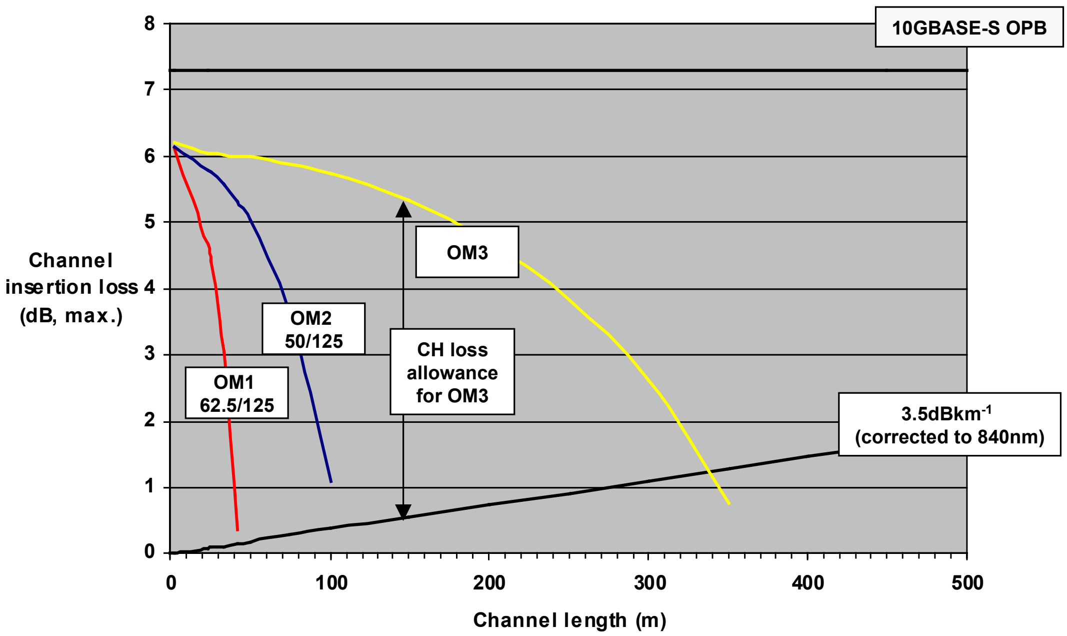

Figure 9 - Connecting hardware (CH) loss allowances for OM1, OM2 and OM3 cabled optical fibres for 10GBASE-S

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4 DATA CENTRE CABLING STANDARDS

In Europe EN 50173-5:2006 covers the design of structured, or generic, cabling within data centres. A similar document is being produced at international level and is expected to be published in 2007 as ISO/IEC 24764.

Both of these cabling design standards will, for the first, time reflect the analyses of clauses 2.4.2.2 and 2.4.3.2 and will contain the type of information shown in Table 5. For the purposes of this paper, Table 5 is restricted to cover 50/125 μm OM2 and OM3 Categories only. This is not, in effect, a restriction for a designer since the procurement of 62.5/125 μm OM2 is almost impossible. 62.5/125 μm OM1 is not listed in the proposed data centre standards and therefore the 1000BASE-LX application is excluded from Table 5.

The cabling structure specified by EN 50173-5:2006 and ISO/IEC 24764 is as shown in Figure 10. There is a desire to be able to connect any equipment outlet (EO, a connection point for a server) to any other EO. In an ideal world this will be able to be accomplished without any intervening transmission equipment thereby saving the cost of the equipment and the rack space associated with it. However, it is recognised that some connections from an EO to the zone or main distributors will be made using balanced cabling which for all the relevant applications will be restricted to 100 meters. Therefore an EO-EO channel should not normally exceed 200 meters but could contain up to ten connections. In such an installation it would be irresponsible to design around OM2 since the expensive 10GBASE-LX4 equipment or the forthcoming -LRM would be required. As a result these applications are also excluded from Table 5.

		Channel length m									
		25	50	75	100	200	300	500	750	1000	2000
Application	OF cable Category and construction	Total connecting hardware attenuation [1)] dB									
10BASE-FL/FB	OM2 50/125	6,70	6,60	6,50	6,45	6,10	5,75	5,05	4,15	3,30	-
	OM3	6,70	6,60	6,50	6,45	6,10	5,75	5,05	4,15	3,30	-
100BASE-FX	OM2 50/125	5,95	5,90	5,85	5,85	5,70	5,55	5,25	4,85	4,50	3,0
	OM3	5,95	5,90	5,85	5,85	5,70	5,55	5,25	4,85	4,50	3,0
1000BASE-SX	OM2 50/125	5,90	5,80	5,70	5,60	5,05	4,35	2,45	-	-	-
	OM3	6,05	5,95	5.90	5,80	5,40	4,95	4,00	2,35	-	-
10GBASE-SR/SW	OM2 50/125	5,65	4,80	3,30	-	-	-	--	-	-	-
	OM3	5,90	5,75	5,60	5,35	3,95	1,50	-	-	-	-
[1)] The figures are rounded down to two decimal places.											

Table 5 - Excerpt from proposed EN 50173-1:2006

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Table 5 shows the allowance for the total insertion loss of the connecting hardware within a channel for the range of applications considered in this paper. Both the attenuation-limited applications such as 10BASE-FL/FB and 100BASE-FX and the bandwidth-limited applications such as 1000BASE-SX and 10GBASE-SR/SW are shown to have allowances of between approximately 4,0 dB and 6.0dB at 200 meters. This is somewhat surprising for those who have not been introduced to the bandwidth-insertion characteristics of earlier figures in this paper.

Any distributor-EO channels longer than 100 meters are unlikely to be supported by balanced cabling and are therefore relatively unrestricted in length. They will de designed as active channels using multimode optical fibre and may even adopt singlemode technology. In these cases the numbers of channel connections will be low as they are for backbone distribution cabling.

The next question is whether it is possible build channels containing ten connections with only 3.95 dB of allowance and are there any other issues in such a channel that would cause problems for the transmission equipment?

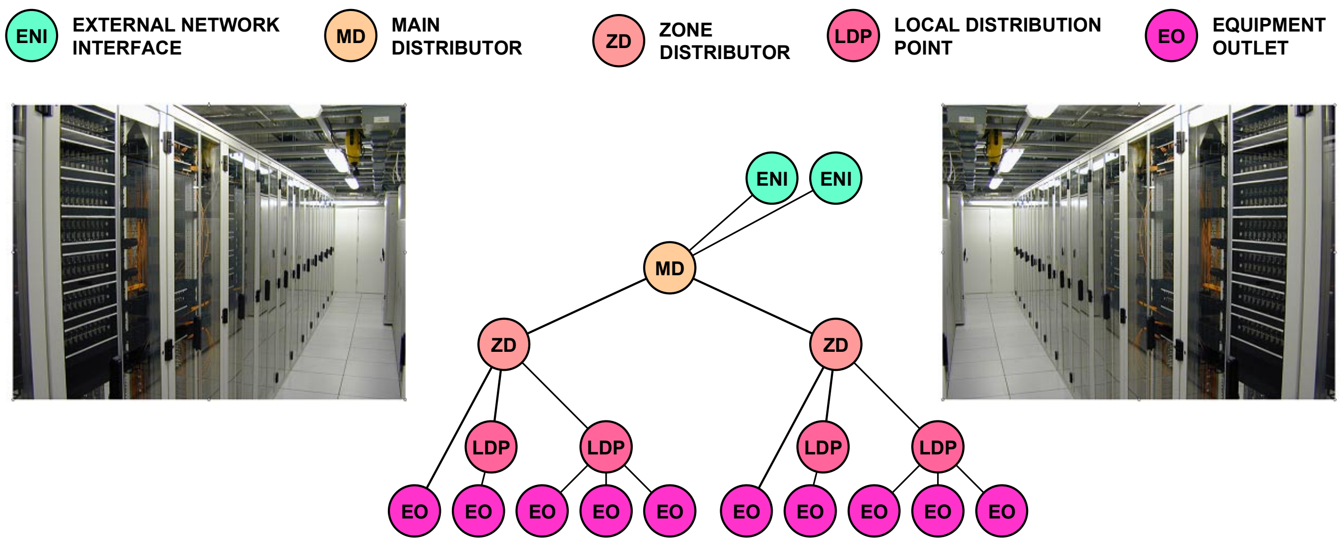

Figure 10 - Cabling structure in data centres according to EN 50173-1

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5 THE STATISTICAL TREATMENT OF OPTICAL FIBRE CONNECTION PERFORMANCE

5.1 Insertion loss distributions

The development of standards for connecting hardware in support of structured, generic cabling, standards has resulted in some impressive interoperability standards for optical fibre connections.

Connecting hardware of the 2.5mm circular ferrule format such as the ST and the SC have been carefully studied and have been specified and toleranced to ensure that:

- 100% of mated connections have an attenuation of no greater than 0.75 dB;
- 95% of mated connections have an attenuation of no greater than 0.50 dB;
- 50% of mated connections have an attenuation of no greater than 0.25 dB;

This level of performance assumes that the optical fibre has been terminated correctly and that the surface of the optical fibre at the connection interface is free from defects and contamination.

The use of Monte Carlo modeling techniques based upon the above statistical attenuation profile shows that as the number of connections in a channel increases the predicted combined performance follows a clear trend as shown in Figure 11 and as summarised below:

- two mated connections have an insertion loss of no greater than 1.35 dB (average worst case of 0.68 dB);
- four mated connections have an insertion loss of no greater than 2.18 dB (average worst case of 0.55 dB
- six mated connections have an insertion loss of no greater than 2.68 dB (average worst case of 0.45 dB);
- eight mated connections have an insertion loss of no greater than 3.48 dB (average worst case of 0.44 dB);
- ten mated connections have an insertion loss of no greater than 3.83 dB (average worst case of 0.38 dB);

This suggests that, providing that the connections behave according to the standards-base statistical profiles, it would be possible to include ten connections within a 200 meter channel constructed from Category OM3 cabling thereby supporting 10GBASE-S.

There are other grounds for further optimism to support this assertion:

- the attenuation of connecting hardware as defined above is specified to be measured using an overfilled LED-type launch condition and the attenuation “seen” by a VCSEL light source with its smaller active area and low mode group launch condition would undoubtedly be lower.
- there is some evidence, through not proven in the case of VCSEL launches, that the higher mode groups are preferentially removed as more and more connections are added resulting in a further improvement in measured values.
- there are a small number of cable system suppliers who have identified a marketing benefit from this approach to channel modeling and have undertaken in-depth proving tests using their own products.

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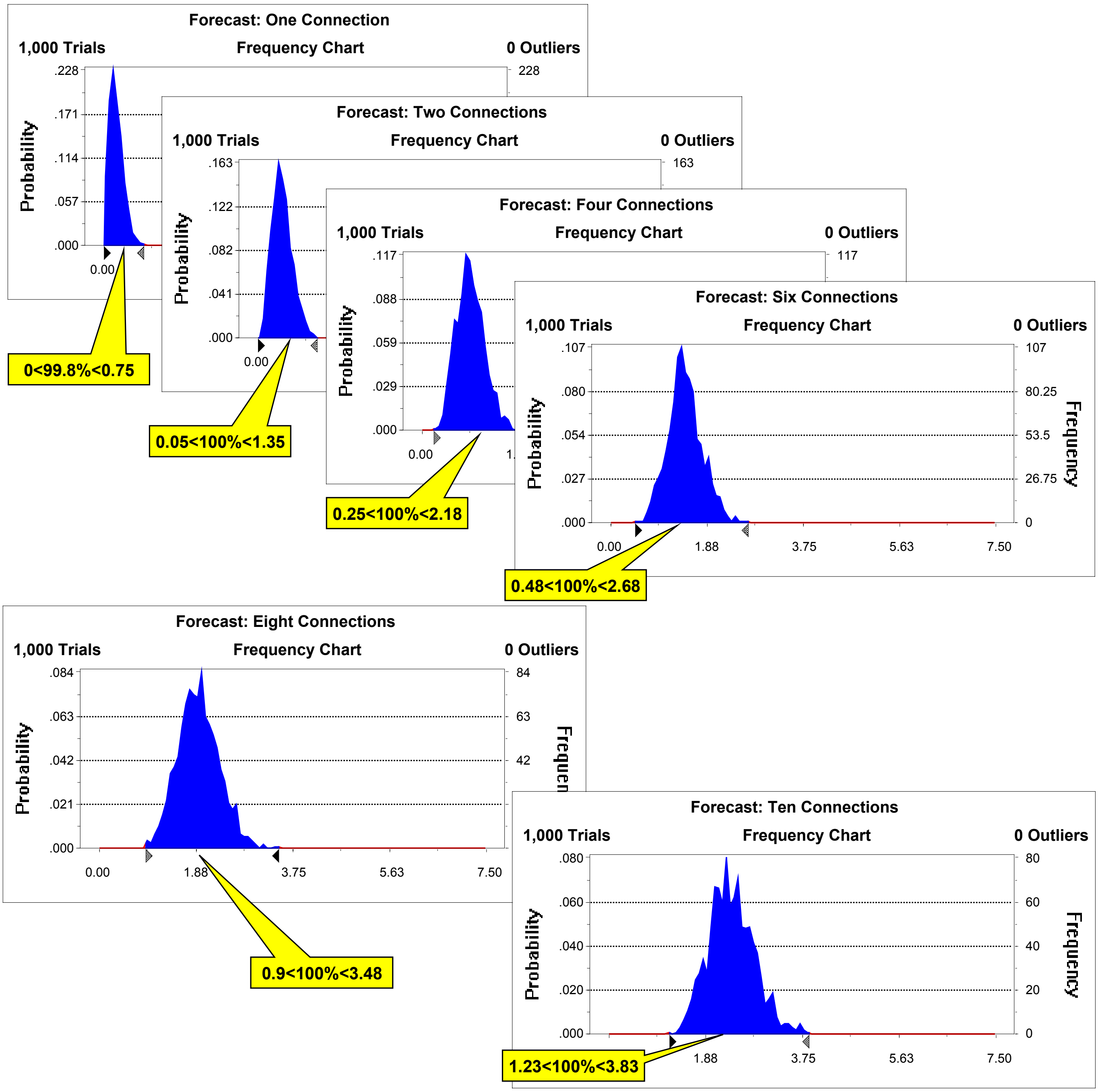

Figure 11 - Predictive Monte Carlo modelling of connection loss

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5.2 Return loss

There is a rather ill-defined limit within the IEEE specifications of 12dB for channel return loss for 10GBASE-S applications. IEEE have not been able to provide detailed answers to questions raised regarding this parameter but for the purposes of this paper it is assumed that this is a firm requirement (further work is being initiated regard this topic in ISO/IEC).

The specification for return loss of multimode connecting hardware in support of the structured, generic cabling, standards is 20 dB minimum. The combined return loss of ten such connections in series would be 10.2 dB. However, a value of 12 dB would be met if each of the connections had a return loss 21.8 dB - hardly unrealistic. This takes no account of the length of the channel and the associated cable insertion loss. A variety of models could be used to analyse this further but the short lengths of cable involved do not make much difference leading to average requirements between 21,6 dB and the 21.8 dB value quoted above.

Once again the VCSEL nature of the launched light may come to assist, independent of the modeling used, in that the active core diameter is less than 30 μm and over this diameter the physical contact of the connections may produce return loss figures significantly better than 20 dB.

Once again it is worth pointing out that some cable system suppliers who have identified a marketing benefit from this approach to channel modeling and have undertaken in-depth proving tests using their own products - apparently without concerns being raised.

5.3 Caution

The Monte Carlo modeling of the insertion loss of multiple connections discussed in 5.1 and the return loss issues raised in 5.2 cannot automatically be applied to all types of optical fibre connection. The SC and ST ferrules certainly conform to the modeling of 5.1 and it evidence from large batches of LC connections suggest that the modeling hold true for them also.

However, flat faced connection systems such as the MT-RJ and MPO cannot be assumed to conform to the same statistical profile. This work needs to be undertaken because the ideal LDP connection (see Figure 10) is a high “fibre count” array connector of the MPO type (see clause 6).

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6 DATA CENTRE IMPLEMENTATIONS

6.1 A structured approach

A data centre can assume a variety of forms - everything from a small computer room or PABX room (which is connected to the main distribution cabling within a typical office building) through to a large, purpose-built, facility for supplying data storage and delivery services to single enterprises (or acting as a co-hosting location for Internet service provision).

For the smaller data centres the standards currently being produced (see clause 4) fill a longstanding gap not covered by the structured, generic, distribution cabling specified in commercial premises standards such as ISO/IEC 11801 and EN 50173-1:2002.

For the purpose-built facilities, the data centre cabling design standards provide an opportunity to create an underfloor cabling structure that is capable of supporting the growth of services provided by that data centre without the need for:

- expensive and time-consuming installation of additional fixed cabling;
- long, meandering equipment-to-equipment connections.

Equally important in a purpose-built facility is the structured planning of cabinet power supplies and cooling systems. These plans can be jeopardised by uncontrolled cabling processes and therefore well planned, structured cabling solutions are an integral part of well-managed and operational data centres.

The structure shown in Figure 10 allows the managed growth of a data centre by the addition of cabinets on a plug-and-play basis. This is shown in Figure 12 and Figure 13.

By implementing the local distribution point (LDP) as a sub-floor cabinet connection point, new cabinets can be built and stored outside the data centre and, as and when required, installed very quickly. This provides the ability to react rapidly to changes in service demand. The initial installation of cabling to the LDP has to be sufficient to support the intended number of EO cabinets (and connections within them) and the initial zone distribution cabinet needs to be able to support the initial quantity of LDPs. After that the growth is organic and controlled.

The structured approach is very demanding of connecting hardware using, as shown in Figure 13, ten connections for a generic EO-EO channel. At this time, most optical fibre connections at the EO, ZD and MD are of the SC (or LC) type. This provides good confidence that the design approaches of clauses 4 and 5 will be viable. However, in order to save space and simplify the cabinet connection process the LDP connection may need to be an array connection of the MPO type. The performance of such a connection will have to be factored into the Monte Carlo modeling of the channel. At this time there is no standardised interoperability performance profile for these connections (as described in clause 5.1 for the SC/ST types) and any work undertaken would be manufacturer-specific.

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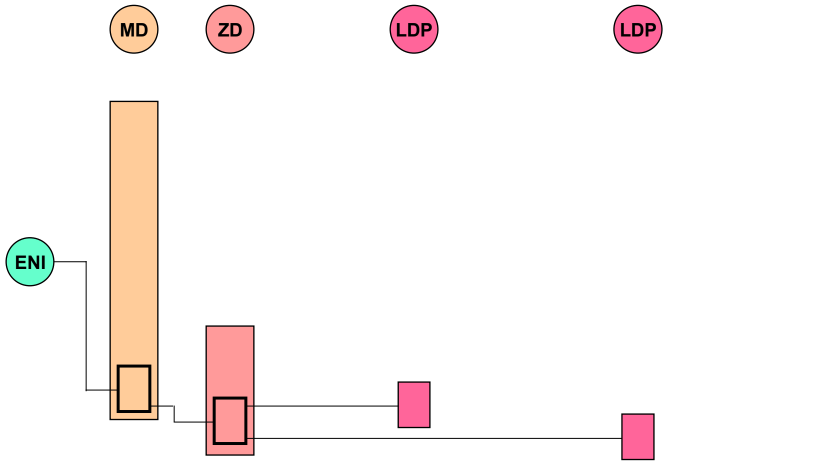
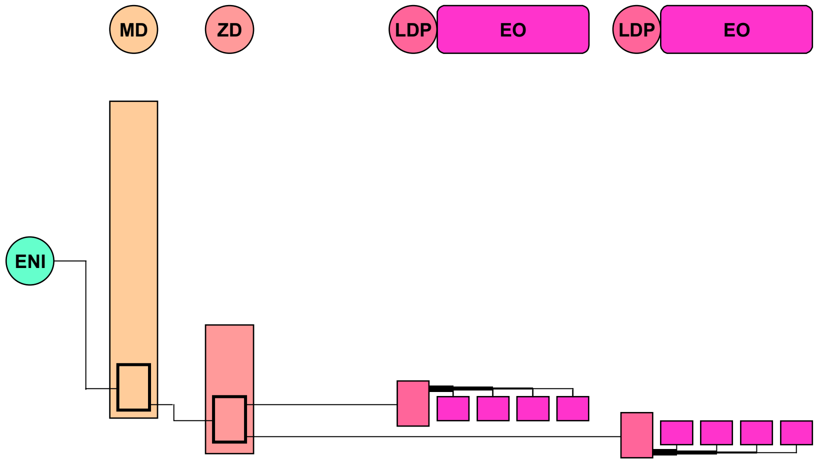
Initial installation of:

- 1 off ENI;
- 1 off MD cabinet;
- 1 off ZD cabinet;
- 2 off LDPs.



Activation installation by adding:

2 off rows EO cabinets;



Any EO to any other EO can be achieved by no more than 6 passive connections:

1: panel connection in EO1
2: LDP connection in LDP1
3: cross-connection in ZD1
4: cross-connection in ZD1
5: LDP connection in LDP2
6: panel connection in EO2

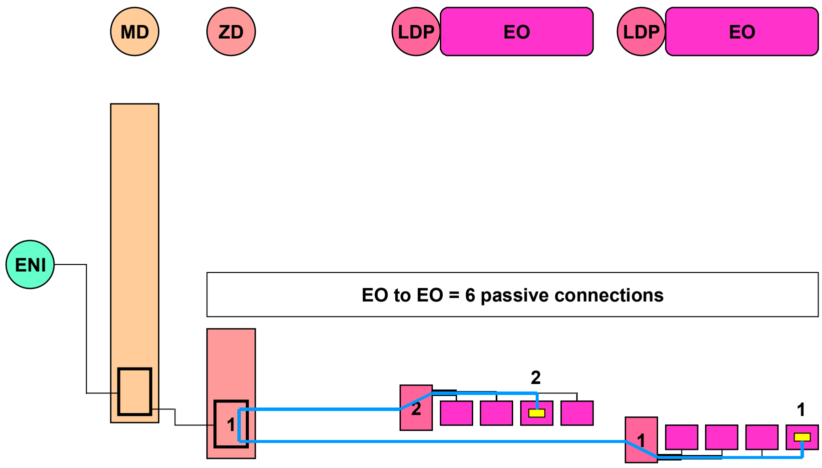


Figure 12 - Data centre evolution (ZD-based)

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Additional installation of:

- 1 off ZD cabinet;
- 2 off LDPs;
- 2 off rows EO cabinets.

Activation installation by adding:

- 2 off rows EO cabinets.

Any EO to any other EO can be achieved by no more than 10 passive connections :

1 and 2: E01, LDP1;

3 and 4: cross-connection in ZD1

5 and 6: cross-connection in MD

7 and 8: cross-connection in ZD2

9 and 10: LDP2 , EO2

Ongoing build to completely fill the available space.

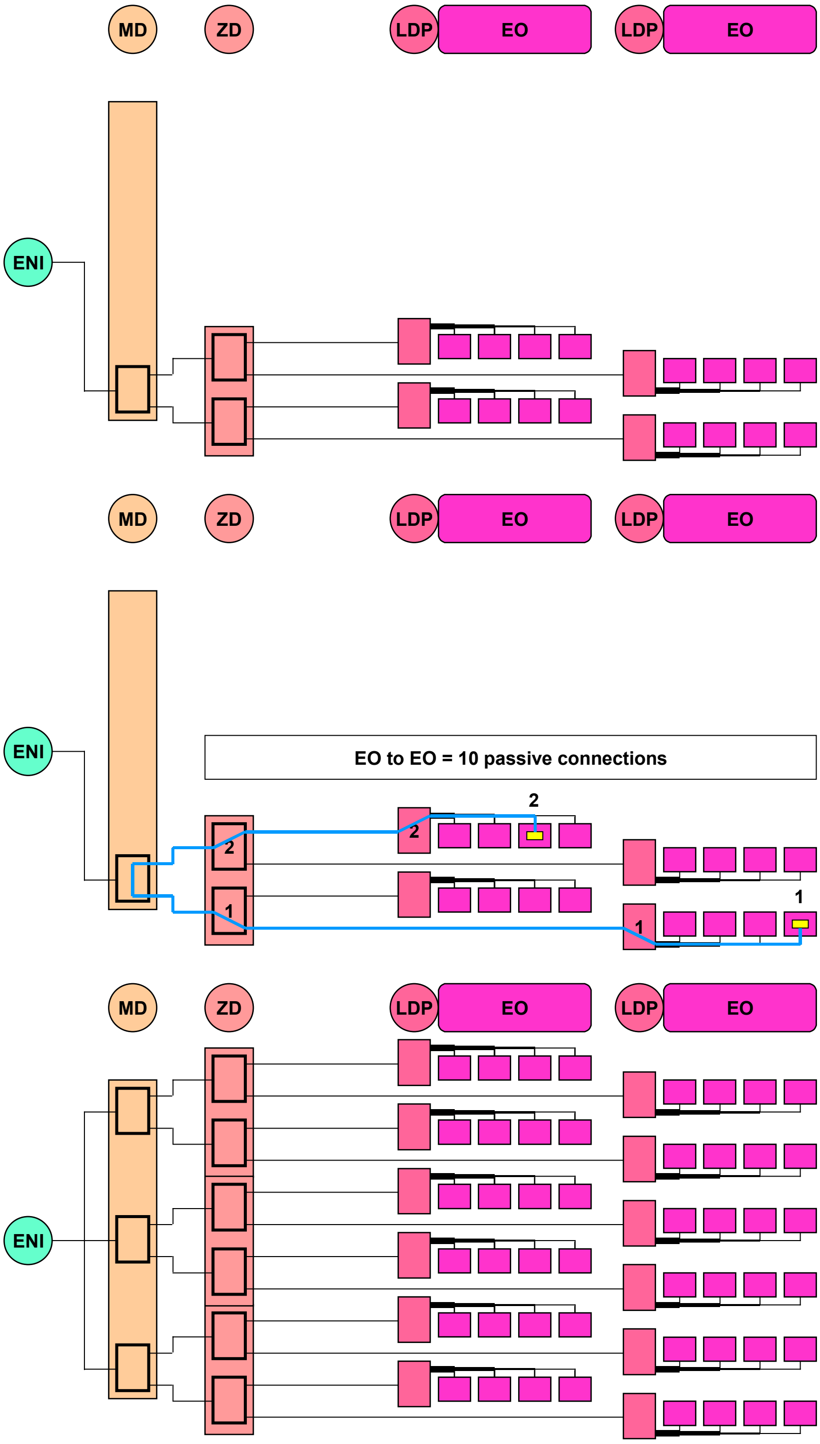

Figure 13 - Data centre evolution (MD-based)

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6.2 The future of data centre connections

The next generation of optical fibre application in data centres are expected to be implemented using array connections i.e. parallel optics. Such equipment is already available. This would suggest the use of array terminations at all points within a data centre which would be configured on-demand by appropriate "termination and polarisation-maintaining" modules.

These are outside the scope of this paper but the concepts explained in this paper will no doubt have to be expanded by future work in this area.

7 CONCLUSIONS

It is generally appreciated that high bandwidth multimode optical fibres deliver bandwidth-demanding applications over greater channel lengths. However, the design approaches applied to such applications detailed in this paper are not widely understood but they deliver a number of significant conclusions as detailed below:

- high bandwidth multimode optical fibres provide increased channel insertion loss capability;
- the actual maximum channel insertion loss depends upon the channel length;
- the increased channel insertion loss capability can be used to support additional connections thereby provide increased channel flexibility of users.

NOTE: It could be argued that high bandwidth multimode optical fibres provide increased network reliability since higher levels of contamination at connection interfaces can be supported by the increased channel insertion loss capability. However, this is a by-product and the FIA should nbto be accepting of poor operational and maintenance practices that lead to such contamination (independent of how common the problem might be).

The use of Category OM3 cabled optical fibre specified in UK, European and international standards can be used as basis for complex channel models in the most bandwidth-demanding premises i.e. data centres and allows plug-and-play approaches to be implemented within them. This represents a key advantage that optical fibre holds over its balanced cabling counterparts but it is not appreciated because the design approaches required are not widely understood.

Finally, it should be remembered that OM3 represents a minimum specification. Suppliers that are capable of providing headroom above the minimum bandwidth specification are able to offer significant further advantages to customers creating complex channel constructions. This is not widely understood by the supply-side of the industry and this paper should encourage them to become involved in this area.

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DEFINITIONS AND ABBREVIATIONS

application	system, with its associated transmission method that is supported by telecommunications cabling
balanced cabling [derived from EN 50173-1]	cabling consisting of one or more symmetrical metallic cable elements (twisted pairs or quads)
bandwidth [from BS7718:1996 - obsolete]	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. A measure of the capacity of an optical fibre to transmit high speed data. NOTE. The bandwidth is limited by several mechanisms: - in multimode fibres, mainly modal distortion and material dispersion - in singlemode, mainly material and waveguide dispersion
channel [from EN 50173-1]	any transmission path comprising passive cabling components between application-specific equipment or between application-specific equipment and an external network interface
connecting hardware [from EN 50173-1]	a device or a combination of devices used to connect cables or cable elements
connection [from EN 50173-1]	mated device or combination of devices including terminations used to connect cables or cable elements to other cables, cable elements or application specific equipment
cross-connect [from EN 50173-1]	method of connecting a cabling subsystem to equipment (or another cabling subsystem) by the use of a patch cord or jumper
generic cabling [from EN 50173-1]	structured telecommunications cabling system, capable of supporting a wide range of applications. Application-specific hardware is not a part of generic cabling
insertion loss (attenuation) [from BS7718:1996 - obsolete]	A decrease of electromagnetic power between two points and the quantitative expression of power decrease which may be expressed by the ratio of the values at two points of a quality 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. Insertion loss (attenuation) is generally expressed in logarithmic units, such as the decibel (dB).
OPB	optical power budget
laser	Light Amplification by the Stimulated Emission of Radiation (a device)
LED	Light Emitting Diode
telecommunications [from EN 50173-1]	branch of technology concerned with the transmission, emission and reception of signs, signals, writing, images and sounds; that is, information of any nature by cable, radio, optical or other electromagnetic systems NOTE: The term telecommunications has no legal meaning when used in this document.
VCSEL	Vertical Cavity Surface Emitting Laser

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REFERENCES

EN 50173:1995	Information technology – Generic cabling systems
EN 50173-1:2002	Information technology – Generic cabling systems – Part 1: General requirement and office areas
EN 50173-5:2006 (in development at the time of writing)	Information technology – Generic cabling systems – Part 5: Data centres
FIA-TSD-2000-1-1	Optical Fibre Cabling: LAN Application Support Guide
IEEE 802.3:2002	IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements: Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications
IEEE 802.3ae:2002	Amendment: Media Access Control (MAC) Parameters, Physical Layers, and Management Parameters for 10 Gb/s Operation
IEEE 802.3aq:2006 (in development at the time of writing)	10GBASE-LRM
ISO/IEC 11801 Ed.1:1995	Information technology – Generic cabling for customer premises
ISO/IEC 11801 Ed.2:2002	Information technology – Generic cabling for customer premises
ISO/IEC 24702:2006 (in development at the time of writing)	Information technology - Generic cabling for industrial premises
ISO/IEC 24764:2007 (in development at the time of writing)	Information technology - Generic cabling for Data Centre premises
IEC TR 61282-2	Fibre optic communication system design guides - Part 2: Multimode and single-mode Gbit/s applications - Gigabit Ethernet model

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AUTHORS BIOGRAPHY

Mike Gilmore, Senior Partner of The Cabling Partnership and Managing Director of e-Ready Building Limited, is involved at the highest level in UK, European and international standardization of IT cabling; an activity which draws together product selection and utilization, LAN/WAN developments, EMC issues and finally, but very significantly, installation practice.

Mike Gilmore began his cabling career with STC Defence Systems as Project Manager with the Fibre Optic Division in Leeds, West Yorkshire where he was involved in the specification of complete systems covering the commercial and military applications for optical fibre within video and data transmission. In 1986, Mike became Managing Director of Optical Core Technology Limited - one of the first specialist installers of optical fibre infrastructures.

In 1988, Mike initiated the British Standards activity to create a Code of Practice for the Installation of Fibre Optic Cabling. Published by the UK Fibreoptic Industry Association in 1991 and by BSI in 1994 (as BS 7718) this document was a world leading text for the design and quality assurance of optical networks.

As the Technical and Standards Director of the UK Fibreoptic Industry Association, Mike is heavily involved in the development of training and competence standards for the fibre installation industry and sets down policy in this area. In addition he chairs the audit and arbitration committees for the FIA. His book "Fibre optic cabling; theory design and installation practice" published in 1991 remains a reference for both experts and entrants into this field.

Since 1991, Mike has been Senior Partner of The Cabling Partnership and has widened the scope of the organisations activity within the European and international cabling standards community. These activities cover all forms of telecommunications cabling.

At the European level Mike is Convenor of CENELEC TC215 Working Group 1, the group that controls the development of European standards for the design and installation of telecommunications cabling including:

- EN 50173-1:2002 Information technology - Generic cabling systems - General requirements and office areas;
- EN 50174-1: Information technology - Cabling installation - Part 1: Specification and Quality Assurance;
- EN 50346: Information technology - Testing of installed cabling.

Mike is currently overseeing the division of EN 50173-1:2002 into a series of standards covering generic cabling in different types of premises;

- prEN 50173-1: Information technology - Generic cabling systems - General requirements;
- prEN 50173-4: Information technology - Generic cabling systems - Office premises;
- prEN 50173-3: Information technology - Generic cabling systems - Industrial premises;
- prEN 50173-4: Information technology - Generic cabling systems - Residential premises;
- prEN 50173-5: Information technology - Generic cabling systems - Data centres.

At international level, Mike is Convenor of the Cabling Implementation Task Group (CITG) within ISO/IEC JTC1 SC25 WG3. This group, established in February 2006, is responsible for the strategic management of the international standards covering

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the specification, QA, installation, administration, operation, maintenance and repair of generic cabling. This work supports all the cabling design standards produced by ISO/IEC JTC1 SC25 WG3 including ISO/IEC 11801, the international equivalent of EN 50173-1, and ISO/IEC 24702 for industrial premises produced by ISO/IEC JTC1 SC25 WG3 IPTG (also convened by Mike Gilmore).

In the UK, Mike is Chairman of TCT/7, the BSI Technical Committee responsible for the three UK BSI Experts Panels on telecommunications cabling. He also chairs two of these Expert Panels (TCT7/-/1 and TCT7/-/3). TCT7/-/1 acts to assist development of European and international standards. TCT7/-/3 manages the implementation of European standards and others in the UK and is responsible for the production and ongoing maintenance of BS 6701: 2004 "Telecommunications equipment and telecommunications cabling - Specification for installation, operation and maintenance".

Mike is a regular speaker at seminars and conferences in all five continents. He has provided the keynote address and opening presentation in many conferences in the UK, Germany and the Netherlands. His seminars, providing regular updates on the progression of cabling standards are particularly well attended and are operating in the UK and continental Europe.

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