TECHNICAL SUPPORT GUIDE

FIA-TSD-2000-4-1-1

OPTICAL FIBRE CABLING
-
INSTALLATION
-
INSTALLATION PRACTICE: SPLICING

Price: £75 (free to FIA members)

THE FIBREOPTIC INDUSTRY ASSOCIATION
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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;
- **t**o 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.

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FIA TECHNICAL SUPPORT GUIDES

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

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

These documents are now **free** to **FIA members** via downloads from the FIA web-site (**www.fia-online.co.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 Guides, both published and planned, 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	2000-3-2-1	OPTICAL FIBRE CABLING: ADMINISTRATION: User Guides
	2000-3-2-2	OPTICAL FIBRE CABLING: ADMINISTRATION: Cords
	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 Installed cabling using LSPM equipment
	2000-4-2-2	OPTICAL FIBRE CABLING: TESTING Installed cabling using OTDR equipment
	2000-4-2-3	OPTICAL FIBRE CABLING: TESTING: 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

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FOREWORD AND EXECUTIVE SUMMARY

Overview

Current specifications for the installation of optical fibre are often needlessly stringent, bearing little relevance to the operational requirements of a cabling system or the practicalities of meeting such a specification. This document defines an approach to, and limits for, commercially viable splice loss specifications whilst ensuring the operational requirements of a cabling system are not compromised.

The approach and limits herein have been developed by analysing the key operational requirements of a typical transmission system. Any given cabling channel will have a defined optical budget - the distribution of losses within that channel being irrelevant providing that the total channel loss is sufficiently low to meet that budget. It is, therefore, not necessary (and may even counterproductive) to specify maximum individual splice losses except where the level of loss indicates that there has been a fault in the splicing process (in excess of 0.3dB when splicing "same product" singlemode or multimode optical fibres).

With regard to jointing of singlemode optical fibres this document recognises that although modern fusion splicing machines have been optimised to reduce the splice loss to a minimum, mode field diameter mismatch can still be a major source of splice loss between two singlemode optical fibres. An analysis of the different IEC specifications for singlemode optical fibre shows that fibres within the same generic group can have mode field mismatches that will produce significant splice losses. Monte Carlo statistical modelling techniques used to model splice losses between "same product" fibres, "same generic type" fibres, "different type" fibres and "unknown" fibres show the effect of mode field diameter mismatch on individual and average splice loss.

This document:

- defines reasonable and commercially viable average splice loss limits for the various fibre types based upon these results and from additional data from splicing equipment manufacturers;
- calculates typical levels of rework are where the FIA limits are not adopted and discusses the associated cost implications;
- provides a technical checklist of the correct splicing and fibre preparation procedures required to ensure that these recommended maximum splice loss limits are achievable

Guidelines for Specifiers

- **DO**, wherever possible, include specifications for the MFD of the fibre to be used as well as the generic type.
- **DON'T** specify incompatible fibres!
- **DON'T** specify maximum individual splice losses of less than 0.3dB.
- **DON'T** set unrealistic average splice loss requirements - design systems with realistic power budgets and use the FIA guidelines to set maximum average splice losses.
- **DO** be clear about the meaning of average splice loss - only specify average losses for splices in the same segment or channel (i.e. do not specify an average splice loss per joint closure).

Guidelines for Installers

- **DON'T** quote for contracts where the optical fibres involved are not fully specified.
- **DO** consider the system topology to calculate the amount of rework and its cost before quoting for a contract.
- **DO** adopt best practices when using splicing equipment.

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INTRODUCTION

The jointing of optical fibres using fusion splicing techniques is a long established approach to the provision of low loss, high return loss and environmentally stable connections both internal and external to building.

Over the years, the capability of fusion splicing equipment has improved substantially as has the control over the tolerances of optical fibres at each side of the joint. This has led to a steady reduction in achievable splice loss. However, there is a point at which significant improvements in spliced loss performance can no longer be made without direct influence over the optical fibres themselves and it is generally recognised that such a point was reached a number of years ago.

Unfortunately, certain clients continue to place unrealistic demands for splice loss performance on installers. Such demands may be flawed in terms of what is specified and/or how it is specified.

In some cases, clients may be influenced by the claims of fusion splicing equipment manufacturers, who rightly provide specifications for how well their machines can perform - generally in favourable, best case, conditions - rather than recognising the fundamental limits defined by the tolerances of the optical fibres that are "seen in the field".

In other cases, clients fail to recognise the range of, and differences between, optical fibres that may be encountered and their influence on the performance of splices made between them.

> For example IEC 60793-2-50:2008 specifies seven different single mode optical fibre types between which fusion splicing will result in modified performance as compared with splicing between singlemode optical fibres of the same type.

The impact of specifying overly ambitious, or incorrectly defined, splice loss requirements should concern both the client and the installer alike. The installer may be faced with a considerable degree of rework that can have dramatic commercial consequences. The client may be faced with considerable project delays - the resolution of which will add further costs to the project.

This FIA Technical Support Document establishes, in a commercially neutral manner, the most appropriate way in which to specify and verify the performance of optical fibre fusion splices. It then proceeds to define reasonable and commercially acceptable limits for the splices under specific conditions.

1 SCOPE

This Technical Support Document defines the following:

- commercially and technically acceptable methods of specification of optical fibre fusion splice loss;
- measurement techniques to be used in support of the methods of specification;
- commercially and technically acceptable limits for splice loss under specific conditions.

In addition, this Technical Support Document provides indications of the effect of splice loss limits upon the level of rework required.

2 REFERENCES

ANSI/TIA/EIA-568-C	Commercial building telecommunications cabling standard
BS 6701	Telecommunications equipment and telecommunications cabling - Specification for installation, operation and maintenance
BS EN 50173-1	Information technology - Generic cabling systems: Part 1: General requirements
IEC 60793-2-10:2011	Optical Fibres - Part 2-10: Product specifications - Sectional specification for class A multimode fibres
BS EN 60793-2-10:2011	Optical Fibres - Part 2-10: Product specifications - Sectional specification for class A multimode fibres
IEC 60793-2-50:2004 (withdrawn)	Optical Fibres - Part 2-50: Product specifications - Sectional specification for class B single-mode fibres
BS EN 60793-2-50:2012 (not published at the time of the update to Issue 3.1 – may be dated 2013)	Optical Fibres - Part 2-50: Product specifications - Sectional specification for class B single-mode fibres
IEC 60793-2-50:2012	Optical Fibres - Part 2-50: Product specifications - Sectional specification for class B single-mode fibres
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

3 DEFINITIONS AND ABBREVIATIONS

3.1 Definitions

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

segment part of a cabling channel (see Figure 1) for which installed performance is specified. A segment may comprise a number of separate sections of fixed cable within which there may be multiple splices.

3.2 Abbreviations

For the purpose of this Technical Support Guide the following abbreviations apply:

D	Detector
OTDR	Optical Time Domain Reflectometer
Rx	Receiver
S	Source
Tx	Transmitter

4 METHOD OF SPECIFICATION

4.1 The system (top-down) approach

A typical transmission system (application) will have a defined optical power budget that translates, directly or indirectly, into minimum and maximum values for the insertion loss of the channel (see Figure 1).

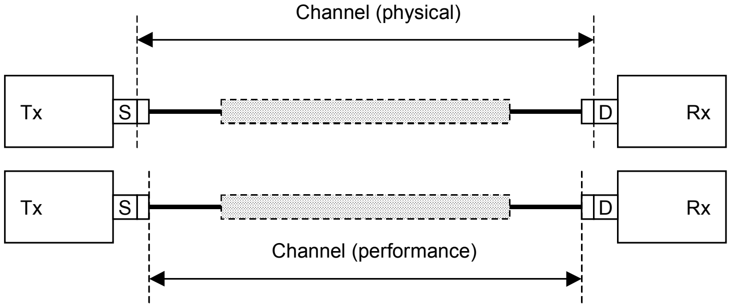

Figure 1: Channel

Within a cabling channel the combined loss of the cables and connections between those cables define the viability of the channel to support the desired application. The insertion loss performance of a single, specific, connection has no other effect on the transmission system other than to add to the total insertion loss of the complete cabling channel.

NOTE: this is not true of the return loss of the connections at or near the transmission equipment.

4.2 Connecting hardware loss specification

The insertion loss of any type of connection in an optical fibre cabling channel, independent of whether it is a demountable connection at patch panels or a “permanent“ joint elsewhere, is a combination of:

- the capability of the connecting hardware used;
- the tolerances of the optical fibre on either side of the connection;
- the process applied.

A good example of this is the specification of insertion loss for SC optical fibre connecting hardware used in generic cabling in accordance with BS EN 50173-1 which states that 100% of all randomly mated connections shall provide an insertion performance of 0.75dB or better. Furthermore, 95% of all randomly mated connections shall provide an insertion performance of 0.5dB or better. Clearly this specification is meant to apply when optical fibres of the same physical construction (core diameter, cladding diameter) are mated and is based upon a detailed analysis of the mechanical tolerances of the connecting hardware components used. It also assumes that the end-faces of the connectors meet the established criteria for cleanliness and freedom for defects i.e. the termination process has been applied correctly. If one or other of the end-faces do not meet these requirements then the connection performance will undoubtedly fall outside these limits.

However, the profile introduced by the “100%/95% random mated” requirements indicates that where a large number of connections are used within a channel then the specification of an average value, with an allowed maximum, for each connection becomes more relevant for design purposes. The average value will fall, asymptotically, as the number of connections increases but the individual maximum remains relevant since exceeding this value suggests a process failure.

Hence the most appropriate specification for a loss event within a channel containing a large number of such events is to define an average performance per event and a restriction on a specific event maximum which is consistent with a properly managed process.

4.3 Splice loss specification

4.3.1 Individual maximum and average splice loss values

Splice loss shall be specified as:

- a maximum value for an individual splice;
- an average value defined as the total loss of all splices within a cabling segment divided by the number of splices in the segment.

In order for a customer to specify relevant values within an Installation Specification or for an installer to commit to meeting a given specification, detailed knowledge of key parameters relating to the optical fibres to be spliced is required. The issues relating to singlemode and multimode optical fibre are addressed in clauses 4.3.2 and 4.3.3 respectively.

4.3.2 Singlemode optical fibre

4.3.2.1 Singlemode optical fibre types

4.3.2.1.1 Standards relationships

When Issue 2 of this document was written, there were 12 ITU-T specifications for singlemode optical fibre. These were:

- ITU-T G.652.A, .B, .C and .D;
- ITU-T G.653.A and .B;
- ITU-T G.654.A, .B and .C;
- ITU-T G.655.A, .B and .C.

These were referenced from IEC 60793-2-50:2004 (published as BS EN 60793-2-50:2004) as follows:

- Type B1.1: equivalent to ITU-T G.652.A and .B;
- Type B1.2: equivalent to ITU-T G.654.A, .B and .C;
- Type B1.3: equivalent to ITU-T G.652.C and .D;
- Type B2: equivalent to ITU-T G.653.A and .B;
- Type B4: equivalent to ITU-T G.655.A, .B and .C.

4.3.2.1.2 Current standards

Since Issue 2 of this document was written the ITU-T have updated their specifications so that there are now 19 ITU-T specifications for singlemode optical fibre:

- ITU-T G.652.A, .B, .C and .D [dated 11/2009];
- ITU-T G.653.A and .B [dated 12/2006];
- ITU-T G.654.A, .B and .C [dated 12/2006];
- ITU-T G.655.A, .B [dated 03/2003];
- ITU-T G.655.C, .D and .E [dated 10/2009];
- ITU-T G.656 [dated 12/2006];
- ITU-T G.657A1.A2, B1 and B2 [dated 11/2009];

4.3.2.1.3 Revisions to standards

IEC 60793-2-50:2012 has been published and has the following cross-references:

- Type B1.1: equivalent to ITU-T G.652.A and .B;
- Type B1.2: equivalent to ITU-T 654.B and .C (G.654.A seems to be no longer supported);
- Type B1.3: equivalent to ITU-T G.652.C and .D;
- Type B2: equivalent to ITU-T G.653.A and .B;
- Type B4: equivalent to ITU-T G.655.C, .D and .E (G.655.A and G.655.B seem to be no longer supported);;
- Type B5: equivalent to ITU-T G.656;
- Type B6_a1: equivalent to ITU-T G.657.A1
- Type B6_a2: equivalent to ITU-T G.657.A2

- Type B6_b1: equivalent to ITU-T G.657.B1
- Type B6_b2: equivalent to ITU-T G.657.B2

BS EN 60793-2-50:2012 has not yet been published so this document uses the references to IEC 60793-2-50:2012.

4.3.2.1.4 Relevance of different singlemode specifications to splice loss

One of the key differentiators between the different Types is mode field diameter.

As shown in Table 1, the mode field diameters of optical fibres meeting these specifications can differ substantially. The tolerances shown in Table 1 are wider than those typically stated by manufacturers.

IEC 60793-2-50: 2008	ITU-T	Nominal MFD_{min} (µm)	Nominal MFD_{max} (µm)	MFD tolerance (µm)	Wavelength (nm)
Type B1.1	**G652.A, .B**	8.6	9.5	0.6	1310
-	**G654.A**		10.5		
Type B1.2_b	**G654.B**	9.5	13.00	0.7	1550
Type B1.2_c	**G654.C**		10.5		
Type B1.3	**G652.C, .D**	8.6	9.5	0.6	1310
Type B2	**G.653.A, .B**	7.8	8.5	0.8	1550
-	**G.655.A**				
-	**G.655.B**				
Type B4_c	**G.655.C**	8.0	11.0	0.6	1550
Type B4_d	**G.655.D**				
Type B4_e	**G.655.E**				
Type B5	**G.656**	7.0	11.0	0.7	1550
Type B6_a1, _a2	**G.657.A1, .A2**	8.6	9.5	0.4	1310
Type B6_b1, _b2	**G.657.B1, .B2**	8.6	9.5	0.4	1310

Table 1: Mode Field Diameter (MFD) specifications of SMF

In order to discuss specification of splice loss it is important to be clear as to whether we are jointing “same product”, “same generic type”, “different type” or “unknown” optical fibres.

- “Same product” means that the optical fibres on each side of the joint have identical mode field diameters as specified Table 1. For example, for Type B1.1 (ITU-T G.652.A and .B), both optical fibres have a mode field diameter of 8.9 +/-0.6 µm.
- “Same generic type” means that the optical fibres on each side of the joint have mode field diameters as specified by a row in Table 1. For example, for Type B1.1 (ITU-T G.652.A and .B), one optical fibre has a mode field diameter of 8.6 +/-0.6 µm and the other optical fibre has a mode field diameter of 9.5 +/- 0.6 µm.
- “Different type” means that the optical fibres on each side of the joint have mode field diameters as specified by two different but known rows from inTable 1. For example, one optical fibre is Type B1.1 (which has a mode field diameter of 8.6 +/-0.6 µm) and the other optical fibre is Type B4 with a mode field diameter of 11.0 +/- 0.6 µm.
- “Unknown” means that the optical fibres on each side of the joint have mode field diameters of any two optical fibres specified in Table 1. This generates a worst case scenario for an installer since it is impossible to determine any information upon which to base a specification.

4.3.2.2 Maximum splice losses

In an ideal world, the FIA would simply define the maximum splice loss between any two singlemode optical fibres beyond which a failure to comply would suggest a mechanical failure of the splice. Unfortunately the world is not ideal. As shown in Table 1 and 5.1 there are many singlemode optical fibres, the inter-splicing of which can generate surprisingly high losses.

In order to simplify matters, the FIA has chosen to only provide a maximum splice loss for the inter-splicing of “same product” singlemode optical fibres or optical fibres from different IEC Type having a common mode field diameter specification i.e. nominal value and tolerance. In such conditions a maximum splice loss specification of 0.3dB is reasonable.

4.3.2.3 Average splice losses

Where singlemode optical fibre cabling is installed the number of splices in a cabling segment can be quite high.

The required average splice loss has to meet the requirements of the transmission equipment to be connected to the cabling channel, where known. If the equipment to be used is unknown, at the time the splicing work is undertaken, then an average splice loss has to be applied which is both economically viable and technically feasible.

The achievable average value depends upon the number of splices within the sample under consideration and, most importantly, the specification(s) of the optical fibres that are spliced. This is discussed in 8.2.

4.3.3 Multimode optical fibre

IEC 60793-2-10:2011 (published as BS EN 60793-2-10:2011) specifies five different multimode optical fibres:

- Type A1a.1: 50/125 GI;
- Type A1a.2: 50/125 GI (the basis for the Category OM3 cabled optical fibre cable specification);
- Type A1a.3: 50/125 GI (the basis for the Category OM4 cabled optical fibre cable specification);
- Type A1b: 62.5/125 GI;
- Type A1d: 100/140 GI.

For multimode optical fibre of a given physical construction, i.e. 50/125 or 62.5/125, a maximum splice loss specification of 0.3dB is reasonable.

Where multimode optical fibre is involved the number of splices in a cabling segment is generally low and the average value may not be relevant. In such cases the maximum value for an individual splice shall be applied to all splices.

5 RESTRICTIONS OF ACHIEVABLE PERFORMANCE

5.1 Single mode optical fibre

The splice loss between two optical fibres depends upon the process used (in terms of cleaving, arc management etc) and the difference in mode field diameter of the optical fibre themselves. The best managed process cannot overcome fundamental mismatches in the optical fibre’s construction.

The loss, due to MFD mismatch, generated by otherwise “perfect” jointing of two optical fibres with different mode field diameters is given by the following equivalent formula:

$$\text{Splice loss} = -10 \log_{10} (4/((d_1/d_2 + d_2/d_1)^2))$$

NOTE: d_1 and d_2 are the mode field diameters of the optical fibres (corrected for the same wavelength).

Using the formulae above when $d_1 = d_2$ the resulting loss is 0 dB. However, most of the IEC product specifications of Table 1 allow optical fibres with a nominal MFD of 8 μm to vary between 7.3 μm and 8.7 μm. Such a variation will lead to measurable splice losses. Furthermore, even if the MFDs of the optical fibres on either side of the splice were identical, the splicing process itself will have an effect on the resulting loss. Based upon laboratory conditions “make and re-make” data from splicing equipment suppliers and the information created within a Monte Carlo modelling tool, the probable splice insertion loss performance of optical fibres of different mode field diameters is approximated in Table 2.

NOTE: the mode field diameters of singlemode optical fibres are specified at defined wavelengths as shown in Table 1. If splicing of IEC Types that are specified at different wavelengths is to be undertaken, then the mode field diameters and their tolerance need to converted to a common wavelength. The FIA recommendation is that the supplier of the optical fibre that is specified at 1310nm be approached for information relating to the MFD values of that optical fibre at 1550nm. A determination of splice loss performance can then be made using Table 2.

The data in Table 2 is for information only and should not be used as a basis for the agreement of a specification.

Maximum splice insertion loss values **M_1 (dB) = maximum individual splice** **M_{10} (dB) = maximum mean splice insertion loss for 10 splices**							
Mode Field Diameter (µm)	**8 +/- 0.7**	**9 +/- 0.7**	**10 +/- 0.7**	**11 +/- 0.7**	**12 +/- 0.7**	**13 +/- 0.7**	**14 +/- 0.7**
8 +/- 0.7	M_1 = 0.14 M_{10} = 0.05	M_1 = 0.28 M_{10} = 0.13	Not viable	Not viable	Not viable	Not viable	Not viable
9 +/- 0.7		M_1 = 0.11 M_{10} = 0.05	M_1 = 0.22 M_{10} = 0.12	Not viable	Not viable	Not viable	Not viable
10 +/- 0.7			M_1 = 0.08 M_{10} = 0.04	M_1 = 0.19 M_{10} = 0.10	Not viable	Not viable	Not viable
11 +/- 0.7				M_1 = 0.08 M_{10} = 0.04	M_1 = 0.17 M_{10} = 0.08	Not viable	Not viable
12 +/- 0.7					M_1 = 0.08 M_{10} = 0.04	M_1 = 0.15 M_{10} = 0.08	M_1 = 0.25 M_{10} = 0.17
13 +/- 0.7						M_1 = 0.08 M_{10} = 0.04	M_1 = 0.13 M_{10} = 0.07
14 +/- 0.7							M_1 = 0.07 M_{10} = 0.04
"Not viable" indicates that an individual splice may exceed 0.3dB - it does not mean that mechanically stable splices cannot be achieved.							

Table 2: Splice loss performance for other product combinations

Table 2 indicates that, even in laboratory conditions, splices between optical fibres having different mode field diameters will produce outcomes that may not be supportable within operational systems.

5.2 Multimode optical fibre

The splice loss between two multimode optical fibres depends upon the process used (in terms of cleaving, arc management etc) and the difference in core diameter and numerical aperture of the optical fibre themselves. The best managed process cannot overcome fundamental mismatches in the optical fibres construction.

It is not recommended to splice multimode optical fibres of differing constructions.

There is no significant difference in splice loss distribution between splicing Type A1a.1 to Type A1a.1 (or A1a.2 to A1a.2) and A1a.1 to A1a.2.

6 WHEN AND HOW TO MEASURE SPLICE LOSS

Measurement of splice loss is well specified in IEC 61280-4-2 for single mode optical fibre and in FIA-TSD-2000-4-2-2 for both singlemode and multimode optical fibres. The splice in question is measured, typically with an OTDR under specified conditions, in both directions and the mean value taken as the test result.

7 MEASUREMENT ACCURACY

As splice loss has improved, its measurement has become more difficult since the value measured approaches the achievable accuracy of the OTDR.

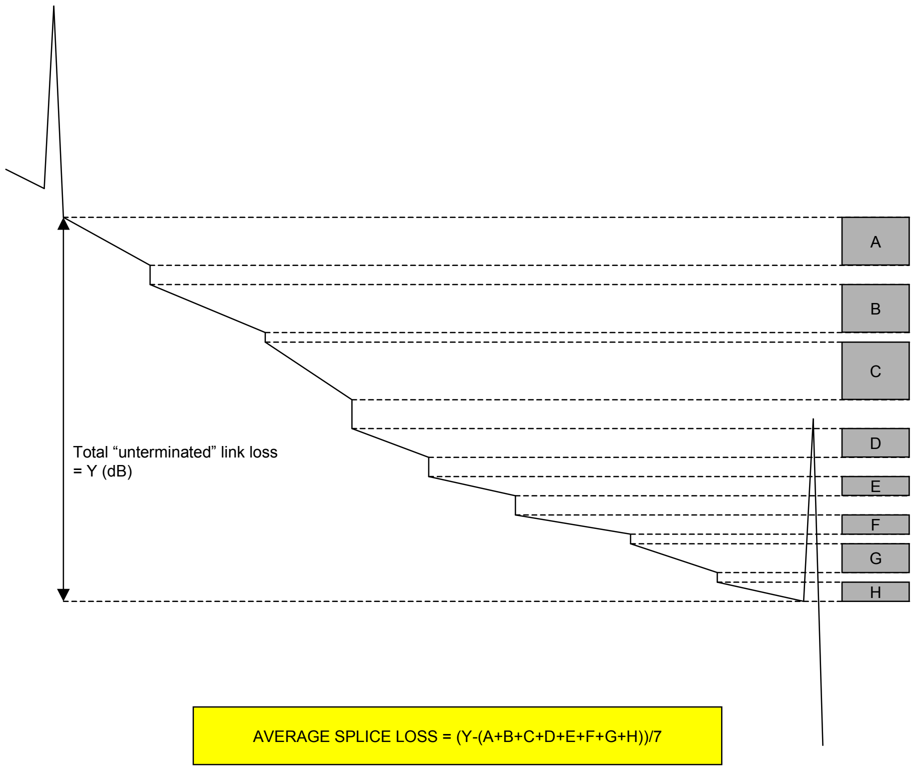

Figure 2: OTDR characteristic used for calculation of average splice loss

It is common for OTDR equipment to provide calculations of splice and other event loss based upon a variety of statistical approaches. Some of these approaches are defined in international standards while others are de-facto methods recognised by the industry itself. Using a maximum specified value of an individual splice of 0.3dB (for a same product SMF splice, a same type SMF B1.1, B1.3, B4, B5 and B6_a or B6_b splice and a same type MMF splice), measurement using OTDR calculations is no problem.

However, the determination of an average value in the region of 0.05dB would require individual measurements of below this figure and where technical disputes arise it may be more appropriate to consider an alternative approach.

One such method of determining average splice loss removes the problem of assessment of very small losses by measuring the, generally, higher attenuation created by the cabling segments between the splices, adding them together and allocating the remaining loss to the total number of splices. This approach is shown in Figure 2.

8 REASONABLE AND COMMERCIALLY VIABLE LIMITS

8.1 Commercial viability

8.1.1 An overview

The installer and the client may have different perspectives of the commercial viability of a splice loss specification. However, those perspectives will be coloured by the same two basic parameters: cost and delay. For the installer any overrun on project cost can be critical to the profitability of the contract in hand and business overall. For the client project delay may be the most significant issue. However there are hidden issues on both sides that need to be considered.

8.1.2 The installer perspective

The primary concern is an increase in costs that cannot be passed on to the client. Rework of the installed cabling joints is the main factor, which is why the FIA limits defined in 8.2 are so important. However, any costs associated with the clarification, re-negotiation or arbitration of specifications as originally quoted also should not be ignored. The resource involved in such discussions is significantly more expensive than that involved in the splicing and commissioning processes. While delay is an automatic consideration, unless it is not being paid for, it should be recognised that people cannot be in two places at once and delays in finishing one project may result in delayed starts of the other projects. Reputation becomes an issue where project delays are experienced - even if they are being paid for.

8.1.3 The client perspective

In an ideal world, a client would prefer not to have to specify splice losses at all i.e. they would all measure 0 dB without any additional cost or delay to a project. In reality, clients need to set a suitable specification for splice loss that balances any potential delay to the project with the necessary system performance. It is therefore in the client's interest to produce a clear and unambiguous specification which guarantees a timely completion of the job in hand. By failing to do so the client risks amassing costs associated with the clarification, re-negotiation or arbitration of specifications.

If the average splice loss is unclear or specified at too low a level then the cost of delivery will increase as will the time taken required to complete the task. Ultimately, it may be impossible to meet the requirement. Therefore, it may have been simpler to specify better the optical fibre between the splices rather than drive down the splice loss itself.

8.2 Single mode optical fibre

In this edition of this FIA Technical Support Document it has been agreed to address only the IEC Types of optical fibres that will be encountered by the vast majority of FIA members in a multi-splice environment i.e. IEC 60793-2-50 Types B1.1, B1.3, B4 and B5.

NOTE: B6 optical fibres could be included in the assessment of B1.1 and B1.3, but are considered to be for use within premises and not likely to be found in multi-splice environments.

Based upon "make and re-make" data from splicing equipment suppliers the FIA recommends the values shown in Table 3 as the minimum specifications to be used in contracts where the optical fibres to be spliced are known to be the same type. It should be noted that as the number of splices to be included in the averaging process increases, then the maximum average splice loss falls. This trend is asymptotic and the "ten splice" average should be used for cabling segments or channel containing more than ten splices.

8.3 Multimode optical fibre

See 4.3.3.

	Average splice loss (dB max.)	
No. of splices over which the average is calculated	**B1.1, B1.3**	**B4 and B5**
2	0.09	0.12
3	0.08	0.10
4	0.08	0.09
5	0.07	0.08
10	0.06	0.08

Table 3: Splice loss limits for same SMF product splices

8.4 Generic cabling standards (BS EN 50173-1, ISO/IEC11801 and ANSI/TIA/EIA/568-C)

The standards for generic cabling standards listed above define a maximum insertion loss for a splice (of any type) for both singlemode and multimode optical fibres to be 0.3dB.

9 REWORK ISSUES FOR SINGLEMODE OPTICAL FIBRE CABLING

9.1 General

Failure to adopt and accept the limits in clause 8 will result in increased levels of rework. The degree of rework will increase as the limits are specified ever more tightly. Ultimately it will become impossible to meet the requirements, independent of the level of rework undertaken, because the client demands exceed the splice loss limits that the tolerances of the optical fibres allow. Before that point is reached there may be other issues that prevent further rework (e.g. using up the available optical fibre length within the closure) without complete re-splicing of a closure.

Clauses 9.2 and 9.3 contain tables indicating the typical levels of rework that may be applicable as the maximum average splice loss is reduced.

Clause 9.2 shows the typical rework levels for the product types IEC 60793-2-50 Types B1.1, B1.3, B4 and B5 that are applicable to fusion splicing equipment that uses core alignment techniques. Clause 9.3 shows the typical rework levels, for those product types, that are applicable to fusion splicing equipment that uses cladding alignment techniques.

Cladding alignment splicing equipment does not compensate for core-cladding concentricity error of the optical fibres and results in the higher level of rework percentages shown in Table 5. However, it should be noted that if the FIA limits of Table 3 are adopted the level of rework for both types of fusion splice equipment is insignificant.

The real impact of core alignment techniques is seen as the maximum average splice loss is reduced below the levels recommended by the FIA in Table 3. In such circumstances core alignment technology results in lower rework levels.

9.2 Rework levels using core alignment splicing equipment

Table 4 contains indicative rework levels for splices produced using core alignment splicing equipment. It should be pointed out that the rework percentages depend upon a number of factors relating to the installation environment. It is believed that the inaccuracy of the figures in Table 4 could be as high as 5% for rework values below 10% and reflects fusion splicing practices rather than optical fibre parameters tolerances.

Same Product within IEC 60793-2-50 Types B1.1/ B1.3											
Allowed maximum splice insertion loss (dB)	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**	**0.10**	**0.11**	**0.12**	**0.13**
Rework (%) 1 splice	26	13	4.7	1.8	0.8	0.3	0.2	0.05	0.01	0.01	0
Rework (%) 2 splice average	23	6.3	1.5	0.3	0.03	0	0	0	0	0	0
Rework (%) 3 splice average	19	3.3	0.5	0.04	0	0	0	0	0	0	0
Rework (%) 4 splice average	15	1.8	0.02	0	0	0	0	0	0	0	0
Rework (%) 5 splice average	15	1.0	0.2	0	0	0	0	0	0	0	0
Rework (%) 10 splice average	8	0.1	0	0	0	0	0	0	0	0	0

Same Product within IEC 60793-2-50 Types B4 and B5											
Allowed maximum splice insertion loss (dB)	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**	**0.10**	**0.11**	**0.12**	**0.13**	**0.14**	**0.15**
Rework (%) 1 splice	45	20	8.7	3.3	1.4	0.6	0.3	0.08	0.03	0.01	0
Rework (%) 2 splice average	45	17	3.8	1.2	0.2	0.07	0.01	0	0	0	0
Rework (%) 3 splice average	45	11	1.7	0.3	0.04	0	0	0	0	0	0
Rework (%) 4 splice average	44	8.3	0.7	0.1	0	0	0	0	0	0	0
Rework (%) 5 splice average	44	5.4	0.4	0	0	0	0	0	0	0	0
Rework (%) 10 splice average	43	1.7	0.01	0	0	0	0	0	0	0	0

Table 4: Impact on yield of splice loss specification for core alignment splicing equipment

9.3 Rework levels using cladding alignment splicing equipment

Table 5 contains indicative rework levels for splices produced using cladding alignment splicing equipment. It should be pointed out that the rework percentages depend upon a number of factors relating to the installation environment. It is believed that the inaccuracy of the figures in Table 5 could be as high as 5% for rework values below 10%.

Same Product within IEC 60793-2-50 Types B1.1/ B1.3											
Allowed maximum splice insertion loss (dB)	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**	**0.10**	**0.11**	**0.12**	**0.13**
Rework (%) 1 splice	63	45	28	16	8.5	4.1	2.0	1.0	0.05	0.02	0.08
Rework (%) 2 splice average	73	47	23	9.2	3.0	1.0	0.2	0	0	0	0
Rework (%) 3 splice average	79	47	19	6.0	1.3	0.2	0.04	0	0	0	0
Rework (%) 4 splice average	84	48	17	3.7	0.5	0.03	0	0	0	0	0
Rework (%) 5 splice average	87	49	14	2.3	0.2	0.01	0	0	0	0	0
Rework (%) 10 splice average	95	50	7.5	0.2	0	0	0	0	0	0	0

Same Product within IEC 60793-2-50 Types B4 and B5											
Allowed maximum splice insertion loss (dB)	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**	**0.10**	**0.11**	**0.12**	**0.13**	**0.14**	**0.15**
Rework (%) 1 splice	64	39	21	13	5.9	3.2	1.7	1.0	0.4	0.2	0.1
Rework (%) 2 splice average	74	40	12	6.4	2.2	0.8	0.3	0.05	0.02	0	0
Rework (%) 3 splice average	79	41	13	3.4	0.7	0.2	0.04	0	0	0	0
Rework (%) 4 splice average	84	42	11	2.2	0.4	0.04	0.01	0	0	0	0
Rework (%) 5 splice average	87	41	8.8	1.4	0.2	0.02	0	0	0	0	0
Rework (%) 10 splice average	95	40	3.6	0.2	0	0	0	0	0	0	0

Table 5: Impact on yield of splice loss specification for cladding alignment splicing equipment

9.4 The cost and project delivery impact of rework

For the purposes of this clause, it is assumed that the operatives observe the recommendations of clause 10.

It is also assumed that the work is undertaken such that all splicing is completed, with appropriate splice protection and housings being applied and fitted within splice enclosures before final acceptance testing is commenced. All applicable installation standards including BS 6701 include text to the effect that "final acceptance shall only proceed following the fitting of all components associated with the telecommunications cabling". This is an efficient use of labour since the skill sets of the splicing/enclosure assembly operatives will be different to those of the testing operatives.

Upon completion of the testing in accordance with the requirements of clauses 6 and 7, rework will be required if the average splice loss of a cabling segment exceeds the specified value. The highest loss splices within a segment will have to be re-accessed and re-made.

However, in the rework phase the resource allocation is fundamentally different to that of the initial work. During rework the re-spliced joints will require real-time measurement to determine the scale, if any, of improvement. As a result, rework requires the simultaneous involvement of both splicing and testing operatives. Furthermore, unless complex loop-back test procedures are planned and implemented, it may require two test operatives to provide bi-directional results upon which to base a recalculated average splice loss (the likelihood of this requirement increases as the segment length increases).

It should also be recognised that during rework the greatest part of the task is the gaining of access to the location of the splice enclosure, its dis-assembly, re-assembly, the reinstatement of the site and associated re-documentation. The allocation of multiple operatives during this process represents a large amount of "dead-time" and potential lost productivity from resources (both human and capital) that could be utilised on other work as a source of revenue generation.

Clearly, the rework percentage increases rapidly as the splice loss limit is reduced below those defined in Table 3. However, the cost of a given rework percentage is significantly affected by the number of optical splices in each closure. For example, if each closure contains twelve splices and the predicted rework level is 10%, then it is probable that at least one splice in every closure will require rework but there may only be one splice in that enclosure that requires attention. In such a situation the cost of rework could be the same or even more than the initial installation cost. However, if each closure only contains four splices the rework cost will be much reduced even though the rework percentage remains at 10%.

10 TECHNICAL CHECKLIST

The limits for maximum average splice loss of Table 3 will only be achieved if the splicing process is undertaken in a professional manner i.e. the operative should in all circumstances avoid "short-cuts". In view of the potential cost of rework as outlined in 9.4 it is strongly recommended that organisations responsible for splicing operatives, either directly or indirectly, develop systems to both educate their staff and limit the opportunities for short-cut practices.

The three golden rules for effective and high performance splicing are

- "**PREPARATION, PREPARATION and PREPARATION**". The importance of preparation at all stages of the splicing process cannot be underestimated;
- "**USE AND MAINTAIN EQUIPMENT AS DIRECTED BY ITS SUPPLIER**";
- "**WORK SAFELY**" in accordance with BS EN 60825-2 (use the FIA Technical Support Documents for further guidance)

Preparation of work area

Ensure that the work area is as clean as possible. Contamination of the work area with cable filling gel attracts dirt (dirt is the enemy of good splices, for a SMF core of 9um diameter, an offset between cores of this magnitude can give a 3dB insertion loss).

Preparation of fusion splicing equipment

Contamination of the fusion splicing equipment with cable filling gel attracts dirt. Ensure that the fusion splicing equipment is as clean as possible. In particular, ensure that the fusion splicing equipment splicer clamps and V-grooves remain clean. This is especially important when using a fusion splicing equipment that uses cladding alignment. If contamination of the clamps or V-grooves is suspected, follow the manufacturers' instructions to clean them.

If the splicer requires optimisation of the arc for the working environment, follow the manufacturer's instruction to do this before starting work.

Choose the correct splice program for the optical fibre type to be jointed.

Prepare the optical fibre cleaver

Contamination of the optical fibre cleaving tool with cable filling gel attracts dirt. Ensure your optical fibre cleaving tool is as clean as possible.

The optical fibre cleaving tool shall have a sharp and correctly adjusted blade. A blunt or incorrectly adjusted blade not only contributes to poor cleave angles, but also to "chipping" or cracking of the fibre and other deformation of the fibre end.

Prepare and clean cable elements

Ensure all gel is cleaned from an optical fibre (using the cleaning materials specified by the cable supplier) before allowing it to touch the optical fibre preparation tools or fusion splicing equipment.

Fitting of splice protection sleeve

Ensure that splice protection sleeve is applied before any further processing of the optical fibre is undertaken.

Prepare the primary coating stripping tool

Ensure your optical fibre primary coating stripping tool is as clean as possible. Where relevant, ensure that the stripping tool is correctly adjusted.

Remove optical fibre primary coating

Use the optical fibre stripping tool in a single pass to remove the primary coating from the optical fibre. Making a second pass increases the risk of contact between the blade and the fibre, with consequent reduction in mechanical strength of the spliced fibre.

Clean the fibre to remove remaining coating debris, cable gel residue etc

Use a clean lint free wipe and clean alcohol (Iso Propyl Alcohol/Propan-2-ol/IPA) to remove any remaining coating from the fibre. Do not touch the stripped region of the fibre with fingers as natural oils from your skin will contaminate the cladding surface.

Cleave the fibre

Once the optical fibre has been cleaved, it shall not be cleaned and shall be placed directly into the fixtures of the fusion splicing equipment. Ensure the end-face of the optical fibre does not come into contact with any surface, including the parts of the fusion splicing equipment. Contamination of the optical fibre end-face is not always removed by the cleaning arc.

Splice the fibre

Most fusion splicing equipment checks the optical fibres prior to splicing to confirm a good splice can be made. Checks can include:

- ***cleave angle***:
    - cleave angles over 1° on optical fibres of IEC 60793-2-50 Types B2, B4 and B5 can contribute significantly to insertion loss.
    - cleave angles over 2° on optical fibres of IEC 60793-2-50 Types B.1.1 and B1.3 can contribute significantly to insertion loss.
    - if the fusion splicing equipment allows, set the cleave angle rejection threshold to these values and do not override during the splicing process.
- ***cracks***:
- ***roll-off or lip***:
- ***dust contamination***:
- ***splice programme***:
    - if a check is made to ensure that the chosen splice program is correct for the optical fibre type in the fusion splicing equipment and an error is notified, do not override the fusion splicing equipment and continue to make a splice. Follow the instructions provided by the fusion splicing equipment supplier (which usually require re-preparation of the optical fibres), or choice of a more appropriate splice programme.

Protect the splice

Fusion splicing equipment manufacturers have taken care to develop programs for their heat shrink ovens that shrink the protection sleeves as fast as possible, without trapping air in the sleeve and without stressing the fibre. Choose the appropriate heat shrink oven program, as provided by the manufacturer of the fusion splicing equipment. When removing the hot sleeve from the heat shrink oven, ensure it is completely cooled to the ambient temperature before placing it into the splice tray. Putting hot sleeves into the splice tray can cause microbend loss due to stress on the fibre.

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