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SERIES L: ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Passive optical devices

SERIES L: ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Passive optical devices

Optical fibre splices

Recommendation ITU-T L.400/L.12

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ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

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Recommendation ITU-T L.400/L.12

Optical fibre splices

Summary

Recommendation ITU-T L.400/L.12 specifies splices of single-mode and multimode optical fibres. It describes suitable procedures for splicing that should be carefully followed in order to obtain reliable splices between single optical fibres or ribbons. The procedures apply to both single optical fibres and ribbons (mass splicing).

Splices are critical points in the optical fibre network, because they strongly affect the quality and lifetime of links. In fact, the splice should ensure high quality and stability of performance with time. High quality in splicing is usually characterized by low splice loss and tensile strength near that of the fibre proof test level. Splices should be stable over the design life of the optical fibre link under its expected environmental conditions.

At present two technologies, fusion and mechanical, can be used for splicing glass optical fibres and the choice between them depends upon the expected functional performance and considerations of installation and maintenance. These splices are designed to provide permanent connections.

The following elements have been modified in this edition of Recommendation ITU-T L.400/L.12:

- maximum attenuation of fibre splices depending on the alignment method (active core, active cladding and passive V-groove alignment);
- maximum attenuation for mechanical splices;
- validation of splicing procedure is added with average and maximum attenuation (97% of the splices) of fibre splices;
- the appendix with Japanese experience is removed;
- inclusion of Appendix II, which shows the increase in attenuation when splicing different types of optical fibres by taking into account the mode field diameter mismatch, the core-cladding concentricity and the cladding diameter;
- inclusion of Appendix III, which explains the fibre imaging process in fusion splicing machines.

History

Edition	Recommendation	Approval	Study Group	Unique ID[*]
1.0	ITU-T L.12	1992-07-31		11.1002/1000/1416
2.0	ITU-T L.12	2000-05-12	6	11.1002/1000/5062
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Keywords

Fusion splice, mechanical splice, optical fibre splice.

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FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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1 Scope

This Recommendation specifies splices of single-mode and multimode optical fibres. It describes suitable procedures for splicing that should be carefully followed in order to obtain reliable splices between single optical fibres or ribbons. The procedures apply to both single optical fibres and ribbons (mass splicing).

In addition, this Recommendation describes the optical, mechanical and environmental properties, recommended test methods and recommended test severities that should be considered for an optical fibre splice. Moreover, validation tests of the splice procedure are given to obtain the expected optical splice properties.

Further information is provided in chapter 6 of [b-ITU-T TR-OFCS]. The fibres should be in accordance with [ITU-T G.651.1], [ITU-T G.652], [ITU-T G.653], [ITU-T G.654], [ITU-T G.655], [ITU-T G.656] and [ITU-T G.657].

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.651.1]	Recommendation ITU-T G.651.1 (2018), *Characteristics of a 50/125 µm multimode graded index optical fibre cable for the optical access network*.
[ITU-T G.652]	Recommendation ITU-T G.652 (2016), *Characteristics of a single-mode optical fibre and cable*.
[ITU-T G.653]	Recommendation ITU-T G.653 (2010), *Characteristics of a dispersion-shifted, single-mode optical fibre and cable*.
[ITU-T G.654]	Recommendation ITU-T G.654 (2020), *Characteristics of a cut-off shifted single-mode optical fibre and cable*.
[ITU-T G.655]	Recommendation ITU-T G.655 (2009), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable*.
[ITU-T G.656]	Recommendation ITU-T G.656 (2010), *Characteristics of a fibre and cable with non-zero dispersion for wideband optical transport*.
[ITU-T G.657]	Recommendation ITU-T G.657 (2016), *Characteristics of a bending loss insensitive single-mode optical fibre and cable*.
[IEC 61300-1]	IEC 61300-1:2016, [1] *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 1: General and guidance*.

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[1] Withdrawn.

[IEC 61300-2-1] IEC 61300-2-1:2009, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-1: Tests – Vibration (sinusoidal).*

[IEC 61300-2-4] IEC 61300-2-4:2019 + AMD1:2020, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-4: Tests – Fibre or cable retention.*

[IEC 61300-2-5] IEC 61300-2-5:2009, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-5: Tests – Torsion.*

[IEC 61300-2-7] IEC 61300-2-7:2013, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-7: Tests – Bending moment.*

[IEC 61300-2-9] IEC 61300-2-9:2017, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-9: Tests – Shock.*

[IEC 61300-2-17] IEC 61300-2-17:2010, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-17: Tests – Cold.*

[IEC 61300-2-18] IEC 61300-2-18:2005, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-18: Tests – Dry heat – High temperature endurance.*

[IEC 61300-2-21] IEC 61300-2-21:2009, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-21: Tests – Composite temperature/humidity cyclic test.*

[IEC 61300-2-22] IEC 61300-2-22:2007, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-22: Tests – Change of temperature.*

[IEC 61300-2-26] IEC 61300-2-26:2006, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-26: Tests – Salt mist.*

[IEC 61300-2-27] IEC 61300-2-27:1995, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-27: Tests – Dust – Laminar flow.*

[IEC 61300-2-45] IEC 61300-2-45:1999, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-45: Tests – Durability test by water immersion.*

[IEC 61300-3-3] IEC 61300-3-3:2009, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-3: Examinations and measurements – Active monitoring of changes in attenuation and return loss.*

[IEC 61300-3-4] IEC 61300-3-4:2012, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-4: Examinations and measurements – Attenuation.*

[IEC 61300-3-6] IEC 61300-3-6:2008, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-6: Examinations and measurements – Return loss.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

None

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 optical fibre splice: Permanent or separable joint whose purpose is to couple optical power between two optical fibres, achieved by either a fusion or a mechanical technique.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

IL	Insertion Loss
MFD	Mode Field Diameter
OTDR	Optical Time Domain Reflectometer
RH	Relative Humidity
RL	Return Loss
UV	Ultraviolet

5 Conventions

None.

6 Types of splices – general description

All optical fibre splices mentioned in this Recommendation should be suitable for indoor applications as well as for outdoor environments when stored in an appropriate enclosure.

6.1 Fusion splices

Different methods exist to obtain a fusion splice of single fibres or ribbons. Electric arc-fusion is the most widely used method to make reliable single or mass optical splices in the field. The fusion process is realized by using specially developed splicing machines.

To make a fusion splice, all protective coatings are removed from the fibres, and the fibres are cleaved and then positioned and aligned between two electrodes in the splicing machine. An electric arc heats the glass until the melting or softening point is reached and at the same time the fibres are brought together longitudinally in such a way that a geometrically continuous glass filament is obtained. The fibre alignment in these machines can be passive (V-groove alignment) or active (light injection and detection system or core and cladding profile monitoring and alignment system). A suitable protection device is then applied to the splice area to protect the bare fibre and to allow handling and storage without adversely affecting the physical integrity of the splice. The cleave quality and the intensity and the duration of the arc, as well as the differences between the fibres (refractive index profile, mode field diameter (MFD), core-cladding concentricity, cladding diameter) to be spliced determine the splice loss. In addition, the quality of coating removal, fibre cleaving, and splice protection contribute to long-term mechanical reliability in the field.

6.2 Mechanical splices

Mechanical splices have different structures and physical designs, and usually include the following basic components:

- a surface for aligning mating fibre ends;
- a retainer to keep the fibres in alignment;
- an index-matching material (gel, grease, adhesive, etc.) placed between the fibre ends.

Mechanical splices can be used for single fibres or ribbons. Some designs allow installation on the fibres at the end of a cable in the factory for faster jointing in the field.

An optical matching material between the ends of the fibres can be used to reduce Fresnel reflections. This material should be chosen to match the optical properties of the fibre. Common index-matching materials include silicon gels, ultraviolet-curable (UV-curable) adhesive, epoxy resins and optical greases. The refractive index of the index-matching material is temperature dependent, which could result in a change in return loss (RL) when the ambient temperature changes. More detailed information on index-matching materials can be found in Appendix I.

As for fusion splices, the cleave quality as well as the differences between the fibres (refractive index profile, MFD, core-cladding concentricity, etc.) to be spliced determine the splice loss.

7 Splicing procedure steps

7.1 Fibre cleaning and end preparation

For gel-filled cables, the fibres should be mechanically cleaned of the water-blocking compound of the cable using lint-free paper tissue or cotton cloth. Commercial solvents are available to assist in this cleaning. Care should be taken that the ribbon matrix material and the fibre coatings are not damaged either mechanically or chemically. Long-term soaking in solvents should not be allowed, as the fibre coating can be damaged. In addition, the solvent supplier should disclose all safety-related information about these products.

The fusion splicing machine or mechanical splice assembly tool should be close to the joint enclosure, so that the fibres are not subjected to excessive bending, tensile or pressure stresses.

The ends of the fibres to be spliced should be identified on the basis of the cable identification system that denotes the fibres in the cable.

If protection tube sleeves are used, they should be placed over one end of the fibres or ribbons to be spliced before splicing. Clamshell-type protectors can be fitted after splicing is complete.

7.2 Coating stripping

Where applicable, secondary coatings (tight buffer or loose tube constructions) should be removed to the distance recommended by the splice protector manufacturer using an appropriate tool in order to expose the primary coating.

Enough coating should be removed from the ends so that all bare fibre is covered by the protection device after cleaving and fusion splicing or by the mechanical splice. Coating removal could be the most critical operation in the splicing procedure, especially if it has to be performed on fibres that have been in the field for many years, because stripability may decline due to ageing. Therefore, this step must be performed carefully because the final strength of the completed splice depends on minimizing the exposure that can cause flaws in the bare fibre.

The stripping method could be chemical, thermal or mechanical, depending on the application and desired performance. In the case of a chemical method, the manufacturer should supply all safety-related information about the stripping product. Typically, for underground, directly buried or aerial applications, mechanical stripping is used. The blade separation and alignment of the semi-circular or V-groove openings should be controlled to penetrate into the soft inner coating layer without scratching the fibre surface. The blades should be examined carefully and frequently. The blades should be well aligned, clean at all times and replaced if damaged or worn. Where the blades are an integral part of the stripper, the tool should be replaced. When thermal stripping methods are used, especially for ribbons, the coating should be heated to the temperature recommended by the ribbon manufacturer, and then removed by a blade. For submarine applications, the chemical method is more suitable for the higher proof test levels required.

Holders are always used for stripping, cleaving and splicing fibre ribbons and are sometimes used for single fibre splicing systems. The ribbons are held in a holder prior to stripping and cleaving, as well as during the fusion process. The holder should ensure a good alignment of the fibres without damaging them. Only the coated part of the fibre or ribbon should be put into the holder, so that clamping does not cause any damage. The holders should be kept clean and free of debris.

7.3 Cleaning of the stripped fibre section

When fibre end cleaning is needed, the stripped fibre sections should be cleaned with paper tissue soaked with reagent grade alcohol to eliminate residual coating, paying attention not to break them. Avoid wiping the fibre more than necessary to clean off debris.

7.4 Fibre cleaving

The bare fibre ends should be cleaved perpendicular or angled to the longitudinal axis; and the cut surface should be mirror-like without chips or hackle.

For fusion splices, end angles should be typically less than 1° from perpendicular for single fibres and less than 3° to 4° for ribbons (depending on the fibre type) to achieve a satisfactory splice. The cleaving tool should be capable of achieving these values with a controlled length of bare fibre, compatible with the splicing system and protection device.

For mechanical splices, two types can be identified.

- Perpendicular cleave, with typically the same cleave angle as fusion splices.
- Angled cleave, with a cleave angle of at least 4°. This is done to eliminate reflected light due to the mismatch between fibre glass and index-matching material at extreme temperature. When splices are assembled with angled cleaves instead of perpendicular cleaves, the reflected light is no longer completely captured and guided by the fibre core, but is directed to the fibre cladding where it is attenuated.

The cleaving tool should be clean and properly adjusted to produce consistent fibre ends with the appropriate cleaving angle. Dirty cleaving tool clamping pads can cause flaws that make the fibre break at the wrong location or reduce the strength of the completed splice. The blade should score the fibre sufficiently to produce a clean break, but should not impact so hard on the fibre that it shatters. Cleaving tools that use bending to stress the fibres should be limited in their travel to avoid over-bending the fibres. For mass fusion, the cleaved bare fibre lengths should be approximately equal across the ribbon to provide uniform overlap on all of the fibres during fusion. The offcuts cleaved from the fibre should be collected and disposed of carefully to prevent injury.

7.5 Splicing

7.5.1 Electric arc-fusion splicing

7.5.1.1 Control of the splicing parameters and conditions

Before using the splicing machine, it is fundamental to check its performance. The condition of the electrodes is a critical factor determining whether fusion splicing will proceed normally, especially when working at environmental extremes.

A good indicator of the electrode condition and whether the machine parameters are set correctly for the type of fibre and environmental conditions is the degree to which fibres are "melt back" when subjected to the electric arc with the fibre feed turned off. Alternatively, some other substitute tests can be used to check the equipment. Some machines can automatically optimize the arc parameters; otherwise, manual adjustments are needed.

Machine performance is sensitive to atmospheric variations. Either automatic or manual adjustment of arc parameters should be made to optimize for the existing conditions.

The splicing machine should have the facility to count and indicate the arc number and the manufacturer should provide the number after which the electrodes should be replaced. The replacement should be in accordance with the instructions of the manufacturer.

Since the optimal electric arc conditions (arc current, arc time, etc.) may depend on both the characteristics of the type of fibre as well as the characteristics of the splicing machine, it is recommended to use an arc test procedure, available in many splicing machines.

NOTE 1 – Some splicing machines can optimize the arc position asymmetrically between the fibre ends of dissimilar fibres. When working under these settings, attention should always be paid to placing the appropriate fibre on the appropriate side of the fibre holder.

NOTE 2 – Some splicing machines offer fibre type recognition algorithms, based on a particular interpretation of the fibre index profile. Care should be taken with these algorithms since index profiles have not been standardized. At least one check per commercial fibre type is recommended.

7.5.1.2 Fusion splicing

When testing of the arc condition is completed, splicing can be commenced. The fibres should be positioned in the V-grooves or fibre clamps of the splicing machine.

Fusion splicing machines, in general, are divided into two types according to alignment: active or passive. The use of either depends on how the fibres are aligned. Active alignment machines use either a vision system or local injection or local detection system and three-dimensional movement of the fibres to actively align the cores or cladding of the two fibres being spliced. The splicing machine minimizes the splice attenuation by either focusing on the core or cladding of the fibres with its vision system to directly align them or optimizing the transmitted light through the fibres and providing an estimate of the splice attenuation after the splice is complete.

Those systems that compensate for core-cladding concentricity errors provide better results in terms of splice attenuation. Splicing machines that use active alignment systems are only suitable for single fibre splicing at this time.

Passive alignment machines use only fibre longitudinal movement, so accurate core alignment mostly depends on good fibre or ribbon geometry. The passive alignment system can be used to splice ribbons or single fibres, and an estimate of splice attenuation may also be provided. For ribbon splicing, however, all current mass fusion machines estimate splice attenuation by observing fibre alignment before or after splicing.

7.5.1.3 Proof test

After the splice is completed, it is recommended to check its minimum strength. It is very important to specify a level of mechanical strength for the splice that is related to its expected lifetime. As performed for optical fibres just after manufacturing, the splice is subjected to a tensile proof test for a short period of time. Some splicing machines perform this test with the spliced fibres in the splicing chucks and some perform it after placing the spliced fibres in the holders for heat-shrink protector application. Splices that have strength below the proof test level will be re-done.

The splicing machine should be able to perform the proof test automatically or manually. The unloading time should be short in order to minimize the strength reduction during the unloading.

Typical values for proof testing range from 2 N to 8 N, depending on the type of equipment and desired strength.

7.5.1.4 Splice protection

After the proof test, the protector should be positioned over the spliced point. The "protector" is a mechanical device or restored coating that provides both mechanical and environmental protection to single or multiple splices. In all cases, the protection device should affect neither the attenuation of the splice nor its functional properties.

The characteristics of the completed fusion splice can be verified using the test methods and recommended acceptance criteria reported in clause 8.

Protector designs may include heat-shrink sleeve, so called clam-shell, fibre re-coating and encapsulating protectors. The protectors for single fibre fusion splices should be capable of accepting coated fibres of (nominal) diameter 200 µm or 250 µm; 900 µm; or 200 µm, 250 µm and 900 µm combinations. Typically, these splice protectors require tools or equipment to install or make.

The protector designs should be suitable for either aerial, underground or buried applications while stored inside an appropriate enclosure. The manufacturer should provide information on the compatibility with the splice trays and on the tools or equipment for its application. In particular, the manufacturer should provide information on the minimum and maximum fibre strip lengths that the protector will accommodate and on the storage dimensions for the completed protector (length, width and height) and on the application details.

For heat-shrink sleeve protectors, the manufacturer should specify the time and the temperature required to complete the shrinkage, which should be taken into account by the oven settings. The function of the strength member, if present, is to improve the mechanical strength of the splice without affecting it, both from an optical and mechanical point of view. It should be straight and free from burrs and sharp edges. During cool-down, care should be taken to prevent deformations that cause bending attenuation.

For UV-curable resin-filled protectors, the manufacturer should specify the total energy (exposure time and the power) applied by the UV lamp.

Complete documentation containing all details, such as the manufacturer's references, the product code and the order mode, the use and application, as well as the repair and maintenance procedures, should be available with the product. The constituent materials should be compatible with the gel inside the cables and the protectors should be supplied with safety and operational instructions.

Figure 1 shows a schematic representation of the fusion splicing procedure.

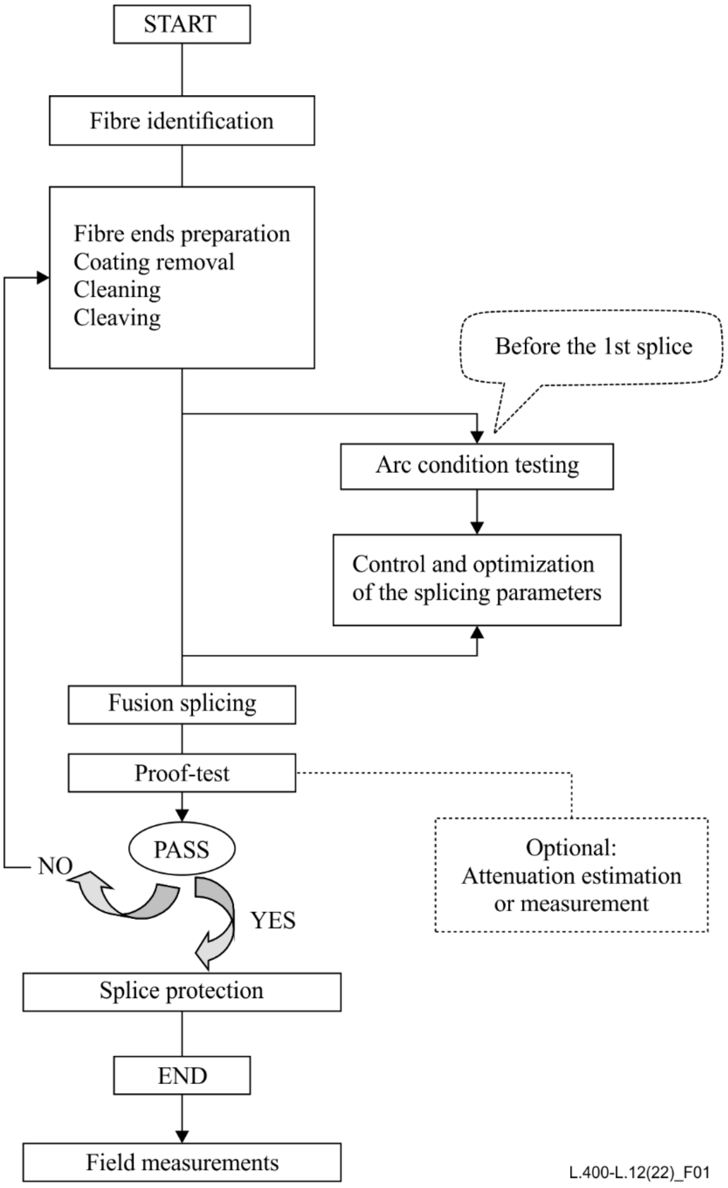


Figure 1 – Schematic representation of the fusion splicing procedure

7.5.2 Mechanical splicing

The mechanical method allows fixing the fibres in a splice-protective housing, generally without the need for electrical power. Some mechanical splices can be tuned by hand for minimum splice loss.

After stripping and cleaving operations, described in clauses 7.1 to 7.4, the bare fibre ends are inserted into the mechanical housing (in a guiding structure, for instance a V-groove) and checked for their physical contact. For angle-cleaved splices, it is recommended to maintain the relative orientation of the angled end faces of the fibres during installation in order to obtain optimal optical performance.

For mechanical splices, proof test is generally not a part of the installation sequence as it is for fusion splices.

Sometimes, the fibre ends are prepared for splicing by grinding and polishing procedures, especially in factory pre-terminated mass splices.

The mechanical splices should be versatile, allowing the splicing of different types of fibres, e.g., coated fibres of (nominal) diameter 250 µm with buffered fibres of 900 µm.

A protective housing provides mechanical and environmental protection of the splices (different for single and multiple splices). They should be suitable for aerial, underground or buried applications. The manufacturer should provide information on the compatibility with the splice organizer trays and on the tools or equipment for their application.

The index-matching material used between the ends of the mating fibres should be chosen to match the optical properties of the glass. The supplier of the index-matching material should provide complete information about its behaviour at different temperatures (especially the extremes) and its estimated lifetime in terms of maintaining initial optical performance.

The characteristics of the completed mechanical splice can be verified using the test methods and recommended acceptance criteria reported in clause 8.

In mechanical splicing, the splice protection is built into the splice design and separate protectors are not required.

A schematic representation of the mechanical splicing procedure is shown in Figure 2.

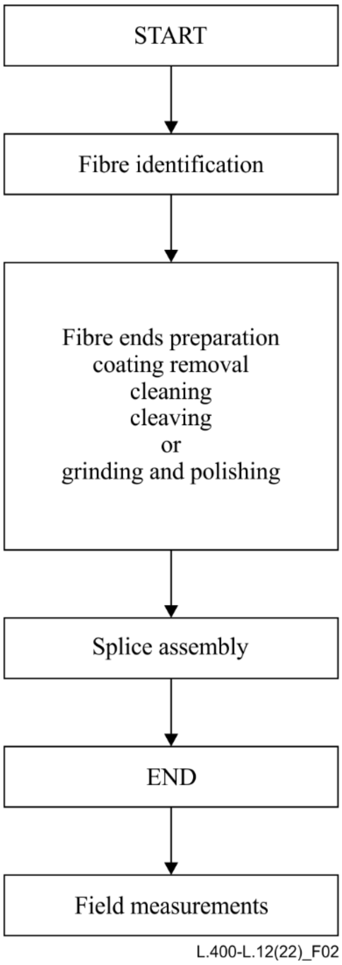


Figure 2 – Schematic representation of the mechanical splicing procedure

7.6 Field splice loss measurements

One critical requirement for an optical fibre communication system is the total end-to-end loss of each link. Considering the number of splices in a link, a realistic maximum splice loss should be set.

In practice, the in-field measurement of each splice loss during the construction of a fibre link is usually estimated by the fusion splicing machine (when loss estimation is a facility) or by a one-way optical time domain reflectometer (OTDR) measurement. Either of these techniques can be used to evaluate gross high splice losses so that the splice may be remade if necessary. After construction is complete, the actual splice loss in the field can be determined by bidirectional OTDR measurement if necessary.

For single-mode fibre the true splice loss is determined by the bidirectional average of the OTDR readings at a splice. A one-way OTDR measurement should not be used as actual splice loss because MFD tolerances and other intrinsic parameter differences in fibres can cause errors. In the case of single-mode fibres, OTDR single-direction readings can be high, being either positive or negative. In addition, any measurable spike from a fusion splice requires that the splice be remade. Acceptance levels for splice loss before remake depend on the loss budget of the link.

More guidance on the interpretation of OTDR backscattering traces of splices can be found in [b-IEC TR 62316].

8 Requirements of the fibre splices and recommended performance tests

8.1 General

This clause validates the splice procedure described in clause 7 and qualifies the properties that should be considered for the optical fibre splice. The specimen is prepared on the same single-mode fibre (by cutting one fibre) that satisfies the specifications of [ITU-T G.651.1], [ITU-T G.652], [ITU-T G.653], [ITU-T G.654], [ITU-T G.655], [ITU-T G.656] and [ITU-T G.657] in order to avoid excessive splice properties that are independent of the splice procedure and caused by mode-field diameter mismatch, cladding diameter tolerance etc.

In reality, spliced fibres have differences in MFD, cladding diameter,-core-cladding eccentricity and even glass composition. The increased splice loss caused by the difference in fibre characteristics is given in Appendix II and can be added to the attenuation values in test 8.2.1 of Table 1 as an estimation of the true loss in case of splicing different fibre types. The maximum allowed attenuation value in the field should be decided by the network operator, as a function of the various kinds of installation (long distance, access, distribution or submarine network). Further information can be found in [b-IEC TR 62000] and in [b-ITU-T G.671].

Recommended test methods are described by referring the corresponding documents of the IEC 61300 series. These tests are to be executed at standard atmospheric conditions according to [IEC 61300-1]:

Temperature (in degrees Celsius)	18-28
Relative humidity (RH) (as a percentage)	25-75
Air pressure (in hectopascals):	860-1060

8.2 Performance requirements for single-mode fibre splices

Table 1 gives the recommended performance requirements for single-mode fibre splices made on the same optical fibre or ribbon. For each test, five test samples should be prepared that meet the maximum attenuation and RL requirements for the grade used of mechanical splice or fibre alignment method for the fusion splice.

NOTE – The tests and test severities correspond with [b-IEC 61753-131-03], [b-EN 50411-3-2] and [b-EN 50411-3-3].

Table 1 – Performance requirements for single-mode fibre splices

No	Test	Method	Test severities	Mechanical splice	Fusion splice with protector
8.2.1	Attenuation/ Insertion loss (IL)	IEC 61300-3-4	Wavelengths: 1 310 nm, 1 550 nm and 1 625 nm	Single fibre and ribbon fibre splices: Grade B ≤0.25 dB max Grade C ≤0.5 dB max	Single fibre splices made by: – Active core alignment: ≤0.1 dB max – Active cladding alignment: ≤0.2 dB max Ribbon fibre splices made by: – Passive alignment by V-groove: ≤0.2 dB max
8.2.2	RL	Method 1 or 2 of IEC 61300-3-6	Wavelengths: 1 310 nm, 1 550 nm and 1 625 nm	When straight cleaved: ≥35 dB (grade 3) ≥45 dB (grade 2) When angle cleaved: ≥60 dB (grade 1)	≥60 dB
8.2.3	Change in attenuation and RL	IEC 61300-3-3	Monitored at 1 310 nm, 1 550 nm, and 1 625 nm	Change in attenuation ≤± 0 2 dB during and after test Meet the RL requirement of the specified RL grade in 8.2.2 during and after the test	Change in attenuation ≤ ± 0.1 dB during test ≤ ± 0.05 dB after test Meet the RL requirement of the specified RL grade in 8.2.2 during and after the test
8.2.4	Vibration (sinusoidal)	IEC 61300-2-1	Sweep (10 Hz to 55 Hz to 10 Hz) at 1 oct/min Amplitude 0.75 mm Duration: 15 cycles 3 axes X-Y-Z	Meet the change in attenuation and RL of No. 8.2.3 during and after the test	Meet the change in attenuation and RL of No. 8.2.3 during and after the test
8.2.5	Shock	IEC 61300-2-9	5 000 m/s^2 (~500*g*) 1 ms pulse 3 axes *X-Y-Z*	Meet the change in attenuation and RL of No. 8.2.3 after the test	Meet the change in attenuation and RL of No. 8.2.3 after the test
8.2.6	Torsion	IEC 61300-2-5	Load 2 N −180 ° and +180 ° at 25 cm from splice protector Duration: 10 cycles	Meet the change in attenuation and RL of No. 8.2.3 during and after the test	Meet the change in attenuation and RL of No. 8.2.3 during and after the test
8.2.7	Fibre retention	IEC 61300-2-4	Load: 2 N primary 5 N secondary at 30 cm from splice protector Duration: 60 s	Meet the change in attenuation and RL of No. 8.2.3 during and after the test	Meet the change in attenuation and RL of No. 8.2.3 during and after the test
8.2.8	Bending moment	IEC 61300-2-7	Load: 2 N in middle of splice protector for 10 s	Meet the change in attenuation and RL of No. 8.2.3 after the test	Meet the change in attenuation and RL of No. 8.2.3 after the test
8.2.9	Cold (Note 2)	IEC 61300-2-17	–40°C, 96 h	Meet the change in attenuation and RL of No. 8.2.3 during and after the test	Meet the change in attenuation and RL of No. 8.2.3 during and after the test

Table 1 – Performance requirements for single-mode fibre splices

No	Test	Method	Test severities	Mechanical splice	Fusion splice with protector
8.2.10	Dry heat (Note 2)	IEC 61300-2-18	+70°C, 96 h	Meet the change in attenuation and RL of No. 8.2.3 during and after the test	Meet the change in attenuation and RL of No. 8.2.3 during and after the test
8.2.11	Composite temperature/ humidity cyclic test	IEC 61300-2-21	–10°C/+65°C ≥93% RH at maximum temperature Dwell time at extreme temperatures: 3 h (24 h/cycle) Duration: 10 cycles	Meet the change in attenuation and RL of No. 8.2.3 during and after the test	Meet the change in attenuation and RL of No. 8.2.3 during and after the test
8.2.12	Change of temperature	IEC 61300-2-22	–40°C and +70°C Dwell time at extreme temperatures: 1 h Rate of change: 1°C/min Duration: 12 cycles	Meet the change in attenuation and RL of No. 8.2.3 during and after the test	Meet the change in attenuation and RL of No. 8.2.3 during and after the test
8.2.13	Dust – Laminar flow	IEC 61300-2-27	<150 µm 25 g/m^3 Duration: 10 min	Meet the change in attenuation and RL of No. 8.2.3 after the test	Not applicable (as no dust can come into the optical path of the fused fibres)
8.2.14	Salt mist (Note 1)	IEC 61300-2-26	50 g/l NaCl solution of pH 6.5 to 7.2 at 35°C for 96 h	No visual evidence of corrosion	No visual evidence of corrosion
8.2.15	Water immersion (Note 3)	IEC 61300-2-45	Between 1 cm and 5 cm below the surface of the water at +45°C Duration: 1 cycle of 7 days	Meet the change in attenuation and RL of No. 8.2.3 during and after the test	Meet the change in attenuation and RL of No. 8.2.3 during and after the test

NOTE 1 – Only recommended when the splice or splice protector contains metallic component(s).

NOTE 2 – Cold and dry heat optional as temperature effects are already assessed during the change of temperature test (No. 8.2.12).

NOTE 3 – Only recommended for splices that may be subject to occasional immersion in water, e.g., due to flooding of pedestals, basements or vaults. To be agreed between supplier and customer.

8.3 Validation of the splicing procedure

For the validation of the splicing procedure, the fibre splices are made on the same optical fibre or ribbon. At least 100 splices should be made to check the requirements of test Nos 8.3.1 and 8.3.2 in Table 2.

NOTE – 100 Splices are needed to obtain a reliable distribution of the optical performance of the splices. This corresponds to the installation tests specified in [b-IEC 61753-131-03], [b-EN 50411-3-2] and [b-EN 50411-3-3].

Table 2 – Requirements for validation of splicing procedure of single-mode fibre splices

No	Test	Method	Test severities	Mechanical splice	Fusion splice without protector
8.3.1	Attenuation/IL	IEC 61300-3-4	Wavelengths: 1 310 nm, 1 550 nm and 1 625 nm	Single fibre and ribbon fibre splices: – Grade B ≤0.12 dB average ≤0.25 dB in 97% of the splices – Grade C ≤0.25 dB average ≤0.5 dB in 97% of the splices	Splices on single fibres made by: – Active core alignment: ≤0.05 dB average ≤0.1 dB in 97% of the splices – Active cladding alignment: ≤0.1 dB average ≤0.2 dB in 97% of the splices Splices on ribbon fibres my by: – Passive alignment by V-groove: ≤0.1 dB average ≤0.2 dB in 97% of the splices
8.3.2	RL	IEC 61300-3-6 method 1 or 2	Wavelengths: 1 310 nm, 1 550 nm and 1 625 nm	When straight cleaved: ≥35 dB (grade 3) ≥45 dB (grade 2) When angle cleaved: ≥60 dB (grade 1)	≥60 dB for all splices

8.4 Performance characteristics for multimode fibre splices

Splicing of multimode fibres with cladding alignment provides sufficient attenuation performance since multimode fibre has a relatively large core diameter compared with a single-mode fibre. Detailed performance criteria need further study since the attenuation of the splice depends not only on splicing conditions, but also on measurement conditions such as the modal power launch conditions.

NOTE – The tests and test severities should correspond with [b-IEC 61753-1] and [b-EN 50411-3-6].

Appendix I

Index of refraction matching materials for mechanical optical fibre splices

(This appendix does not form an integral part of this Recommendation.)

The most common index-matching materials are silicon gels and silicon greases. UV-curable adhesives and epoxy resins are also sometimes used as matching materials.

Gels and greases are used more often because they provide superior strain relief and viscoelasticity in the fibre-to-fibre gap. This allows them to accommodate differential thermal expansion and mechanical stresses without causing delamination in the gap or inducing excessive stress in the fibre.

Curing silicone gels, UV-curable adhesives and epoxy resins are cross-linked, cured materials. As such, they are chemically active until they are cured and they have limited shelf life in their uncured state (6 months is typical). Curing gels must be cured at the time of splicing by means of mixing two component fluids or by exposure of an uncured fluid to elevated temperature. They should be chemically and physically stable once cured.

Non-curing silicone and other greases are suspensions of a microscopic powder thickener in an optical fluid and are sometimes also called gels, optical coupling compounds or optical couplants. They are non-curing, ready-to-use, single component materials, with no intrinsic shelf-life limit due to cure reaction components. Their physical consistency is that of a grease – while they will flow from a dispensing syringe under pressure, they do not migrate when at rest in the fibre splice.

Most pre-index-matched mechanical splices use non-curing index-matching grease. Some optical greases have been shown to separate into their constituent fluid and thickener after long periods at elevated temperature (so called oil separation). Some materials have exhibited a tendency to dry out over many months or to evolve gas micro-bubbles that introduce a hazy appearance (so called evaporation or appearance). If the materials are not properly filtered, de-aerated and packaged they contain entrained microscopic air bubbles, dust, fibres and other particles that can degrade RL and IL in the splice (so called colour, appearance or particulate contamination). The long-term environmental stability of index-matching greases should be confirmed before use in applications with a wide temperature range, or other severe or unusual environmental conditions. Lot test requirements for these materials is recommended as shown in Table I.1. Other requirements should be added to suit the particular splice design and environmental conditions.

Table I.1 – Recommended specifications for index-matching greases in fibre splices

Property	Method	Requirement
Colour	Visual	Water white, non-yellowing
Appearance	Visual	No bubbles, voids or visible particles
Refractive index at 25°C, 589 nm	See [b-ASTM D1218-21]	1.463 ± 0.003 (for silica fibre)
Evaporation, 24 h at 100°C	See [b-ASTM D972-16]	0.2%, max
Oil separation, 24 h at 100°C	See FTM 791, method 321.2 of [b-FED-STD-791C]	0.2%, max
Particulate contamination	See FTM 791B, method 3005 of [b-FED-STD-791C]	<300 particles/cm^3, diameter 10 μm to 34 μm No particles above 35 μm

Appendix II

Optical fibre splice attenuation with different types of fibres

(This appendix does not form an integral part of this Recommendation.)

The optical performance of the fusion splices described in clause 8 are specified when the splices were made with identical fibres.

In reality, the splices are made between different fibres with different MFDs, core-cladding concentricity and cladding diameter.

The relationship between the splice loss and these fibre parameters is given by the equation:

$$Loss\ (dB) = -10log_{10}\left[\underbrace{\frac{(2.\omega_1.\omega_2)^2}{(\omega_1^2+\omega_2^2)^2}}_{\text{Mode field diameter mismatch factor}}.exp\left\{\underbrace{\frac{-2.d^2}{\omega_1^2+\omega_2^2}}_{\text{Core lateral offset factor}}-\underbrace{2.\pi^2.\frac{n_0^2}{\lambda^2}.\frac{(\omega_1^2.\omega_2^2)}{(\omega_1^2+\omega_2^2)}.sin^2(\theta)}_{\text{Fibre axis angle offset factor}}\right\}\right]$$

where

ω_1 = mode field radius of transmit fibre

ω_2 = mode field radius of receive fibre

d = lateral displacement of cores

λ = wavelength of transmitted light

n_0 = index of refraction

θ = angular misalignment of fibre axes.

The factor related to the MFD mismatch is often the largest contributor to the splice loss. When using identical fibres, the loss contribution caused by the MFD mismatch becomes minimal.

The factor related to the core offset is related to the core-cladding concentricity and cladding diameter differences. Fusion splice machines with active core alignment minimize the core offset and therefore reduce the loss contribution related to core offset. Fusion splicing machines using active cladding alignment do not take the differences of core-cladding concentricity into account and therefore give slightly higher splice losses compared to the active core alignment method. Finally, fusion splicing machines using a passive V-groove alignment system are subject to both core-cladding concentricity differences and cladding diameter difference.

The factor containing the fibre axis offset angle θ is most of the time negligible, unless there is contamination on the cladding that will misalign the fibre in the fibre clamping mechanism.

The values in Tables II.1, II.2 and II.3 were obtained by a Monte Carlo simulation. The assumption was made that the distributions of MFD, core-cladding concentricity and cladding diameter were Gaussian and following values for the nominal and the standard deviations on the nominal values were used:

- MFD: nominal values 8.6 µm, 9.2 µm and 12.5 µm, standard deviation 0.10 µm;
- core-cladding concentricity error: nominal value 0.2 µm, standard deviation 0.07 µm;
- cladding diameter: nominal value 125.0 µm, standard deviation 0.15 µm.

For fusion splicing equipment with active core alignment, the effects of the core-cladding concentricity and cladding diameter are considered to be minimal. Table II.1 shows the loss contribution of fusion splices between single-mode fibres with various MFD ranges.

Table II.1 – Contribution of mode field diameter mismatch to splice loss of single-mode fibre splices with active core alignment

Nominal MFD fibre No. 1	Nominal MFD fibre No. 2	Average splice loss increase	Maximum splice loss increase (99.9%)
9.2 µm	9.2 µm	0.001 dB	0.012 dB
9.2 µm	8.6 µm	0.021 dB	0.060 dB
9.2 µm	12.5 µm	0.403 dB	0.519 dB
8.6 µm	12.5 µm	0.594 dB	0.725 dB

Table II.2 shows the loss contributions of the MFD mismatch and the core-cladding concentricity when using fusion splicing techniques with active cladding alignment.

Table II.2 – Contribution of mode field diameter mismatch and core-cladding concentricity to splice loss of single-mode fibre splices with active cladding alignment.

Nominal MFD fibre No. 1 with maximum core-cladding concentricity error 0.5 µm	Nominal MFD fibre No. 2 with maximum core-cladding concentricity error 0.5 µm	Average splice loss increase	Maximum splice loss increase (99.9%)
9.2 µm	9.2 µm	0.019 dB	0.085 dB
9.2 µm	8.6 µm	0.040 dB	0.115 dB
9.2 µm	12.5 µm	0.415 dB	0.540 dB
8.6 µm	12.5 µm	0.608 dB	0.745 dB

Table II.3 shows the loss contributions of the core-cladding concentricity and cladding diameter when using fusion splice techniques with V-groove alignment (V-groove angle 90°).

Table II.3 – Contribution of mode field diameter mismatch, core-cladding concentricity and cladding diameter to splice loss of single-mode fibre splices with passive V-groove alignment

Nominal MFD fibre No. 1 with maximum core-cladding concentricity error 0.5 µm and nominal cladding diameter 125.0 µm	Nominal MFD fibre No. 2 with maximum core-cladding concentricity error 0.5 µm and nominal cladding diameter 125.0 µm	Average splice loss increase	Maximum splice loss increase (99.9%)
9.2 µm	9.2 µm	0.024 dB	0.145 dB
9.2 µm	8.6 µm	0.045 dB	0.175 dB
9.2 µm	12.5 µm	0.419 dB	0.550 dB
8.6 µm	12.5 µm	0.611 dB	0.745 dB

Appendix III

Fibre imaging in fusion splicing machines

(This appendix does not form an integral part of this Recommendation.)

The imaging process of optical fibres during fusion splice is an important component both for fibre alignment and loss estimation. When performing loss estimation, the goal of the fibre imaging system is to determine the refractive index geometry in the vicinity of the splice point, while for fibre alignment in preparation for fusion splicing, the goal of the fibre imaging system is to determine the relative position and orientation of the fibre tips.

The fibre imaging systems embedded in commercial fusion splice machines generally consist of illumination sources, objective lenses and cameras, providing magnified transverse imaging of optical fibre. The light-emitting diode is the most used illumination source due to its monochromatic illumination. The objective lens is used to capture and focus an image, and the camera could be a charge-coupled device or complementary metal oxide semiconductor, digitizing the final fibre image. The fibre imaging system usually utilizes two orthogonal imaging paths or incorporates lenses and mirrors to observe the fibre from two perpendicular directions. Figure III.1 provides two typical schematics of orthogonal fibre imaging system, of which Figure III.1-a is for single fibre comprising two orthogonal paths and Figure III.1-b is for ribbon, using two illumination sources, lenses and cameras with a movable mirror. Note that each fibre in a ribbon has a slightly different distance to the objective lens, such a defocusing effect can be compensated for by utilizing a special objective lens.

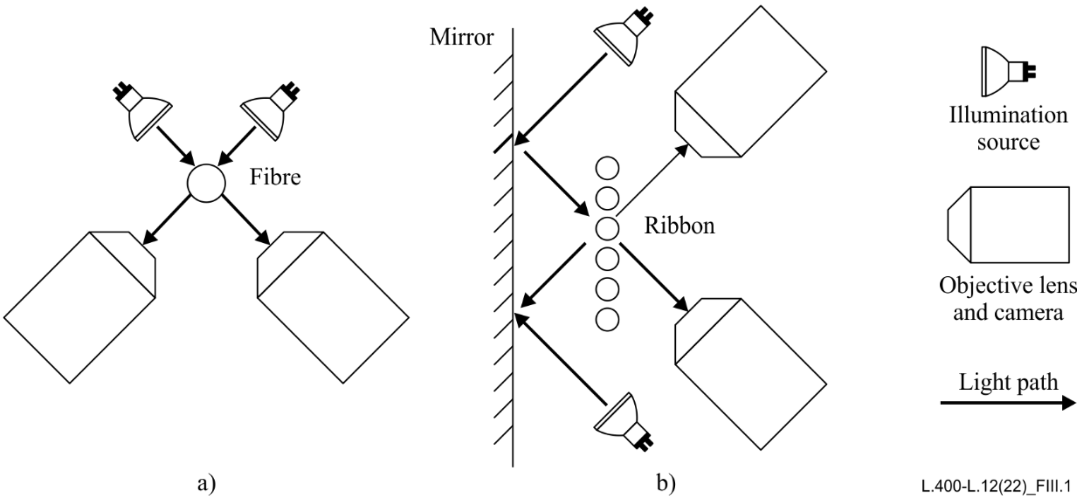


Figure III.1 – Schematic diagrams of typical orthogonal imaging systems: a – single fibre; b – ribbon

When imaged transversely, the fibre cladding exhibits a wide bright band positioned in the centre sandwiched by two dark bands, and the curved surface of the fibre magnifies the core region making the core appears out of proportion to the cladding diameter. The refractive index profile geometry of the optical fibre determines how it interacts with the illumination rays during fibre imaging. Snell's law can be used to trace the trajectory of illumination rays as they pass through the optical fibre. Figure III.2 gives a simple trace model of illumination rays that is helpful for understanding the transverse fibre image. The rays incident to the centre region exhibit a straighter trajectory than those incident at more oblique angles, and the rays far from the core region (shown as the shaded region in Figure III.2) are refracted so strongly that they are not captured by the objective lens, resulting in dark sections in the fibre image. No information about the shaded regions can be obtained from fibre image; however, this is usually not a problem since mostly the core region or the edge of cladding is important for fibre alignment or loss estimation.

Note that for most optical fibres, the cladding surface is a perfect cylinder, and as the wavelength of light inside the fibre is reduced in scale by an amount equal to the cladding refractive index, the core region is magnified when compared to other portions of the image. The magnification is equal to the refractive index of the cladding. It also should be noted that the weak refractive index contrast between the core and cladding has a relatively small impact on the trajectory of illumination rays, so the core is nearly invisible when the objective lens is exactly focused on the fibre. The fibre image is usually defocused deliberately to make the core region distinct.

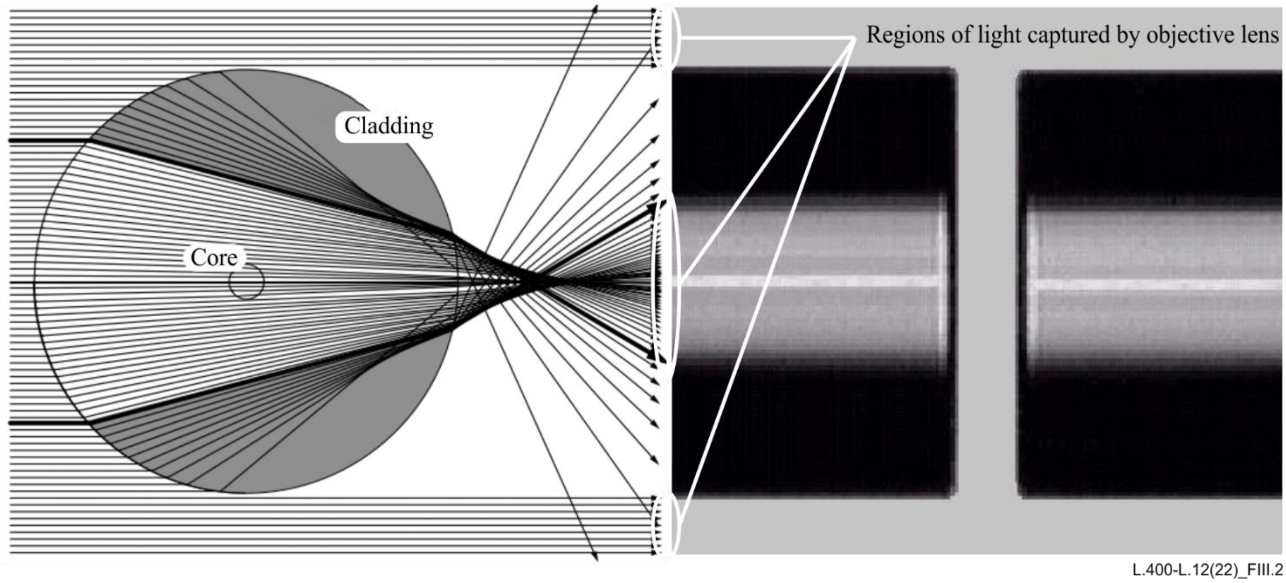
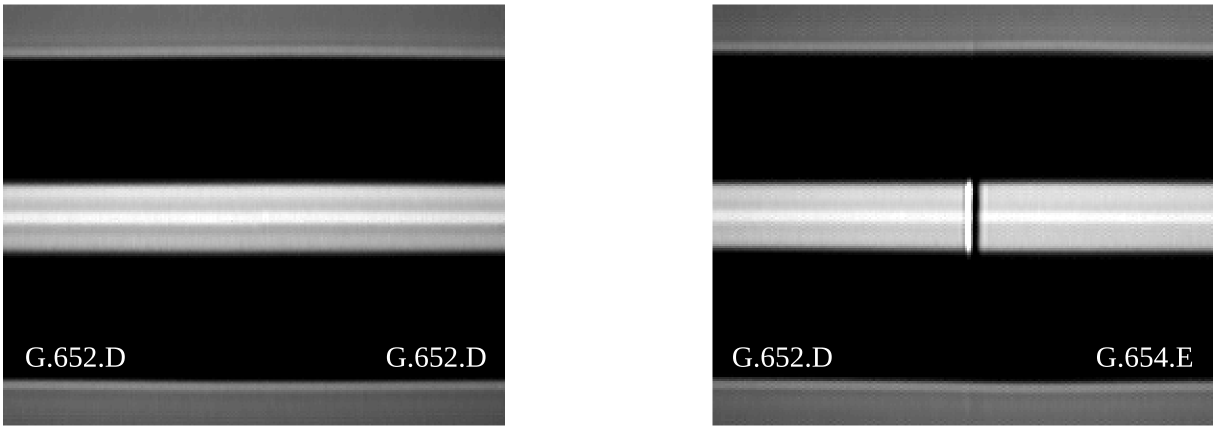


Figure III.2 – Traces of illumination rays passing through an optical fibre

When identical fibres make up a fusion splice, the fibre image position is uniform across the splice point under precise alignment of the two fibres, as indicated in Figure III.3-a. The refractive index profile of a fibre is the same as that of others, making it difficult to detect the position of splice point on the captured image. When different types of fibres are spliced together, e.g., G.652.D and G.654.E, a distinct vertical line shows up at the position of a splice point, as indicated in Figure III.3-b. This comes from the lateral refraction of illumination rays occurring at the splice point where the refractive index has a transverse difference. Since the refractive index of G.652.D fibre is higher than that of the G.654.E type, illumination rays are refracted towards the direction of the G.652.D fibre, resulting in a bright line on this side, while leaving a dark line on the G.654.E side. It should be noted that this vertical line caused by lateral refraction does not affect the light travelling along the core. When performing fusion splice on different types of fibres with distinct refractive index profiles, the test methods for splice loss in documents of the IEC 61300 series can be adopted to examine the quality of splice point if needed.



(a) (b)

Figure III.3 – Image of splice point: a-identical G.652.D fibres; b-G.652.D and G.654.E fibres

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[2] Superseded.

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