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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Transmission media and optical systems characteristics – Optical fibre cables

# Test methods for installed single-mode optical fibre cable links

Recommendation ITU-T G.650.3

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# Recommendation ITU-T G.650.3

## Test methods for installed single-mode optical fibre cable links


### Summary

Recommendation ITU-T G.650.3 outlines the tests normally carried out on installed single-mode optical fibre cable links. It includes a collection of references to the main measurement methods and gives an indication of which are most suitable for installed cable links, depending on the required inspection level. Optical fibre cable links are comprised of multiple cable sections, splices and other connections. This term is more completely defined in this Recommendation.

This Recommendation uses a tiered approach. The first level indicates measurements that are normally carried out to commission new optical fibre cable links. The second level indicates measurements that may be carried out to satisfy service level agreements (e.g., when a dark fibre contract is signed) or to verify attributes of older links that may be used at higher bit rates or over extended wavelength ranges.

Recommendation ITU-T G.650.3 (2017) introduces the provision of information of splice loss measurement based on the quasi-bidirectional technique in Appendix IV. The method for differentiating splice loss and macrobending loss in installed links, which was issued as Amendment 1 to ITU-T G.650.3 (2008), is also included as Appendix III.



### History

| Edition | Recommendation | Approval | Study Group | Unique ID* |
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### Keywords

Fibre characterization, optical fibre cable link.


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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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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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# Recommendation ITU-T G.650.3

## Test methods for installed single-mode optical fibre cable links

## 1 Scope

This Recommendation describes test methods that are particularly suited to the characterization of single-mode optical fibre cable links. The methods are not intended for application to links that contain optical network elements, amplifiers, dispersion compensators, passive splitters or combiners. Measurements associated with these devices in combination with optical fibre cable are defined in ITU-T G.66x or ITU-T G.67x series Recommendations. These measurements of the cable links between such devices and the calculation methods for combining the results of concatenated cable links are also presented.

This Recommendation uses a tiered approach. The first level indicates measurements that are normally carried out to commission new optical fibre cable links. The second level indicates measurements that may be carried out to satisfy service level agreements (e.g., when a dark fibre contract is signed) or to verify attributes of older links that may be used at higher bit rates or over extended wavelength ranges.

## 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.650.1] Recommendation ITU-T G.650.1 (2010), *Definitions and test methods for linear, deterministic attributes of single-mode fibre and cable*.

[ITU-T G.650.2] Recommendation ITU-T G.650.2 (2015), *Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable*.

[ITU-T G.652] Recommendation ITU-T G.652 (2016), *Characteristics of a 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.657] Recommendation ITU-T G.657 (2016), *Characteristics of a bending-loss insensitive single-mode optical fibre and cable*.

[ITU-T G.671] Recommendation ITU-T G.671 (2012), *Transmission characteristics of optical components and subsystems*.

[ITU-T G.957] Recommendation ITU-T G.957 (2006), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.

[IEC 60793-1-40] IEC 60793-1-402001, *Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation*.

[IEC 61280-4-2] IEC 61280-4-2:2014, *Fibre-optic communication subsystem test procedures – Part 4-2: Installed cable plant – Single-mode attenuation and optical return loss measurement*.

[IEC 61280-4-4] IEC 61280-4-4:2017, *Fibre optic communication subsystem test procedures – Part 4-4: Cable plants and links – Polarization mode dispersion measurement for installed links*.

[IEC 61281-1] IEC 61281-1 (1999), *Fibre optic communication subsystems – Part 1: Generic specification*.

[IEC/TR 61282-7] IEC/TR 61282-7:2003, *Fibre optic communication system design guides – Part 7: Statistical calculation of chromatic dispersion*.

[IEC/TR 61282-9] IEC/TR 61282-9:2016, *Fibre optic communication system design guides – Part 9: Guidance on polarization mode dispersion measurements and theory*.

[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*.

[IEC 61300-3-35] IEC 61300-3-35:2015, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-35: Examinations and measurements –Visual inspection of fibre optic connectors and fibre-stub transceivers*.

[IEC/TR 61931] IEC/TR 61931 (1998), *Fibre optic – Terminology*.

## 3 Definitions

### 3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

**3.1.1 differential group delay (DGD)**: [ITU-T G.650.2]

**3.1.2 fibre optic cable plant (FOCP)**: [IEC 61281-1]

**3.1.3 fusion splice**: [IEC/TR 61931]

**3.1.4 mechanical splice**: [IEC/TR 61931]

**3.1.5 connector, fibre optic**: [IEC 61281-1]

**3.1.6 optical device**: [IEC 61281-1]

**3.1.7 optical return loss (ORL)**: [IEC 61281-1]

**3.1.8 [optical (fibre)] splice**: [IEC/TR 61931]

**3.1.9 polarization mode dispersion (PMD)**: [ITU-T G.650.2]

**3.1.10 reflectance**: [ITU-T G.671]

### 3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

**3.2.1 attenuation of an optical fibre cable link**: The summation of the attenuations of fibre cable sections, splices between cable sections and connections between, and at the end of, cable sections. The definition of attenuation is given in [ITU-T G.650.1]. Some examples of link attenuation measurement results are found in [b-ITU-T G-Sup.39].

**3.2.2 chromatic dispersion of an optical fibre cable link**: The summation of the chromatic dispersions of the individual cables that comprise the link at the wavelengths of interest. See [b-ITU-T G-Sup.39] for more information on how the dispersion from different cable sections is summed.

**3.2.3 fibre characterization**: A comprehensive suite of measurements that is carried out on an optical fibre cable link to determine the key performance attributes of that link that may affect current or future applications that operate over the link. Fibre characterization also allows the quality of the optical fibre cable link to be assessed, including the identification of the type and grade of fibre installed. Full fibre characterization includes connector end face inspection, insertion loss measurements, return loss measurements, optical time domain reflectometer (OTDR) testing, chromatic dispersion testing, polarization mode dispersion measurement and spectral attenuation.

**3.2.4 single-mode optical fibre cable link**: A collection of passive fibre optic components that together form a continuous optical fibre pathway between two end points. The end points will typically be patch panels or optical distribution frames where the fibres are terminated with connectors. The link will typically be comprised of many optical fibre cable sections, jointed end to end. A complex link may contain additional connectors at intermediate patch panels and therefore be made up of two or more concatenated simple links.

**3.2.5 uniformity of fibre link**: The longitudinal variation in the attenuation coefficient or chromatic dispersion coefficient along that link.

## 4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

| | |
|---|---|
| BOTDA | Brillouin Time Domain Analysis |
| CD | Chromatic Dispersion |
| CWDM | Coarse Wavelength Division Multiplexing |
| DFB | Distributed Feedback |
| DGD | Differential Group Delay |
| DWDM | Dense Wavelength Division Multiplexing |
| LSPM | Light Source and Power Meter |
| MFD | Mode Field Diameter |
| OCWR | Optical Continuous-Wave Reflectometer |
| ORL | Optical Return Loss |
| OTDR | Optical Time Domain Reflectometer |
| PMD | Polarization Mode Dispersion |

## 5 Conventions

None.

## 6 Test methods

### 6.1 Test methods for characteristics of optical fibre cable links following installation

The purpose of testing an optical fibre cable link following installation is primarily concerned with proving that the components used (fibres, connectors, etc.) meet their specifications and that the installation has been carried out to a good standard of workmanship (e.g., splice losses meet their specification and the cable link is free from damage).

Primarily, it is the attenuation characteristics of the optical fibre cable link that are commonly tested as part of commissioning a new installation, as these are the characteristics that may be most affected by the installation process and the quality of installation workmanship.

The criteria for newly installed optical fibre links are defined by the operating company. As an example, for attenuation, these criteria may apply not only to the overall link attenuation, but also to the individual cable sections and fibres, the individual splice and connector losses, and other uniformity characteristics. One approach to defining the overall attenuation limit is to consider the attenuation coefficient and length of the individual cable sections, the number of splices or connectors and their maximum allowed losses, and combine the values according to the formulas of Appendix I of [ITU-T G.652].

See clause 6.2 for additional testing that may be required for service contract requirements or for higher (10 Gbit/s per channel and above) transmission rates, or for transmission over extended wavelength ranges. [b-ITU-T G-Sup.40] is a guide on the relationship and definition of various attributes and measurement methods found in ITU-T documents and the mapping to IEC documents.

### 6.1.1 Connector end face inspection

Before testing commences, it is recommended that the end face of the connectors at each end of the link be inspected to ensure that they are clean and free from any damage. If there is any dirt present, then the connector end face should be cleaned (according to the connector manufacturer's instructions) in order to obtain reliable test results and satisfactory long-term performance. Following cleaning procedures, the best practice is to re-inspect to ensure cleaning effectiveness.

Video inspection probes may be used to carry out this inspection safely with no risk to eyesight from energized fibres. They also permit the inspection of the end faces of connectors installed behind patch panels without risk of damage or interruption of traffic on other fibres.

End face images may be stored and analysed if required. [IEC 61300-3-35] provides acceptance criteria for levels of damage and defects that may be tolerated without adverse effect on optical performance.

### 6.1.2 Link attenuation

The link attenuation is very important for all applications regardless of data rate. It is usual to measure the overall link attenuation at wavelengths that are representative of the wavelengths at which the link will be operated. Commonly, this measurement is carried out at 1 310 nm and 1 550 nm, although, if applications using the L-band (1 565 nm to 1 625 nm) are to be used, then testing at 1 625 nm is also recommended (see [b-ITU-T L.313/L.66] on wavelength allocation for maintenance). The recommended technique is to use a light source and power meter (LSPM) method as detailed in [IEC 61280-4-2] to compare the power level injected at one end of the link with the power level received at the other end of the link. The difference between these two power levels is the overall link attenuation measured in decibels. Since this technique operates in the same way as the system operates, it is the preferred technique for determining the total link attenuation. It may be a requirement for this measurement to be carried out in both directions on every fibre in the link, since it is not usually known at this stage which direction each fibre will operate in. Note, however, that the total link attenuation should be similar in both directions when measured using this technique.

While insertion loss is the most fundamental attenuation measurement for links, the OTDR (see clause 6.1.3) is often used either as a bidirectional measurement or as a unidirectional measurement. The use of OTDR can shorten the measurement time, but also has risks. For either case, the OTDR can, for example, miss a broken fibre near the end of the link, unless tail cords are used. It can also allow crossed-over fibres to go undetected. It is well known that bidirectional OTDR measurement is more accurate than unidirectional measurement, but unidirectional measurements are often done as an initial check. When the results of such a check are marginal, follow-up with bidirectional measurement is recommended. See [b-IEC/TR 62316] for more information on the interpretation of backscattering traces.

If a complex link is to be formed by patching together a number of simple links, then the total attenuation of the complex link is obtained by simply adding together the decibel attenuation figures for each simple link.

### 6.1.3 Splice loss, splice location, fibre uniformity and length of cable sections and links

For these characteristics, the OTDR measurement method is recommended. Dependent upon the measurement configuration, this method may also be used to measure the overall link attenuation. This is described in [IEC 61280-4-2] for measuring the attenuation of installed links or in [ITU-T G.650.1] for fibres and cables. An OTDR is an instrument able to measure the optical power backscattered along a fibre as a function of distance. The detailed measurement technique, test apparatus and measurement procedure are described in [IEC 61280-4-2].

Normally, for commissioning a new cable link, OTDR testing is carried out in both directions on every fibre using at least two wavelengths. These wavelengths should be representative of the wavelengths at which the fibre may operate, e.g., 1 310 nm and 1 550 nm for ITU-T G.652-type fibres and 1 550 nm and 1 625 nm for ITU-T G.655-type fibres.

The OTDR testing should be carried out using a launch lead that is long enough (typically 1 km to 2 km) to allow measurement of the first connector in the link, a similar length tail lead should also be connected at the far end of the fibre under test to allow the loss of the connector at the far end to be measured.

Detailed analysis of these OTDR traces then allows accurate measurement of total link attenuation, total link optical return loss, as well as a full breakdown of component losses along the link including fibre section attenuation, splice losses, connector insertion and return loss. In addition, excessive mismatches between fibres in different cable sections along the route can be identified, as well as any problems, e.g., bends on the fibre. See Appendix I for examples of OTDR traces and their analysis.

If the OTDR is only used for length measurements or for overall attenuation checking of the cable link using a launch lead and a tail lead, then unidirectional OTDR test results can be used. If more careful evaluation of non-uniformities must be investigated, bidirectional OTDR test results need to be considered as confirmation. See Appendix I for an example of bidirectional analysis.

In practical engineering, unidirectional OTDR test results can be used to roughly judge the splice quality, but accurate splice loss measurement must be based on the bidirectional OTDR test. A formula for calculation of splice loss is:

$$\frac{\alpha_{A-B} + \alpha_{B-A}}{2}$$

where

$\alpha_{A-B}$ is the shown (not real) splice loss test from the A-end to the B-end of cable sections;

$\alpha_{B-A}$ is the shown (not real) splice loss test from the B-end to the A-end of cable sections.

NOTE – OTDRs can be used to test cable attenuation for all link lengths supported by ITU-T applications, dependent upon the performance of the OTDR used. Consult OTDR manufacturers' specifications for suitability of OTDR modules for testing particular links. For concatenated cable links, the total attenuation can be derived directly by summing the attenuations of individual cable links.

If the bidirectional OTDR test cannot be employed, the quasi-bidirectional test method can be considered a candidate for measuring splice loss. It is noted that the quasi-bidirectional test is not recommended as a standard method since it is challenging to deploy on existing networks. See Appendix IV for an overview of the quasi-bidirectional test.

### 6.1.4 Measurements of other parameters needed following installation

The sheath isolation and the pneumatic resistance of the joint boxes are examples of tests that are sometimes performed. These characteristics are not directly related to the transmission performance of optical cable sections, but can affect the mechanical reliability. Standard tests for these attributes have not been developed, but continue to be under study.

## 6.2 Test methods for verification of service contracts or transmission at particular bit rates

This second level of testing, defined as fibre characterization, indicates measurements that may be carried out to satisfy service level agreements (e.g., when a dark fibre contract is signed) or to verify attributes of older links that may be used at higher bit rates (10 Gbit/s or above) or over extended wavelength ranges [e.g., dense wavelength division multiplexing (DWDM) in the L-band or coarse wavelength division multiplexing (CWDM) over the O-, E-, S-, C- and L-bands].

In addition to the testing detailed in clause 6.1, fibre characterization also includes chromatic dispersion (CD) and polarization mode dispersion (PMD) measurements, and may extend the wavelength ranges covered by the attenuation-related measurements of clause 6.1, e.g., by including 1 625 nm OTDR testing or spectral attenuation measurements over the O-, E-, S-, C- and L-bands.

Fibre characterization is defined in clause 3.2.3. Often it is important to carry out full fibre characterization, particularly on a dark fibre contract, because once the fibres are brought into service it may not be possible to access the fibres again to assess their suitability for further upgrades in the future.

### 6.2.1 Connector end face inspection

This is required in accordance with clause 6.1.1.

### 6.2.2 Overall link attenuation

This is required in accordance with clause 6.1.2. Measurements at additional wavelengths may also be required.

### 6.2.3 Attenuation and related characteristics

For higher bit-rate transmission, the attenuation, splice loss, attenuation uniformity and section length after cable installation also require verification. The test methods for these characteristics are the backscattering technique; as described in clause 6.1.3. Measurements at additional wavelengths may also be required.

### 6.2.4 Spectral attenuation

If the optical fibre cable link is to be used for CWDM applications, then there may be a wide variation in the attenuation of the link across the broad range of wavelengths used. In this case, it is recommended that the attenuation of the link be measured at all relevant wavelengths. This may be achieved as described in clause 5.4.3 of [ITU-T G.650.1] using a suitable broadband light source and an optical spectrum analyser to compare the input and output spectra of the link to determine the attenuation as a function of wavelength across the wavelength range of interest. It is only required to carry out this measurement in one direction on the link.

### 6.2.5 Polarization mode dispersion

For transmission rates lower than 10 Gbit/s or short distance transmission, measurement of the PMD of cable links may not be required. [IEC 61280-4-4] provides a detailed description of the PMD measurement of links, and further guidance on PMD measurements is given in [IEC/TR 61282-9].

There are several test methods identified in [IEC 61280-4-4] and [IEC/TR 61282-9] as being suitable for measuring PMD of installed links. Particular care should be applied in selecting the method used, depending on aspects such as whether the cable can move during the measurement.

It is sufficient to measure the PMD of the fibre in just one direction. The range of wavelengths used should be representative of the wavelengths at which the fibres are utilized.

The above test methods can all be used to test individual cable links and some equipment may also be used to test through amplifiers. For a complex link made up of a number of concatenated simple links, the overall PMD can be calculated from the individual PMD values by adding them in quadrature. This means that the total PMD of the complex link is the square root of the sum of the squares of the PMD of the individual links. The detailed calculation method is described in [b-IEC/TR 61282-3]. For example, if there are three simple links making up a complex link, then the total PMD of the complex link can be calculated as follows:

$$\mathrm{PMD_{Total}} = \sqrt{\left(\mathrm{PMD}_1^2 + \mathrm{PMD}_2^2 + \mathrm{PMD}_3^2\right)}$$

### 6.2.6 Chromatic dispersion

CD measurement is not essential for a low bit-rate or short distance transmission, although it is useful for identifying the type of fibre installed, i.e., ITU-T G.652-type fibre or the other fibre types.

NOTE – If the cable section is less than 40 km long to comprise an optical link used for 2.5 Gbit/s transmissions, CD does not need to be tested. This measurement is conditional with respect to the planned bit rate, transmission distance and fibre type.

For CD, there are a number of test methods that can be used. These are detailed in clause 5.5 of [ITU-T G.650.1]. Field test equipment is available from a number of manufacturers for testing installed links that implement the following test methods:

– phase shift technique and differential phase shift technique;

– time of flight technique including single-ended (OTDR based) and dual-ended methods.

It is not necessary for this measurement to be conducted from both ends of the link.

The wavelength range of the measurement should include the anticipated wavelength range of any transmission systems that may operate over the link. For DWDM systems, it may be sufficient to measure just the C-band or the C- and L-bands, however for CWDM systems, the wavelength range should cover the full O-, E-, S-, C- and L-bands.

The above test methods can all be used to test individual cable links; also, some equipment can be used to test through amplifiers as well as some types of dispersion-compensating modules. For a complex link made up of a number of concatenated simple links, the overall CD (in picoseconds per nanometre) at a particular wavelength can be calculated simply by adding the individual CD values together. Note that for typical dispersion-compensating modules and for standard fibres operating at wavelengths below their zero dispersion wavelength, the dispersion values will be negative. Further guidance on calculating overall CD is given in clause 10.3 of [b-ITU-T G-Sup.39] and [IEC/TR 61282-7].

### 6.2.7 Optical return loss

Two measurement methods for reflections of the optical path (optical cable sections) are described in Appendix I of [ITU-T G.957]. One is with the optical continuous-wave reflectometer (OCWR) and the other is with the OTDR. The OCWR gives a measurement of the total optical return loss (ORL) of the entire link, whereas the OTDR provides reflectance measurements of discrete events, such as connectors, as well as a calculation of the total ORL of the link. Further details of ORL testing of fibre optic components may be found in [IEC 61300-3-6].

# Appendix I

## Optical time domain reflectometer trace analysis

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

### I.1 Optical time domain reflectometer trace example

Figure I.1 shows an example of an OTDR trace taken at 1 550 nm of a link approximately 20 km long. This link has been measured using a launch lead and a tail lead, each about 3.8 km long. The cable sections in the link are generally about 2 km long, although there are a few shorter sections. Note that the markers A and B are positioned to display the total loss of the link including the losses associated with the connectors at both ends of the link.

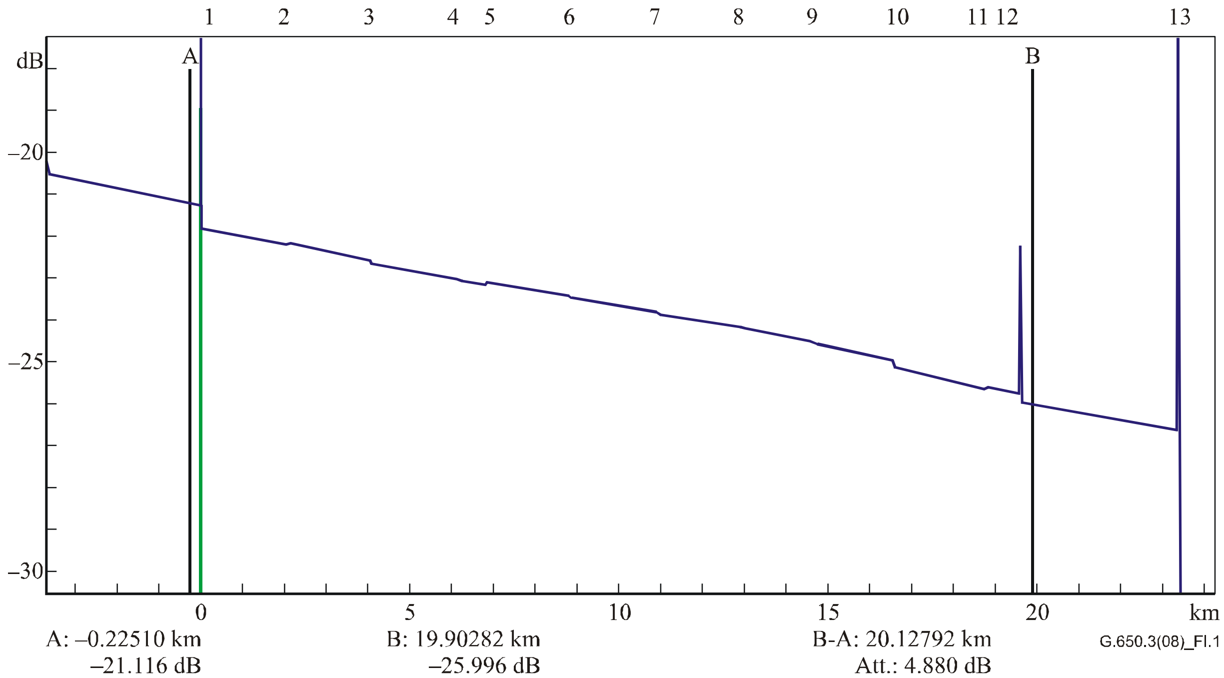


**Figure I.1 – Sample optical time domain reflectometer trace**

### I.2 Optical time domain reflectometer event table example

Table I.1 shows the complete analysis of the events on the trace shown in Figure I.1. Note that some splices (e.g., event 5) are shown as having a negative loss. This is due to slight variations in the backscattering characteristics of the fibre on either side of the splice. Where the fibre after the splice scatters more light than the fibre before the splice, the apparent loss is reduced and may even show up as an apparent gain. If the opposite is true (i.e., the fibre before the splice scatters more light than the fibre after the splice) then the apparent loss may be larger than the true loss. This is the case for the connector at the first patch panel (event 2) and for event 10 on Figure I.1 and Table I.1. This is why it is necessary to carry out OTDR testing from both ends of the fibre using a launch lead and a tail lead and to average the results bidirectionally. Some OTDRs allow this procedure to be carried out in real time using an OTDR at each end of the link, otherwise this bidirectional analysis may be carried out using PC-based software.

**Table I.1 – Optical time domain reflectometer event table from trace in Figure I.1**

| | Event (13) | Distance (km) | Attenuation (dB) | Reflectance (dB) | Slope (dB/km) | Rel. dist. (km) | Link budget (dB) |
|---|---|---|---|---|---|---|---|
| 1 | | 0.000 00 | 0.534 | −52.39 | 0.200 | 3.682 82 | |
| 2 | | 2.072 58 | −0.038 | | 0.198 | 2.072 58 | 0.944 |
| 3 | | 4.101 04 | 0.076 | | 0.190 | 2.028 46 | 1.291 |
| 4 | | 6.151 88 | 0.007 | | 0.196 | 2.050 84 | 1.768 |
| 5 | | 6.825 91 | −0.094 | | 0.203 | 0.674 02 | 1.912 |
| 6 | | 8.832 62 | 0.004 | | 0.191 | 2.006 72 | 2.202 |
| 7 | | 10.964 04 | −0.034 | | 0.194 | 2.131 42 | 2.619 |
| 8 | | 12.948 37 | 0.029 | | 0.192 | 1.984 33 | 2.966 |
| 9 | | 14.829 75 | 0.025 | | 0.190 | 1.881 38 | 3.353 |
| 10 | | 16.652 93 | 0.362 | | 0.184 | 1.823 18 | 3.714 |
| 11 | | 18.718 48 | −0.062 | | 0.190 | 2.065 55 | 4.468 |
| 12 | | 19.611 85 | | −53.69 | 0.187 | 0.893 37 | 4.574 |
| 13 | | 23.407 22 | | | 0.193 | 3.795 37 | 5.484 |

NOTE – In the event column, graphical symbols are used to denote particular types of event – the following icons are commonly used:

denotes a connector interface at the start or end of a launch or tail lead

denotes a fusion splice (non-reflective loss event) in the link under test

denotes a connector (reflective loss event) in the link under test

denotes the end of the fibre under test (when the tail lead has not been used)

## I.3 Optical time domain reflectometer bidirectional trace analysis

Figure I.2 shows a typical bidirectional OTDR display – the trace from Figure I.1 is shown reversed and superimposed on the trace from the opposite end of the same fibre, so that the position of all of the events correlates. Table I.2 shows the results bidirectionally averaged. Note for example that the high loss splice that was event 10 in Table I.1 is now event 3, and there is a "gainer" (apparent negative splice loss) when measured from the opposite end. Note also that the loss of the connector (now event 12) is much less when measured in this direction, significantly reducing the bidirectionally averaged connector loss.

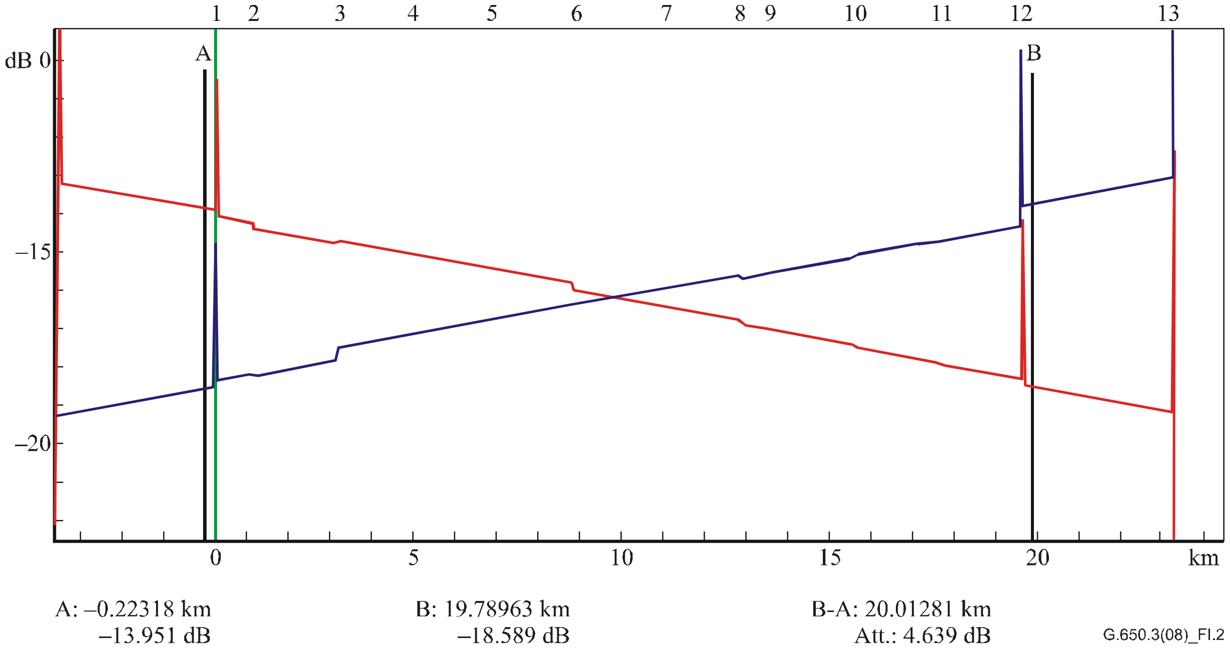


**Figure I.2 – Bidirectional optical time domain reflectometer trace display**

## Table I.2 – Bidirectional optical time domain reflectometer trace loss analysis

| Way O→E (13) | | Way O←E (13) | | Distance (km) | Attenuation (dB) | Attenuation (dB) | Average (dB) | Slope (dB/km) | Slope (dB/km) | Average (dB/km) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 13 | | | | | | | | |
| 1* | | 12* | | 0.000 00 | 0.169 | | | 0.193 | 0.193 | 0.193 |
| 2* | | 11 | | 0.914 47 | 0.136 | −0.062 | 0.037 | 0.195 | 0.187 | 0.191 |
| 3* | | 10 | | 2.973 62 | −0.062 | 0.362 | 0.150 | 0.190 | 0.190 | 0.190 |
| 4* | | 9 | | 4.814 07 | 0.009 | 0.025 | 0.017 | 0.192 | 0.184 | 0.188 |
| 5* | | 8 | | 6.677 54 | −0.006 | 0.029 | 0.011 | 0.190 | 0.190 | 0.190 |
| 6* | | 7 | | 8.676 59 | 0.177 | −0.034 | 0.071 | 0.190 | 0.192 | 0.191 |
| 7* | | 6 | | 10.795 21 | 0.014 | 0.004 | 0.009 | 0.188 | 0.194 | 0.191 |
| 8* | | 5 | | 12.816 00 | 0.110 | −0.094 | 0.008 | 0.191 | 0.191 | 0.191 |
| 9* | | 4 | | 13.476 59 | 0.034 | 0.007 | 0.021 | 0.186 | 0.203 | 0.195 |
| 10* | | 3 | | 15.531 91 | 0.077 | 0.076 | 0.077 | 0.187 | 0.196 | 0.191 |
| 11* | | 2 | | 17.527 76 | 0.067 | −0.038 | 0.014 | 0.187 | 0.190 | 0.189 |
| 12* | | 1 | | 19.62 528 | 0.136 | 0.534 | 0.335 | 0.182 | 0.198 | 0.190 |
| 13* | | | | | | | | 0.197 | 0.200 | 0.199 |

# Appendix II

## Optical path parameters specified in ITU-T Recommendations

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

| **Specified parameters** | **[b-ITU-T G.691]** | **[b-ITU-T G.692]** | **[b-ITU-T G.693]** | **[b-ITU-T G.695]** | **[b-ITU-T G.696.1]** | **[b-ITU-T G.698.1]** | **[b-ITU-T G.959.1]** |
|---|---|---|---|---|---|---|---|
| | **STM-64 and other SDH** | **Multi-channel** | **Intra-office** | **CWDM** | **Intra-Domain DWDM** | **DWDM** | **OTN** |
| Attenuation (max/min) | S | S | S | S | S | S | S |
| Chromatic dispersion (max/min) | S | S | S | S | S | S | S |
| Differential group delay (max) | S | NS | S | S | S | S | S |
| Reflections (min optical return loss, max discrete) | S | S | S | S | S | S | S |

# Appendix III

## Method for differentiating splice loss and macrobending loss in installed links

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

### III.1 General

When large loss is observed at a fusion splice point after cable installation by OTDR measurement, it usually means that the loss is due to a low quality fusion splice or other causes, e.g., fibre macrobending in a closure. Fibre macrobending in a closure is caused by rough fibre handling following a fusion splice in a cable installation or by other causes, e.g., fibre axial strain.

Optical system performance might be degraded at longer wavelengths for an optical fibre cable link with fibre macrobending. Hence, it is quite important to identify the location of fibre macrobending for a cable link.

This appendix describes a simple method for differentiating splice loss and macrobending loss in installed links. The method is based on OTDR measurement at two wavelengths and it is recommended that a bidirectional OTDR method be used that can determine the exact loss at the splice point. This optional method can be used to identify the main loss factor when large loss is observed in an OTDR trace in the vicinity of a splice.

The application of the method is limited to ITU-T G.652-type fibres. A general application of the method to ITU-T G.657-type fibres is difficult to implement, because of low bending loss, and is not recommended.

Moreover, if the exact fibre types in the link are unknown, it is difficult to apply this method, since the method is only effective for ITU-T G.652-type fibres.

### III.2 Theory

#### III.2.1 Definition of macrobending indicator

Measurement of the macrobending indicator is based on an OTDR measurement at two different wavelengths. The macrobending indicator, $k$, is defined as follows [b-Ryu]:

$$k = (A_1 - A_2)/(\lambda_1 - \lambda_2) \text{ (dB/nm)} \qquad \text{(III-1)}$$

In Equation III-1, it is assumed that OTDR measurement is performed at wavelengths of $\lambda_1$ and $\lambda_2$ (in nanometres) and that the measured loss at a fibre splice point at each wavelength is $A_1$ and $A_2$ (in decibels), respectively. Wavelengths $\lambda_1$ and $\lambda_2$ should be set at values longer than the cable cut-off wavelength.

Figure III.1 shows examples of the calculation results of the macrobending indicator using the theory of [b-Marcuse, 1976] and [b-Sharma] when a fibre is wound one turn with a radius of $R$ (in millimetres). In the calculation, $\lambda_1$ was fixed at 1 310 nm and $\lambda_2$ was changed as shown on the horizontal axis.

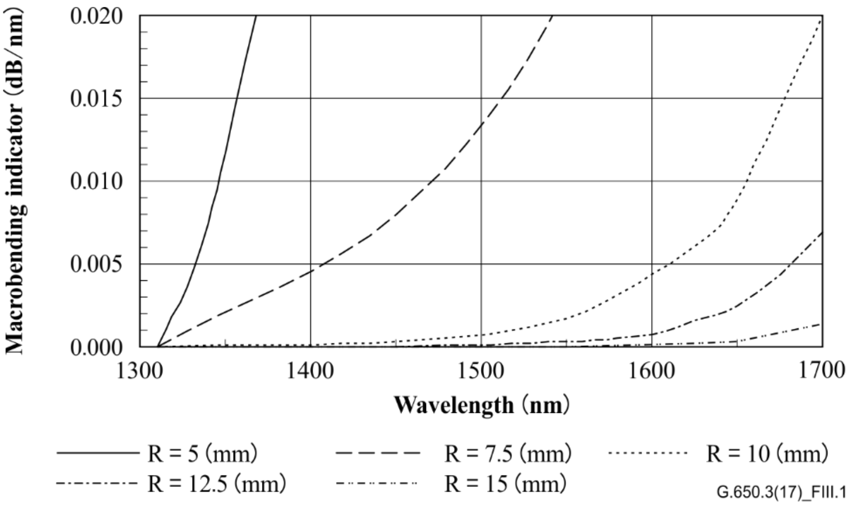


**Figure III.1 – Macrobending indicator vs wavelength ($\lambda_2$) for various bending radii ($\lambda_1$ = 1 310 nm)**

From Figure III.1, it is clear that as $\lambda_2$ increases, the macrobending indicator becomes larger, which means that the detection sensitivity of macrobending has improved.

### III.2.2 Features of macrobending indicator

As described in Appendix I, in the OTDR measurement, accurate loss values can be derived by averaging bidirectional measurement results. The necessity for bidirectional measurement is due to different Rayleigh backscattering coefficients of the spliced fibres.

Figure III.2 shows an OTDR set-up for measuring the macrobending indicator. In the set-up, Fibre A and Fibre B are spliced. Macrobending exists on the Fibre B side.

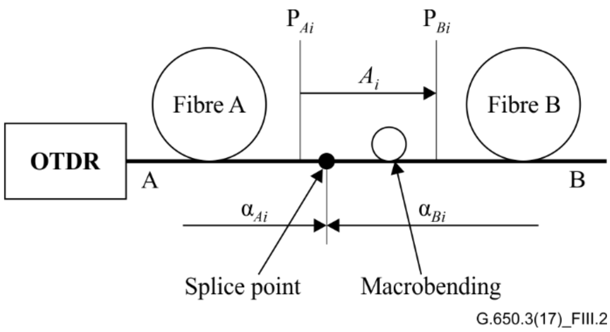


**Figure III.2 – Measurement set-up of macrobending indicator**

Here it is assumed that the OTDR measurement is carried out from side A and that $P_{Ai}$ is optical power immediately before the splice point at a wavelength $\lambda_i$ ($i$ = 1, 2), and $P_{Bi}$ is power right after the point with macrobending. It is also assumed that the splice loss for this case is negligibly small. Rayleigh backscattering coefficients for fibre A and fibre B at a wavelength $\lambda_i$ are assumed to be $\alpha_{Ai}$ and $\alpha_{Bi}$, respectively. It is well known that $\alpha_{Ai}$ and $\alpha_{Bi}$ are inversely proportional to $\lambda_i^4$, so that they can be expressed as:

$$\alpha_{A\,i} = \alpha_A / \lambda_i^4 \quad \text{(III-2)}$$

$$\alpha_{Bi} = \alpha_B / \lambda_i^4 \quad \text{(III-3)}$$

The loss $A_i$ at a wavelength $\lambda_i$ can be derived as:

$$A_i = 10\,log_{10}\{(\alpha_{Ai} P_{Ai})/(\alpha_{Bi} P_{Bi})\} = 10\,log_{10}\{(\alpha_A P_{Ai})/(\alpha_B P_{Bi})\} \quad \text{(III-4)}$$

From Equations III-1 and III-4, the macrobending indicator becomes:

$$k = \{10\,log_{10}(P_{A1}/P_{B1}) - 10\,log_{10}(P_{A2}/P_{B2})\}/(\lambda_1 - \lambda_2) \quad \text{(III-5)}$$

In Equation III-5, the influence of the Rayleigh backscattering coefficient has been cancelled due to the differential operation in the definition of *k*. Equation III-5 shows that *k* is only dependent on the exact power before and after the fibre macrobending point at each wavelength.

The results above show that bidirectional measurement is not necessary for the determination of *k*. This feature is quite important, since it is not always easy to perform OTDR measurement from both sides of the cable because both end points are at different locations geographically.

Then a case with the splice loss is taken into account. Regarding the splice loss, if the fibres with a different mode field diameter (MFD) are spliced, the loss due to MFD mismatch is observed. The influence of the loss-increase due to MFD mismatch is discussed in clause III.4.2. Figure III.3 shows a measurement configuration for such a case.

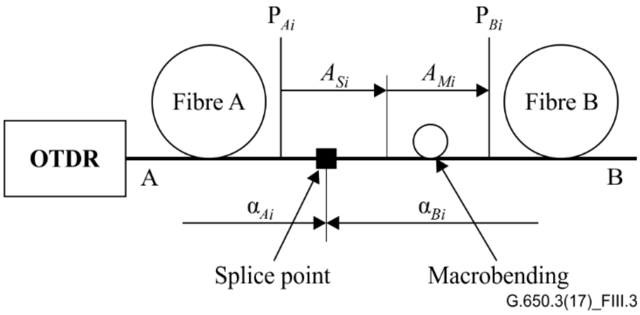


**Figure III.3 – Macrobending indicator measurement set-up with both macrobending and splice loss**

The optical power $P_{Ai}$ and $P_{Bi}$ are assumed as in Figure III.2. $A_{Si}$ and $A_{Mi}$ denote the loss due to the splice and macrobending, respectively. The macrobending indicator *k* becomes:

$$k = (A_{S1} - A_{S2})/(\lambda_1 - \lambda_2) + (A_{M1} - A_{M2})/(\lambda_1 - \lambda_2) \quad \text{(III-6)}$$

The macrobending indicator due to the splice loss is defined as:

$$k_S = (A_{S1} - A_{S2})/(\lambda_1 - \lambda_2) \quad \text{(III-7)}$$

and that due to the macrobending is:

$$k_M = (A_{M1} - A_{M2})/(\lambda_1 - \lambda_2) \quad \text{(III-8)}$$

From Equations III-6, III-7, and III-8:

$$k = k_S + k_M \quad \text{(III-9)}$$

From Equation III-9, it can be said that the total macrobending indicator is the summation of both contributions.

## III.3 Considerations on practical applicability

This clause discusses a practical detection limit of the macrobending indicator. Regarding conventional OTDR systems, the detection limit of optical loss is δ (dB) considering the accuracy of the OTDR equipment.

The detection limit of the macrobending indicator $k_{min}$ can be expressed as:

$$k_{min} = \delta/(\lambda_2 - \lambda_1) \text{ (dB/nm)} \qquad \text{(III-10)}$$

Figure III.4 shows applicable measurement conditions of the macrobending indicator with one turn for various bending radii when δ is assumed to be 0.1 (dB), considering the accuracy of the conventional OTDR measurement.

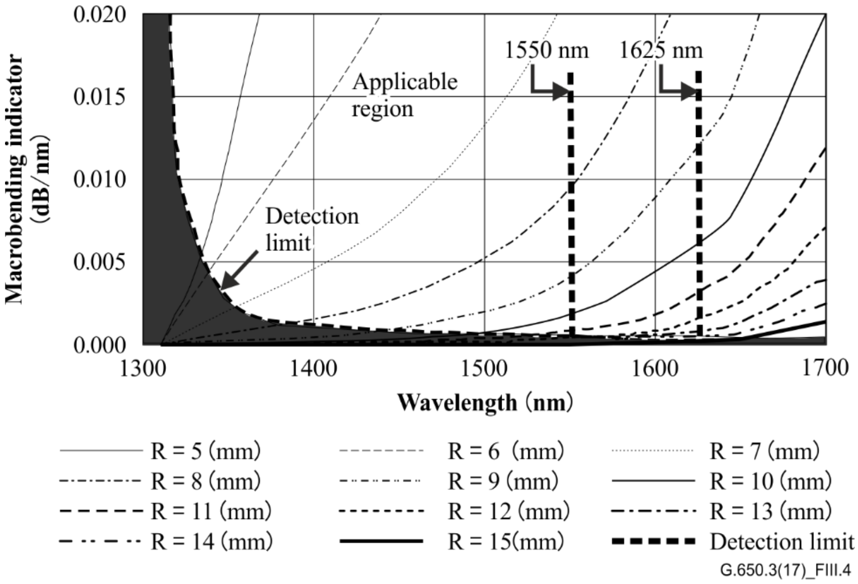


**Figure III.4 – Applicable measurement conditions**

It can be made clear from Figure III.4 that as $\lambda_2$ becomes longer, the macrobending with a larger radius can be detected. In other words, the detection sensitivity becomes improved for longer $\lambda_2$.

From Figure III.4, an approximate detection limit of the maximum bending radius can be summarized as in Table III.1.

**Table III.1 – Detection limit of maximum bending radius**

| Wavelength $\lambda_2$ (nm) | 1 550 | 1 625 |
|---|---|---|
| Maximum detection limit of bending radius (mm) | 11 | 13 |

## III.4 Measurement examples and influence of various conditions on measurement results

In this clause, some measurement examples are shown in terms of the influence of various conditions on the measurements results.

### III.4.1 High splice loss

Table III.2 shows splice loss of two ITU-T G.652-type fibres when they are spliced with the fibre core axis misalignment to emulate a large splice loss condition. It is known from Table III.2 that splice loss decreases as the wavelength becomes longer. This is because at longer wavelength the MFD becomes larger, thus the loss increase due to the core axis misalignment is alleviated. Figure III.5 shows the macrobending indicator calculated from Table III.2. It can be seen from Figure III.5 that the macrobending indicator becomes a negative value due to the reasons above. In this case, applicable measurement conditions in Figure III.4 may be degraded since the macrobending indicator is the summation of both splice and macrobending losses as shown in Equation III-9.

**Table III.2 – Splice loss in case of fibre core axis misalignment**

| Wavelength (nm) | Loss (from side A) (dB) | Loss (from side B) (dB) | Average (dB) |
|---|---|---|---|
| 1 310 | 0.89 | 1.29 | 1.09 |
| 1 450 | 0.79 | 1.18 | 0.99 |
| 1 550 | 0.74 | 1.13 | 0.93 |
| 1 625 | 0.69 | 1.10 | 0.90 |

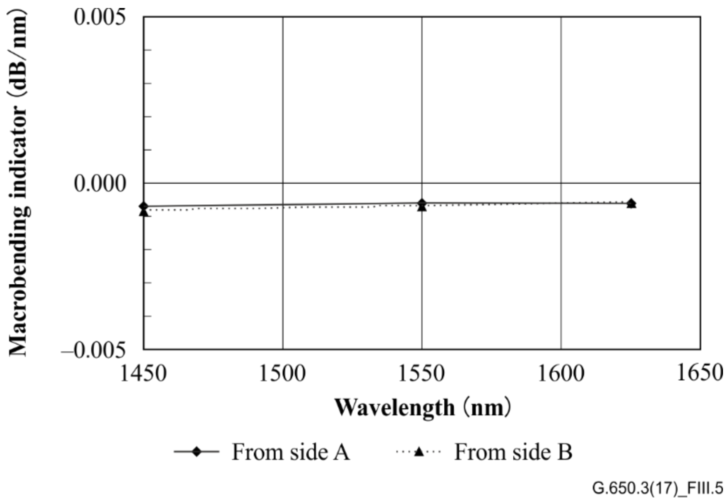


**Figure III.5 – Macrobending indicator with large splice loss**

### III.4.2 Mode field diameter mismatch

This clause discusses the influence of the MFD mismatch on the macrobending indicator, since the MFD of the commercial ITU-T G.652-type fibres is different from one fibre to another as long as the MFD is within the specified values in [ITU-T G.652].

According to [ITU-T G.652], the MFD at 1 310 nm of G.652.B is specified as follows:

– range of nominal values: 8.6 µm to 9.5 µm;

– tolerance: ±0.6 µm.

So, for the consideration of the influence of the MFD mismatch, it is sufficient to consider the MFD range 8.0 µm to 10.1 µm.

Figure III.6 shows the calculation results of the macrobending indicator considering the splice loss theory of [b-Marcuse, 1977] when fibres with MFD of 8.0 µm and 10.1 µm are spliced.

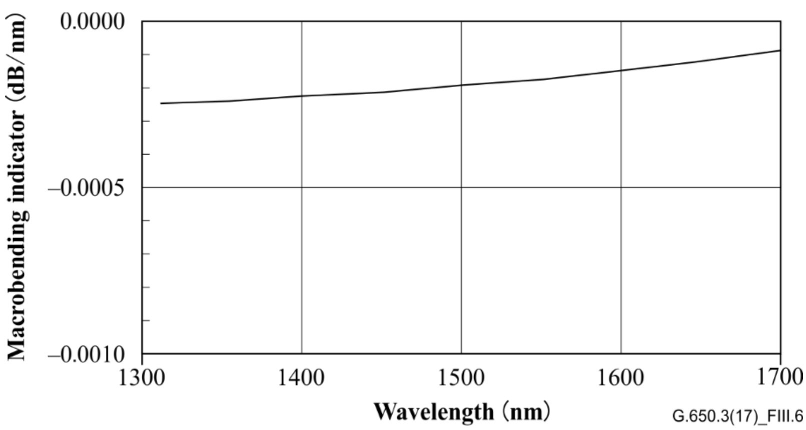


**Figure III.6 – Macrobending indicator when different mode field diameter fibres are spliced**

From Figure III.6, it can be seen that the macrobending indicator becomes a negative value, and the minimum value is about −0.000 25 dB/nm. The absolute value of the macrobending indicator is fairly small as compared with the detection limit discussed in clause III.3. Hence, it can be concluded that the influence of the MFD mismatch on the macrobending indicator can be neglected in practical applications.

## Appendix IV

## Splice loss measurement using quasi-bidirectional technique

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

### IV.1 Introduction

This appendix introduces test methods for measuring splice loss by the quasi-bidirectional technique. These test methods are considered when the bidirectional OTDR test cannot be employed in the field.

There are two quasi-bidirectional methods that can be used for an accurate evaluation of splice loss, and they are based on OTDR of [b-Di Vita] and Brillouin time domain analysis (BOTDA) of [b-Takahashi, 2014a] and [b-Takahashi, 2014b] techniques. Both methods can obtain bidirectional information from measurement results assisted by the end-reflection of the fibre. The methods are not recommended as standard methods, since it is challenging to deploy them on existing networks. They often require a reflector at the fibre-end and more complicated test apparatus than a conventional OTDR test.

### IV.2 Test method using quasi-bidirectional technique

#### IV.2.1 End-reflection assisted optical time domain reflectometer

##### IV.2.1.1 General

In OTDR testing, Rayleigh backscattering generated by a probe pulse propagating in a fibre link is recognized as a unidirectional OTDR trace. When there is a strong reflection at the far end of the fibre, Rayleigh backscattering generated by the reflected probe pulse is also reflected at the far end, and then detected as a signal. This is called a second order backscatter trace (often called a ghost trace), and it appears after the unidirectional (namely first order) OTDR trace. It is emphasized that these traces contain information on opposite directions of the fibre link between first and second order traces.

Figure IV.1 shows a schematic of the use of an end-reflection assisted OTDR.

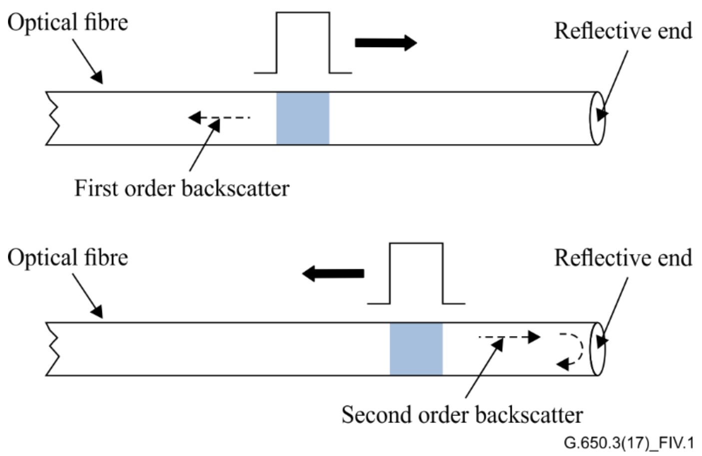


**Figure IV.1 – Schematic of the use of an of end-reflection assisted optical time domain reflectometer**

##### IV.2.1.2 Test apparatus

The test apparatus is shown in Figure C.1 of [IEC 60793-1-40].

The method requires a high dynamic range as regards OTDR performance, because the OTDR probe pulse experiences round-trip propagation with twice the total attenuation of the fibre link and the return loss of the end-reflection. An end-reflection with higher reflectivity (~100%) is desirable in terms of obtaining the second backscatter trace more effectively. It is noted that the tail of the pulse recovery at the strong reflection does not allow the characterization of the splice loss near the reflective end. Otherwise, a specially designed OTDR with a short recovery time would be needed.

#### IV.2.1.3 Measurement procedure

Figure IV.2 shows an example of the result obtained with an end-reflection assisted OTDR. The true splice loss can be determined by taking the average of two events at symmetrical positions, based on the fibre-end reflection from the OTDR trace on a logarithmic scale.

Further information about this method can be found, for example, in [b-Gold].

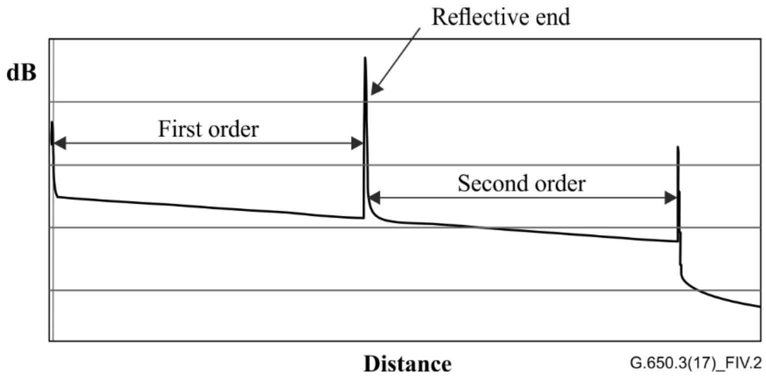


**Figure IV.2 – Example result with an end-reflection assisted optical time domain reflectometer**

### IV.2.2 End-reflection assisted Brillouin time domain analysis

#### IV.2.2.1 General

It is known that Brillouin gain analysis can also be used for loss distribution measurement [b-Horiguchi]. If pump and probe pulses with an optical frequency difference of 10 GHz to 11 GHz collide in a fibre, the probe pulse is amplified by Brillouin gain. Conceptually, the loss distribution can be analysed from the gain distribution, since the Brillouin gain reflects the loss experienced by the pump pulse. The fundamental difference compared with OTDR approaches is that this method is not based on a backscattering technique, and uses the probe pulse reflected at the fibre-end.

Figure IV.3 shows a schematic of end-reflection assisted BOTDA.

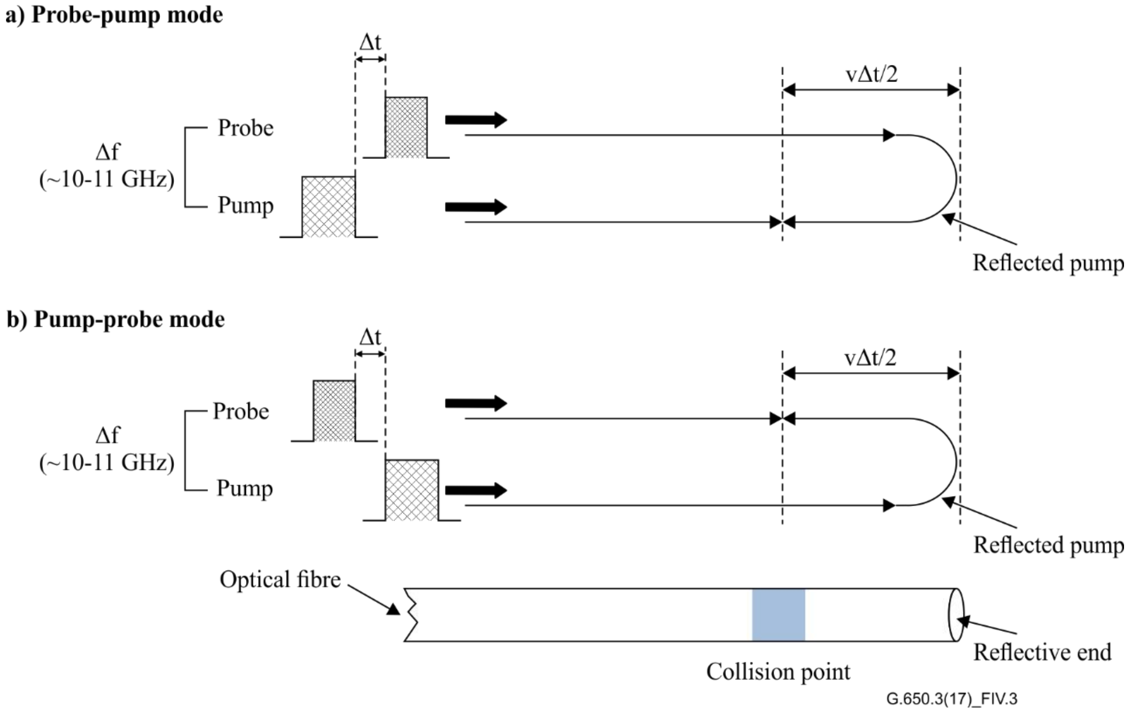


**Figure IV.3 – Schematic of end-reflection assisted Brillouin time domain analysis**

### IV.2.2.2 Test apparatus

Figure IV.4 shows the test apparatus used for end-reflection assisted BOTDA. It consists of a distributed feedback (DFB) laser, frequency and intensity modulators, a pulse generator and polarization controllers. The frequency modulator is used to control the frequency difference between the pump and the probe pulses. The intensity modulators and the pulse generator can change the time delay, $\Delta t$, with which the pump and probe pulses are launched into the fibre. The polarization scrambler changes the polarization state between the pump and probe pulses. The narrow-band optical filter eliminates the reflected pump pulse to be detected.

The positive and negative values of $\Delta t$ are for the probe-pump and pump-probe modes, respectively. The time delay, $\Delta t$, is changed from $2L/v$ to $-2L/v$, where $L$ is the link length and $v$ is the light velocity in the fibre. The spatial resolution of the loss distribution is given by $vT_p/2$ ($T_p$ is the pulse width of the pump pulse).

Although this method is not affected by the problem of the pulse recovery as seen in OTDR approaches, since it acquires the Brillouin gain on the probe pulse, it requires more complicated test apparatus than the conventional OTDR test method. This method requires frequency shift averaging at 10 GHz to 11 GHz by changing the optical frequency of the probe or pump at the frequency modulator in order to avoid the influence of parameters such as the fibre type and temperature versus strain distribution in the fibre link.

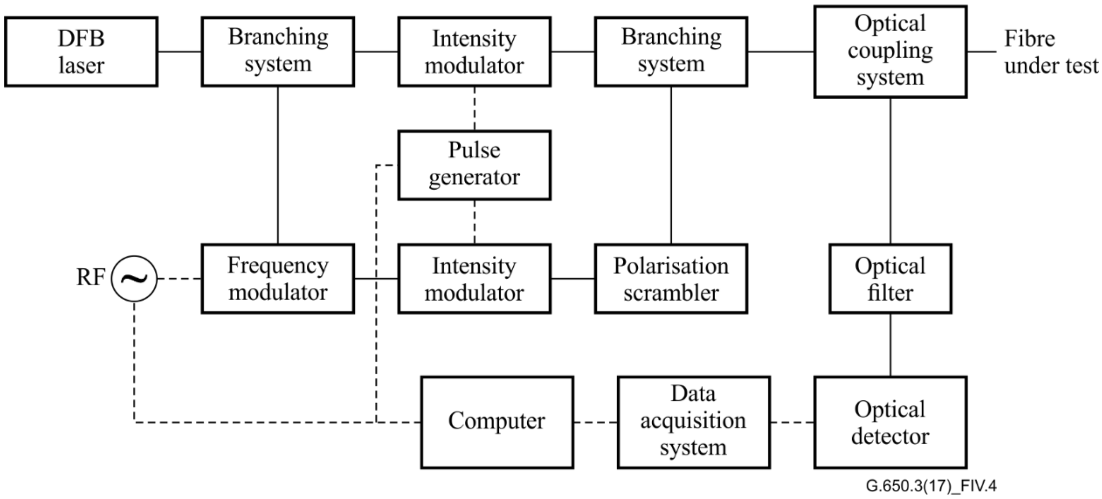


**Figure IV.4 – Test apparatus in end-reflection assisted Brillouin time domain analysis**

### IV.2.2.3 Measurement procedure

The measurement procedure is as follows.

a) Align the fibre under test with the optical coupling system.

b) Measure the power of the reflected probe pulse without the pump pulse.

c) Measure the power of the reflected probe pulse for *N* iterations, while changing the time delay for the scanning collision points between the pump and the probe pulses along the fibre under test. *N* is the averaging number.

d) Analyse the gain distribution from the difference between the reflected probe powers in steps b) and c).

e) Change the optical frequency of either the probe or pump, and repeat steps b) to e).

f) Average the gain distributions of step e).

g) Obtain the true splice loss from two averaged symmetrical events based on the fibre-end reflection ($\Delta t = 0$) from the trace on the logarithmic scale.

Figure IV.5 shows an example of the results. The apparent gain or loss events on the trace are observed at the splices between ITU-T G.652- and ITU-T G.657-type fibres. The true splice losses are obtained as 0.21 dB for splice A and 0.41 dB for splice B.

Figure IV.6 compares results for four splices obtained by OTDR and end-reflection assisted BOTDA. The horizontal and vertical axes show the results obtained by bidirectional OTDR and end-reflection assisted BOTDA, respectively. The solid line shows the agreement between both splice loss values. With unidirectional OTDR, there was a discrepancy of more than ±0.3 dB. The results obtained with the end-reflection assisted BOTDA were in good agreement with those obtained using bidirectional OTDR measurement with a discrepancy of less than ±0.1 dB.

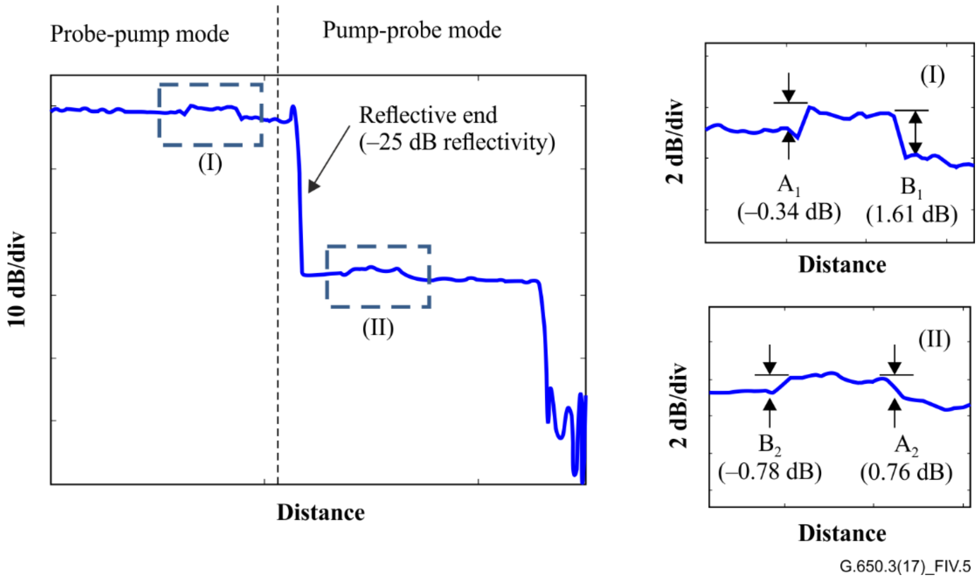


**Figure IV.5 – Example results for end-reflection assisted BOTDA**

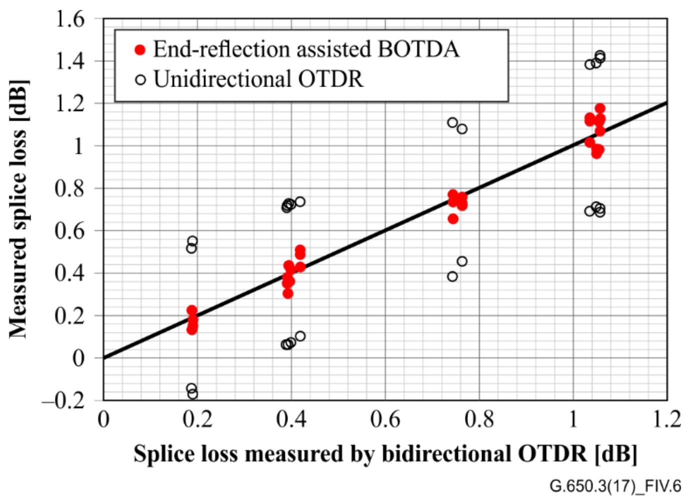


**Figure IV.6 – Comparison of results**

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| Series K | Protection against interference |
| Series L | Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant |
| Series M | Telecommunication management, including TMN and network maintenance |
| Series N | Maintenance: international sound programme and television transmission circuits |
| Series O | Specifications of measuring equipment |
| Series P | Telephone transmission quality, telephone installations, local line networks |
| Series Q | Switching and signalling, and associated measurements and tests |
| Series R | Telegraph transmission |
| Series S | Telegraph services terminal equipment |
| Series T | Terminals for telematic services |
| Series U | Telegraph switching |
| Series V | Data communication over the telephone network |
| Series X | Data networks, open system communications and security |
| Series Y | Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities |
| Series Z | Languages and general software aspects for telecommunication systems |

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