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Maintenance and operation – Optical fibre cable maintenance

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# Optical fibre maintenance depending on topologies of access networks

Recommendation ITU-T L.310

ITU-T L-SERIES RECOMMENDATIONS

**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.310

## Optical fibre maintenance depending on topologies of access networks


### Summary

Recommendation ITU-T L.310 deals with optical fibre maintenance depending on topologies of access networks. It describes the fundamental requirements, maintenance section, testing and maintenance items, and methods for developing a suitable guide to maintaining point-to-multipoint and ring optical networks, respectively.



### History

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

Network, optical fibre maintenance, OTDR reflecting device, OTDR testing point-to-multipoint access, ring access network.


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## Table of Contents

## Introduction

The point-to-multipoint and ring network architectures are very important in terms of constructing optical fibre networks both effectively and inexpensively. However, some considerations on the testing and maintenance methods are required for the point-to-multipoint and ring network architectures in addition to conventional single star architecture. In this Recommendation, topology-specific maintenance items and test methods are identified for the point to multi-point and ring network architecture.

# Recommendation ITU-T L.310

## Optical fibre maintenance depending on topologies of access networks

## 1 Scope

This Recommendation describes the maintenance section, testing and maintenance functions, and methods for both point-to-multipoint and ring networks in the access network.

## 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 L.300] Recommendation ITU-T L.300/L.25 (2015), *Optical fibre cable network maintenance.*

[ITU-T L.301] Recommendation ITU-T L.301/L.41 (2000), *Maintenance wavelength on fibres carrying signals.*

[ITU-T L.302] Recommendation ITU-T L.302/L.40 (2000), *Optical fibre outside plant maintenance support, monitoring and testing system*.

[ITU-T L.313] Recommendation ITU-T L.313/L.66 (2007), *Optical fibre cable maintenance criteria for in-service fibre testing in access networks.*

[ITU-T L.314] Recommendation ITU-T L.314/L.85 (2010), *Optical fibre identification for the maintenance of optical access networks.*

[IEC 61746-1] IEC 61746-1 (2009), *Calibration of optical time-domain reflectometers (OTDR).*

[IEC 61753-041-2] IEC 61753-041-2 (2014), *Fibre optic interconnecting devices and passive components – Performance standard – Part 041-2: Non-connectorized single-mode OTDR reflecting device for category C – Controlled environment*.

[IEC 61753-042-2] IEC 61753-042-2 (2014), *Fibre optic interconnecting devices and passive components – Performance standard – Part 042-2: Plug-pigtail-style and plug-receptacle-style of OTDR reflecting devices for category C – Controlled environments.*


## 3 Definitions

### 3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

**3.1.1 surveillance**: [ITU-T L.300]

**3.1.2 control**: [ITU-T L.300]

**3.1.3 OTDR reflecting device**: [IEC 61753-041-2]

### 3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

**3.2.1 maintenance section**: An area of optical fibres that is tested and maintained in an access network.

**3.2.2 apparent return loss**: A return loss calculated from the difference between superimposed backscatter level from multiple branch fibres and reflection level on OTDR trace. The "apparent" is used to distinguish from the return loss measured without any branches as in [IEC 61746-1].

## 4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

| | |
|---|---|
| ADM | Add-Drop Multiplexer |
| B-OTDR | Brillouin Optical Time Domain Reflectometer |
| CB | Customer Building |
| CO | Central Office |
| FBG | Fibre Bragg Grating |
| H-OTDR | High spatial resolution Optical Time Domain Reflectometer |
| ID light | Identification light |
| OLT | Optical Line Terminal |
| ONU | Optical Network Unit |
| OTDR | Optical Time Domain Reflectometer |
| PON | Passive Optical Network |

## 5 Conventions

None.

## 6 Fundamental requirements

### 6.1 Network topologies

#### 6.1.1 Point-to-multipoint access network

The basic configuration of a point-to-multipoint access network is shown in Figure 1.

Case 1: Indoor splitter in CO;

Case 2: Outdoor splitter;

Case 3: Indoor splitter in CB.

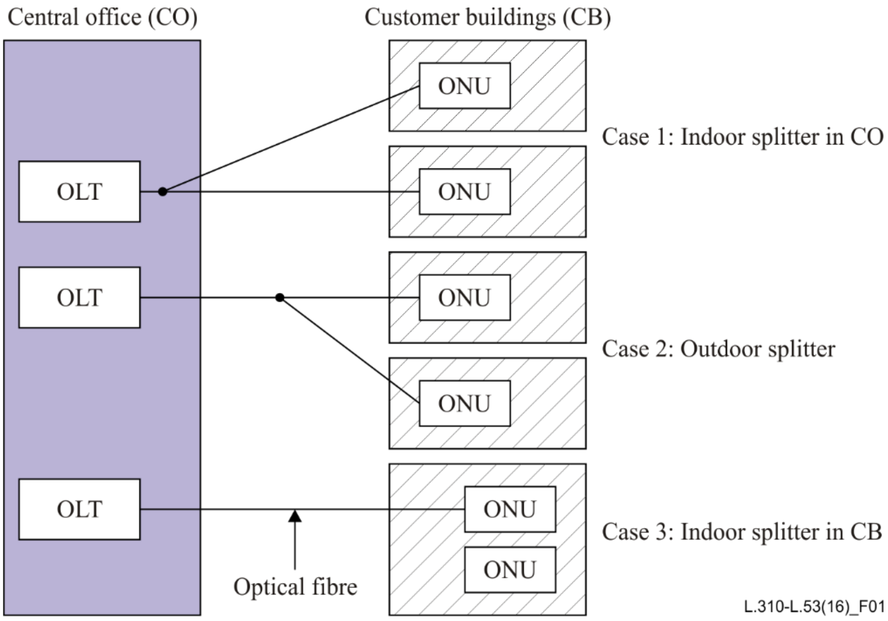


**Figure 1 – Configuration of point-to-multipoint access network**

### 6.1.2 Ring access network

The basic configuration of a ring access network is shown in Figure 2.

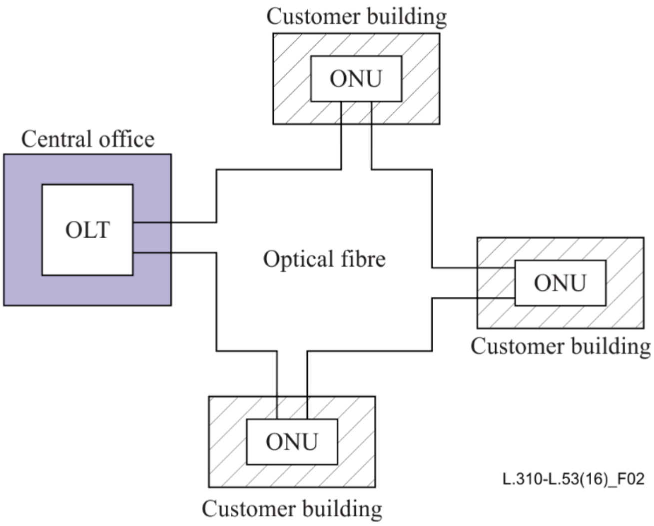


**Figure 2 – Configuration of ring access network**

## 6.2 Maintenance section

A maintenance section is classified as follows.

### 6.2.1 Maintenance section of point-to-multipoint access network

The maintenance sections of the point-to-multipoint access network in Figure 1 are as follows:

Case 1: Optical fibre between the OLT and the ONU as shown in Figure 1 case 1 (All sections);

Case 2: Optical fibre between the OLT and the ONU as shown in Figure 1 case 2 (All sections);

Case 3: Optical fibre between the OLT and the indoor splitter.

### 6.2.2 Maintenance section of ring access network

The maintenance section of the ring access network in Figure 2 consists of all sections of the ring access network.

## 6.3 Testing and maintenance items

### 6.3.1 Testing and maintenance items for point-to-multipoint access networks

Maintenance items for point-to-multipoint access networks are classified as shown in Table 1.

**Table 1 – Testing and maintenance items for point-to-multipoint access networks**

| Category | Activity | Testing and maintenance item | Status |
|---|---|---|---|
| Preventative maintenance | Surveillance<br>(e.g., Periodic testing, Continuous testing) | Detection of fibre loss increase<br>Detection of signal power loss increase<br>Detection of water penetration | Optional<br>Optional<br>Optional |
| | Testing<br>(e.g., Fibre degradation testing) | Measurement of fibre fault location<br>Measurement of fibre strain distribution<br>Measurement of water location | Optional<br>Optional<br>Optional |
| | Control<br>(e.g., Network element control) | Fibre identification<br>Fibre transfer | Optional<br>Optional |
| After installation before service or post-fault maintenance | Surveillance<br>(e.g., Reception of transmission system alarm or customer trouble report) | Refer to alarm from path operation system<br>Refer to alarm from customer service operation system | Optional<br>Optional |
| | Testing<br>(e.g., After installation testing, Fibre fault testing) | Confirmation of fibre condition<br>Fault identification between transmission equipment and fibre network<br>Measurement of fibre fault location<br>Fault responsibility demarcation of trunk cable and/or branch cable<br>Measurement of splitter degradation<br>Fault classification | Required<br>Required<br>Required<br>Optional<br>Optional<br>Optional |
| | Control<br>(e.g., Cable install/repair/ replacement) | Fibre identification<br>Fibre transfer<br>Storage of outside plant database<br>Information on cable route | Required<br>Optional<br>Required<br>Optional |

### 6.3.2 Testing and maintenance items for ring access networks

Maintenance items for ring access networks are classified as shown in Table 2.

**Table 2 – Testing and maintenance items for ring access networks**

| Category | Activity | Testing and maintenance item | Status |
|---|---|---|---|
| Preventative maintenance | Surveillance | Detection of fibre loss increase<br>Detection of signal power loss increase<br>Detection of water penetration | Optional<br>Optional<br>Optional |

**Table 2 – Testing and maintenance items for ring access networks**

| Category | Activity | Testing and maintenance item | Status |
|---|---|---|---|
| | Testing | Measurement of fibre fault location<br>Measurement of fibre strain distribution<br>Measurement of water location | Optional<br>Optional<br>Optional |
| | Control | Fibre identification<br>Fibre transfer | Optional<br>Optional |
| After installation before service or post-fault maintenance | Surveillance | Refer to alarm from path operation system<br>Refer to alarm from customer service operation system | Optional<br>Optional |
| | Testing | Confirmation of fibre condition<br>Fault identification between transmission equipment and fibre network<br>Measurement of fibre fault location | Required<br>Required<br>Required |
| | Control | Fibre identification<br>Fibre transfer<br>Storage of outside plant database<br>Information on cable route | Required<br>Optional<br>Required<br>Optional |

## 7 Testing and maintenance methods

There are several ways to implement these testing and maintenance items. Optical time domain reflectometer (OTDR) testing, loss testing, monitoring a proportion of the signal power (power monitoring) and identification light detection are commonly used. The most common methods are described below.

### 7.1 Testing and maintenance methods for point-to-multipoint access networks

**Table 3 – Suitable test methods for point-to-multipoint access networks**

| Category | Activity | Item | Methods |
|---|---|---|---|
| Preventative maintenance | Surveillance | Detection of fibre loss increase<br>Detection of signal power loss increase<br>Detection of water penetration | OTDR/loss testing<br>Power monitoring<br>OTDR testing |
| | Testing | Measurement of fibre fault location<br>Measurement of fibre strain distribution<br>Measurement of water location<br>Measurement of trunk fibre and/or branch fibre degradation<br>Measurement of splitter degradation | OTDR testing (Note 1)<br>B-OTDR testing<br>OTDR testing (Note 1)<br>OTDR testing (Note 1/Note 4)<br>OTDR testing (Note 1/Note 4) |
| | Control | Fibre identification<br>Fibre transfer | OTDR testing (Note 1)/ID light detecting (Note 2)<br>Switching (Note 3) |

**Table 3 – Suitable test methods for point-to-multipoint access networks**

| Category | Activity | Item | Methods |
|---|---|---|---|
| After installation before service or post-fault maintenance | Surveillance | Refer to alarm from path operation system<br>Refer to alarm from customer service operation system | On-line/External medium<br>On-line/External medium |
| | Testing | Confirmation of fibre condition<br>Fault identification between transmission equipment and fibre network<br>Measurement of fibre fault location<br>Fault responsibility demarcation of trunk cable and/or branch cable<br>Measurement of splitter degradation<br>Fault classification | OTDR/loss testing (Note 1)<br>OTDR/loss testing (Note 1)<br>OTDR testing (Note 1)<br>OTDR testing (Note 1/Note 4)<br>OTDR testing (Note 1/Note 4)<br>OTDR testing (Note 1) |
| | Control | Fibre identification<br>Fibre transfer<br>Storage of outside plant database<br>Information on cable route | OTDR testing (Note 1)/ID light detecting (Note 2)<br>Switching (Note 3)<br>On-line/External medium<br>On-line/External medium |

NOTE 1 – High spatial resolution OTDR (H-OTDR) is available for monitoring optical fibres to and beyond an outside splitter.
NOTE 2 – ID light such as 270 Hz, 1 kHz, or 2 kHz modulated light as defined in [ITU-T L.314].
NOTE 3 – Switching includes mechanical and manual switching.
NOTE 4 – OTDR reflecting device is available for multi-stage deployment to demarcate fault responsibility effectively.

## 7.2 Testing and maintenance methods for ring access networks

**Table 4 – Suitable test methods for ring access networks**

| Category | Activity | Item | Methods |
|---|---|---|---|
| Preventative maintenance | Surveillance | Detection of fibre loss increase<br>Detection of signal power loss increase<br>Detection of water penetration | OTDR/loss testing<br>Power monitoring<br>OTDR testing |
| | Testing | Measurement of fibre fault location<br>Measurement of fibre strain distribution<br>Measurement of water location | OTDR testing<br>B-OTDR testing<br>OTDR testing |
| | Control | Fibre identification<br>Fibre transfer | ID light detecting (Note 1)<br>Switching (Note 2) |
| After installation before service or post-fault maintenance | Surveillance | Refer to alarm from path operation system<br>Refer to alarm from customer service operation system | On-line/External medium<br>On-line/External medium |

**Table 4 – Suitable test methods for ring access networks**

| Category | Activity | Item | Methods |
|---|---|---|---|
| | Testing | Confirmation of fibre condition | OTDR/loss testing |
| | | Fault identification between transmission equipment and fibre network | OTDR/loss testing |
| | | Measurement of fibre fault location | OTDR testing |
| | Control | Fibre identification | ID light detecting (Note 1) |
| | | Fibre transfer | Switching (Note 2) |
| | | Storage of outside plant database | On-line/External medium |
| | | Information on cable route | On-line/External medium |
| NOTE 1 – ID light such as 270 Hz, 1 kHz, 2 kHz modulated light as defined in [ITU-T L.314].<br>NOTE 2 – Switching includes mechanical and manual switching. | | | |

## 8 Testing and maintenance wavelength

It is important to choose the correct wavelength for monitoring and testing optical fibre networks. Specifically, maintenance functions should be performed without interfering with data transmission signals. [ITU-T L.301] provides general requirements for the selection of the maintenance wavelength. Table 5 expands on these requirements and appropriate wavelengths for given testing and maintaining items that are the same for both point-to-multipoint and ring access networks.

**Table 5 – Maintenance wavelength selection**

| Category | Activity | Item | Wavelength |
|---|---|---|---|
| Preventative maintenance | Surveillance | Detection of fibre loss increase | Maintenance wavelength (Note) |
| | | Detection of signal power loss increase | Signal wavelength |
| | | Detection of water penetration | Any wavelength on fibres not carrying signals |
| | Testing | Measurement of fibre fault location | Any wavelength on fibres not carrying signals |
| | | Measurement of fibre strain distribution | Any wavelength on fibres not carrying signals |
| | | Measurement of water location | Any wavelength on fibres not carrying signals |
| | Control | Fibre identification | Maintenance wavelength (Note) |
| | | Fibre transfer | None |
| After installation before service or post-fault maintenance | Surveillance | Refer to alarm from path operation system | None |
| | | Refer to alarm from customer service operation system | None |
| | Testing | Confirmation of fibre condition | Any wavelength |
| | | Fault identification between transmission equipment and fibre network | Any wavelength |
| | | Measurement of fibre fault location | Any wavelength |

**Table 5 – Maintenance wavelength selection**

| Category | Activity | Item | Wavelength |
|---|---|---|---|
| | Control | Fibre identification | Any wavelength |
| | | Fibre transfer | None |
| | | Interface with outside plant database | None |
| | | Interface with mapping system | None |
| NOTE – Refer to [ITU-T L.301]. | | | |

## 9 Requirements for in-service testing beyond optical splitter utilizing OTDR reflecting devices in point-to-multipoint access network

### 9.1 General

In a point-to-multipoint access network with passive optical splitters, the operator often needs to diagnose faults that have occurred in a branch fibre section. An OTDR reflecting device, which allows communication lights to pass while reflecting the OTDR test light, may help to enhance the effectiveness of OTDR testing when distinguishing faults in a branch fibre section.

The methodology utilizing an OTDR reflecting device is based on a comparison of two sets of results for an OTDR test, in which the change in the peak reflection level at the OTDR reflecting device is monitored. Alternatively, it can be conducted by comparing apparent return losses, which are analysed from OTDR test results if the Rayleigh backscattering level at the end of a branch fibre with the maximum loss can be detected by OTDR.

This clause describes the requirements and technical considerations regarding the deployment and operational conditions, and the procedure for in-service testing beyond an optical splitter when OTDR reflecting devices are installed on the optical network unit (ONU) side of a point-to-multipoint access network.

### 9.2 Requirements for deployment conditions

#### 9.2.1 Network configuration

Network configurations to which the methodology using an OTDR reflecting device can be applied are classified as shown in Figure 3.

The test access device should be used to perform in-service testing. The reflections from the OTDR reflecting devices to the optical line terminal (OLT) should be attenuated by an appropriate method in accordance with [ITU-T L.313].

The branch fibres with the OTDR reflecting device should all have different lengths. For the multiple-stage configuration, the number of splitters is assumed to be consistent for all ONUs within the passive optical network (PON) under test. Mixed deployment with different numbers of splitter-stages is not dealt with in this Recommendation.

The OTDR reflecting devices are installed at positions where branch fibres are terminated.

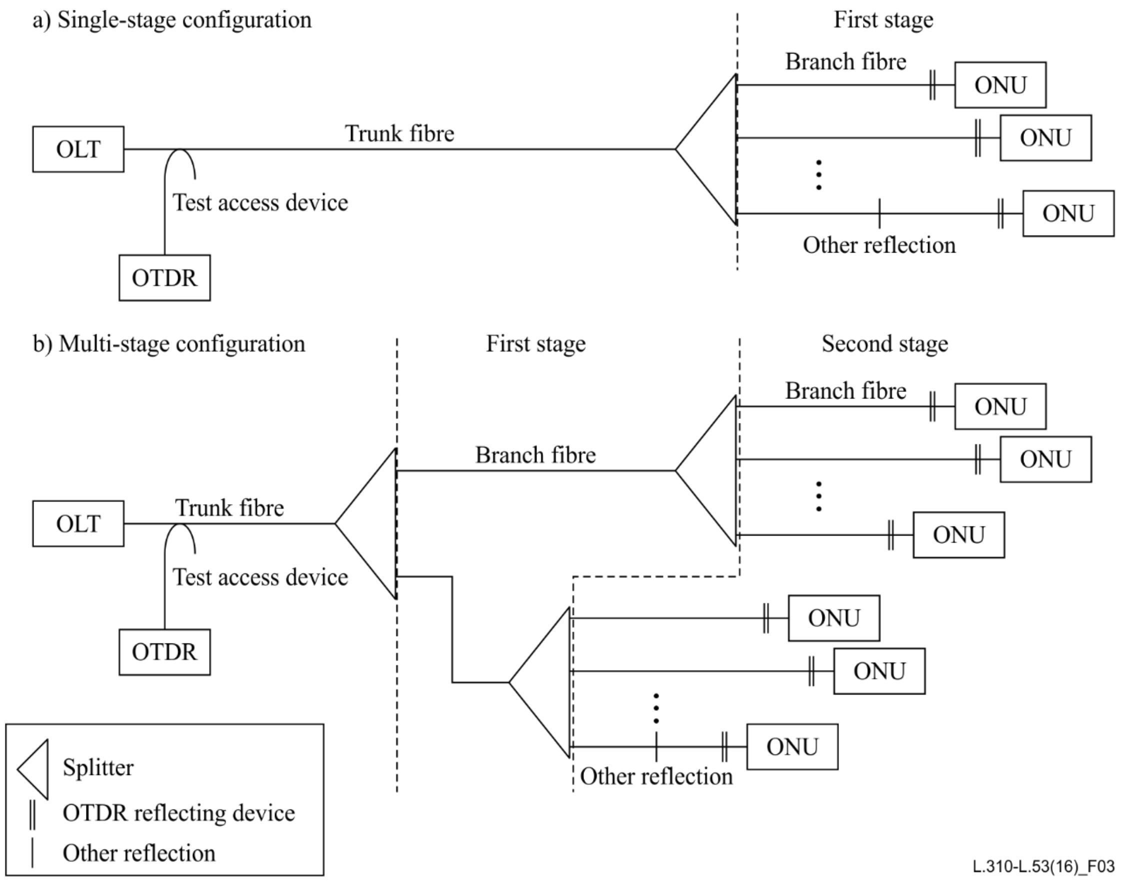


**Figure 3 – Network configurations for in-service testing with OTDR reflecting devices**

### 9.2.2 OTDR reflecting device

#### 9.2.2.1 Optical performance

An OTDR reflecting device should allow communication lights to pass with minimal attenuation. The return losses of an OTDR reflecting device differ for communication and OTDR (maintenance) wavelengths. The return loss at the communication wavelength should be comparable to that of passive optical devices such as optical connectors. A low return loss at the OTDR wavelength is appropriate in that it allows us to distinguish it from other reflections in the branch fibre section.

In the presence of other reflections in the branch fibre section (e.g., from a connector) whose return loss is $C_o$, in the $n$-th splitter stage, the return loss of the OTDR reflecting device at the OTDR wavelength, $C_f$ ($C_f > 0$), should be lower than that of other factors in the relevant splitter stage in order to have the maximum reflection in the OTDR trace in the relevant splitter stage. The return loss of an OTDR reflecting device at the OTDR wavelength, $C_f$, is given by,

$$C_f < C_o - 2(n\Delta A + B + D) \quad \text{(dB)} \qquad (1\text{-}1)$$

Where $\Delta A$ is the uniformity of the splitter loss, $B$ is the maximum branch fibre loss of the relevant stage, and $D$ is the maximum additional loss to be detected in the branch fibre section of the relevant stage.

#### 9.2.2.2 Implementation

There are several possible implementations of the OTDR reflecting device. An FBG-based implementation or thin film-based implementation is typically used in such components as field mountable connectors, optical connectors and fibre pigtails.

The specifications and implementations of an OTDR reflecting device are defined in detail in, for example, [IEC 61753-041-2], [IEC 61753-042-2].

### 9.3 Requirements for operational conditions

#### 9.3.1 Wavelength

The OTDR wavelength and reflective wavelength of an OTDR reflecting device should comply with clause 8. To take account of the expanding communication wavelength band in PONs, it is recommended that both wavelengths be in 1650 nm-band.

#### 9.3.2 Input power

The launched peak power of the OTDR test light through the test access device to the trunk fibre should be maintained during two cycles of OTDR testing. Fluctuation in the launched peak power of the OTDR test light leads to a measurement error, namely additional loss caused by the fault.

Alternatively, if the sum of the Rayleigh backscattering levels of multiple branch fibres can be detected by OTDR, the apparent return loss calculated from the OTDR trace can be used to evaluate the additional loss instead of maintaining the launched peak power.

#### 9.3.3 Spatial resolution

The spatial resolution of the OTDR testing should be set smaller than the minimum difference in branched lengths, and given by $v\tau/2$, where $v$ is the optical velocity in the fibre, and $\tau$ is the pulse width used for OTDR testing.

#### 9.3.4 Minimum detectable power

The OTDR minimum detectable power, $P_d$, should be lower than the Fresnel level of the OTDR reflecting device as follows,

$$P_d < P_{in} - C_f - 2(L + D) \quad \text{(dBm)} \qquad (1\text{-}2)$$

Where $P_{in}$ is the OTDR output power, and $L$ is the maximum total loss through the test access device to the OTDR reflecting device.

### 9.4 Procedure and interpretation of results

The fault location demarcation procedure consists of comparing the peak reflection levels at OTDR reflecting devices for the initial situation with those after the fault. The measurement results in the initial situation should be stored.

If the peak reflection levels at all OTDR reflecting devices decrease compared with the initial situation or none of the OTDR reflecting devices can be detected, then there is a fault in the previous stage.

If the peak levels of reflection at one of the OTDR reflecting devices are decreased or one of the OTDR reflecting devices cannot be detected on OTDR trace, then there is a fault in the branch fibre section of the relevant stage. Any additional loss caused by faults is given by half of the difference between the peak levels before and after the fault occurs. The exact location cannot be determined, but the fibre section can be identified.

# Appendix I

## Practical solutions for point-to-multipoint access network

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

### I.1 Japanese experience

This appendix describes a fault identification method using a high-resolution optical time domain reflectometer for point-to-multipoint optical networks.

### I.1.1 Introduction

Broadband network provision will require the use of thousands of optical fibres in optical access networks. An optical fibre line testing system is essential for reducing construction and maintenance costs and improving service reliability. We have already developed such a system called AURORA (AUtomatic optical fibeR OpeRAtion support system) [b-Tomita]. In addition, we have extended the application of this system to various network structures [b-Enomoto1]. Now, passive optical networks (PONs) with optical splitters installed in optical closures and cabinets near customers' premises are being introduced into access networks to provide high-speed IP services [b-Enomoto2]. However, this testing system is incapable of monitoring the optical fibre cables of PONs with branched optical fibres. Therefore, we designed and evaluated a prototype system that can isolate optical fibre faults in PONs.

### I.1.2 Optical fibre line testing system for PON

#### I.1.2.1 System configuration

Figure I.1 shows the configuration of our optical fibre line testing system for monitoring PON with an optical splitter installed in an aerial optical closure. It consists of test equipment (TE) containing an optical time domain reflectometer (OTDR), optical fibre selectors (FS) that select test fibres, optical couplers and optical filters. The TE and FSs are installed in the cable termination room of a central office. Optical couplers introduce a test light into fibre lines and optical filters installed in the front of an optical line terminal (OLT) and optical network units (ONUs) allow the communication light to pass but cut off the test light. The optical filters installed in the front of the ONUs reflect the test light from the OTDR for isolating fibre fault. The control terminal orders the TE to perform various optical fibre tests through a data communication network (DCN). The TE controls the OTDR and FSs, and returns the test results to the control terminal. This system carries out automatic OTDR measurements, reveals fibre characteristics and isolates faults and their location with no degradation in transmission quality.

There are two methods for monitoring the branched optical fibre network of a PON using an OTDR. One involves measuring backscattered light from branched optical fibres [b-Sankawa]. This approach is suitable for locating fault optical fibres when each branched optical fibre is over 100 m long. We chose the second method, which involves measuring the individual reflection values of optical filters installed in front of the ONU [b-Hogari] because the length of each branched optical fibre between a splitter and an ONU is less than 100 m.

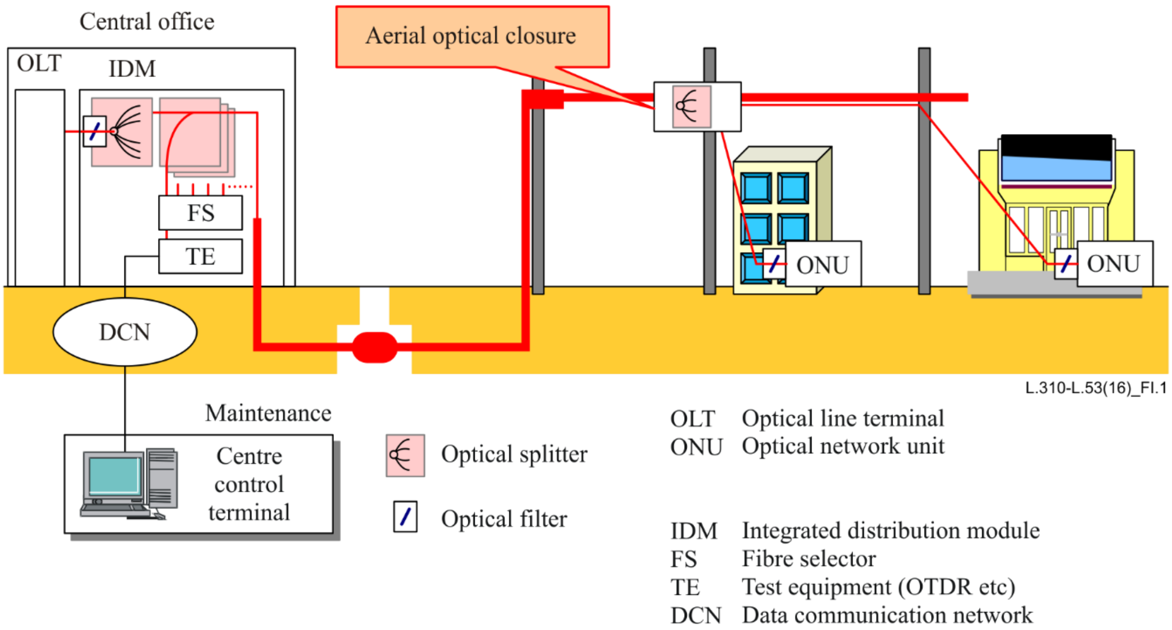


**Figure I.1 – Configuration of optical fibre line testing system for monitoring**

### I.1.2.2 Fault isolation technique

Figure I.2 shows the fault isolation technique for branched optical fibres with an optical splitter. As the lengths of the branched optical fibres are different, the Fresnel reflections from optical filters #1 and #2 can be distinguished. We can determine that the optical fibre with optical filter #1 is faulty because the reflection value of optical filter #1 changes from its initial level.

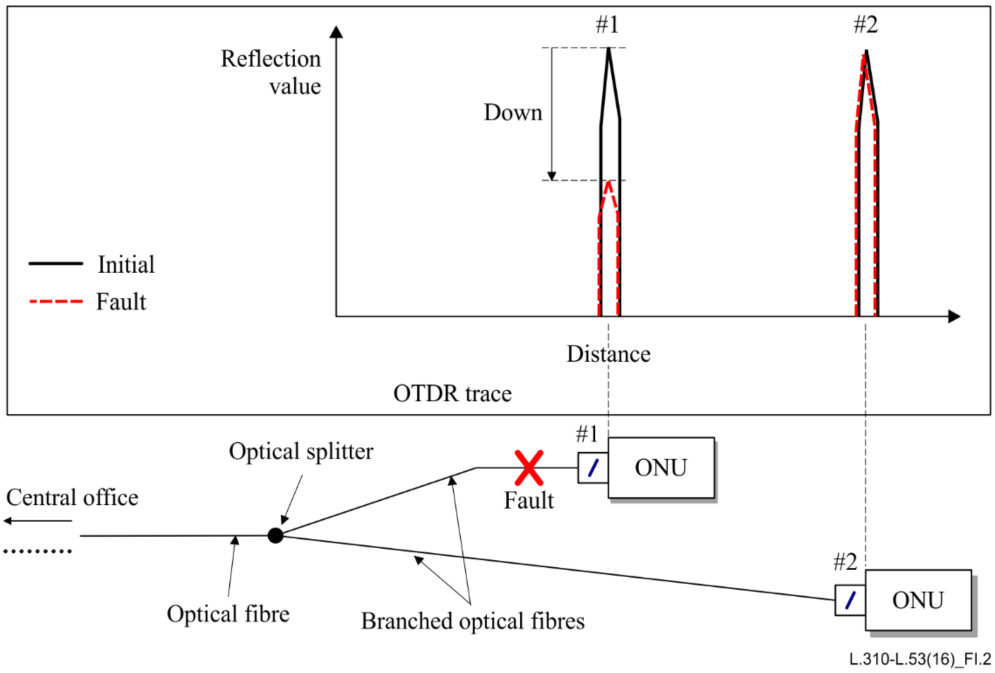


**Figure I.2 – Branched optical fibre fault isolation**

## I.1.3 Evaluation of prototype system

### I.1.3.1 Experimental setup

Figure I.3 shows the experimental setup we used for our prototype system evaluation and a measured high resolution OTDR (H-OTDR) trace of branched optical fibres with a 4-branch optical splitter. The H-OTDR wavelength was 1.65 μm and the pulse width was less than 10 ns. The Fresnel reflection of #1 is from the end of the branched optical fibre. The Fresnel reflections of #2 and #3 are from the optical filters. We applied fibre Bragg grating technologies to the optical filters to obtain a high return loss [b-Hogari]. The optical filter must also allow communication lights to pass whose wavelengths are 1.3 and 1.55 μm, but cut off the test light whose wavelength is 1.65 μm. The return losses of the end of branched optical fibre #1 and optical filters #2 and #3 were −14.9, −1.5 and −1.8 dB at 1.65 μm, respectively.

#### I.1.3.2 Comparison of reflection values from optical filters and ends of branched optical fibres

We measured the difference between the insertion losses of branched optical fibres #1 and #2 including a 4-branch optical splitter using a 1.65 μm light source and an optical power meter. The difference was 0.7 dB at 1.65 μm. The reflection value of optical filter #2 was 6.2 dB higher than that of the end of branched optical fibre #1 in the H-OTDR trance. From these results, we confirmed that the reflection value from each optical filter was higher than those from the ends of the branched optical fibres.

#### I.1.3.3 Fault isolation resolution

We evaluated the fault isolation resolution of this prototype system. Figure I.3 shows that we can distinguish the Fresnel reflections from optical filters #2 and #3 whose distance differed by 2.0 m. We confirmed that our prototype system could isolate a fault in an optical fibre when the difference between the distances of the branched optical fibres is more than 2.0 m.

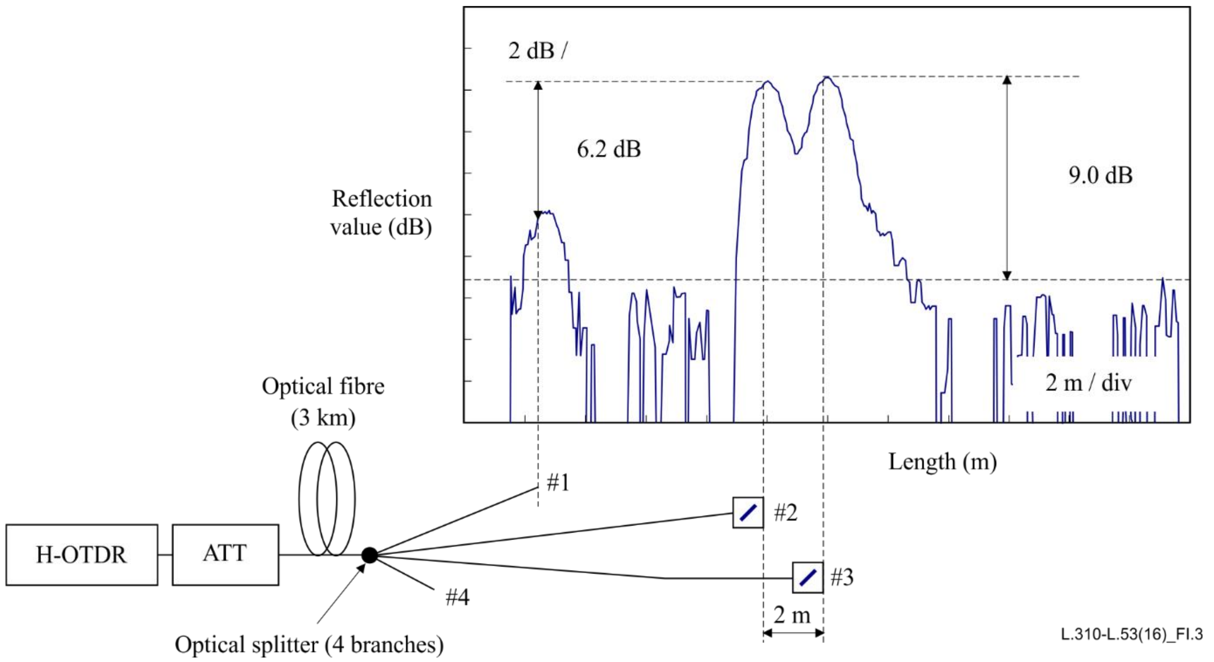


**Figure I.3 – Experimental setup for prototype system evaluation and measured H-OTDR trace**

#### I.1.3.4 System dynamic range

We evaluated the dynamic range of this prototype system. We measured the insertion loss from the H-OTDR to the front of optical filter #3 using a 1.65 μm light source and an optical power meter. The insertion loss was 24.7 dB. The difference between the reflection values of optical filter #3 and the peak noise level was 9.0 dB in the H-OTDR trace. Therefore, the dynamic range of this prototype system was over 31.5 dB at 1.65 μm when the optical filter return loss was over −2.5 dB and the fault isolation threshold value was 1.9 dB. This prototype system could isolate a faulty fibre in a PON with a 32-branch splitter whose insertion loss was 17.5 dB and with 10 km fibres (0.5 dB/km) when the coupling loss including that of an FS and an optical coupler was below 9.0 dB.

### I.1.4 Conclusions

We described the fault fibre isolation function of an optical fibre line testing system based on H-OTDR and optical filters using fibre Bragg grating technologies for a PON. We evaluated a prototype system and its dynamic range was over 31.5 dB. We confirmed that this prototype system has sufficient dynamic range for isolating fibre faults in a PON with a 32-branch optical splitter.

## I.2 Chinese experience

This clause describes two typical fault identification methods using an OTDR with the assistance of OTDR reflecting devices for point-to-multipoint optical networks, one with single-stage OTDR reflecting devices at the ONU side, the other with multi-stage deployment of OTDR reflecting devices.

### I.2.1 Introduction

The basic configuration of a point-to-multipoint access network shown in Figure 1 can be typically implemented in two scenarios.

Scenario 1: point-to-multipoint access network with one-stage optical splitters, in which the optical distribution network (ODN) can be divided into two sections of the trunk fibre and the branch fibre.

Scenario 2: point-to-multipoint access network with two-stage optical splitters (typically 1:4 or 1:8 for the first stage), in which the ODN can be divided into three sections of the trunk fibre, the 1st and 2nd stage branch fibre.

OTDR can be used to measure the location of the reflection or attenuation events in the point-to-multipoint fibre access system. But in some situations, it is quite difficult to detect attenuation events simply by OTDR traces, especially for those traces in the branch fibre sections in the two-stage optical splitter deployment scenarios (scenario 2). In the initial phase of PON construction, there are not many end-users connected beyond the optical splitter(s) in the ODN. In the worst case, only one end-user is connected to the second-stage optical splitter. It is difficult to demarcate the fault between the 1st and 2nd stage branch fibres for the lack of reference change for other end-users. Therefore, OTDR reflecting devices can be used to facilitate fault demarcation and evaluation.

### I.2.2 Fault identification method with single-stage OTDR reflecting devices

#### I.2.2.1 Typical fault location analysis procedure

Typical fault location analysis procedure is as follows.

Step 1: Measure the transmission through the ODN periodically using OTDR and store the results including the apparent return loss or the peak reflection level of the optical splitters and OTDR reflecting devices in the outside plant database.

Step 2: If transmission system alarm or customer trouble report is received, OTDR test will be initiated.

Step 3: OTDR test results are analysed by the following methods to determine the fault location.

**Scenario 1**

If the apparent return loss or the peak reflection level of all the OTDR reflecting devices and the splitter increase compared with the database or all the OTDR reflecting devices cannot be detected, then there is fault caused by attenuation event or reflection event in the trunk fibre, and the accurate location can be determined by its backscattered signal.

If the apparent return loss or the peak reflection level of the OTDR reflecting device of one specific branch increases or one specific OTDR reflecting device cannot be detected, then there is fault caused by attenuation event or reflection event in that branch fibre. For attenuation event, its insertion loss is about half of the differential apparent return loss or peak reflection level between the measured value and the one stored in the database, but the exact location cannot be determined.

**Scenario 2**

If the apparent return loss or the peak reflection level of some of the OTDR reflecting devices and the relevant second-stage optical splitter increase compared with the database, or some of the OTDR reflecting devices and the relevant second-stage optical splitter cannot be detected, then there is fault caused by attenuation event or reflection event in the relevant distribution fibre section. For attenuation event, its insertion loss is about half of the differential apparent return loss or peak reflection level, but the exact location is quite difficult to determine. For reflection event, its accurate location may be found by OTDR with high dynamic range.

Analyses of other situations are the same as described in scenario 1.

### I.2.2.2 Evaluation of test results

The OTDR reflecting device can be implemented in several ways. It may be a stand-alone device. It is also possible to be integrated into the ONU or other elements of the ODN, such as the branch fibre pigtail, the connector, or the splitter.

Stand-alone OTDR reflecting devices and reflecting devices integrated into the ONU were used in the test. The latter one is implemented by the use of dielectric films coated on the end face of the SC/PC plug-pigtail ceramic ferrule of the ONU optical module (shown in Figure I.4), with reflectivity of the OTDR wavelength (1650 nm) higher than 99%.The insertion loss and the return loss at PON communication wavelengths are less than 0.3 dB and greater than 20 dB respectively. It has the characteristics of low cost and less operational complexity during installation.

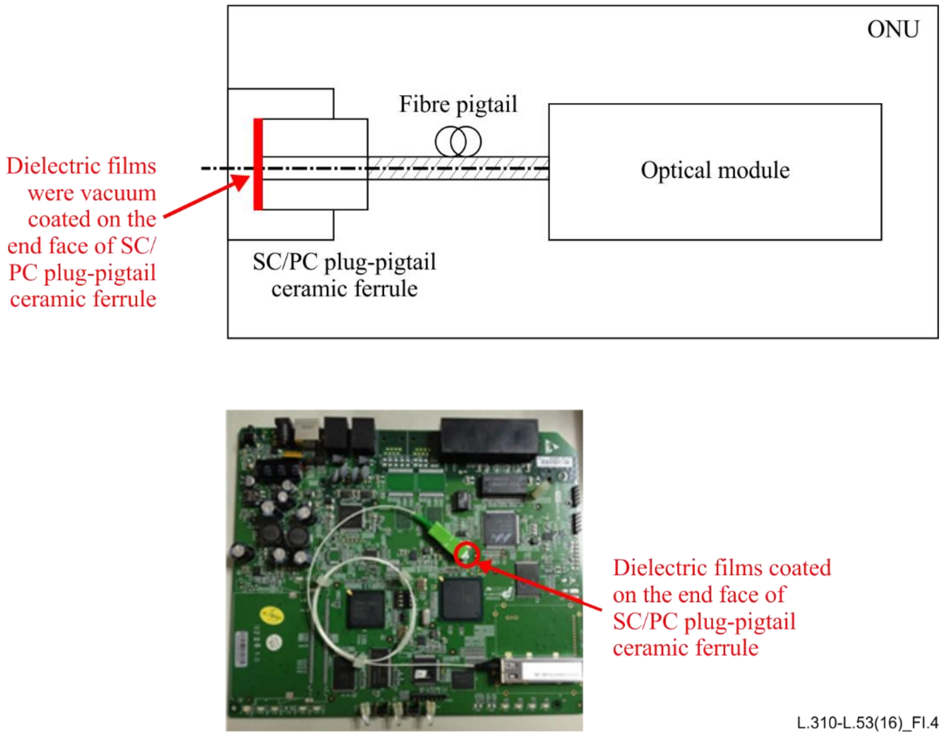


**Figure I.4 – ONU with integrated OTDR reflecting device**

A test was carried out to evaluate the effectiveness of OTDR reflecting devices in the detection of attenuation events. Figure I.5 shows the setup of the test, in which two-stage optical splitters were used with the splitting ratios of 1:4 and 1:8 respectively. We created fibre bending events with the attenuation of 1.0 dB, 2.1 dB, 3.1 dB, 3.9 dB and 4.9 dB, respectively, in the 100-metre 2nd stage branch fibres, and connected them one by one between OTDR reflecting devices and second-stage optical splitters of the branches with distribution fibres of 1 km, 2 km and 4 km, respectively. Table I.1 illustrates the measured peak reflection level of the OTDR reflecting devices with different fibre bending events.

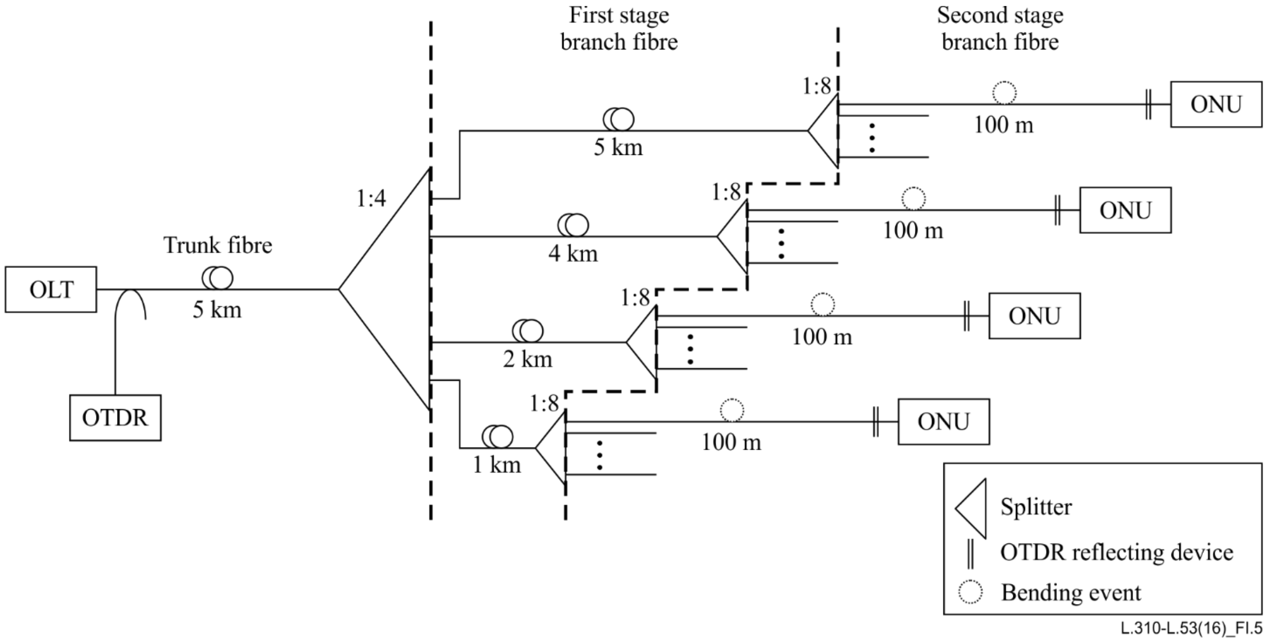


**Figure I.5 – Test setup for evaluation of the effectiveness of the OTDR reflecting device**

**Table I.1 – Measured peak reflection level of the OTDR reflecting devices with different fibre bending events**

| Peak reflection level of the OTDR reflecting devices | 1-km 1st stage branch fibre (dB) | 2-km 1st stage branch fibre (dB) | 4-km 1st stage branch fibre (dB) |
|---|---|---|---|
| No bending | 24.9 | 22.4 | 21.0 |
| 1.0-dB bending | 27.0 | 24.7 | 22.8 |
| 2.1-dB bending | 29.2 | 26.8 | 24.7 |
| 3.1-dB bending | 31.6 | 29.2 | 27.0 |
| 3.9-dB bending | 33.0 | 30.3 | 28.5 |
| 4.9-dB bending | 35.5 | 33.1 | 31.2 |

The attenuation of the fibre bending events can be calculated by half of the difference between the peak reflection level of the OTDR reflecting devices with and without bending. It can be seen that the calculated values shown in Table I.2 are quite similar to the original ones, which prove the effectiveness of this method.

**Table I.2 – Calculated attenuation of different bending events**

| Measured attenuation of the bending events | 1-km 1st stage branch fibre (dB) | 2-km 1st stage branch fibre (dB) | 4-km 1st stage branch fibre (dB) |
|---|---|---|---|
| 1.0-dB bending | 1.05 | 1.15 | 0.9 |
| 2.1-dB bending | 2.15 | 2.2 | 1.85 |
| 3.1-dB bending | 3.35 | 3.4 | 3.0 |
| 3.9-dB bending | 4.05 | 3.95 | 3.75 |
| 4.9-dB bending | 5.3 | 5.35 | 5.1 |

More tests were carried out to evaluate the major benefits brought by the OTDR reflecting device using test setup shown in Figure I.6. An OTDR module embedded in the OLT PON port was utilized. There were two-stage optical splitters with the splitting ratios of 1:4 and 1:8 respectively. Two types of the ONU were used. One type is the ONU with integrated thin-film reflecting device, the other type is common ONU without stand-alone or integrated reflecting device.

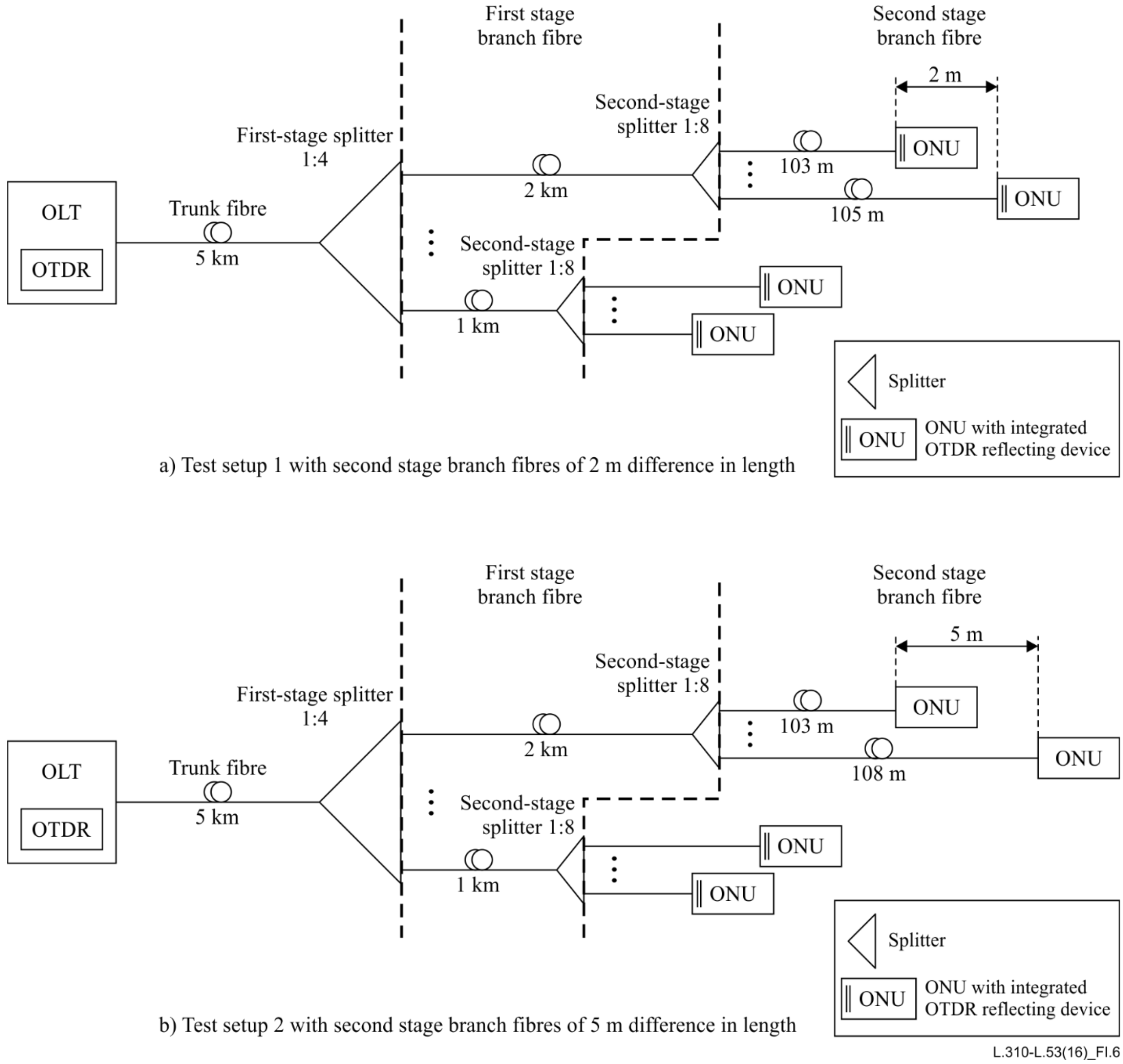


**Figure I.6 – Test setup for the evaluation of the OTDR reflecting device**

Two ONUs with integrated reflecting devices were connected to the 2nd stage branch fibres of 2 m difference in length (Figure I.6(a)). They can be clearly distinguished in the OTDR trace (Figure I.7) by using single pulse of 5 ns width. When two ONUs without reflecting devices are used, which are connected to the 2nd stage branch fibres of even 5 m difference in length (Figure I.6(b)), it is impossible to distinguish them (Figure I.8) by the same OTDR pulse. This test proves that the OTDR reflecting device can greatly enhance the fault isolation resolution capability.

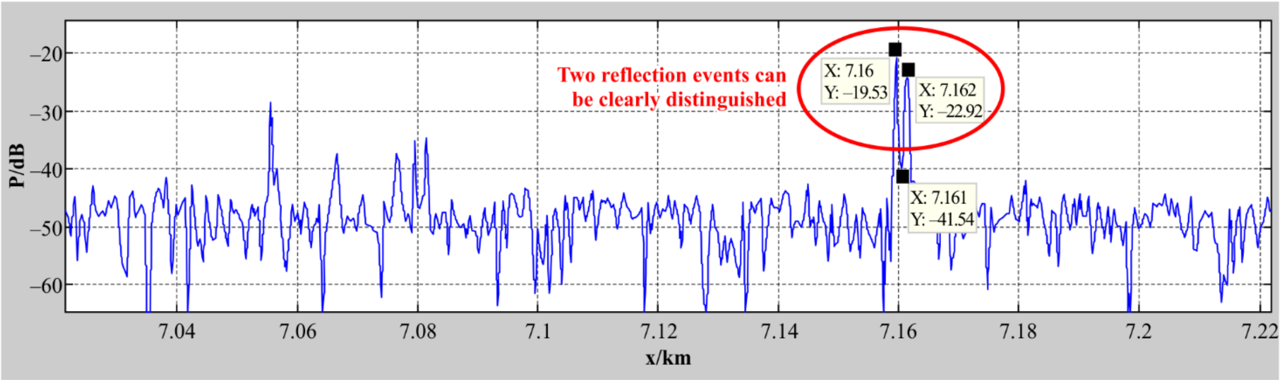


**Figure I.7 – OTDR trace for test setup 1**

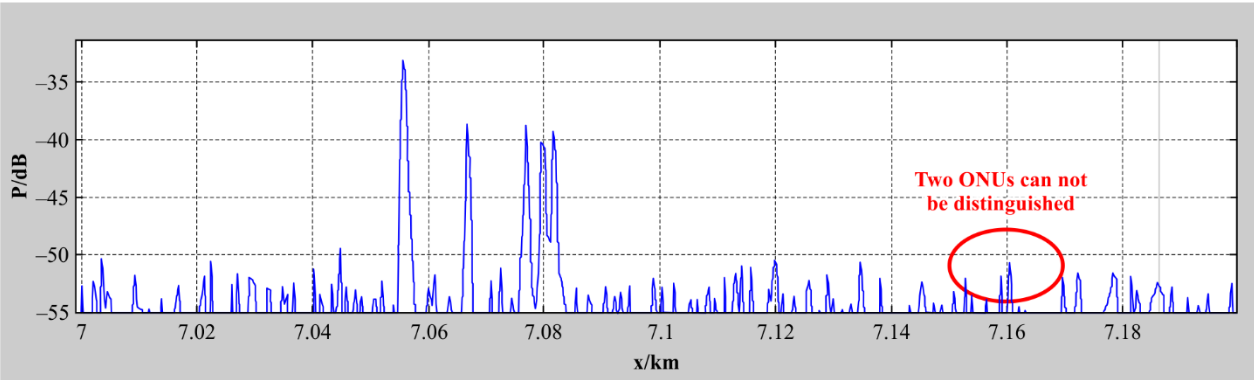


**Figure I.8 – OTDR trace for test setup 2**

In the test, it takes 1 s to detect the two ONUs with integrated reflecting devices which connected to fibres with 2 m of length difference. This result also shows that with the reflecting device, it can detect events/faults easily without long averaging time or using complicated algorithm. When the reflecting devices are installed in the real network, it only takes a few seconds for the routine test to check the condition of the optical link, so that the efficiency of maintenance can be improved.

The dynamic range of the OTDR module embedded in the OLT PON port used in the test is not as high as common stand-alone OTDR devices. Even with this kind of OTDR, it can still distinguish two ONUs with 2 m fibre length difference, when the total link attenuation was 33 dB. Therefore, with OTDR reflecting devices, it can loosen the requirement of the OTDR capability, so that the maintenance cost can be reduced.

### I.2.3 Fault identification method with multi-stage deployment of OTDR reflecting devices

#### I.2.3.1 System configuration

Figure I.9 shows a typical system configuration of optical fibre line testing system. This system consists of a network management system (NMS), an optical testing module, which contains an OTDR and a test control unit, a wavelength division multiplexer (WDM) to introduce a test light into an optical fibre line, and OTDR reflecting devices, which are deployed at the output end of the first-stage optical splitter, second-stage optical splitter and in front of ONUs.

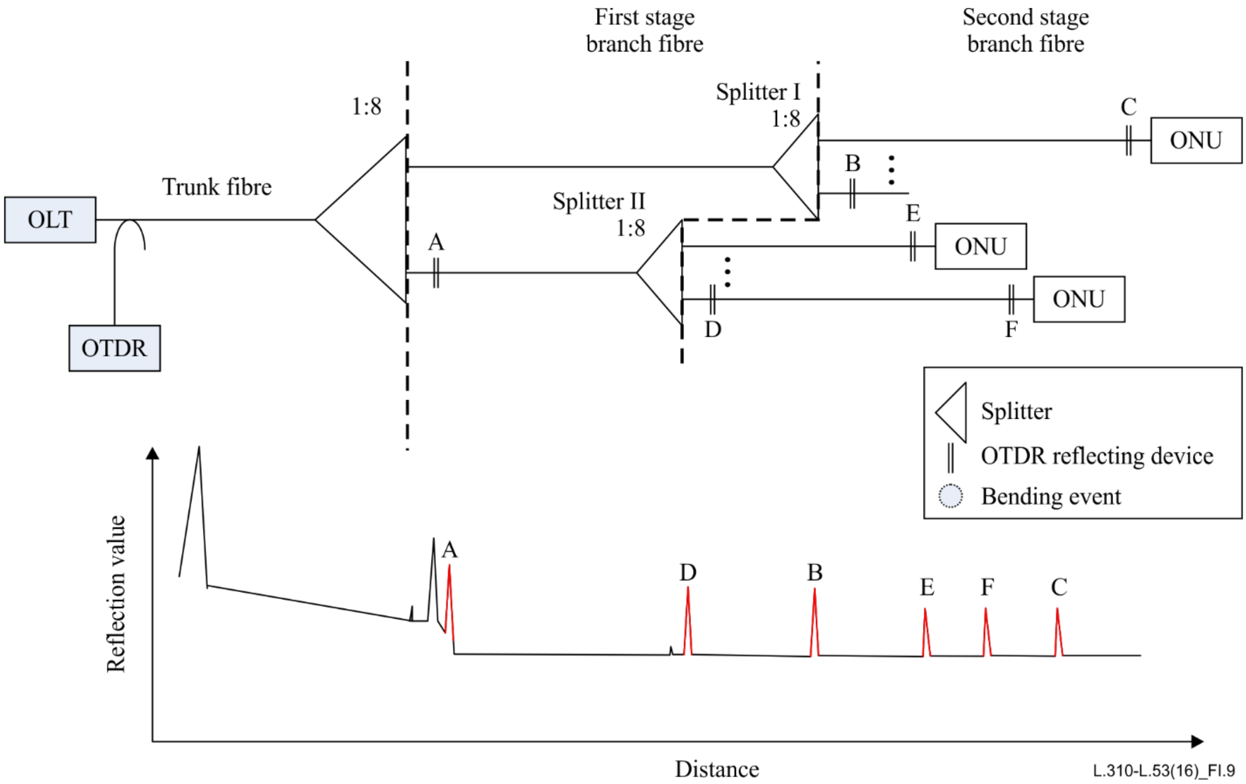


**Figure I.9 – Test system configuration for fault demarcation and evaluation**

The optical fibre line testing system periodically collects and analyses the whole network status information, including the apparent return loss of the OTDR reflecting devices at both the optical splitter and the ONU sides, by using OTDR. The reflection peaks caused by different ONUs are easily overlapped on the OTDR trace, so narrow pulse width (3 ns or 5 ns) of OTDR is preferred. The dynamic range of OTDR at narrow pulse width is about 7 dB. The second stage splitters and ONUs locate at the noise zone in OTDR trace, and only reflection peaks can be displayed on OTDR trace. The optical energy at narrow pulse and the reflection from the OTDR reflecting device is very weak, so there is no ghost effect observed. Also, special system algorithm is developed to remove impact of ghost peaks in the OTDR trace, as the position of the ghost peak is traceable. All these analysis data will be recorded for further comparison.

When fault occurs, OTDR testing will be initiated. If the apparent return loss of the OTDR reflecting devices in front of end-users and after the relevant second-stage optical splitter increases compared to the values recorded, there is an attenuation event in the relevant 1st stage branch fibre section. If the apparent return loss of the OTDR reflecting devices in front of end-users increases and the apparent return loss of the OTDR reflecting devices after the relevant second-stage optical splitter remains unchanged, then there is an attenuation event in the 2nd stage branch fibre section.

### I.2.3.2 Evaluation

In order to evaluate the capability of demarcating fault responsibility with multi-stage deployed OTDR reflecting devices for optical fibre line testing system, an evaluation of a prototype system is provided, in which the splitting ratios of the first stage optical splitter and second stage optical splitter are 1:8 and 1:8, respectively. In addition, the fibre bending events are configured as follows.

1) Optical fibre bending events are configured in the 1st stage branch fibre in front of the 2nd stage optical splitter I with the attenuation of 1.6 dB, as shown in Figure I.10.

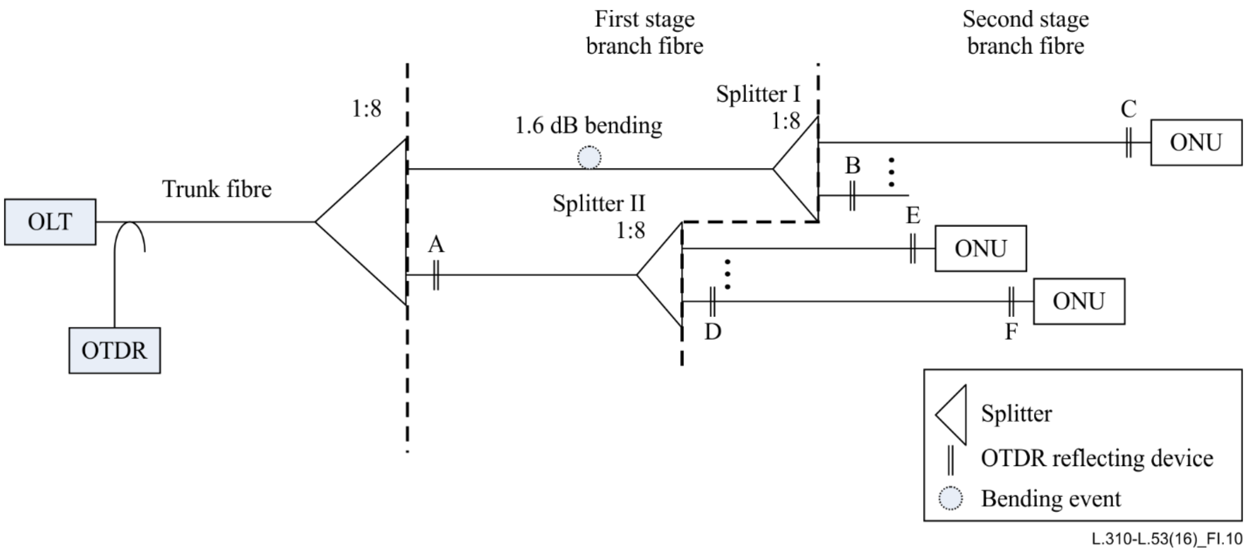


**Figure I.10 – Configuration for optical fibre bending event (1)**

2) Optical fibre bending events are configured in the 2nd stage branch fibre in front of ONU C with the attenuation of 2.1 dB, as shown in Figure I.11.

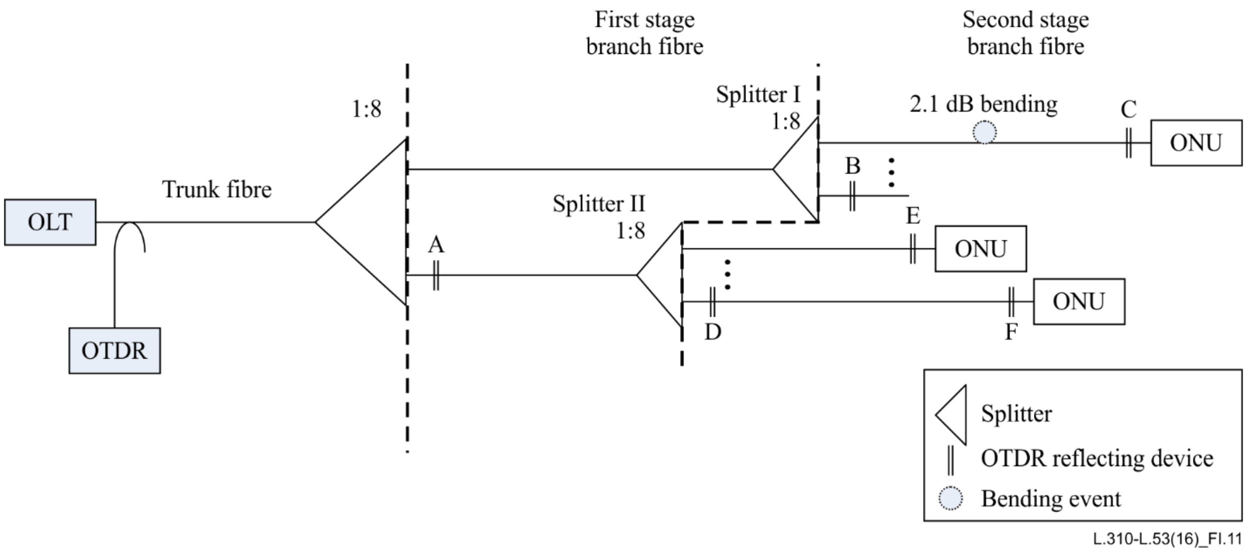


**Figure I.11 – Configuration for optical fibre bending event (2)**

3) Two fibre bending events are configured in the 1st and 2nd stage branch fibres simultaneously with the attenuation of 0.9 dB and 1.1 dB, respectively, and the two bending events are located in front of the second stage optical splitter II and ONU E respectively, as shown in Figure I.12.

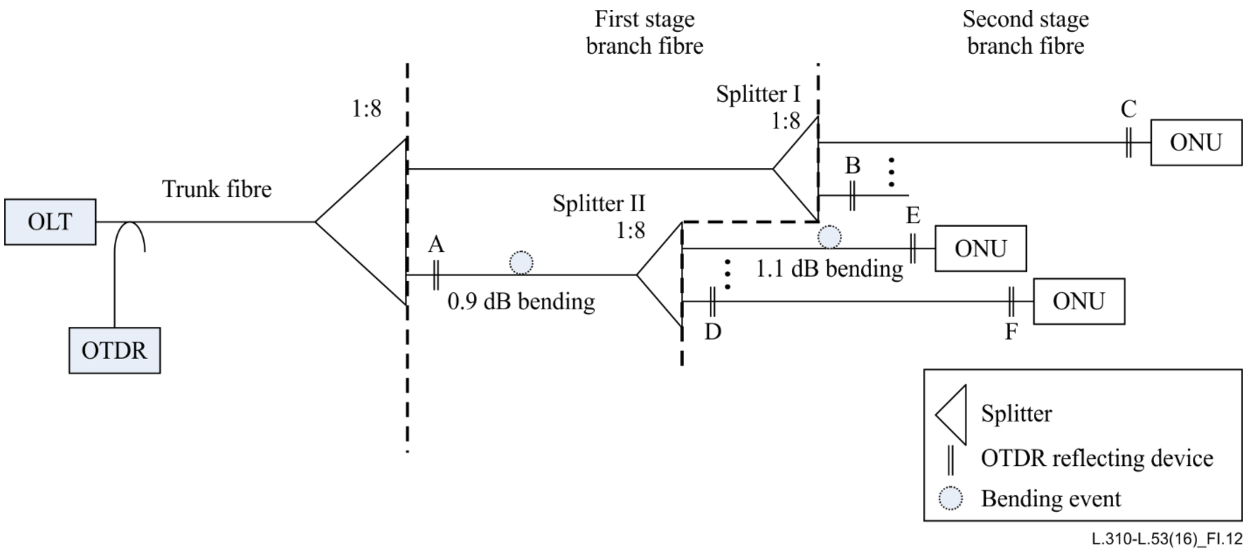


**Figure I.12 – Configuration for optical fibre bending event (3)**

Essentially, the OTDR reflecting device should have the capability of good reflectance for specific OTDR wavelength 1625/1650 nm and good transparency for other communication wavelengths. The specifications for OTDR reflecting devices are shown in Table I.3 and Table I.4.

**Table I.3 – Wavelength range for the OTDR reflecting device**

| | **Wavelength range (nm)** |
|---|---|
| Passband wavelength | 1260~1360 and 1460~1585 |
| Reflecting wavelength | 1610~1660 |

**Table I.4 – Specifications for the OTDR reflecting device**

| | **Passband wavelength** | **Reflecting wavelength** |
|---|---|---|
| Insertion Loss | < 1.2 dB | < 1.2 dB |
| Return Loss | > 18 dB | 17±1 dB |

The measured return loss values of optical reflectors are shown in Table I.5.

**Table I.5 – Measured apparent return loss of the OTDR reflecting devices with different fibre bending events**

| **Apparent return loss** | **OTDR reflecting device A (dB)** | **OTDR reflecting device B (dB)** | **OTDR reflecting device C (dB)** | **OTDR reflecting device D (dB)** | **OTDR reflecting device E (dB)** | **OTDR reflecting device F (dB)** |
|---|---|---|---|---|---|---|
| No bending | 40.2 | 62.0 | 62.1 | 60.6 | 60.4 | 60.8 |
| 1.6-dB bending at the 1st stage branch fibre | 40.1 | 65.4 | 65.5 | 60.6 | 60.3 | 60.7 |
| 2.1-dB bending at the 2nd stage branch fibre | 40.1 | 62.1 | 67.1 | 60.6 | 60.3 | 60.7 |

**Table I.5 – Measured apparent return loss of the OTDR reflecting devices with different fibre bending events**

| Apparent return loss | OTDR reflecting device A (dB) | OTDR reflecting device B (dB) | OTDR reflecting device C (dB) | OTDR reflecting device D (dB) | OTDR reflecting device E (dB) | OTDR reflecting device F (dB) |
|---|---|---|---|---|---|---|
| 0.9-dB bending at the 1st stage branch and 1.1-dB bending at the 2nd stage branch fibre | 40.0 | 62.2 | 62.3 | 62.2 | 64.6 | 62.5 |

The fibre bending-induced attenuation can be calculated by taking half of the difference of the apparent return loss of OTDR reflecting devices between normal and bending event conditions. The calculated values and the results of fault responsibility demarcation are consistent with the measured values, as shown in Table I.6.

**Table I.6 – Calculated values and fault responsibility demarcation**

| Measured attenuation of the bending events | Calculated attenuation (dB) | Fault responsibility demarcation |
|---|---|---|
| 1.6-dB bending at the 1st stage branch fibre | 1.7 | 1st stage branch fibre |
| 2.1-dB bending at the 2nd stage branch fibre | 2.5 (Not consistent with the E/F OTDR reflecting devices data in Table I.5) | 2nd stage branch fibre |
| 0.9-dB bending at the 1st stage branch fibre and 1.1-dB bending at the 2nd stage branch fibre | 0.8 and 1.3 (Not consistent with the B/C OTDR reflecting devices data in Table I.5) | 1st and 2nd stage branch fibres |

### I.2.4 Conclusion

Several tests were carried out to evaluate the effectiveness of the OTDR reflecting device, which used stand-alone reflecting device and reflecting device integrated into the ONU. Test results confirmed that single-stage and multi-stage deployment of OTDR reflecting devices in point-to-multipoint optical networks are effective methods to achieve fault demarcation and identification, especially for the attenuation events in the branch fibres. It is also proved that the installation of OTDR reflecting devices can enhance the fault isolation resolution capability, reduce the detection time and relax the requirement of the OTDR performance, so that the capability and efficiency of the network maintenance can be improved.

# Appendix II

## Practical solutions for ring access network

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

### II.1 Indonesian experience

This appendix describes the synchronous digital hierarchy (SDH) test light module that is used in SDH ring optical access network (OAN) topology.

#### II.1.1 Introduction

The module is used mainly in the following situation:

– when it is necessary to bypass an add drop multiplexer (ADM) and carry test light in order to monitor SDH ring topology.

In this situation, the SDH test light module splits the test light (1550 or 1650 nm wavelength) from the information light at the ADM input section to recombine them at the ADM output. This avoids interference or attenuation of the test signal.

#### II.1.2 SDH test light module

In order to allow the optical overstepping of ADM line terminals, Telkom automatic remote optical fiber operation support system (T-AURORA) – The Indonesian version of optical fibre outside plant maintenance support, monitoring, and testing system – or manual optical time domain reflectometer (OTDR) system uses SDH test light.

This SDH test light module is made up of two WDM couplers and is located at the ADM line terminals sites; each WDM 1310/1550 nm arm connects the line to east/west ADM arm, while 1650 nm arms allows the test light sent by the OTDR to step over ADM (Figure II.1-1).

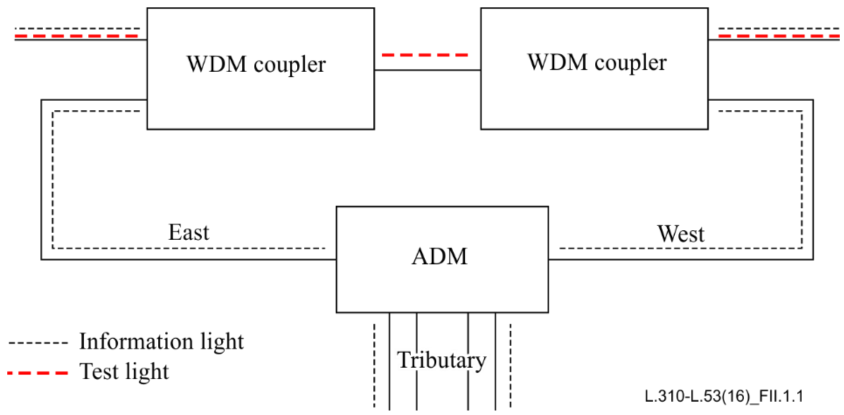


**Figure II.1-1 – SDH test light module**

In our case, SDH Test Light module is divided into 2 types (based on the application in the field):

1) **Model A**
   - Information and test light use 1310 and 1550 nm wavelength consecutively. The uniqueness of this module is that the input of information light, and the input of test light, can be interchangeable. Non-integrated operation support system (OSS) such as manual OTDR is used as test light source.

2) **Model B**
   - This module is suited for supporting T-AURORA system where 1310/1550 nm is used for information light and 1650 nm wavelength is dedicated to test light.

The differentiation between Model A and B is on the wavelength used for each information light and test light. On implementation, filtering on each ADM input and output is required to avoid the test light entering the ADM.

Prototype of SDH test light module (Model A) is depicted in Figure II.1-2.

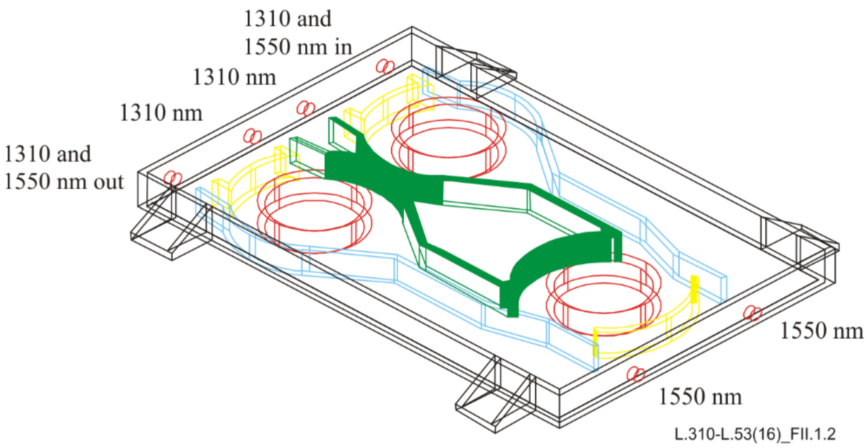


**Figure II.1-2 – Prototype of SDH test light module (Model A)**

The insertion of the SDH test light module contributes significantly in the monitoring of the physical optical cable in SDH ring topology. Without the SDH test light module, the monitoring capability of OTDR or T-AURORA is limited up to the nearest ADM span (Figure II.1-3).

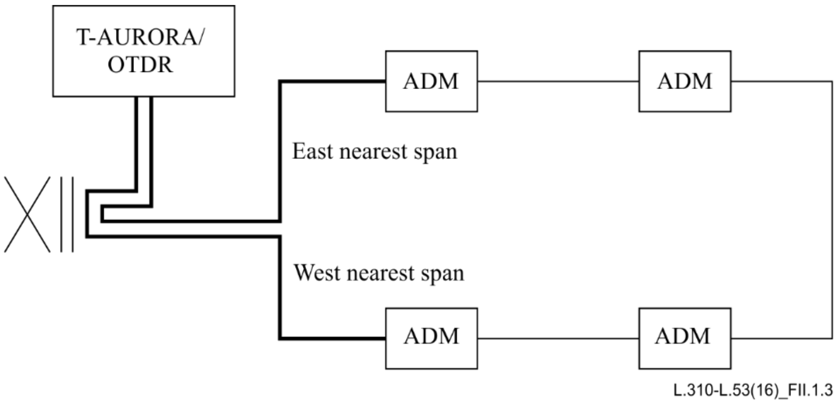


**Figure II.1-3 – Monitoring optical cable without inserting SDH test light**

Introduction SDH test light module in SDH ring enhances the capability of carrying test light to all spans in ring by over stepping ADM (Figure II.1-4).

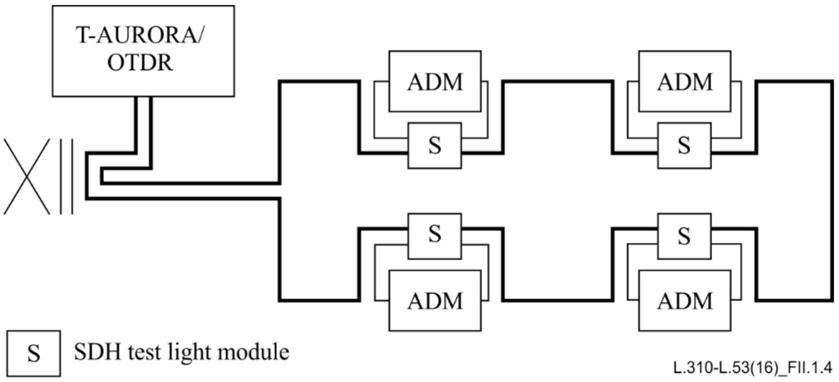


**Figure II.1-4 – Insertion SDH test light in SDH ring OAN**

### II.1.3 OTDR trace simulation of SDH test light module

The simulation has been set up to analyse the performance and how the SDH test light module works in SDH ring. The configuration is shown in Figure II.1-5.

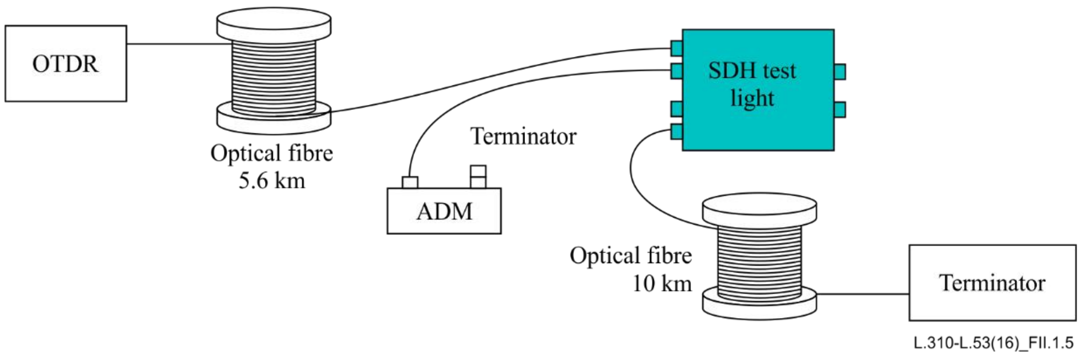


**Figure II.1-5 – OTDR trace simulation of SDH test light module**

The result of OTDR trace simulation depicted in the picture below shows that the test light (dotted line) is passed through to the end of the fibre cable, whereas the information light is terminated at 5.6 km (Figure II.1-6).

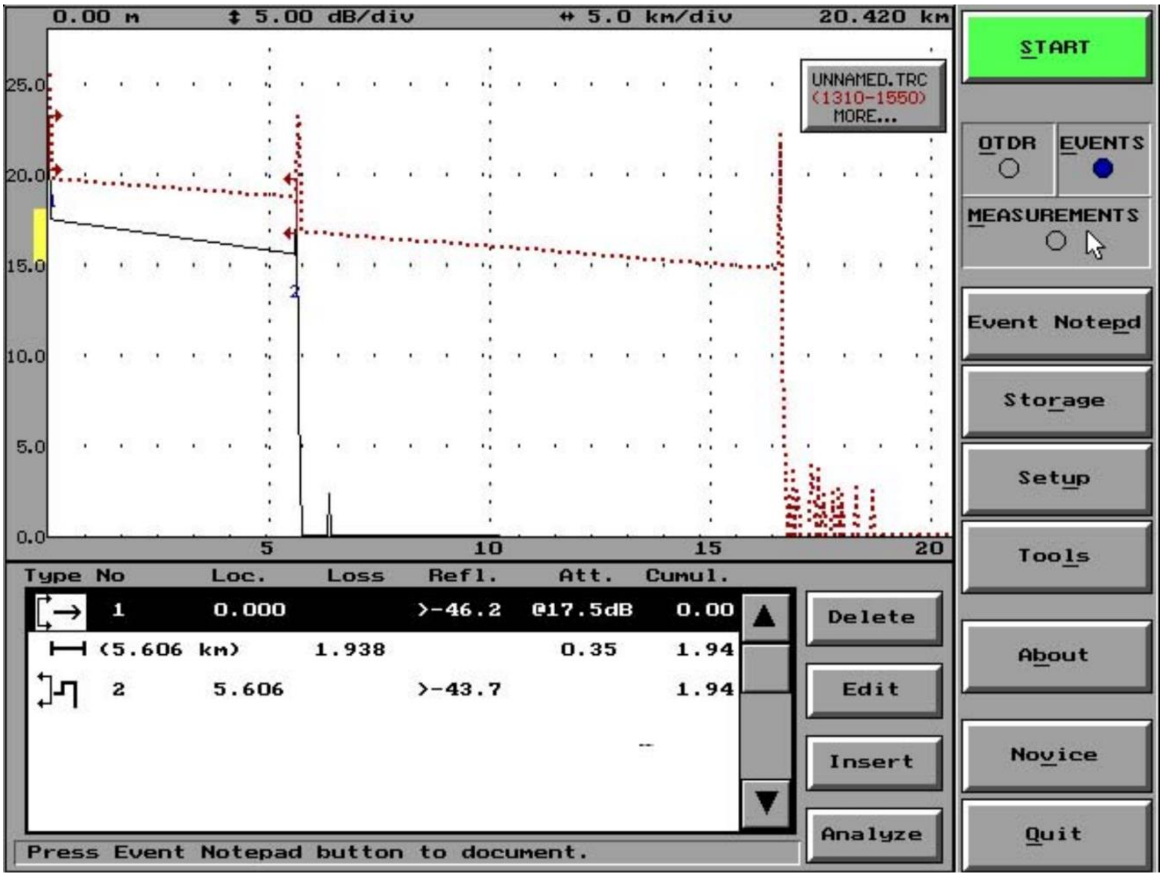


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**Figure II.1-6 – Result of OTDR trace simulation**

### II.1.4 Conclusion

The description of SDH test light module has been given to be accommodated in our OSS for optical cable monitoring. This module can be used to bypass test light from ADM to ensure the continuity of monitoring wavelength path.

This contribution is addressed to share experience relating operation and maintenance process of optical access network.

## II.2 Japanese experience

This appendix describes a test light bypass module for monitoring ADM ring optical networks.

### II.2.1 Introduction

Ring networks using add/drop multiplexers (ADM), which are installed in central offices and customer buildings, are being introduced into metropolitan areas to provide broadband networks. However, conventional testing method is incapable of monitoring optical fibre cables between customer buildings. Therefore, we suggest a method using the test light bypass module for this purpose.

### II.2.2 Testing system configuration

Figure II.2-1 shows the configuration of our optical fibre line testing system with test light bypass modules for monitoring ADM ring networks.

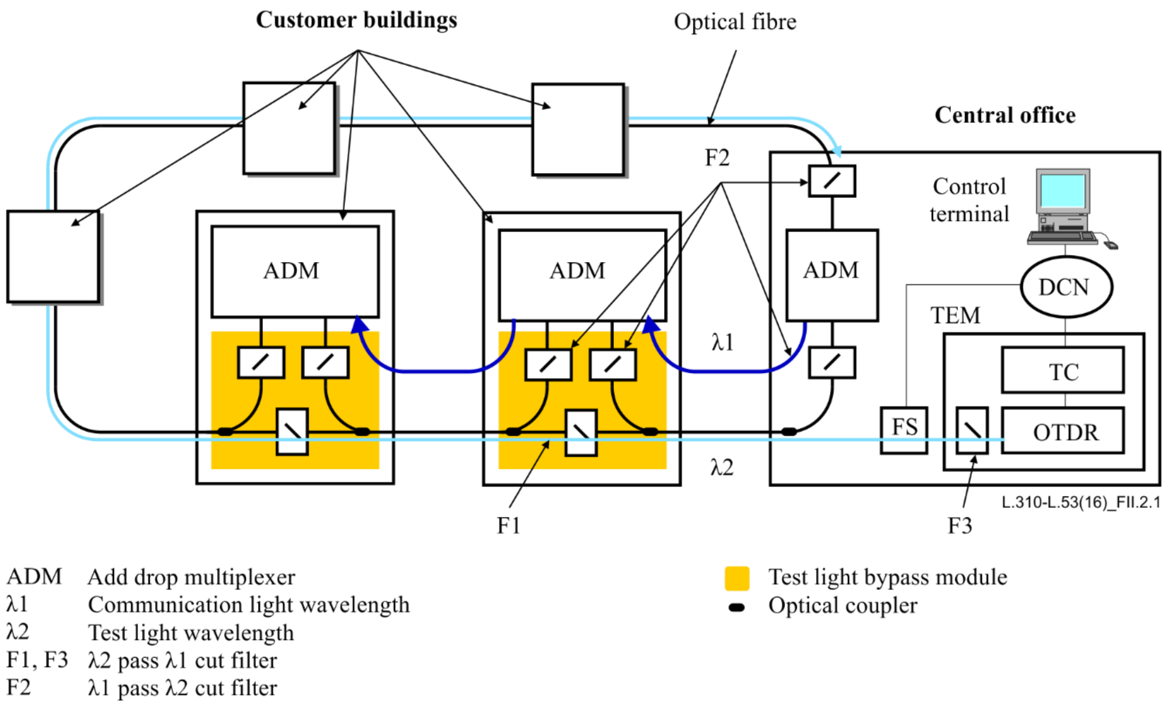


**Figure II.2-1 – Testing system configuration**

It consists of a control terminal, test equipment modules (TEM) each of which contains an optical time domain reflectometer (OTDR) and a test equipment controller (TC), optical fibre selectors (FS) that select test fibres, optical couplers and optical filters. The TEMs and FSs are installed in the cable termination room of a central office.

Optical couplers in the central office introduce a test light into fibre lines and optical couplers in customer buildings pass the test light to the next cable. We also installed three kinds of filter, F1, F2 and F3. The F2 filters allow the communication light (λ1) to pass but cut off the test light (λ2). They are arranged in front of the ADM. The F1 and F3 filters allow the test light to pass but cut off the communication light. They are installed between the couplers of the customer buildings and in front of the OTDR, respectively.

The control terminal orders the TC to perform various optical fibre tests through a data communication network (DCN). The TC controls the OTDR and FSs, and returns the test results to the control terminal. This system carries out automatic OTDR measurements and reveals fibre characteristics and fault locations between customers' buildings with no degradation in transmission quality.

### II.2.3 Test light bypass module configuration

As we already use the 1.31 µm ad 1.55 µm wavelengths for communication, we use the 1.65 µm wavelength for maintenance testing in accordance with [ITU-T L.301]. As the ADM communication light is 1.31 µm and the test light is 1.65 µm, we employed 1.31/1.65 µm wavelength division multiplexing (WDM) couplers to obtain low insertion losses. Moreover, we used the F1 filter that allows 1.65 µm light to pass but cuts off 1.31 µm light and the F2 filters that allows 1.31 µm light to pass but cuts off 1.65 µm light. As the communication light is 1.55 µm, we employed 1.55/1.65 µm wavelength division multiplexing (WDM) couplers, the F1 filter that allows 1.65 µm light to pass but cuts off 1.55 µm light and the F2 filters that allows 1.55 µm light to pass but cuts off 1.65 µm light.

### II.2.4 OTDR trace of field optical fibre cable

Figure II.2-2 shows the OTDR trace of a field optical fibre cable with two test light bypass modules located 1.0 and 1.2 km from a central office. Figure II.2-2 confirms that our testing system can monitor cables between buildings.

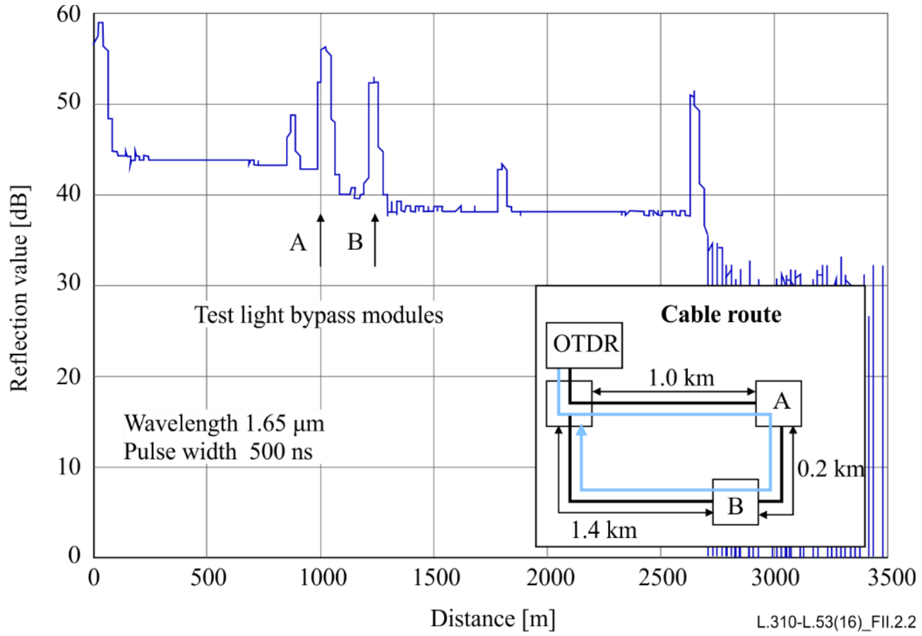


**Figure II.2-2 – OTDR trace of field optical fibre cables with test light bypass modules**

### II.2.5 Conclusions

We described an optical fibre line testing system that uses test light bypass modules. We confirmed that this system can monitor optical fibre cables of an ADM ring network and causes no degradation in transmission quality.

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