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SERIES L: CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Optical fibre cable maintenance criteria for in-service fibre testing in access networks

ITU-T Recommendation L.66

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Optical fibre cable maintenance criteria for in-service fibre testing in access networks

Summary

In the FTTx era, we must provide effective and efficient maintenance for optical cable networks. With a view to realizing a highly reliable optical cable network that transports WDM signals with a wide spectral bandwidth, we need to establish maintenance criteria for testing in-service fibre lines without interfering with optical communication signals in the access network.

This Recommendation deals with important considerations with respect to the maintenance band and maintenance test light filtering requirements for testing in-service fibre lines without interfering with optical communication signals in access networks.

Source

ITU-T Recommendation L.66 was approved on 18 May 2007 by ITU-T Study Group 6 (2005-2008) under the ITU-T Recommendation A.8 procedure.

FOREWORD

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Optical fibre cable maintenance criteria for in-service fibre testing in access networks

1 Scope

This Recommendation mainly describes the maintenance band and requirements for maintenance test light filtering (such as cut-off bandwidth, isolation and other optical characteristics) for testing in-service fibre lines without interfering with optical communication signals in access networks.

This Recommendation provides guidance on the use of an out-of-band remote test system. An alternative approach is to monitor key parameters of the transmission equipment, such as the OLT transmitted power and the ONU received power, but this approach is not examined in this Recommendation.

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.694.1] ITU-T Recommendation G.694.1 (2002), *Spectral grids for WDM applications: DWDM frequency grid*.

[ITU-T G.694.2] ITU-T Recommendation G.694.2 (2003), *Spectral grids for WDM applications: CWDM wavelength grid*.

[ITU-T G.695] ITU-T Recommendation G.695 (2006), *Optical interfaces for coarse wavelength division multiplexing applications*.

[ITU-T G.698.1] ITU-T Recommendation G.698.1 (2006), *Multichannel DWDM applications with single-channel optical interfaces*.

[ITU-T G.983.1] ITU-T Recommendation G.983.1 (2005), *Broadband optical access systems based on Passive Optical Networks (PON)*.

[ITU-T G.983.3] ITU-T Recommendation G.983.3 (2001), *A broadband optical access system with increased service capability by wavelength allocation*.

[ITU-T G.984.1] ITU-T Recommendation G.984.1 (2003), *Gigabit-capable Passive Optical Networks (G-PON): General characteristics*.

[ITU-T L.25] ITU-T Recommendation L.25 (1996), *Optical fibre cable network maintenance*.

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

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

[ITU-T L.42] ITU-T Recommendation L.42 (2003), *Extending optical fibre solutions into the access network*.

[ITU-T L.53]	ITU-T Recommendation L.53 (2003), *Optical fibre maintenance criteria for access networks*.
[IEC 61746]	IEC 61746 (2005), *Calibration of optical time-domain reflectometers (OTDR)*.

3 Definitions

For the purpose of this Recommendation, the definitions given in ITU-T Recommendations G.698.1, G.983.1 to G.983.8, G.984.1, L.25, L.40, L.41 and L.53 apply.

4 Abbreviations

This Recommendation uses the following abbreviations:

BER Bit Error Rate

CO Central Office

FTTx "*Fibre to the x*", where "x" indicates the final location on the user side of any one of a variety of optical fibre architectures, e.g., FTTH, FTTB, FTTC.

OLT Optical Line Terminal

ONT Optical Network Terminal

OPM Optical Power Meter

OTDR Optical Time Domain Reflectometer

PON Passive Optical Network

WDM Wavelength Division Multiplex

5 Fundamental requirements for in-service fibre line testing

With a view to realizing a highly reliable optical access network that transports WDM signals with a wide spectral bandwidth, in-service fibre line monitoring techniques are important in terms of providing effective and efficient maintenance of optical cable networks. The fundamental requirements of in-service fibre line testing are as follows:

– It should be carried out without degrading optical communication signals in the optical access network.

– It must be capable of evaluating optical fibre characteristics even if there is interference with the communication light.

6 Testing and measurement methods

There are several ways to implement maintenance functions. OTDR testing, loss testing, monitoring a proportion of the signal power (power monitoring) and identification light detection are commonly used. These testing methods for point-to-point optical networks are stipulated in [ITU-T L.25] and [ITU-T L.40]. As regards point-to-multipoint and ring optical networks, their testing methods are also described in [ITU-T L.53].

7 Requirements for in-service fibre line testing

7.1 Test light wavelength allocation

The wavelength allocation of a broadband optical access system and spectral grids for PON and WDM applications are defined by [ITU-T G.983.3], [ITU-T G.694.1], [ITU-T G.694.2] and [ITU-T G.698.1], respectively. Communication wavelength bands extend to a long wavelength band (L-band: 1565-1625 nm) and the minimum channel spacing is defined as 12.5 GHz. To eliminate interference with the test light, the maintenance test light wavelength must not be a wavelength that is used for communication signals. The maintenance wavelength for in-service testing is defined by [ITU-T L.41]. There are several recommended maintenance wavelength bands depending on the communication light wavelength used by a given transmission system. When the communication wavelength band extends to the L-band, the ultra long wavelength (U-band) of 1650 nm is used for maintenance testing as shown in Figure 1.

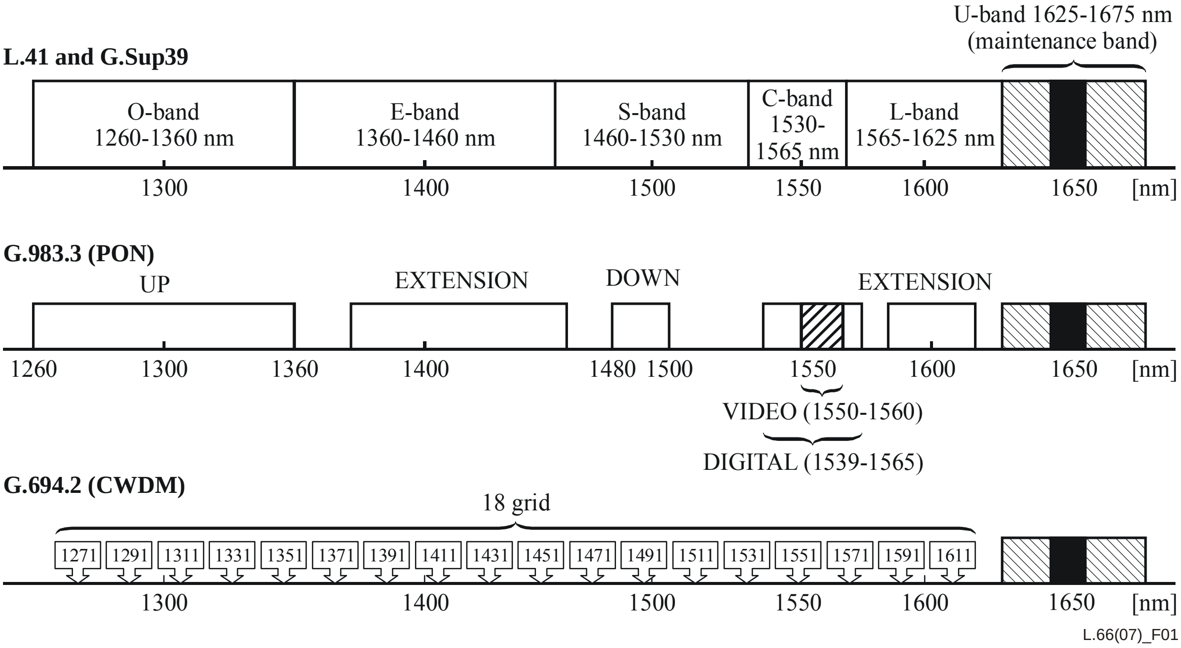


Figure 1 – Maintenance wavelength allocation

7.2 Wavelength bandwidth of test light

The wavelength bandwidth of the test light source should be designed taking into consideration the cut-off bandwidth of the optical filter. Figure 2 shows the wavelength spectra for a test light source and a test light cut-off filter when the L-band is used as the communication light. The diagram in Figure 2 shows the wavelength allocations for the light source and the cut-off filter. The low edge of *A* and the high edge of *C* for the test light source and the low edge of *B* and the high edge of *D* for the cut-off filter should satisfy the relationship in Equation 7-1.

$$B < A < \lambda_{test} < C < D \text{ [nm]} \quad (7\text{-}1)$$

When we consider the expanding communication wavelength band described above, it is useful to design the centre wavelength of the test light λ_{test} at 1650 nm. This is because the U-band is not used for communication signals.

Furthermore, to prevent any deterioration in the effective cut-off value of the optical filter, side-band noise from the test light source, which is not covered by the cut-off wavelength band of the optical filter, should also be sufficiently suppressed when compared with the cut-off characteristic of the optical filter (*Lt* dB).

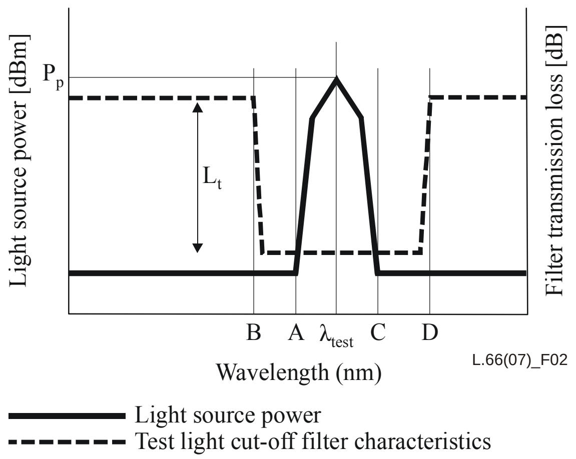


Figure 2 – Light source and cut-off filter wavelength allocations

7.3 Requirements for test light cut-off filter

The test light should not affect the transmission quality of the optical transmission system and each system has particular specifications such as the minimum output power of the transmitters and the minimum sensitivity of the receivers and S/X ratio. Figure 3 shows a test set-up for an in-service line. Here, a test light is launched into a transmission line by an optical coupler toward an ONT. *Pcd* and *Pt* are the optical power of the OLT and the test light just below the optical coupler, respectively. *Pcd* and *Pt* are obtained by subtracting the insertion losses of the optical coupler from the minimum output power of the OLT transmitter and the peak power of the test light source (*Pp* dBm). The test light is attenuated by the test light cut-off filter at the end of the optical fibre line whose cut-off value is *Lt* dB. The required cut-off of the optical filter needed to avoid any deterioration in the BER is given by Equation 7-2. This is because the difference between the optical powers of the communication light and the test light adjacent to the ONT should be sufficiently smaller than the S/X ratio (*SX* dB).

$$Pcd - (Pt - Lt) >> SX$$

$$Lt >> SX - Pcd + Pt \text{ [dB]} \qquad (7\text{-}2)$$

Here, the fibre losses and connection losses in the optical fibre line are regarded as being independent of the wavelength.

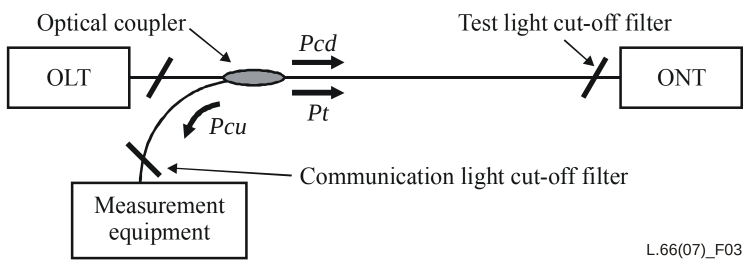


Figure 3 – Test set-up for in-service line

Test light cut-off filters should eliminate the maintenance test light without having any detrimental effect on transmission quality. Therefore, wavelength *B* should be longer than the transmission wavelength and shorter than wavelength *A*, and wavelength *D* should be longer than wavelength *C* as shown in Figure 2.

The required crosstalk needed to avoid any deterioration in the transmission quality by the test light is considered as a requirement of the test light cut-off filter. To avoid any effects of other transmission lights, PON and WDM transmission systems, which are stipulated in [ITU-T G.983.3] and [ITU-T G.698.1], respectively, have specified tolerances to the reflected optical power and maximum optical crosstalk, respectively. In these systems, the parameters of the tolerance to the reflected optical power and the maximum optical crosstalk correspond to the S/X ratio. By attenuating the test light power less than the tolerance to other communication lights of the transmission system, in-service testing can be carried out without any affect on transmission quality.

High total optical power systems that exhibit non-linear effects are not considered here because transmission systems for the optical access network have low output optical power.

7.4 Requirements for measurement equipment

The requirements for measurement equipment for in-service testing should be also considered. In-service testing must be carried out on the premise that light with a wavelength other than the communication light wavelength is input into the detector of the measurement equipment. Therefore, in order to accurately measure the characteristics of the optical fibre line in such a situation, the measurement equipment (such as an OTDR and an OPM) should have a tolerance to the communication light power. In Figure 3, the communication light passes through the optical coupler for in-service testing and is launched into the measurement equipment. To suppress the effect of the communication light, it is useful to install an optical filter adjacent to the measurement equipment that allows test light to pass but not communication light. In terms of OTDR measurement, the introduced communication light (*Pcu* [dBm]) must be much lower than the Rayleigh backscattered signal of the test light. The Rayleigh backscattered coefficient (*Crb* dB) is expressed in Equation 7-3 by using Rayleigh backscattered parameter (*K*) and OTDR pulse width *Tp* as defined in [IEC 61746].

$$Crb = 10\log_{10}\left(k \cdot Tp\right) \qquad \text{[dB]} \qquad (7\text{-}3)$$

Therefore, the optical filter requirement as regards suppressing the fluctuation of the OTDR trace is given by the following equation.

$$Pcu - Lc << (Pp - Ldm) + Crb$$

$$Lc >> Pcu - \left\{(P_P - Ldm) + Crb\right\} \qquad \text{[dBm]} \qquad (7\text{-}4)$$

In Equation 7.4, *Pp* is the peak power of the test light source, *Ldm* is the optical loss corresponding to the OTDR dynamic range and *Lc* is the cut-off of the optical filter installed adjacent to the measurement equipment. Here, if the communication signal power is regarded as a sort of noise in the OTDR trace, in order to reduce the fluctuation caused by the communication signal in the OTDR trace to less than 0.2 dB, the attenuated communication signal power *Pcu* – *Lc* [dBm] must be 10 dB less than the Rayleigh backscattered signal (*Pp* – *Ldm*) + *Crb* [dBm].

Appendix I

Japanese experience: Fibre Bragg grating filter-embedded in an optical connector

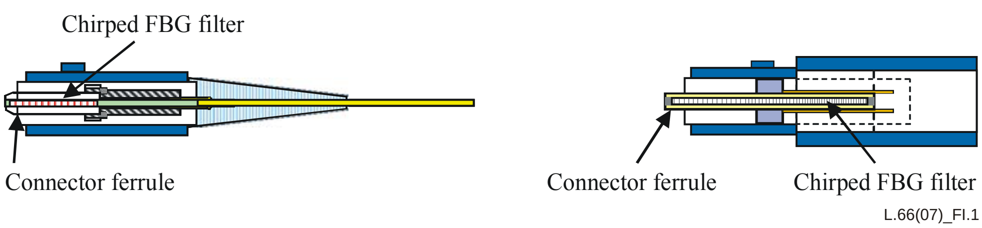
(This appendix does not form an integral part of this Recommendation)

I.1 Introduction

In the fibre to the home (FTTH) era, it is expected that broadband network provisioning will require thousands of optical fibres to be accommodated in a central office for optical access networks. An optical fibre line testing system could be used to reduce maintenance costs and improve service availability depending on the PON's element manager capabilities and the maintenance procedures adopted by the network supplier. When monitoring optical fibres transmitting communication lights, a wavelength of 1650 nm is used for maintenance testing in accordance with [ITU-T L.41] together with optical filters that allow the communication light to pass but that cut off the test light in front of optical line terminals (OLTs) and optical network terminals (ONTs). A termination cable, which is located very close to an ONT, has an SC-type connector with an optical filter. It is necessary to provide a filter that can be easily embedded in a connector to realize a more economical termination cable. A fibre Bragg grating (FBG) filter is suitable for this purpose. This appendix describes the design and fabrication of an FBG filter with excellent wideband cut-off characteristics.

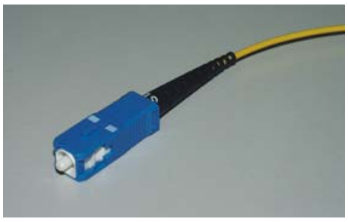
I.2 Structure of filter-embedded connectors

Figure I.1 shows the structure of the filter-embedded connector and plug-adapter connector. A chirped FBG filter with a Bragg wavelength of 1650 nm, which was fabricated by the phase-mask method, is embedded in the connector ferrules. The FBG filter has a considerable advantage in that its steep optical spectrum separates the 1650 nm test light from the L-band communication light. Figure I.2 shows photographs of these filter-embedded connectors. The filter-embedded plug-adapter connector can easily and economically replace the optical filter currently used in the testing system without the need to reinstall the optical fibre cables on a user's premises when services are changed.

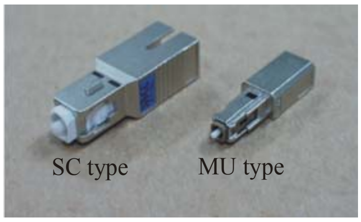


(a) Filter-embedded connector **(b) Filter-embedded plug-adapter connector**

Figure I.1 – Structure of filter-embedded connector and plug-adapter connector



(a) Filter-embedded connector



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(b) Filter-embedded plug-adapter connector

Figure I.2 – Photographs of filter-embedded connector and plug-adapter connector

I.3 Design and fabrication of chirped FBG filter

The spectrum of the test light source of the testing system and the target spectrum of the chirped FBG filter are shown in Figure I.3. We stipulate that the centre wavelength of the test light should be 1650 ± 5 nm. For in-line monitoring with no degradation in transmission quality, the FBG filter must provide more effective isolation (as described in clause 7.3) in the 1650 ± 5 nm test wavelength band than in the communication band.

The chirped FBG filters were fabricated by the phase-mask method using conventional fibre that was hydrogen-loaded. A KrF excimer laser operating at 248 nm was used as the UV light source. The FBG filters must be shorter than the connector ferrules to avoid any deterioration in the cut-off characteristics caused by the change in temperature. The fabricated FBG filters were annealed before assembly and embedded in connector ferrules.

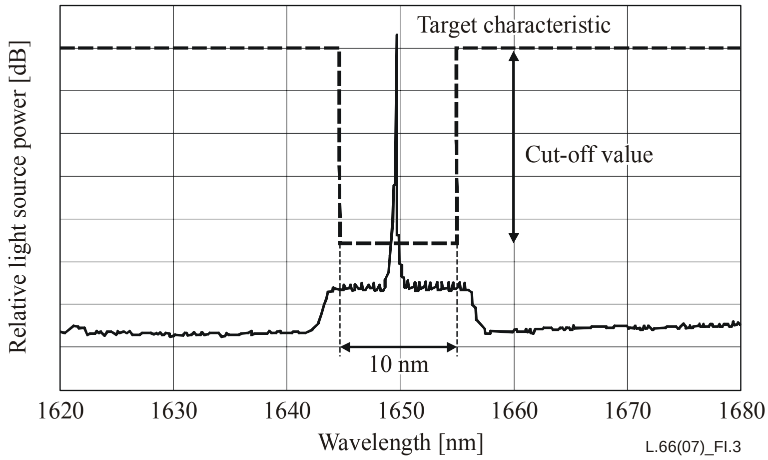


Figure I.3 – Spectrum of test light source and target characteristic of chirped FBG filter

I.4 Performance of filter-embedded connector

Figure I.4 shows the insertion loss spectra of typical termination cables used in the field. There are various available cut-off values corresponding to the transmission system requirements based on the S/X ratio. The average insertion loss at the communication light wavelength was less than 1 dB. In a network application, the fibre Bragg grating filter should be applied as close as possible to the end of the optical network or optical distribution network to allow the section of network under surveillance to be monitored. This has typically been in the optical connector in front of the ONT.

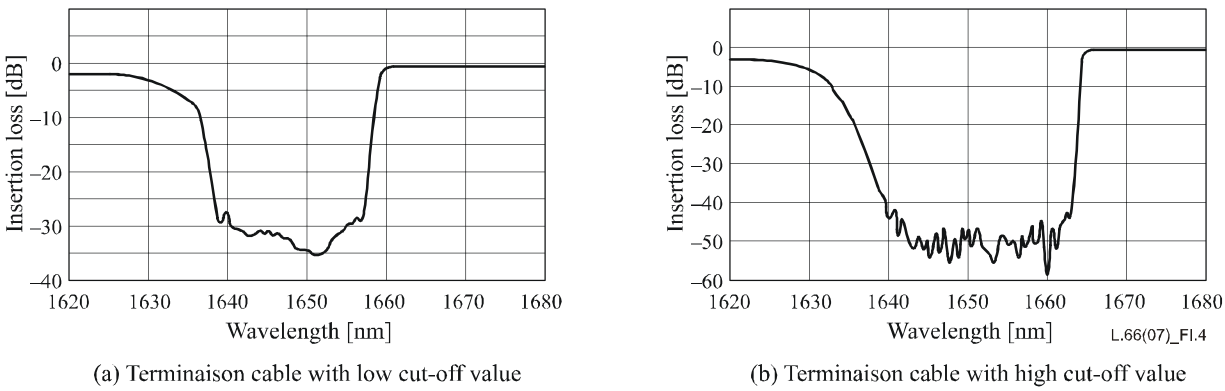


Figure I.4 – Insertion loss spectra of typical termination cables

Appendix II

Japanese experience: Spectral filtering criteria for U-band test light for in-service line monitoring

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

II.1 Introduction

The wavelength band is allocated between the O-band and the L-band. [ITU-T G.983.3] describes the extension band for video services on B-PON or GE-PON. U-band in-service line monitoring is an attractive way of cost-effectively maintaining optical fibre networks. The fundamental requirements for an optical fibre maintenance system that uses a 1650 nm test light source and a fibre Bragg grating (FBG) filter were reported in [b-NAKAO]. However, a conventional test light has spontaneous emission sideband noise around the peak spectrum. The sideband suppression ratio (SBSR) of a conventional distributed feedback laser diode (DFB-LD) is about –40 to –50 dB. When monitoring an in-service line in the optical fibre network, the effective rejection ratio of the test light must be taken into account. Otherwise, the sideband noise of the test light is launched into the ONT and degrades the transmission quality. The effective rejection ratio of the test light depends on its spectrum from the OTDR and the rejection band of the filter in front of the ONT. Therefore, a suitable test light spectrum and rejection band for the filter, and spectral filtering criteria for in-service line monitoring must be designed [b-HONDA].

II.2 Filtering characteristic of sideband noise of test light

Figure II.1 shows the configuration for measuring the characteristics of the test light and the FBG filter. The test light source was a 1650 nm band LD with an FBG external cavity that had a reflection band of about 3 nm.

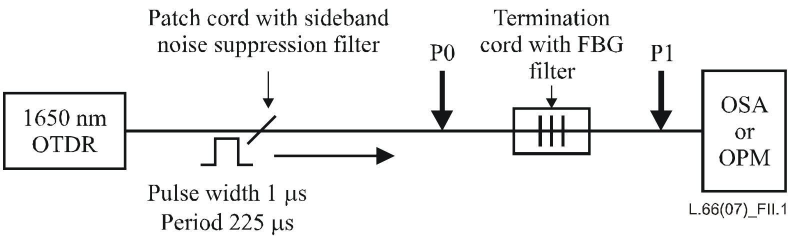
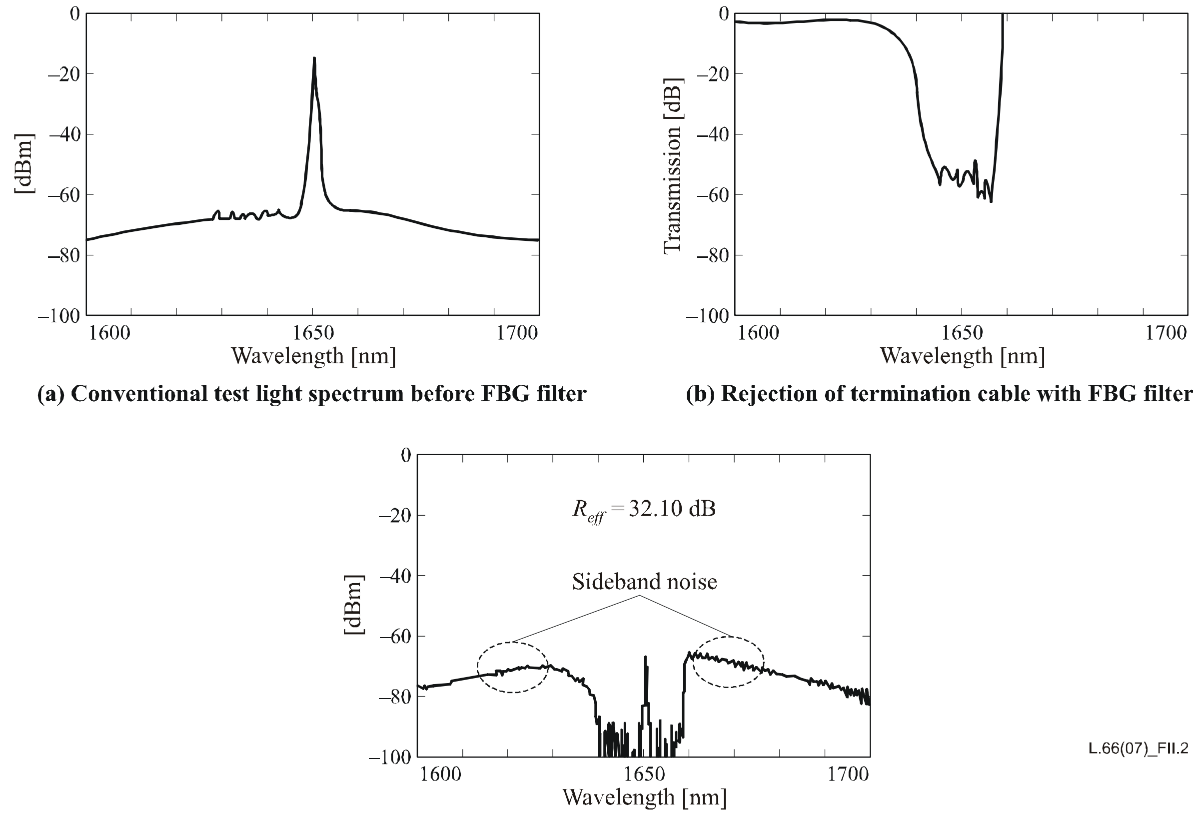


Figure II.1 – Configuration for system examination

Figure II.2 (a) shows the conventional test light spectrum from a 1650 nm OTDR. The spectrum was measured by using an optical spectrum analyser (OSA) whose resolution and video bandwidth were 0.07 nm and 10 Hz, respectively. The peak power (SBSR) pulse width and pulse period of the OTDR were 15.85 dBm, about –50 dB, 1 and 225 μs respectively (duty: 0.4%). The centre wavelength and full width at half maximum were 1650.53 nm and 0.18 nm, respectively. The sideband noise of the test light appeared in the L-band and should be eliminated for in-service line monitoring. Figure II.2 (b) shows the rejection of the FBG filter embedded in the termination cable. The FBG filter had a loss of more than –40 dB at 1649.3 ± 7.8 nm and a loss of –52.48 dB at the peak wavelength of 1650.5 nm. The effective rejection ratio of the termination cable with an FBG filter was obtained by measuring the optical power before (P0) and after (P1) the FBG filter with an optical power meter (OPM). The peak power of the OTDR was calculated from the average OPM value and the duty ratio. When a conventional test light was input into the fibre, the effective loss of the test light peak was –32.10 dB. The effective rejection ratio of the filter in the termination cable was degraded to –20.38 dB. Figure II.2 (c) shows the spectrum of a conventional test light after it had passed through the termination cable with an FBG filter measured at P1. The large sideband noise passing through the termination cord degrades the effective loss.



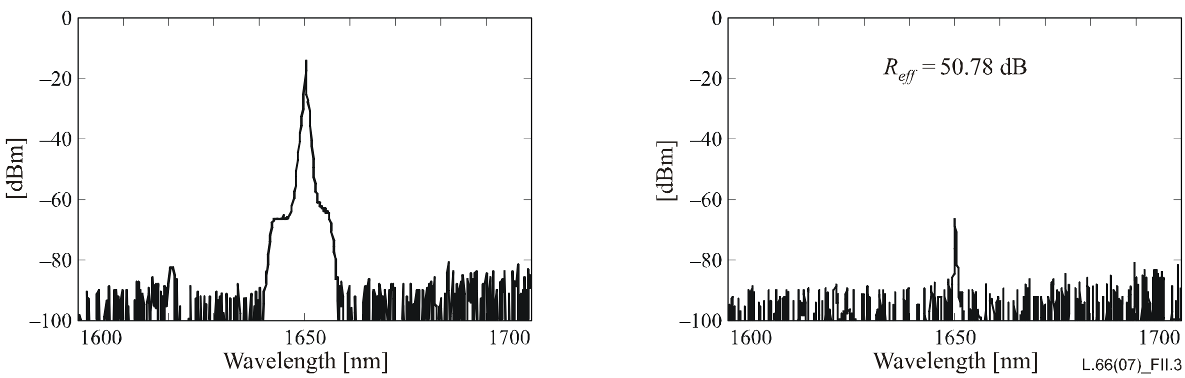
(a) Conventional test light spectrum before FBG filter

(b) Rejection of termination cable with FBG filter

(c) Conventional test light spectrum after FBG filter

Figure II.2 – Spectra of the conventional 1650-nm OTDR test light before (P0) and after (P1) FBG filter

Figure II.3 shows the spectra of the test light when employing a filter patch cord at P0 and P1 in Figure II.1. The sideband noise was greatly suppressed to less than –80 dB outside the FBG rejection band. In addition, the requirement for the sideband noise spectra of the test light source is decided by the effective rejection ratio of the optical filter, which is based on transmission system requirements.



(a) Test light spectrum with 80 dB SBSR before FBG filter

(b) Test light spectrum with 80 dB SBSR after FBG filter

Figure II.3 – Spectra of test light with 80-dB SBSR before (P0) and after (P1) FBG filter

II.3 References

[b-NAKAO] NAKAO (N.), IZUMITA (M.), INOUE (T.), ENOMOTO (Y.), ARAKI (N.), TOMITA (N.): Maintenance method using 1650-nm wavelength band for optical fibre cable networks, *Journal of Lightwave Technology*, Vol. 19, issue 10, pp. 1513-1520, October 2001.

[b-HONDA] HONDA (N.), IZUMITA (H.), NAKAMURA (M.): Spectral Filtering Criteria for U-Band Test Light for In-Service Line Monitoring in Optical Fibre Networks, *Journal of Lightwave Technology*, Vol. 24, issue 6, pp. 2328-2335, June 2006.

Appendix III

In-service fibre line testing for PONs

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

III.1 Fundamental requirements for in-service fibre line testing for PONs

Passive optical networks (PONs) with optical splitters installed in optical closures and cabinets near customers' premises are now being introduced into access networks to provide high-speed IP services. The optical fibre maintenance criteria for PONs are defined by [ITU-T L.53], and optical time domain reflectometers (OTDR) are commonly used for locating faults from a central office (CO). However, a conventional OTDR test from a CO cannot pinpoint the location of faults in the branched fibre regions between an optical splitter and ONTs in PONs because of the accumulation of Rayleigh backscattered lights from the branched fibres, which are inseparable in an OTDR trace.

When a fault occurs in the branched fibre regions, carrying out an OTDR test from the customers' premises is a simple and cost-effective technique for locating faults in PONs that include an optical splitter. This corresponds to testing point-to-point networks from COs. Furthermore, the technique must allow in-service line monitoring because other branched fibres accommodated in the same optical splitter may still be active. Therefore, the requirements related to testing from the customer's side in PONs correspond to the requirements described in [ITU-T L.25] and [ITU-T L.40].

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