INTERNATIONAL TELECOMMUNICATION UNION

TELECOMMUNICATION
STANDARDIZATION SECTOR

STUDY PERIOD 2009-2012

STUDY GROUP 15

TD 505 Rev.1 (PLEN/15)

English only

Original: English

| Question(s): | 6/15 | Geneva, 5-16 December 2011 |

TEMPORARY DOCUMENT

| **Source:** | Editor G.697 |
| **Title:** | Draft revised Recommendation ITU-T G.697 (for Consent) |

Introduction

This document contains draft revised G.697 for consent. Changes with respect to the in-force version of G.697 are shown with revision marks. It is based upon the in-force version of G.697, dated November 2009, including the text of the in-force Corrigendum 1, dated February 2011, shown using revision marks.

VERSION	REVISION HISTORY	DATE
2.0	EDITOR'S INPUT INTO CORRESPONDENCE	21 JUN 2011
2.1	OUTPUT CORRESPONDENCE	11 OCT 2011

Overview of modifications to G.697

This document shows changes with respect to the version approved in November 2009. Also the changes from Corrigendum 1 dated February 2011 are shown via revision marks.

The following changes have been made:

- Modifications in the final paragraph of Appendix V.1 according to Corrigendum 1, February 2011;
- Further modifications to Appendix V.1 to account for modifications to Recommendation G.694.1. A revision of Recommendation ITU-T G.694.1 is planned for Consent at the SG15 Plenary Meeting in December 2011.

| **Contact:** | Peter Stassar
Huawei Technologies Co., Ltd.
P. R. China | Tel: +31-20-4300832
Fax:
Email: peter.stassar@huawei.com |

Recommendation ITU-T G.697

Optical monitoring for dense wavelength division multiplexing systems
Version 2.1
Based upon in-force version dated November 2009 and Corrigendum 1 dated February 2011

Summary

Recommendation ITU-T G.697 defines optical monitoring (OM) that can help in dense wavelength division multiplexing (DWDM) systems to perform the following activities:

–   configuration management for system and channel activation, addition of new channels, etc.;

–   fault management to detect and to isolate faults;

–   degradation management in order to keep the system running and to detect degradations before a fault occurs.

DWDM technology is improving at a rapid pace, continuously stretching the channel count, channel speeds and reach limits. Long-haul multi-span DWDM systems are capable of taking optical signals thousands of kilometres without electrical terminations or regeneration.

This continuing trend is driving the increasing importance of optical monitoring, which is the subject of this Recommendation.

This edition of this Recommendation provides information on optical channel power changes due to gain variations, optical signal-to-noise ratio (OSNR) measurements, and introduces new appendices on possible positions for monitoring equipment and parameter encoding.

Introduction

Fully regenerated optical networks traditionally had optical-to-electrical conversions at all network elements. Transmission performance is measured at the electrical layer with performance parameters such as errored seconds (ES) and severely errored seconds (SES). Since synchronous digital hierarchy (SDH) has built-in overhead in its frame structure to measure error performance at section, line and path layers, it is relatively easy to measure network performance at all network elements within a fully regenerated SDH network. Current optical networks typically include many transparent optical network elements between electrical regeneration points. This necessitates performance monitoring in the optical domain to assess the health of the optical channel (OCh).

Moreover, DWDM technology is improving at a rapid pace, continuously stretching the channel count, channel speeds and reach limits. Long-haul multi-span DWDM systems are capable of taking optical signals thousands of kilometres without electrical terminations or regeneration. This reduces the number of electrical monitoring points.

Recommendation ITU-T G.697 is an initial step towards addressing these needs through optical monitoring.

Recommendation ITU-T G.697

Optical monitoring for dense wavelength division multiplexing systems

1   Scope

The purpose of this Recommendation is to indicate a minimum, but not exhaustive, set of optical parameters that can be used to perform the optical monitoring (OM) functions in dense wavelength division multiplexing (DWDM) systems and optical network elements (e.g., reconfigurable optical add-drop multiplexers (ROADMs)), particularly relevant to those network elements without optical-electrical-optical conversions. In order to achieve this objective, this Recommendation:

1)   indicates the methods for measuring the optical signal degradation;

2)   classifies those methods by type;

3)   defines the suitable optical parameters to detect optical signal degradation; and

4)   describes the applications or conditions where these optical parameters can be relevant.

This Recommendation refers to DWDM systems and optical network elements with optical channels with bit rates up to approximately 10 Gbit/s using non-return to zero (NRZ) or return to zero (RZ) line coding. Bit rates above 10 Gbit/s and systems employing other modulation formats are for further study.

2   References

2.1   Normative 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.650.2]   Recommendation ITU-T G.650.2 (2007), *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 (2005), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.653]   Recommendation ITU-T G.653 (2006), *Characteristics of a dispersion-shifted single-mode optical fibre and cable*.

[ITU-T G.655]   Recommendation ITU-T G.655 (2006), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable*.

[ITU-T G.663]   Recommendation ITU-T G.663 (2000), *Application related aspects of optical amplifier devices and subsystems*.

[ITU-T G.664]   Recommendation ITU-T G.664 (2006), *Optical safety procedures and requirements for optical transport systems*.

[ITU-T G.692]   Recommendation ITU-T G.692 (1998), *Optical interfaces for multichannel systems with optical amplifiers*.

[ITU-T O.201]   Recommendation ITU-T O.201 (2003), *Q-factor test equipment to estimate the transmission performance of optical channels*.

3   Terms and definitions

3.1   Terms defined in this Recommendation

This Recommendation defines the following terms:

3.1.1   fully regenerated optical networks: Optical networks where optical-electrical-optical conversion is performed in each network element using re-amplification, reshaping and retiming (3R) regeneration.

3.1.2   transparent optical network element: An optical network element where there is no optical-electrical-optical conversion of the optical signal.

3.1.3   chromatic dispersion slope: The slope of the curve of chromatic dispersion coefficient versus wavelength.

3.2   Terms defined elsewhere

This Recommendation uses the following term defined in [ITU-T G.650.2]:

–   Stimulated Brillouin scattering (SBS)

This Recommendation uses the following terms defined in [ITU-T G.663]:

–   Polarization mode dispersion (PMD) (1st and higher orders)
–   Four-wave mixing (FWM)
–   Amplified spontaneous emission (ASE) Noise in OA
–   Chromatic dispersion
–   Reflections (see reflectance)
–   Cross Phase Modulation (XPM)
–   Self Phase Modulation (SPM)
–   Stimulated Raman Scattering (SRS)

This Recommendation uses the following term defined in [ITU-T G.692]:

–   Frequency (or wavelength) deviation from nominal (see central frequency deviation)

This Recommendation uses the following term defined in [ITU-T. O.201]:

–   Q-factor

This Recommendation uses the following terms defined in [b-ITU-T G.Sup39]:

–   Optical Signal-to-Noise Ratio (OSNR)
–   Inter-channel crosstalk
–   Interferometric crosstalk

4   Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

3R   Re-amplification, Reshaping and Retiming

ASE   Amplified Spontaneous Emission

BER	Bit Error Ratio
DCM	Dispersion Compensation Module
Demux	Demultiplexer
DWDM	Dense Wavelength Division Multiplexing
EME	Embedded Monitoring Equipment
EMP	External Monitoring Point
ES	Errored Second
ESR	Errored Second Ratio
FWM	Four-Wave Mixing
Mux	Multiplexer
NOC	Network Operations Centre
NRZ	Non-Return to Zero
OA	Optical Amplification
OADM	Optical Add-Drop Multiplexer
OD	Optical Demultiplexing
OLA	Optical Line Amplifier
OM	Optical Monitoring
OM	Opitcal Multiplexing
ONE	Optical Network Element
OSA	Optical Spectrum Analyser
OSNR	Optical Signal-to-Noise Ratio
OTN	Optical Transport Network
PDL	Polarization-Dependent Loss
PMD	Polarization Mode Dispersion
ROADM	Reconfigurable Optical Add-Drop Multiplexer
RZ	Return to Zero
SBS	Stimulated Brillouin Scattering
SDH	Synchronous Digital Hierarchy
SES	Severely Errored Second
SESR	Severely Errored Second Ratio
SLA	Service Level Agreement
SPM	Self Phase Modulation
SRS	Stimulated Raman Scattering
XPM	Cross Phase Modulation

5   Optical monitoring overview

The management of existing SDH networks relies on monitoring digital parameters such as bit error ratio (BER), errored second ratio (ESR) and severely errored second ratio (SESR), which are measured at the electrical layer (at 3R regenerators), as described in [b-ITU-T G.826].

A similar approach is used in the OTN (using ITU-T G.709 framing) for monitoring the end-to-end connections and the optical connections at the electrical level.

While these methods give a reliable measure of the end-to-end performance of an optical channel, they cannot be applied inside a transparent optical domain where no 3R regenerators are available to terminate the frame overhead. Therefore, they may not provide sufficient information to isolate the root cause of problems in complex DWDM networks.

Moreover, the rapid progress in optical technology is leading to ever-increasing channel counts and transmission speeds and to longer all-optical connections inside an optical domain.

This leads to an increasing influence of linear and non-linear distortions, which makes system commissioning an increasingly complex task.

An optimum solution for an optical transport network combines:

–   Proper network design to limit noise sources, dispersion and intermodulation effects.
–   Suitable alarms for the active optical components within the network for fault detection and isolation.
–   The use of appropriate optical monitoring throughout the network to monitor the most critical optical parameters.

Individually, these three actions cannot guarantee a suitable optical quality but, when combined, they provide a suitable solution for the management of optical transport networks.

An appropriate level of optical monitoring gives some visibility inside optical networks ensuring that channel paths are properly configured and optical parameters are appropriate for reliable service delivery. The collection of optical monitoring data in a network operations centre (NOC) makes the management of complex DWDM networks easier.

The objectives of optical monitoring are to detect anomalies, defects, degradations and faults affecting the quality of the optical layer. The optical parameters to be monitored should be established and defined according to specific requirements.

The ability to improve the end-to-end monitoring with distributed optical monitoring may have both reliability and cost benefits for configuration management and fault/degradation management, since some defects, degradations and faults affecting the quality of the optical layer are more easily detected and isolated through optical monitoring.

Aging effects, changes in noise due to changes in the temperature and humidity, are impairments that can seriously degrade the quality of the signal transmission. Optical monitoring makes it possible to detect these degradations in a reliable way.

Optical monitoring is a proactive process which can help to manage SLAs and to mitigate operational costs (although often at the expense of increased equipment costs). Optical monitoring is increasing in importance as maintaining a high degree of equipment reliability, coupled with the ability to diagnose degradations and failures quickly, and locate and repair network problems, is becoming more and more challenging as network complexity increases.

Optical monitoring is an important complement to the monitoring techniques applied at the digital client layers of the optical layer network.

Optical monitoring is a key element in the management of the optical networks, since it is possible to manage only what it is possible to measure.

While optical monitoring is implemented (and in service) in many current optical transmission systems, there are significant differences between the optical monitoring requirements between them. This is due to the presence of different transmission and control system design, and different strategies for impairment management in the various systems. For this reason, a general requirement as to which parameter value with which particular accuracy is a reliable indicator of the operational condition of such a system cannot be generalized. Even within a single system, the parameters that are of importance may vary between different network elements and the monitoring requirements, even for internal control, are different for the various network elements. Consequently, a general requirement for supervision of particular parameters will normally lead to a sub-optimal (and, therefore, non-cost-effective) solution. An appropriate optical supervision scheme will, for this reason, always be related to the particular transmission and control system design, engineering rules and implementation of impairment management of such a system. However, based on what is feasible from the technological point of view and on what network operators need, some monitoring choices can be identified, as outlined in this Recommendation.

6 Classification of monitoring methods

The following clauses describe two different forms of signal monitoring, namely time domain and frequency domain methods, and explain the differences between signal monitoring and equipment monitoring, as well as the differences between embedded and external monitoring devices.

6.1 Signal monitoring

This Recommendation is limited to non-intrusive measurements that allow in-service monitoring of the optical signal quality.

The measurements defined in this Recommendation do not measure every single impairment listed in Table 1 but, rather, the effect of these impairments on the parameters that can be measured.

A distinction between frequency- and time-domain measurement methods can be made.

6.1.1 Time domain methods

Methods which analyse the behaviour of the optical signal in the time domain tend to be closer to the full BER measurement than those in the frequency domain. These methods are sensitive to both noise and distortion effects. Sampling oscilloscopes and Q-factor meters, as described in [b-ITU-T O.201], are representative of sampling methods (synchronous methods). However, time domain methods generally need optical demultiplexing, optical to electrical conversion and, in the case of sampling methods, synchronization to the bit rate. Also, the difference in the characteristics of the reference receiver compared to the system receiver and the effect of residual dispersion at the measurement point, as discussed in clause III.2, has to be considered.

6.1.2 Frequency (or wavelength) domain methods

Frequency/wavelength domain methods of optical monitoring analyse the spectral characteristics of the optical signal. These spectral methods have in common that they do not sample the signal or synchronize to it, thereby eliminating the entire reference receiver. Typically, they employ a spectrum analyser device, which may be of varying resolution, and may or may not sense all channels simultaneously.

The simplest form of a spectral analysis is simple power monitoring of each channel. This can be done with, for example, a diffraction grating and detector array to sense all of the channel powers

simultaneously. At the expense of an increase in the complexity and resolution, this method can also be extended to look at the precise shape of the signal spectrum.

The fundamental property of these spectral methods is that they are averaging methods that, by definition, do not sense the pulse distortion. This means that quality monitoring by spectral methods will be insensitive to all of the effects due to distortions.

6.2 Equipment monitoring (indirect methods)

Indirect methods make use of an empirical correlation between equipment failures and signal quality. Equipment failures such as power supply failures, laser temperature, etc., may be detected by built-in self-test functions. These indicators are likely to be very system- and implementation-dependent.

Indirect methods mainly indicate that the system is operating, and one assumes that the signal quality is also degraded, when an equipment parameter is outside the specified range.

However, a correct equipment parameter is no guarantee of signal integrity since there may be other impairments that affect the signal quality (e.g., fibre attenuation).

6.3 Embedded monitoring equipment

Embedded monitoring equipment is usually tightly integrated with the management functions of an optical network element. For cost reasons, embedded monitoring is usually limited to a few basic parameters.

Different monitoring points placed in the same network element can share the embedded monitoring equipment.

6.3.1 Embedded monitoring equipment accuracy

It is desirable that the accuracy of embedded monitoring devices is sufficiently high to provide meaningful input for automated management decisions, should any be defined. This can often be achieved with relatively low effort compared to a general-purpose test instrument since, in many cases, only the deviation from a known nominal value is of interest, and the normal operating range of network elements is narrow.

6.4 External monitoring equipment

External monitoring equipment typically serves a different purpose than embedded monitoring equipment. It is normally used for measuring additional, more sophisticated performance parameters, or when a more accurate value of certain performance parameters is required.

The main applications are the location of hard-to-find failures that cannot be isolated by the embedded monitoring devices, as well as function tests and accurate parameter measurements during installation, commissioning or repair.

In contrast to embedded monitoring equipment, external monitoring instruments are usually not permanently installed, but rather connected on-demand to critical network segments and used in an interactive mode, often remote-controlled from a NOC.

6.4.1 External monitoring equipment accuracy

External monitoring equipment generally has higher accuracy and a wider measurement range than embedded monitoring devices since it must provide reliable absolute measurements over the full operating range of an optical transmission system, and the higher cost implied by this can be shared over a large number of optical network elements.

7 Optical impairments

This clause lists and categorizes the main systems impairments at the optical layer that limit the capacity of the system to transport information.

A list of the possible main system impairments is given in Table 1.

Table 1 – Optical impairments

Variation of the impairment	Relative frequency of occurrence	Description
Attenuation	High	
Optical channel power changes due to gain variations	High	
Frequency (or wavelength) deviation from nominal	High	[ITU-T G.692]
Polarization mode dispersion (PMD) (1st and higher orders)	Medium	Appendix II of [ITU-T G.663]
Four-wave mixing (FWM)	Medium	Appendix II of [ITU-T G.663]
Amplified spontaneous emission (ASE) noise in OA	Medium	Appendix II of [ITU-T G.663]
Chromatic dispersion	Medium	Appendix II of [ITU-T G.663]
Chromatic dispersion slope	Medium	[ITU-T G.652], [ITU-T G.653], [ITU-T G.655]
Reflections	Medium	Appendix III of [ITU-T G.663]
Laser noise	Medium	
Inter-channel crosstalk	Medium	[b-ITU-T G-Sup.39]
Interferometric crosstalk	Medium	[b-ITU-T G-Sup.39]
Cross phase modulation (XPM)	Low	Appendix II of [ITU-T G.663]
Self phase modulation (SPM)	Low	Appendix II of [ITU-T G.663]
Stimulated Brillouin scattering (SBS)	Low	Appendix II of [ITU-T G.650.2], Appendix II of [ITU-T G.663]
Stimulated Raman Scattering (SRS)	Low	Appendix II of [ITU-T G.663]

All these impairments are capable of being severe enough to cause severe degradation of an optical signal up to a level where the receiver is no longer able to detect the data with a reasonable error ratio. For any of the impairments, there exists a curve of penalty versus the probability of occurrence per unit time (see Appendix I).

The levels of relative frequency of occurrence in Table 1 are:

– Low: When the probability of the effect being severe enough to cause a penalty of X dB is ≈ 1 event per 10 years.

– Medium: When the probability of the effect being severe enough to cause a penalty of X dB is ≈ 1 event per year.

– High: When the probability of the effect being severe enough to cause a penalty of X dB is ≈ 10 events per year.

NOTE 1 – The above figures refer to the steady state period of the life of the systems. An event could cause X dB penalty on a single optical channel, or on a multichannel system. Indicative values for X dB penalty are given in Appendix II.

NOTE 2 – The relative frequency of occurrence of the optical impairments given in Table 1 refers to optical channels with bit rates up to approximately 10 Gbit/s. At present, there is not enough experience to prepare a similar table for optical channels with bit rates up to 40 Gbit/s; however, it can be expected that the possible impairments due to chromatic dispersion and to PMD at this bit rate could have a different impact compared to the case of optical channels with a bit rate of 10 Gbit/s. This possible impact is also a function of the modulation format adopted.

8   Optical monitoring parameters

The list of the optical parameters that can be measured using current technology in optical transmission systems is given below:

–   Channel power.

–   Total power.

–   Optical signal-to-noise ratio (OSNR) when no significant noise shaping is present.

–   Channel wavelength.

–   Q-factor.

Appendix III contains information concerning the performance obtainable from currently available monitoring technology.

9   Correlation between impairment effects and optical monitoring parameters degradation

**Table 2 – List of correlation between the underlined impairments
and monitoring parameters**

Parameters	Total power	Channel power	Channel wavelength	OSNR	Q-factor
Variation of attenuation	X	X		X	X
Frequency (or wavelength) deviation from nominal		X	X	X	X
Optical channel power changes due to gain variations		X		X	X

9.1   Variation of attenuation

For further study.

9.2   Frequency (or wavelength) deviation from nominal

There is a direct correlation between the impairment of "frequency deviation from nominal" and the optical monitoring parameter "channel wavelength". The required measurement accuracy for the channel wavelength depends upon the "maximum central frequency deviation" for the channel. [ITU-T G.692] gives a value for this parameter of n/5 (where n is the channel spacing) for applications with channel spacing of 200 GHz and above, but no value is given for channel spacing below this.

9.3   Optical channel power changes due to gain variations

There is a direct correlation between the impairment "optical channel power changes due to gain variations" and the optical monitoring parameter "channel power". For slow variations in channel gain, the optical channel power monitoring will provide adequate information to establish the location of the gain variation. However, DWDM systems may involve many built-in control loops, such as laser wavelength tuning and output power control, channel equalization power control, amplifier gain control and transient control and channel receiver power and dispersion controls, to maintain end-to-end transmission performance. These control loops may operate over millisecond or even microsecond timescales and will respond to or even create sub-second photonic events that may impact the end-to-end transmission quality. Since it is not practical to monitor channel power with a time granularity sufficiently small to capture these events, it is helpful to acquire the maximum and minimum of control function input and output parameters within a coarser time granularity.

10   Applications

In DWDM systems, optical monitoring could help in the following activities:

i)   Configuration management for system and channel activation, addition of new channels, etc.

ii)   Fault management to detect and to isolate faults.

iii)   Degradation management in order to keep the system running and to detect degradations before a fault occurs.

In order to achieve the above objectives, one or more of the following monitoring choices could be considered for internal monitoring in DWDM systems with the resulting data available both locally and from a remote location. The choice of which option to include depends upon the specific characteristics of the DWDM system (e.g., length, number of spans, number of channels, inaccessibility of the sites) as well as cost/benefit considerations:

a)   Total power at input of various stages of optical amplification.

b)   Total power at output of various stages of optical amplification.

c)   Channel power at the DWDM transmitter output before the multiplexer.

d)   Channel power at the DWDM receiver input after the demultiplexer.

e)   Channel power at the output of various stages of optical amplification.

f)   Channel OSNR at the output of various stages of optical amplification.

g)   Channel wavelength deviation at least at one point along the optical path.

A tap at the output of the various stages of optical amplification enables a more detailed analysis of the optical channel status to be performed via external measurement equipment. Whether or not to include this tap depends upon the specific characteristics of the DWDM system as well as cost/benefit considerations.

11   Optical safety considerations

See [ITU-T G.664] for optical safety considerations.

Appendix I

Severity of optical impairments

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

The optical impairments listed in Table 1 are all capable of causing severe degradation of an optical signal to the point of failure of the receiver to be able to detect the data with a reasonable error ratio. For any of the impairments, it is possible to plot a curve of penalty versus occurrence rate (the probability of occurrence per unit time). An example curve in the case of attenuation might take the form of the curve below.
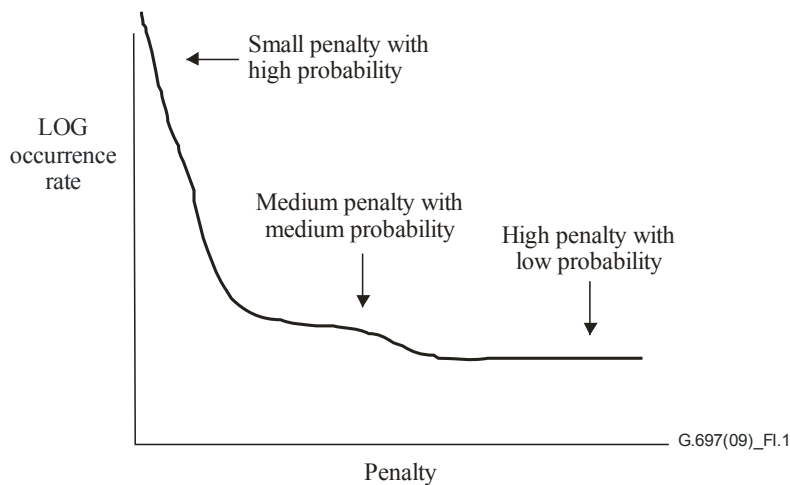
Figure I.1 – Example curve of penalty versus occurrence rate due to attenuation variation

The shape of the curve and the probability levels will, of course, be different for each of the impairments on the list. On the curve for attenuation, small impairments of the order of 0.1 dB being very probable and large impairments (for example, 6 dB or greater) being very much less probable. The curve for a different impairment will have a different shape. For example, SBS might look like the curve below.
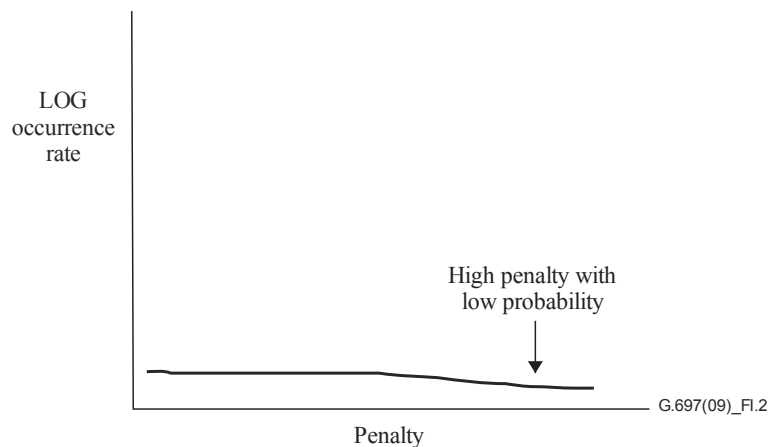
Figure I.2 – Example curve of penalty versus occurrence rate due to SBS variation

Here, the occurrence rate is very low (failure of the dither circuit or very much higher power in the fibre than expected) but the penalty generated can be very severe.

Since this is the case, the approach that has been taken within this Recommendation is to define an approximate penalty that is considered as constituting a significant impairment (e.g., 3 dB) and then give an indication of the frequency with which this occurs in a typical optical network.

Appendix II

Penalty severity value X

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

One operator, referring to a 10,000 km DWDM network, suggests defining the X value equal to a 3 dB penalty as a figure that constitutes a significant impairment.

Appendix III

Optical monitoring performance

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

This appendix contains information concerning the performance obtainable from currently available optical monitoring technology. This information should not be interpreted as a requirement or specification, but is intended to help in identifying those cases where a particular desired optical monitoring performance requirement can (or cannot) be met using currently available technology. Requirements for optical monitoring performance can only be generated with respect to a particular function and for a particular system design and, in most cases, practical and cost-effective specifications for any individual monitoring solution may be very different from the data given below.

Table III.1 gives information on the standard measurement performance that might be obtainable with low cost measurement equipment embedded in the ONEs at the DWDM receiver input. Table III.2 gives information on the standard measurement performance that might be obtainable with low cost measurement equipment embedded in the ONEs at multichannel points where there is no requirement to measure OSNR. Table III.3 gives the same information for low cost measurement equipment embedded in the ONEs that can measure OSNR. Table III.4 gives measurement performance for premium measurement equipment with costs appropriate to measurements in a much-reduced number of places in the network by the maintenance staff.

**Table III.1 – Performance of embedded optical monitoring
at the DWDM receiver input**

Parameter	Accuracy	Repeatability	Measurement range
Channel power	±2 dB (Note 1)	±0.5 dB	Receiver operating range (Note 2)
NOTE 1 – Since this function must be performed within every DWDM receiver, it must be very simple to remain cost effective and, for this reason, this value is relaxed compared to the value in Table III.2. NOTE 2 – The input power range over which the receiver would normally be expected to operate.			

Table III.2 – Performance of embedded optical monitoring without OSNR

Parameter	Accuracy	Repeatability	Measurement range
Total power	±1 dB (Note 1)	±0.5 dB	(−60 to +5) + tap loss dBm (Note 2)
Channel power	±1 dB (Note 1)	±0.5 dB	(−60 to −10) + tap loss dBm (Note 2)
NOTE 1 – This value includes contributions from both measurement uncertainty and tap loss variation. In some systems, the tap loss variation may lead to worse accuracy than this, although this may be compensated by calibration (with additional cost). NOTE 2 – Since different systems use monitoring taps with different splitting fractions (e.g., 5% or 2%), the measurement range is shown at the output of the tap. To derive the measurement range, the tap loss must be added to the values. For example, a 2% tap would make the values 17 dB higher.			

Table III.3 – Performance of embedded optical monitoring with OSNR

Parameter	Accuracy	Repeatability	Measurement range
Total power	±1 dB (Note 1)		
Channel power	±1 dB (Note 1)	±0.5 dB	(–40 to –10) + tap loss dBm (Note 2)
Channel wavelength	±75 pm		
OSNR where no significant noise shaping is present (in 0.1 nm optical bandwidth)	±1.5 dB	±0.5 dB	For channel power ≥25 dBm OSNR 10 to 30 dB for ≥100 GHz spacing OSNR 10 to 25 dB for 50 GHz spacing (Note 3)
NOTE 1 – This value includes contributions from both measurement uncertainty and tap loss variation. In some systems, the tap loss variation may lead to worse accuracy than this, although this may be compensated by calibration (with additional cost).			
NOTE 2 – Since different systems use monitoring taps with different splitting fractions (e.g., 5% or 2%), the measurement range is shown at the output of the tap. To derive the measurement range, the tap loss must be added to the values. For example, a 2% tap would make the values 17 dB higher.			
NOTE 3 – This measurement range may not be obtainable in cases where there is significant spectral broadening due to non-linear effects in the link.			

Table III.4 – Performance of premium optical monitoring equipment

Parameter	Accuracy	Repeatability	Measurement range
Total power	±0.2 dB (Note 1)		
Channel power	±0.4 dB (Note 1)	±0.2 dB	(–80 to +23) + tap loss dBm (Note 2)
Channel wavelength	±0.5 pm		
OSNR where no significant noise shaping is present (in 0.1 nm optical bandwidth)	±0.4 dB OSNR < 20 ±0.7 dB OSNR < 30		0 to 42 dB for 100 GHz spacing 0 to 28 dB for 50 GHz spacing (Note 3)
Q-factor	±10%	±5%	4 to 14
Others			
NOTE 1 – This value does not include any contribution from tap loss variation which would have to be compensated by calibration.			
NOTE 2 – Since different systems use monitoring taps with different splitting fractions (e.g., 5% or 2%), the measurement range is shown at the output of the tap. To derive the measurement range, the tap loss must be added to the values. For example, a 2% tap would make the values 17 dB higher.			
NOTE 3 – This measurement range may not be obtainable in cases where there is significant spectral broadening due to non-linear effects.			

III.1   OSNR measurement

OSNR measurement currently uses the principle of measuring the noise between channels in order to estimate the noise at the channel wavelength. See Figure III.1 below.
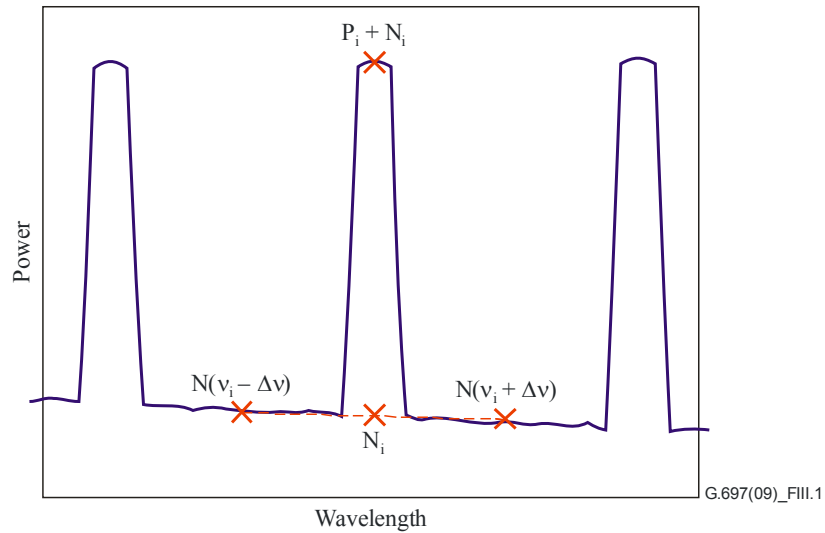
$P_i + N_i$

$N(v_i - \Delta v)$ $N(v_i + \Delta v)$

N_i

G.697(09)_FIII.1

Power

Wavelength

Figure III.1 – OSNR measurement method

This method works well for simple point-to-point systems with nothing but fibre and amplifiers in the optical path. For more complex DWDM systems, however, the introduction of any element which causes shaping of the noise between channels renders this method inaccurate.

In the section of a DWDM system illustrated in Figure III.2, for example, there is a simple OADM, which is configured to drop and add a single channel.

A   B

G.697(09)_FIII.2
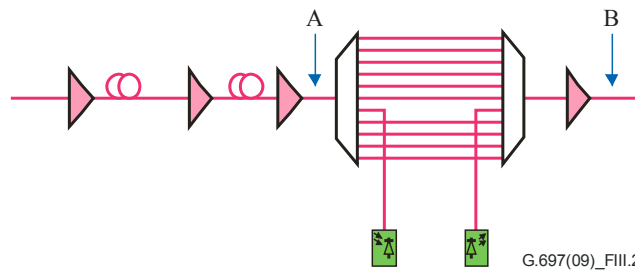
Figure III.2 – Section of a DWDM system with an OADM

The optical spectra that might be found at points marked A and B are shown in Figures III.3 and III.4, respectively.
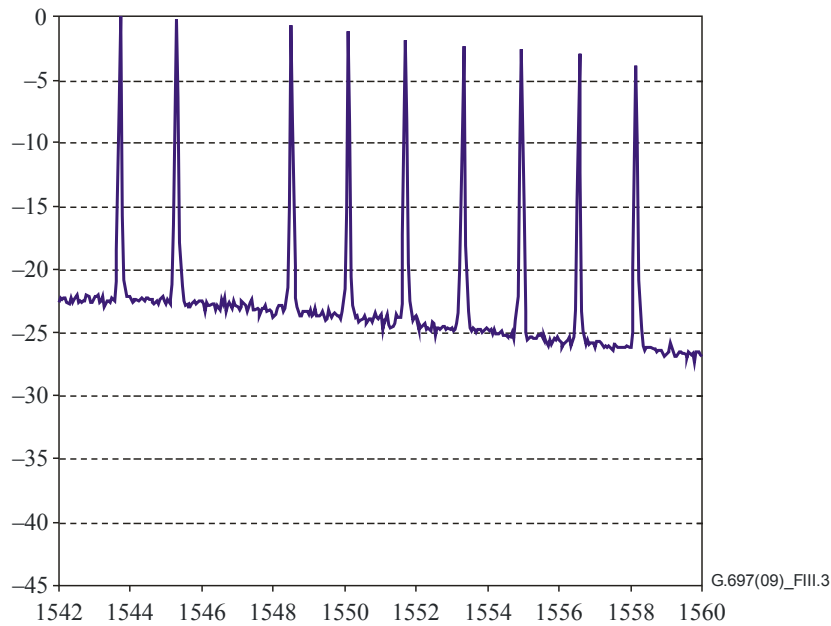
Figure III.3 – Optical spectrum at point A

As can be seen from Figure III.3, at point A the method of OSNR measurement illustrated in Figure III.1 gives accurate results as the variation in noise with wavelength is fairly slow.

NOTE – Channel 3 of this hypothetical 10-channel system is not present.

Figure III.4 shows the spectrum after the Mux of the OADM and a booster amplifier. Here, the situation is radically different. The noise between the channels has been strongly shaped by the combined filtering function of the Demux/Mux. As can be seen by the noise peak at the wavelength of the missing channel in this example, there is about 15 dB more noise at the channel wavelengths than at the mid-points between channels and, hence, the OSNR estimate at this point is about 15 dB optimistic. For the wavelength that has been added, however, we have the reverse situation and the noise level at the mid-points is much higher than the noise added at the channel wavelength. The OSNR estimate for this channel is, therefore, seriously pessimistic.

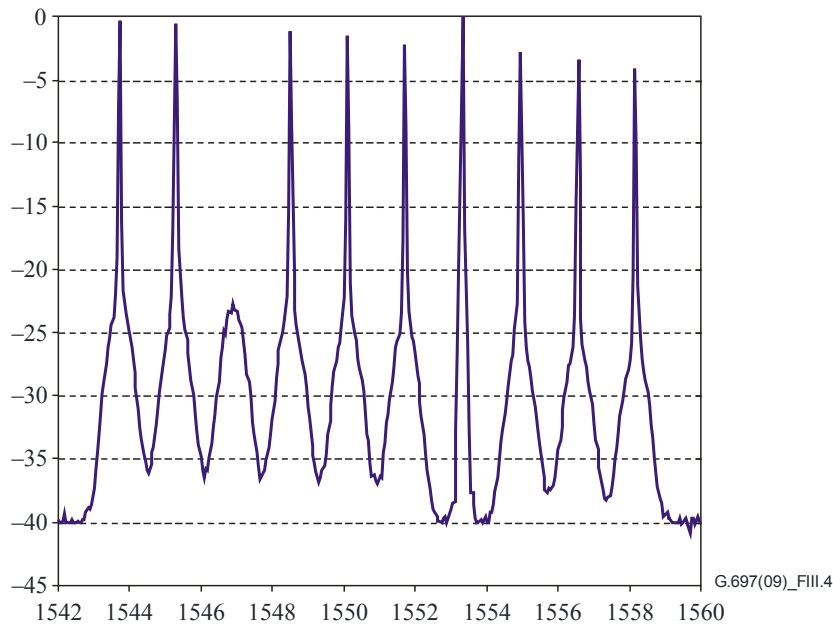[b-IEC 61280-2-9] could be a useful reference for additional information on OSNR measurements.

G.697(09)_FIII.4

Figure III.4 – Optical spectrum at point B

For a realistic OSNR measurement in the presence of noise shaping, it is essential to measure the filtered noise value in the passband of the optical filters in a system (often called 'in-band' OSNR measurement). Three methods of achieving this are described in the following clauses.

III.1.1   Narrow-band optical spectrum analyser method

In the case where the signal spectrum does not occupy the full channel bandwidth and the optical filter shape has a flat region, the OSNR can be measured with a narrow-band optical spectrum analyser. An example of this is shown in Figure III.5 for the case of a 10 Gbit/s signal in a 100 GHz channel spacing system. Here, the OSNR can be estimated by measuring the signal power and the noise in the flat region away from the signal. Care must be taken to measure the signal with a sufficiently large resolution bandwidth to capture all of the signal power, while measuring the noise with a small enough resolution bandwidth to exclude the signal. This may require a different resolution bandwidth for each part of the measurement and for the noise power to be scaled from the measurement bandwidth to the usual reference value of 0.1 nm.
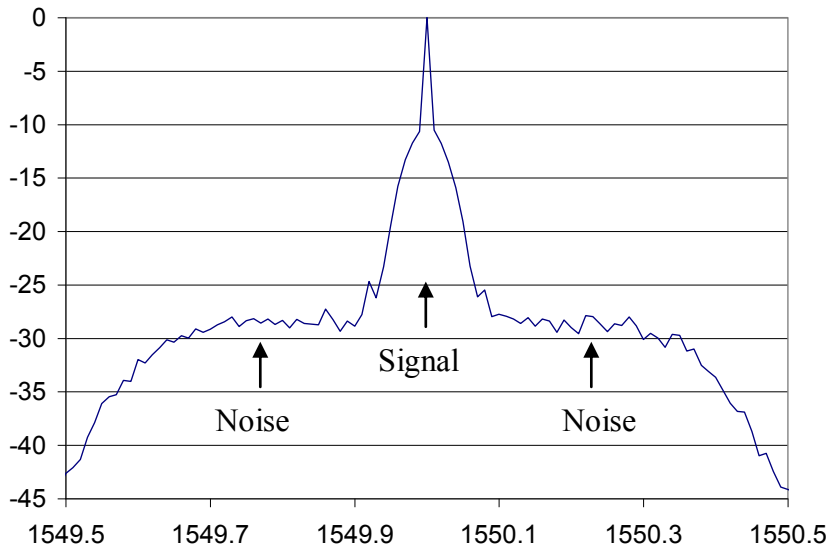
Figure III.5 – Optical spectrum where signal does not occupy full channel bandwidth

However, as the baud rate becomes comparable with the channel spacing, the signal spectrum completely overlaps with the noise floor as illustrated in Figure III.6. In this case, a different measurement principle is required. Also, in the case where the signal traverses multiple optical filters, the combined filter function becomes progressively less flat-topped, thereby making accurate determination of the noise level more difficult.
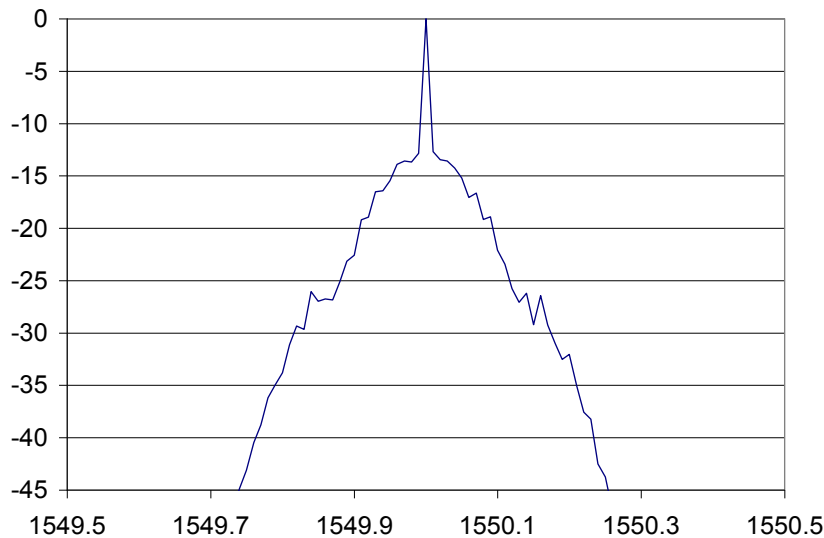
Figure III.6 – Optical spectrum where signal occupies full channel bandwidth

III.1.2 Time domain extinction measurement

In this method, the signal for the channel to be measured is gated on and off at the entry point into the optical system using an acoustic-optical switch. The signal at the point to be measured is then sampled using a second switch, either in phase to measure the signal or out of phase to measure the noise power. This method requires fast high-extinction acoustic-optical switches or a gated optical

spectrum analyser (OSA). The average signal level of the channel being measured is kept the same as during normal operation to maintain the operating point of the amplifiers.

Obvious drawbacks of this method of measurement are that it requires equipment to be inserted at multiple points in the system and that it cannot be used to measure OSNR while the channel is in service.

III.1.3   Polarization extinction measurement

An alternative method of separating the signal from the noise is to exploit the fact that, to a first approximation, the optical transmission signal is polarized, whereas the ASE noise is unpolarized. In its simplest form, a combination of a variable polarization controller and a polarization splitter/filter is used to separate the polarized signal from the unpolarized noise as shown in Figure III.7.
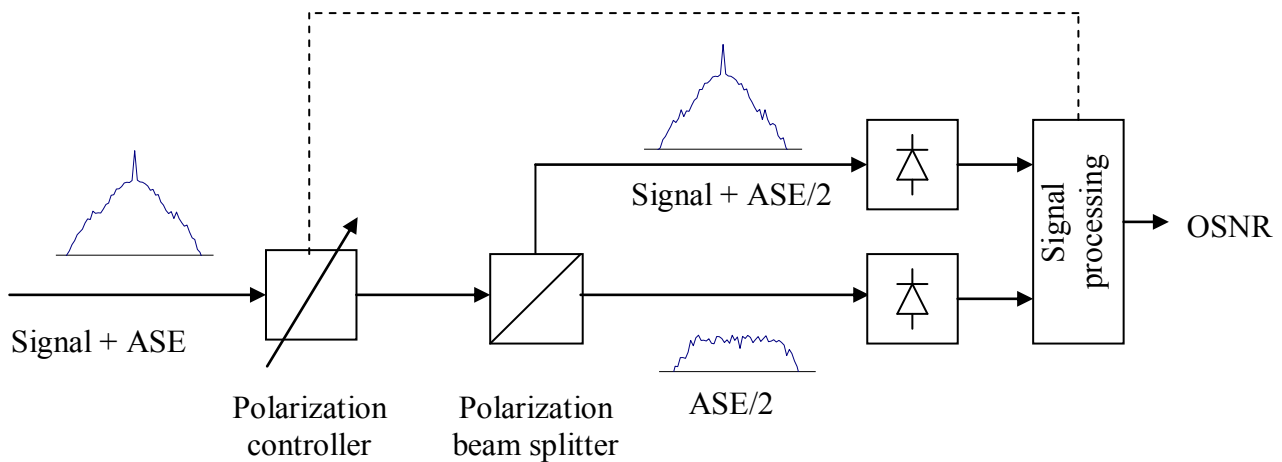

Figure III.7 – Polarization extinction method block diagram

By variation of the polarization controller in front of the polarization beam splitter, it is possible to suppress the polarized signal and get access to the non polarized in-band noise at one branch, where the other branch shows the signal plus noise [b-Rasztovits-Wiech].

Four problems with this measurement method are:

–   If the polarization state of the signal at the measurement point evolves rapidly (this is likely to be a particular problem with aerial fibre) or the signal becomes de-polarized, then it is very difficult to obtain a good extinction of the signal.

–   In the case where there is crosstalk between the channels, the crosstalk may or may not be included in the noise measurement depending on the relative polarizations of the signal and the crosstalk.

–   Polarization-dependent loss (PDL) can lead to significant measurement error due to the noise with the same polarization as the signal having a different amplitude to the noise with the orthogonal polarization.

–   For a polarization multiplexed signal, there is a separate signal on each of the two orthogonal polarizations so it is not possible to extinguish the signal using a polarization beam splitter. Hence, it is not possible to use this method of OSNR measurement for these signals.

III.2 Q-factor measurement

A Q-factor measurement occupies an intermediate position between the classical optical parameters (power, optical signal-to-noise ratio (OSNR) and wavelength) and the digital end-to-end performance parameters based on BER.

A Q-factor is measured in the time domain by analysing the statistics of the pulse shape of the optical signal. Full details can be found in [ITU-T O.201]. A Q-factor is a comprehensive measure for the signal quality of an optical channel taking into account the effects of noise, filtering and linear/non-linear distortions on the pulse shape, which is not possible with simple optical parameters alone.

Under ideal conditions (only additive Gaussian noise, no linear or non-linear distortions, etc.), the BER of a binary optical channel should be the same as that indicated by a Q-factor measurement. However, these idealized conditions are rarely present in real systems and the correlation between the Q-factor of an optical signal and the BER measured after regeneration is influenced by the different receiver characteristics (noise bandwidth, impulse response, etc.) in the regenerator compared to that of the Q-factor meter.

An additional factor that has a serious effect on the validity of a Q-factor measurement at any point in an optical path is the residual dispersion present at that point. Figure III.8 shows the block diagram for a simple five-span transmission system incorporating dispersion compensation modules (DCMs) in the line amplifiers. In such a system, while the end points labelled E and F usually have nominally zero residual dispersion, Q-factor measurements at intermediate points of the optical path are only possible with proper dispersion compensation at those points.
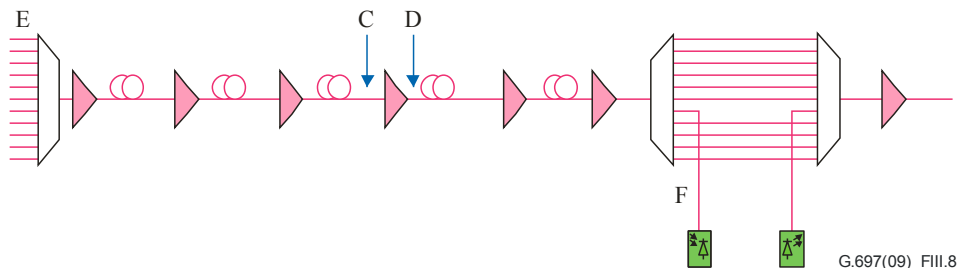

G.697(09)_FIII.8

Figure III.8 – Five-span transmission system incorporating DCMs in the line amplifiers

Figure III.9 shows the residual dispersion versus distance for a system where the dispersion of each nominally 80 km span is compensated by an 80 km DCM embedded in each line amplifier, and an additional DCM within the receiving preamplifier. In this case, for example, the Q-factor measured at point C (the input to the third line amplifier) is quite different to the Q-factor at point D (the output of the same amplifier) due to the large difference in residual dispersion of the two points.
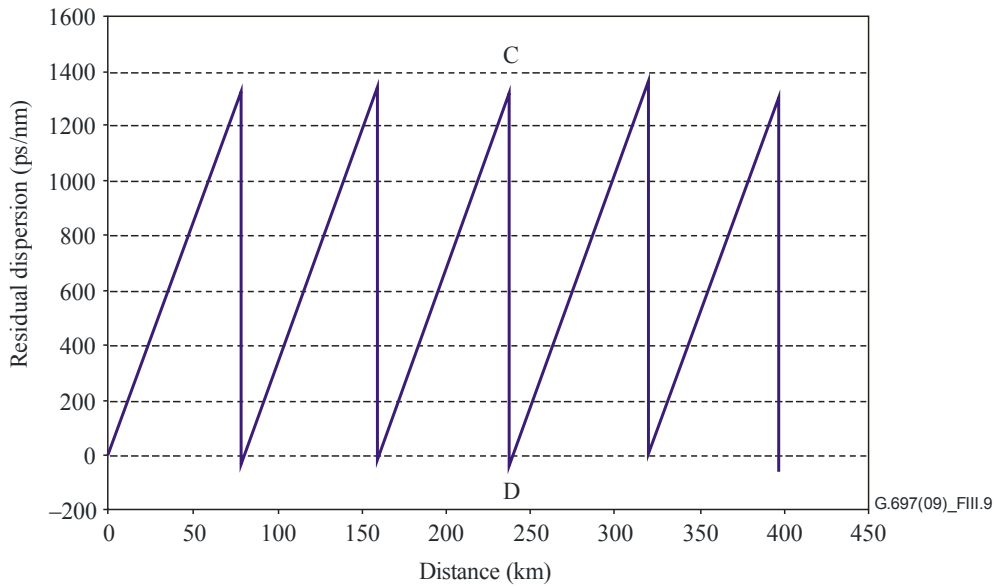
Figure III.9 – Residual dispersion versus distance for a simple system

A solution to the dispersion map, illustrated in Figure III.9, is to only measure the Q-factor at the amplifier outputs (e.g., point D).

The residual dispersion map in Figure III.9 is for a wavelength where the fibre dispersion is reasonably accurately compensated for by the DCM. In long-haul systems that cover a large wavelength range, however, the fact that the slope of the fibre dispersion with wavelength typically does not exactly match the inverse of the slope of the DCM dispersion with wavelength means that the residual dispersion map is different over the range of channel wavelengths. This is illustrated in Figure III.10 where the residual dispersion maps of the extreme wavelength channels are also shown.
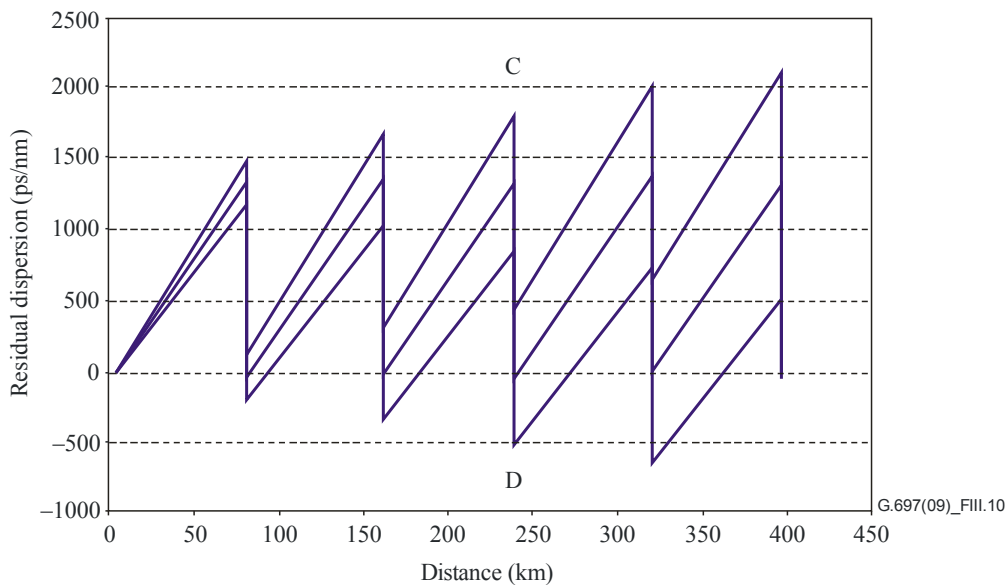

**Figure III.10 – Residual dispersion versus distance for a simple system
with a wide wavelength range**

In the case of a more complex dispersion map, as illustrated in Figure III.11, where there are DCMs in the transmitter and the receiver as well as embedded in the line amplifiers, the points with zero dispersion do not now necessarily coincide with the output of line amplifiers. Here, additional compensation devices in the measuring equipment would be required for Q-factor measurement to be valid at these monitoring points.
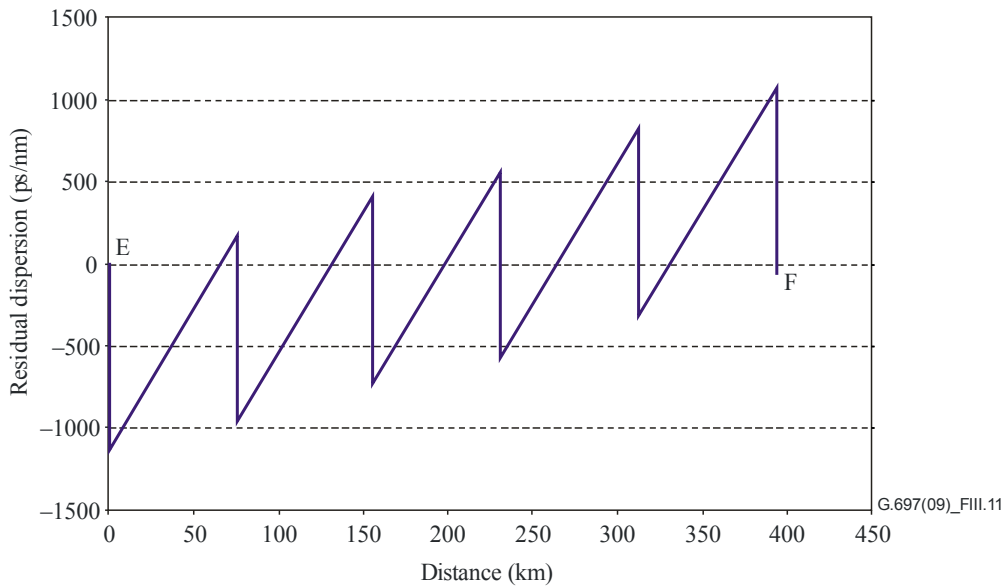

Figure III.11 – Residual dispersion versus distance for a more complex system

Appendix IV

Possible positions for suitable monitoring equipment
and their relative functions in several optical network elements

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

IV.1   Introduction

While optical monitoring is implemented (and in service) in many current optical transmission systems, there are significant differences between the optical monitoring deployments between them. This is due to the presence of different transmission and control system design, the size of the network and different strategies for impairment management in the various systems. For this reason, a general requirement as to which parameter value with which particular accuracy is a reliable indicator of the operational condition of such a system cannot be generalized.

The choice of which option to deploy depends upon the specific characteristics of the ONE. In particular for a DWDM system by its characteristics (e.g., length, number of spans, number of channels, inaccessibility of the sites) as well as cost/benefit considerations. In particular, it has to be considered that as the number of monitoring points grows there is an increasing consumption of signal power with a consequent reduction of the DWDM system reach.

As a conclusion, it is underlined that the possible positions for suitable monitoring points and their relative functions in several optical network elements which are shown in this appendix should be considered as examples and not as requirements. These examples are of interest because they can show what is feasible from the technological point of view and what network operators could need.

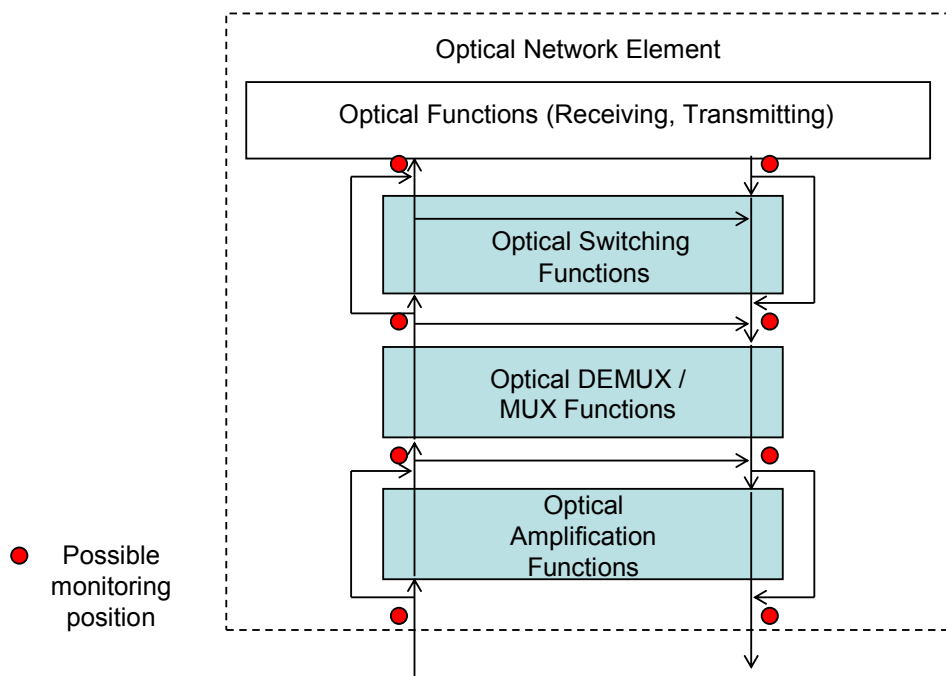A general model for possible monitoring positions in an optical network element is shown in Figure IV.1.

Figure IV.1 – Example of EME positioning inside an optical network element

IV.2 Embedded monitoring points

IV.2.1 DWDM line segment

An example of positioning of embedded monitoring equipment (EME) in a long-distance DWDM line segment with optical channels operating at 10 Gbit/s is shown in Figure IV.2.
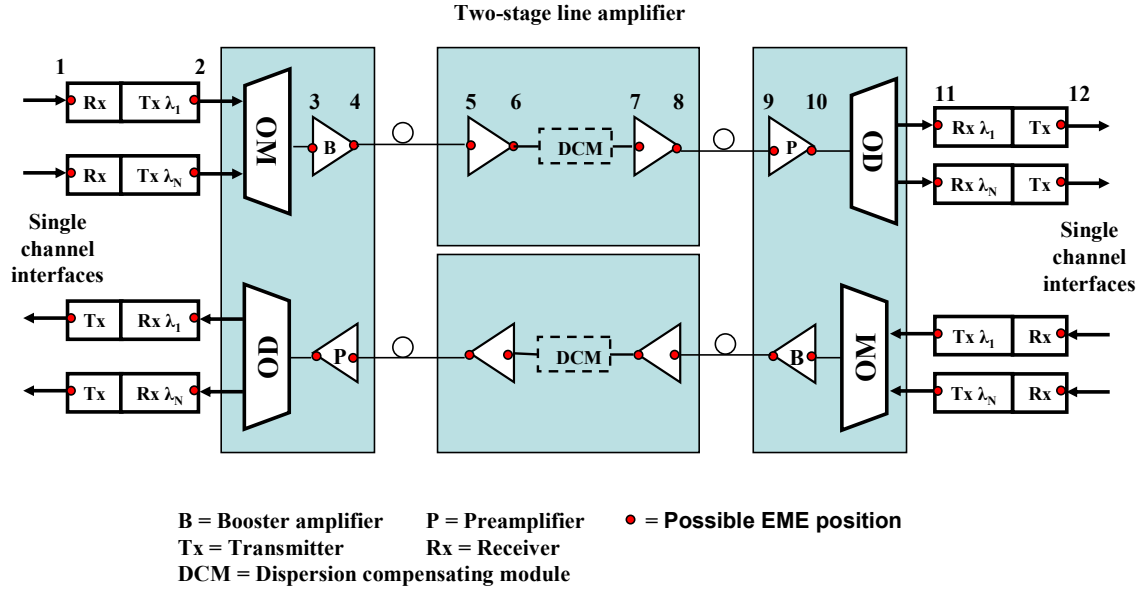

Two-stage line amplifier

B = Booster amplifier   P = Preamplifier   ● = Possible EME position
Tx = Transmitter   Rx = Receiver
DCM = Dispersion compensating module

Figure IV.2 – Example of EME positioning inside a long-distance DWDM line segment

The optical parameters listed in clause 10 can be measured in the various monitoring points of Figure IV.2 according to Table IV.1.

Table IV.1 – Possible monitoring in a DWDM line segment

Monitoring parameters	EME position
a) Total power at input of various stages of optical amplification	3, 5, 7, 9
b) Total power at output of various stages of optical amplification	4, 6, 8, 10
c) Channel input power	1, 11
d) Channel output power	2, 12
e) Channel power at the output of various stages of optical amplification	4, 6, 8, 10
f) Channel OSNR at the output of various stages of optical amplification	4, 6, 8, 10
g) Channel wavelength	2
NOTE – This table lists possible monitoring positions. The appropriate choice of monitoring depends on the particular system (see clause IV.1).	

IV.2.2 ROADMs

An example of positioning of embedded monitoring equipment in a reconfigurable optical add-drop multiplexer (ROADM) is shown in Figure IV.3.
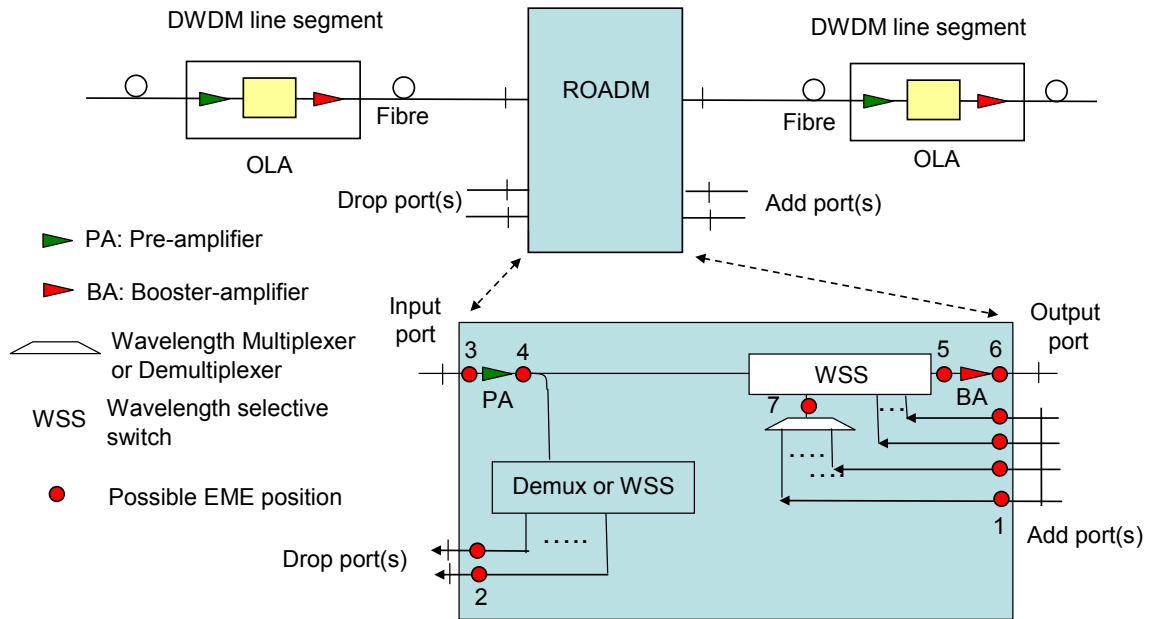
Figure IV.3 – Example of EME positioning inside a ROADM

The optical parameters listed in clause 10 can be measured in the various EMEs of Figure IV.3 according to Table IV.2.

Table IV.2 – Possible monitoring in an example ROADM

Monitoring parameters	EME position
a) Total power at input of various stages of optical amplification	3, 5
b) Total power at output of various stages of optical amplification	4, 6
c) Channel input power	1
d) Channel output power	2
e) Channel power at the output of various stages of optical amplification	4, 6
f) Channel OSNR at the output of various stages of optical amplification	4, 6
g) Channel wavelength	1
h) Total power	7
NOTE – This table lists possible monitoring positions. The appropriate choice of monitoring depends on the particular system (see clause IV.1).	

The position and the function of the EMEs inside the WSS are for further study.

IV.3   External monitoring points

IV.3.1 DWDM line segment

An example of positioning of external monitoring points (EMPs) in a long-distance DWDM line segment with optical channels operating at 10 Gbit/s is shown in Figure IV.4.
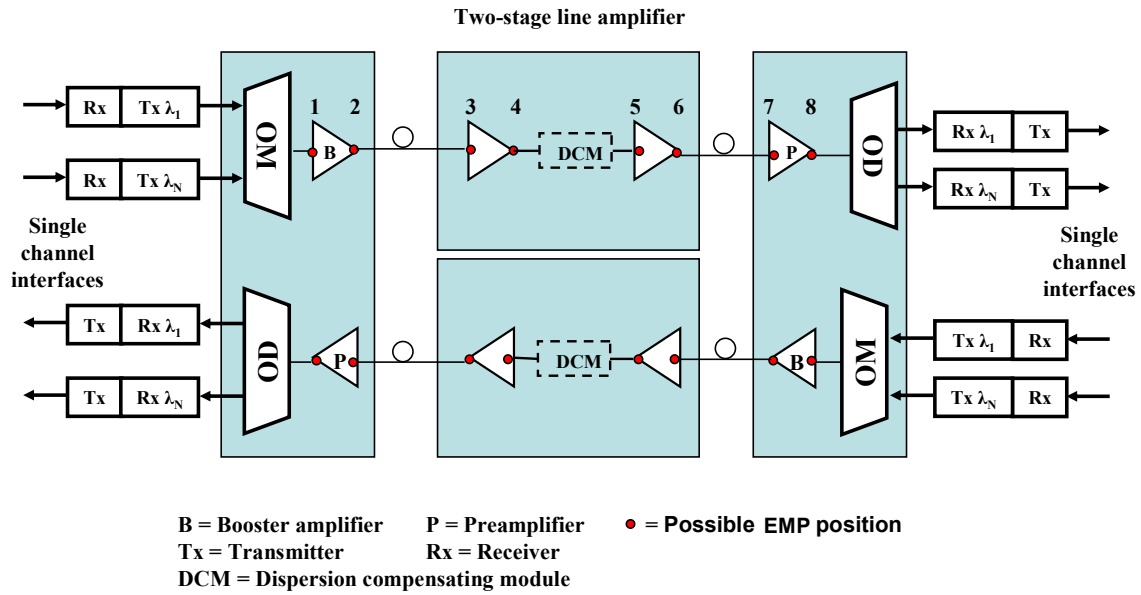
Two-stage line amplifier

B = Booster amplifier P = Preamplifier ● = Possible EMP position
Tx = Transmitter Rx = Receiver
DCM = Dispersion compensating module

Figure IV.4 – Example of EMP positioning inside a long-distance DWDM line segment

All of the optical parameters listed in clause 10 can be measured in the various monitoring points of Figure IV.4 with suitable external measurement equipment. The appropriate choice of which monitoring points are provided depends on the particular system (see clause IV.1).

IV.3.2 ROADMs

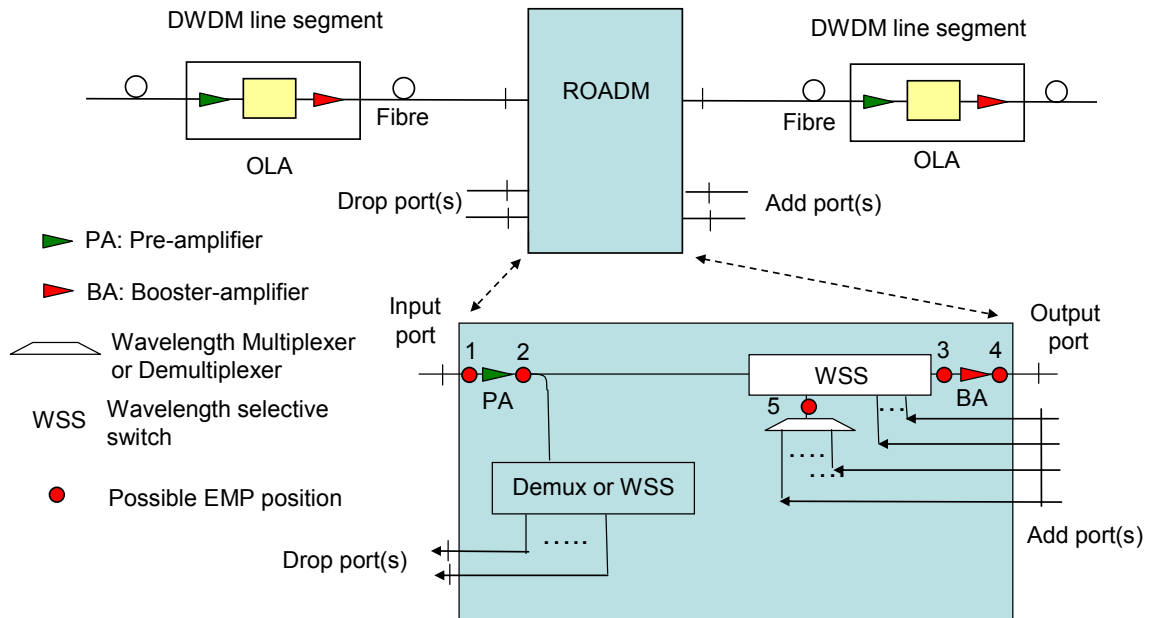An example of positioning of external monitoring points in a ROADM is shown in Figure IV.5.

Figure IV.5 – Example of EMP positioning inside an example ROADM

All of the optical parameters listed in clause 10 can be measured in the various monitoring points of Figure IV.5 with suitable external measurement equipment. The appropriate choice of which monitoring points are provided depends on the particular system (see clause IV.1).

Appendix V

Parameter encoding

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

This appendix contains a possible encoding scheme for the communication of information relating to optical parameters. The use of this information, how it is communicated, whether information for any particular parameter is included and whether the value for any parameter is obtained by measurement, measurement prior to system installation or purely provisioned, is outside the scope of this appendix.

V.1 Wavelength ID (32 bits)

This field contains the wavelength label and is composed by 4 sub-fields:

− **Grid** (3 bits, 0 to 2): The value for grid is set to 1 for the ITU-T DWDM grid as defined in [b-ITU-T G.694.1], set to 2 for the ITU-T CWDM grid as defined in [b-ITU-T G.694.2]. The values of 0 and 3 to 7 are reserved for future use.

− **Channel spacing** (4 bits, 3 to 6): The channel spacing encoding when Grid is set to "1" (DWDM) is shown in Table V.1 and the channel spacing encoding when Grid is set to "2" (CWDM) is shown in Table V.2

Table V.1 – DWDM channel spacing encoding

Channel spacing (GHz)	Value
100	1
50	2
25	3
12.5	4
Flexible grid	5
Reserved for future use	0, 5 6 to 15

For channel spacings of greater than 100 GHz, there is more than one possible choice of grid (see [b-ITU-T G.694.1]) so the appropriate element of the 100 GHz spaced grid should be encoded.

Table V.2 – CWDM channel spacing encoding

Channel spacing (nm)	Value
20	1
Reserved for future use	0, 2 to 15

− n (16 bits, 7 to 22): The value used to compute the frequency as shown below:
When the grid is "1", frequency (THz) = 193.1 THz + n * channel spacing (THz)
For the case where the channel spacing value is set to "5", a channel spacing of 6.25 GHz should be used in the above formula.
When the grid is "2", wavelength (nm) = 1471 nm + n * channel spacing (nm)
n is encoded as a 16-bit two's complement number.

– **m** (9 bits, 23 to 31): When the grid is "1" and the channel spacing value is set to "5" this is the value used to compute the slot width as: slot width (GHz) = 12.5 GHz * m (see [b-ITU-T G.694.1]) otherwise set to 0.
 m is encoded as a 9-bit unsigned integer.**Reserved (9 bits, 23 to 31): Set to 0, reserved for future use**.

As an example, the encoding of the 193.85 THz element (approximately 1546.518 nm) from the 50 GHz spaced grid in [b-ITU-T G.694.1] would be grid = 1, channel spacing = 3̶2, n = 15, Reserved = 0. This results in an encoding of 000000000 0000000000001111 0̶0̶1̶1̶ 0010 001 or 0x00000791̶0̶x̶0̶0̶0̶0̶0̶7̶9̶7̶.

V.2 Parameter ID source (8 bits)

This field defines the source of the parameter ID lookup table. The value "1" corresponds to this Recommendation, all other values are reserved for future use.

V.3 Parameter ID (8 bits)

When the parameter ID source is equal to "1", the parameter encoding shown in Table V.3 applies. For all other values of the parameter ID source, the parameter encoding is given in the document referred to in V.2.

Table V.3 – Parameter ID encoding

Value	Parameter	Unit	Notes
1	Total power	dBm	
2	Channel power	dBm	
3	Frequency deviation from nominal	GHz	For DWDM channels
4	Wavelength deviation from nominal	nm	For CWDM channels
5	OSNR	dB (0.1 nm)	Referred to a 0.1 nm noise bandwidth
6	Q	–	Linear Q
7	PMD	ps	Mean DGD. This parameter is normally only measured at time of installation
8	Residual dispersion	ps/nm	This parameter is normally only measured at time of installation

All other values of the parameter ID are reserved for future use.

V.4 Value of parameters (32 bits)

The parameter value is encoded as a 32-bit floating-point number according to [b-IEEE 754]. The 32-bit number is divided in to a sign (1 bit), an exponent (8 bits) and a mantissa (23 bits). The parameter value is then:

$$\text{Value} = (-1)^{\text{sign}} \times 2^{(\text{exponent} - 127)} \times (\text{number between 1.0 and 2.0 derived from mantissa})$$

For details see [b-IEEE 754].

Bibliography

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

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

[b-ITU-T G.709]   Recommendation ITU-T G.709/Y.1331 (2003), *Interfaces for the Optical Transport Network (OTN)*.

[b-ITU-T G.826]   Recommendation ITU-T G.826 (2002), *End-to-end error performance parameters and objectives for international, constant bit-rate digital paths and connections*.

[b-ITU-T G-Sup.39]   ITU-T G-series Recommendations – Supplement 39 (2003), *Optical system design and engineering considerations*.

[b-IEC 61280-2-9]   IEC 61280-2-9 (2009), *Fibre optic communication subsystem test procedures – Part 2-9: Digital systems – Optical signal-to-noise ratio measurement for dense wavelength-division multiplexed systems*

[b-IEEE 754]   IEEE 754 (2008), *Standard for Binary Floating-Point Arithmetic*

[b-Rasztovits-Wiech]   Rasztovits-Wiech, M., Danner, M., Leeb, W. R. (1998), *Optical signal-to-noise measurement in WDM networks using polarization extinction*, Proceedings or the European Conference on Optical Communications (ECOC 1998), pp. 549-550.

_____