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DIGITAL SYSTEMS AND NETWORKS

Transmission media characteristics – Characteristics of  
optical components and subsystems

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**Optical monitoring for DWDM systems**

ITU-T Recommendation G.697

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ITU-T G-SERIES RECOMMENDATIONS  
**TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS**

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
Radiotelephone circuits	G.450–G.469
Links with mobile stations	G.470–G.499
TESTING EQUIPMENTS	G.500–G.599
TRANSMISSION MEDIA CHARACTERISTICS	G.600–G.699
General	G.600–G.609
Symmetric cable pairs	G.610–G.619
Land coaxial cable pairs	G.620–G.629
Submarine cables	G.630–G.649
Optical fibre cables	G.650–G.659
<b>Characteristics of optical components and subsystems</b>	<b>G.660–G.699</b>
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
QUALITY OF SERVICE AND PERFORMANCE - GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DIGITAL TERMINAL EQUIPMENTS	G.7000–G.7999
DIGITAL NETWORKS	G.8000–G.8999

*For further details, please refer to the list of ITU-T Recommendations.*

# ITU-T Recommendation G.697

## Optical monitoring for DWDM systems

### Summary

This Recommendation defines Optical Monitoring (OM) that can help in 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.

### Source

ITU-T Recommendation G.697 was approved on 13 June 2004 by ITU-T Study Group 15 (2001-2004) under the ITU-T Recommendation A.8 procedure.

### Keywords

DWDM, optical monitoring.

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## CONTENTS

	<b>Page</b>
1 Scope .....	1
2 References.....	1
2.1 Normative references.....	1
2.2 Informative references.....	2
3 Terms and definitions .....	2
3.1 Definitions .....	2
3.2 Terms defined in other Recommendations.....	2
4 Abbreviations.....	3
5 Optical monitoring overview .....	3
6 Classification of monitoring methods.....	5
6.1 Signal monitoring .....	5
6.2 Equipment monitoring (indirect methods) .....	5
6.3 Embedded monitoring equipment .....	6
6.4 External monitoring equipment.....	6
7 Optical impairments .....	6
8 Optical monitoring parameters .....	7
9 Correlation between impairment effects and optical monitoring parameters degradation .....	8
9.1 Variation of attenuation.....	8
9.2 Frequency (or wavelength) deviation from nominal .....	8
9.3 Optical channel power changes due to gain variations .....	8
10 Applications.....	8
11 Optical safety considerations.....	9
Appendix I – Severity of optical impairments .....	9
Appendix II – Penalty severity value X.....	10
Appendix III – Optical monitoring performance .....	10
III.1 OSNR measurement .....	12
III.2 Q-factor measurement .....	14

## **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 ES and SES. Since 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 optical transparent 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 will reduce the number of electrical monitoring points.

This Recommendation is an initial step towards addressing these needs through optical monitoring.

# ITU-T Recommendation G.697

## Optical monitoring for DWDM 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 optical transmission systems, particularly relevant to those network elements without o/e/o 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 with optical channels with bit rates up to approximately 10 Gbit/s.

### 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.

- Supplement 39 to G-series Recommendations (2003), *Optical system design and engineering considerations*.
- ITU-T Recommendation G.650.2 (2002), *Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable*.
- ITU-T Recommendation G.652 (2003), *Characteristics of a single-mode optical fibre and cable*.
- ITU-T Recommendation G.653 (2003), *Characteristics of a dispersion-shifted single-mode optical fibre and cable*.
- ITU-T Recommendation G.655 (2003), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable*.
- ITU-T Recommendation G.663 (2000), *Application related aspects of optical amplifier devices and subsystems*.
- ITU-T Recommendation G.664 (2003), *Optical safety procedures and requirements for optical transport systems*.
- ITU-T Recommendation G.692 (1998), *Optical interfaces for multichannel systems with optical amplifiers*.
- ITU-T Recommendation O.201 (2003), *Q-factor test equipment to estimate the transmission performance of optical channels*.

## 2.2 Informative references

- ITU-T Recommendation G.709/Y.1331 (2003), *Interfaces for the Optical Transport Network (OTN)*.
- ITU-T Recommendation G.826 (2002), *End-to-end error performance parameters and objectives for international, constant bit-rate digital paths and connections*.
- IEC 61280-2-9 (2002), *Fibre optic communication subsystem test procedures – Part 2-9: Digital systems – Optical signal-to-noise ratio measurement for dense wavelength-division multiplexed systems*.

## 3 Terms and definitions

### 3.1 Definitions

This Recommendation defines the following terms:

**3.1.1 fully regenerated optical networks:** Optical networks where o/e/o conversion is performed in each network element using 3R regeneration.

**3.1.2 transparent optical network element:** An optical network element where there is no o/e/o 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 in other Recommendations

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

- Stimulated Brillouin Scattering (SBS)

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

- Polarization Mode Dispersion (PMD) (1st and higher orders)
- Four-Wave Mixing (FWM)
- Amplified Spontaneous Emission (ASE) Noise in OA
- Chromatic Dispersion
- Reflections
- Cross-Phase Modulation (XPM)
- Self-Phase Modulation (SPM)
- Stimulated Raman Scattering (SRS)

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

- Frequency (or wavelength) deviation from nominal

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

- Q-factor

This Recommendation uses the following terms defined in ITU-T Sup. 39:

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

## 4 Abbreviations

This Recommendation uses the following abbreviations:

ASE	Amplified Spontaneous Emission
BER	Bit Error Ratio
DCM	Dispersion Compensation Module
Demux	Demultiplexer
DWDM	Dense Wavelength Division Multiplexing
ES	Errored Second
ESR	Errored Second Ratio
FWM	Four-Wave Mixing
Mux	Multiplexer
NOC	Network Operations Centre
OA	Optical Amplification
OADM	Optical Add-Drop Multiplexer
OM	Optical Monitoring
ONE	Optical Network Element
OSNR	Optical Signal-to-Noise Ratio
OTN	Optical Transport Network
PMD	Polarization Mode Dispersion
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 ITU-T Rec. G.826.

A similar approach is used in the OTN (using G.709/Y.1331 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 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 systems 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 suboptimal (and, therefore, non-cost-effective) solution. An appropriate optical supervision scheme will, for this reason, always be related to the particular transmission and control systems 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 ITU-T Rec. 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 some 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/G.697 – 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 Rec. G.692
Polarization Mode Dispersion (PMD) (1st and higher orders)	Medium	Appendix II/G.663
Four-Wave Mixing (FWM)	Medium	Appendix II/G.663
Amplified Spontaneous Emission (ASE) noise in OA	Medium	Appendix II/G.663

**Table 1/G.697 – Optical impairments**

Variation of the impairment	Relative frequency of occurrence	Description
Chromatic dispersion	Medium	Appendix II/G.663
Chromatic dispersion slope	Medium	ITU-T Recs G.652, G.653, G.655
Reflections	Medium	Appendix III/G.663
Laser noise	Medium	
Inter-channel crosstalk	Medium	ITU-T Sup. 39
Interferometric crosstalk	Medium	ITU-T Sup. 39
Cross-Phase Modulation (XPM)	Low	Appendix II/G.663
Self-Phase Modulation (SPM)	Low	Appendix II/G.663
Stimulated Brillouin Scattering (SBS)	Low	Appendix II/G.650.2, Appendix II/G.663
Stimulated Raman Scattering (SRS)	Low	Appendix II/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  $\approx 1$  event per 10 years.
- Medium: when the probability of the effect being severe enough to cause a penalty of X dB is  $\approx 1$  event per year.
- High: when the probability of the effect being severe enough to cause a penalty of X dB is  $\approx 10$  events per year.

NOTE – 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.

## **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/G.697 – 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 Rec. 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

For further study.

## 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.

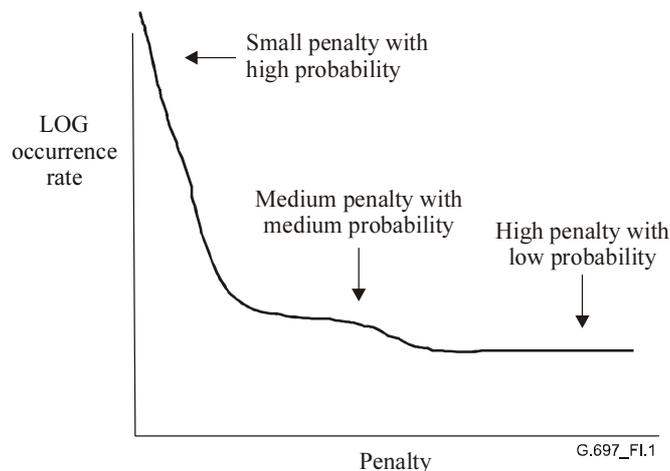
## 11 Optical safety considerations

See ITU-T Rec. G.664 for optical safety considerations.

## Appendix I

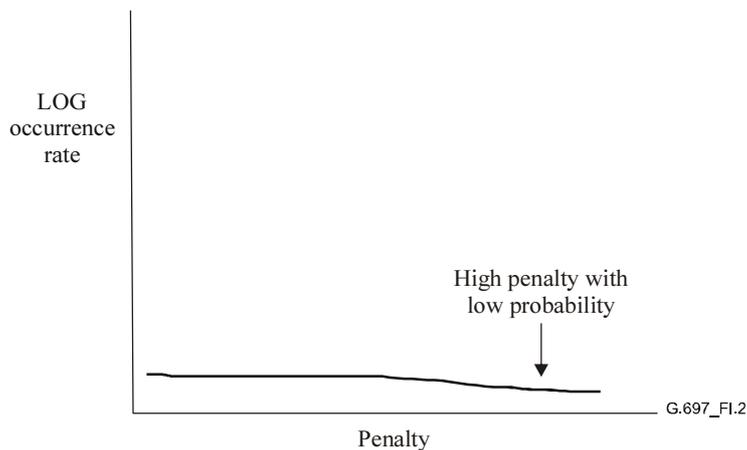
### Severity of optical impairments

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 vs. 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/G.697 – Example curve of penalty vs. 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 (say 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/G.697 – Example curve of penalty vs. 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 indications of the frequency with which this occurs in a typical optical network.

## Appendix II

### Penalty severity value X

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 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 an 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/G.697 – 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/G.697 – 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/G.697 – 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/G.697 – 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			

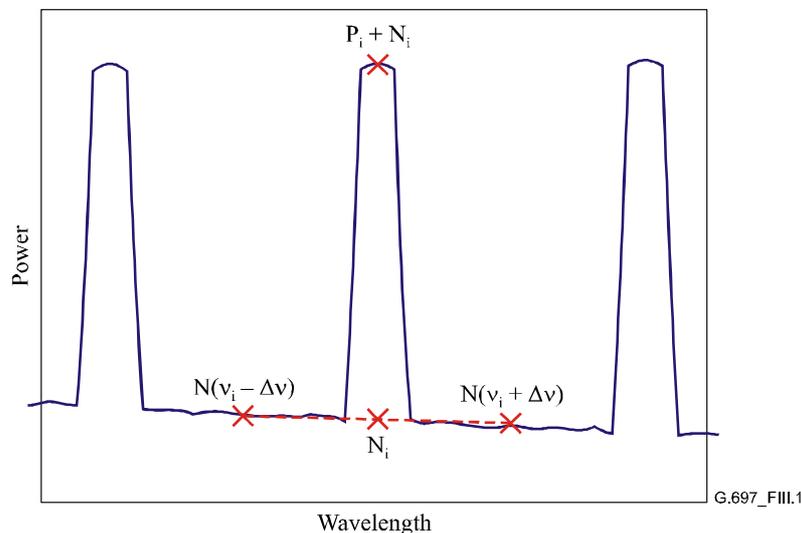
NOTE 1 – This value does not include any contribution from tap loss variation which would have to be compensated by calibration.

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

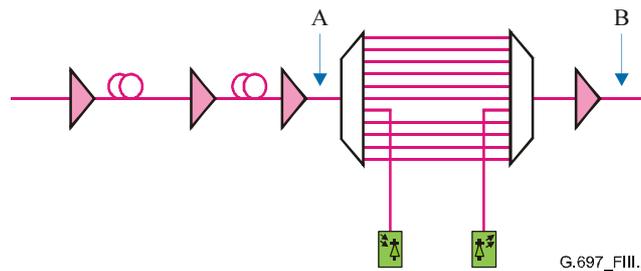
OSNR measurement currently uses the principle of measuring the noise between channels in order to estimate the noise at the channel wavelength. See Figure III.1 below.



**Figure III.1/G.697 – OSNR measurement method**

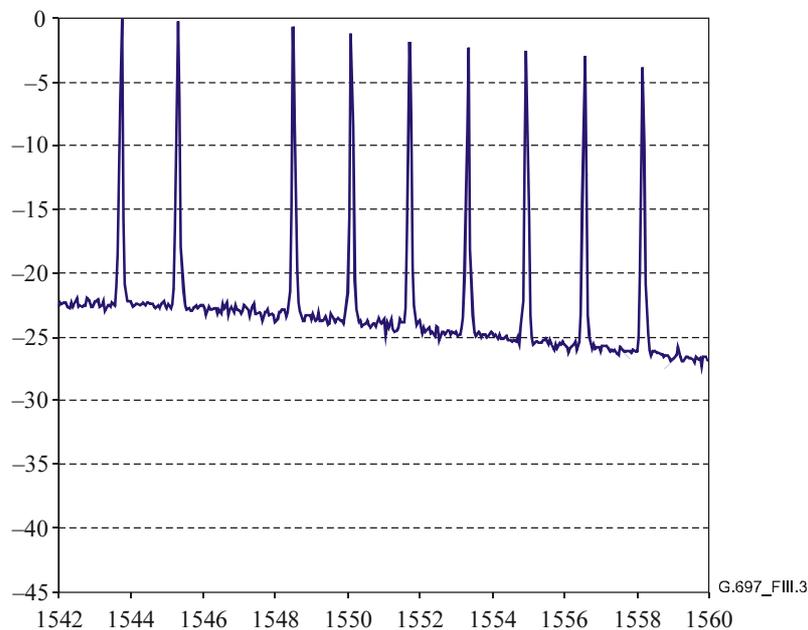
This method works well for simple point-to-point systems with nothing but fibre and amplifiers in the optical path. For more complex DWDM systems, however, the introduction of any element which causes shaping of the noise between channels, renders this method inaccurate.

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.



**Figure III.2/G.697 – Section of a DWDM system with an OADM**

The optical spectra that might be found at points marked A and B is shown in Figures III.3 and III.4 respectively.



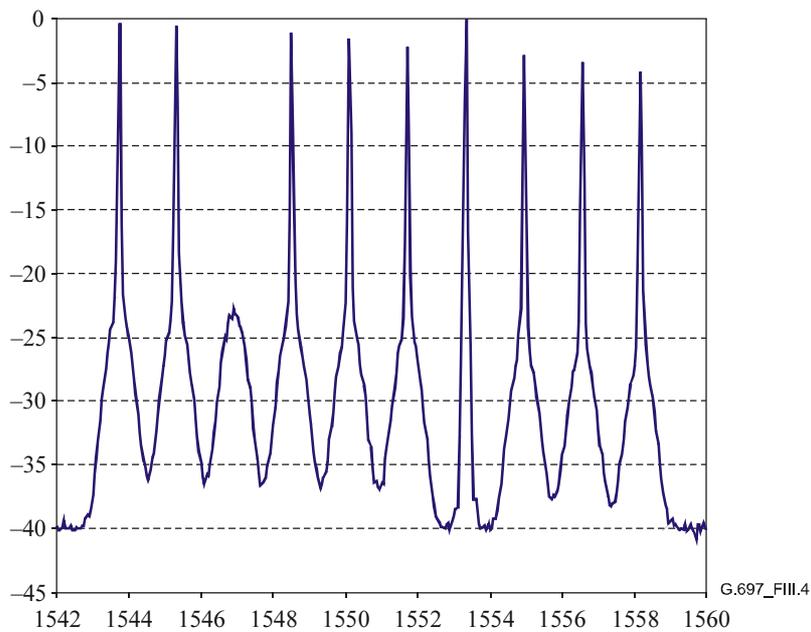
**Figure III.3/G.697 – Optical spectrum at point A**

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.

IEC 61280-2-9 (2002) could be a useful reference for additional information on OSNR measurements.



**Figure III.4/G.697 – Optical spectrum at point B**

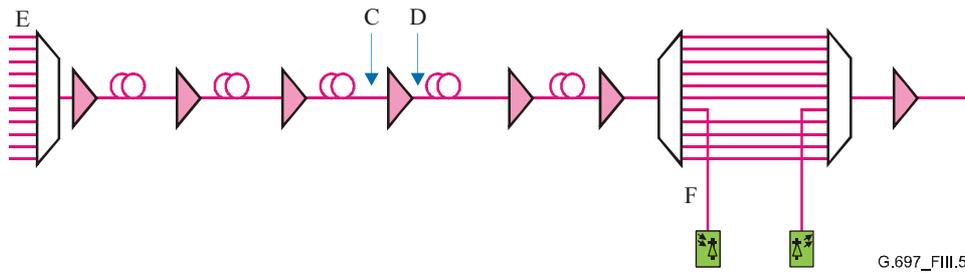
### III.2 Q-factor measurement

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 Rec. 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.

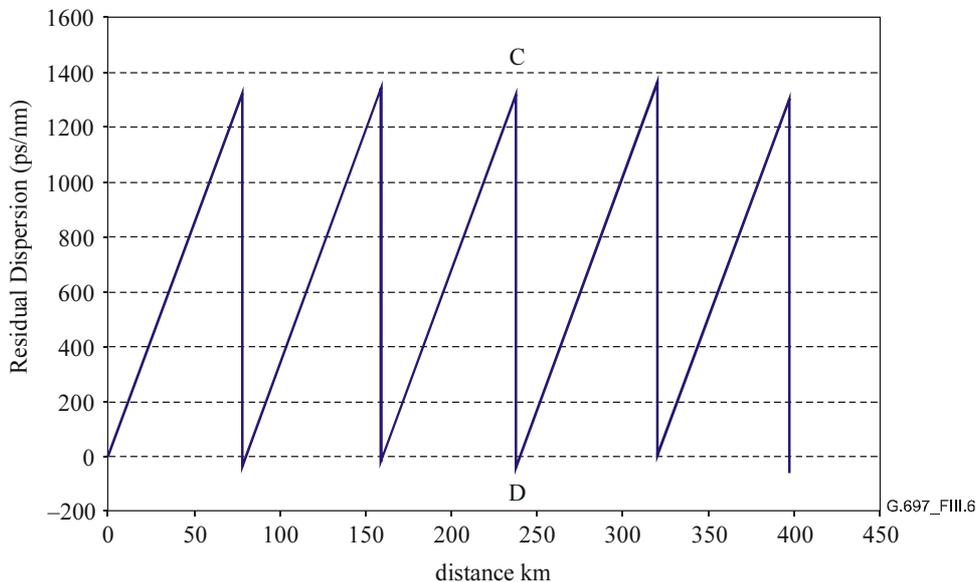
Under ideal conditions (only additive Gaussian noise, no linear or non-linear distortions, etc.), the BER of a binary optical channel should be the same as that indicated by a Q-factor measurement. However, these idealized conditions are rarely present in real systems and the correlation between the 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.5 shows the block diagram for a simple 5-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.



**Figure III.5/G.697 – 5-span transmission system incorporating DCM in the line amplifiers**

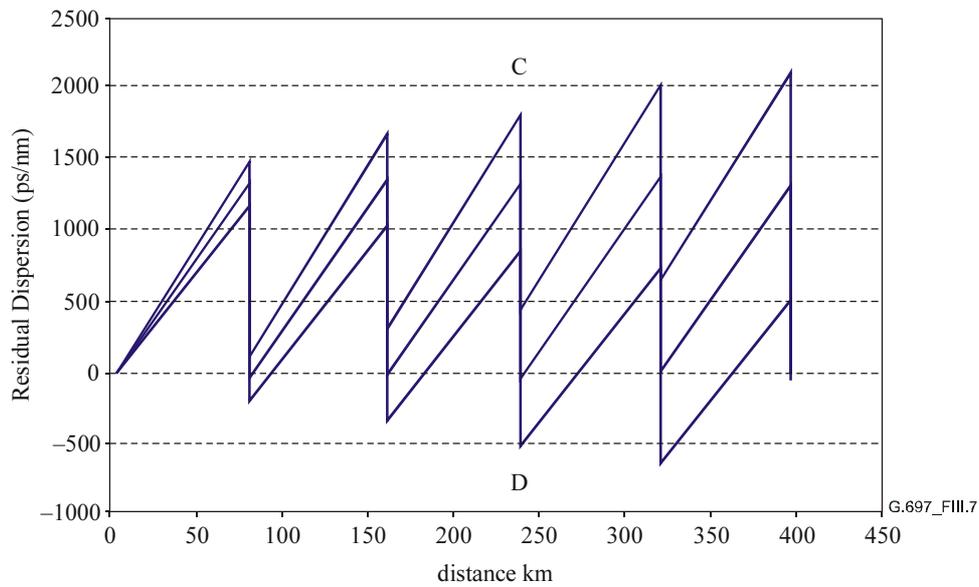
Figure III.6 shows the residual dispersion vs. distance for a system where the dispersion of each nominally 80 km span is compensated by an 80 km DCM embedded in each line amplifier, and an additional DCM within the receiving preamplifier. In this case, for example, the Q-factor measured at point C (the 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.6/G.697 – Residual dispersion vs. distance for a simple system**

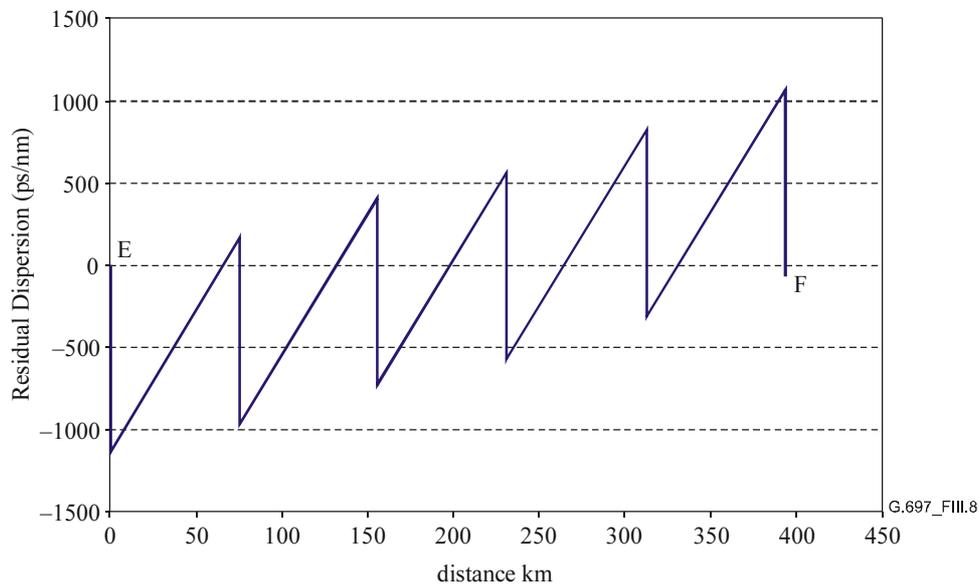
A solution to the dispersion map, illustrated in Figure III.6, is to only measure the Q-factor at the amplifier outputs (e.g., point D).

The residual dispersion map in Figure III.6 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.7 where the residual dispersion maps of the extreme wavelength channels are also shown.



**Figure III.7/G.697 – Residual dispersion vs. distance for a simple system with a wide wavelength range**

In the case of a more complex dispersion map, as illustrated in Figure III.8, 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.8/G.697 – Residual dispersion vs. distance for a more complex system**



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