International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.698.1

(11/2009)

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

Transmission media and optical systems characteristics – Characteristics of optical systems

---

Multichannel DWDM applications with single-channel optical interfaces

Recommendation ITU-T G.698.1

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
TRANSMISSION MEDIA AND OPTICAL SYSTEMS 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.639
Free space optical systems	G.640–G.649
Optical fibre cables	G.650–G.659
Characteristics of optical components and subsystems	G.660–G.679
Characteristics of optical systems	**G.680–G.699**
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
MULTIMEDIA QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
PACKET OVER TRANSPORT ASPECTS	G.8000–G.8999
ACCESS NETWORKS	G.9000–G.9999

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

Recommendation ITU-T G.698.1

Multichannel DWDM applications with single-channel optical interfaces

Summary

Recommendation ITU-T G.698.1 provides optical parameter values for physical layer interfaces of dense wavelength division multiplexing (DWDM) systems primarily intended for metro applications. Applications are defined using optical interface parameters at the single-channel connection points between optical transmitters and the optical multiplexer, as well as between optical receivers and the optical demultiplexer in the DWDM system. This Recommendation uses a methodology which fixes the maximum attenuation of the multiplexer/demultiplexer and fibre together and, therefore, does not specify the maximum fibre-link length explicitly. This Recommendation includes unidirectional DWDM applications at 2.5 and 10 Gbit/s with 100-GHz channel frequency spacing, as well as applications at 10 Gbit/s with 50 GHz channel frequency spacing.

This latest revision of Recommendation ITU-T G.698.1 includes the use of optical add-drop multiplexers (OADMs) within the black link.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T G.698.1	2005-06-29	15
2.0	ITU-T G.698.1	2006-12-14	15
3.0	ITU-T G.698.1	2009-11-13	15

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

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

CONTENTS

Recommendation ITU-T G.698.1

Multichannel DWDM applications with single-channel optical interfaces

1 Scope

The purpose of this Recommendation is to provide optical interface specifications towards the realization of transversely compatible dense wavelength division multiplexing (DWDM) systems primarily intended for metro applications.

This Recommendation defines and provides values for single-channel optical interface parameters of physical point-to-point and ring DWDM applications (with transmission distance in the range of about 30 km to about 80 km) on single-mode optical fibres through the use of the "black link" approach.

Applications containing amplifiers within the black link are outside of the scope of this Recommendation.

This Recommendation describes DWDM systems that include the following features:

– Channel frequency spacing: 50 GHz and wider (defined in [ITU-T G.694.1]);

– Bit rate of signal channel: up to 10 Gbit/s.

Specifications are organized according to application codes.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

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

[ITU-T G.671] Recommendation ITU-T G.671 (2009), *Transmission characteristics of optical components and subsystems*.

[ITU-T G.691] Recommendation ITU-T G.691 (2006), *Optical interfaces for single channel STM-64 and other SDH systems with optical amplifiers*.

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

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

[ITU-T G.698.2] Recommendation ITU-T G.698.2 (2009), *Amplified multichannel dense wavelength division multiplexing applications with single channel optical interfaces*.

[ITU-T G.709] Recommendation ITU-T G.709/Y.1331 (2003), *Interfaces for the optical transport network (OTN)*.

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

[ITU-T G.959.1] Recommendation ITU-T G.959.1 (2008), *Optical transport network physical layer interfaces*.

[IEC 60825-1] IEC 60825-1 (2007), *Safety of laser products – Part 1: Equipment classification and requirements*.

[IEC 60825-2] IEC 60825-2 (2007), *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*.

3 Terms and definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 channel insertion loss [ITU-T G. 671]

3.1.2 channel spacing [ITU-T G.671]

3.1.3 completely standardized OTUk (OTUk) [ITU-T G.709]

3.1.4 dense wavelength division multiplexing (DWDM) device [ITU-T G.671]

3.1.5 differential group delay [ITU-T G. 671]

3.1.6 frequency grid [ITU-T G.694.1]

3.1.7 joint engineering [ITU-T G.957]

3.1.8 optical tributary signal [ITU-T G.959.1]

3.1.9 optical tributary signal class NRZ 10G [ITU-T G.959.1]

3.1.10 optical tributary signal class NRZ 2.5G [ITU-T G.959.1]

3.1.11 reflectance [ITU-T G. 671]

3.1.12 ripple [ITU-T G.671]

3.1.13 transverse compatibility [ITU-T G.957]

3.2 Terms defined in this Recommendation

This Recommendation does not define any terms.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ASE Amplified Spontaneous Emission

BER Bit Error Ratio

DGD Differential Group Delay

EX Extinction Ratio

FEC	Forward Error Correction
NA	Not Applicable
NE	Network Element
NRZ	Non-Return to Zero
OA	Optical Amplifier
OADM	Optical Add-Drop Multiplexer
OD	Optical Demultiplexer
OM	Optical Multiplexer
ONE	Optical Network Element
OTUk	Completely standardized optical channel transport unit – k
PMD	Polarization Mode Dispersion
RP_R	Link reference point at the DWDM network element aggregate input
RP_S	Link reference point at the DWDM network element aggregate output
R_S	Single-channel reference point at the DWDM network element tributary output
S_S	Single-channel reference point at the DWDM network element tributary input
WDM	Wavelength Division Multiplexing

5 Classification of optical interfaces

5.1 Applications

This Recommendation provides the physical layer parameters and values for single-channel interfaces of DWDM multichannel optical systems in physical point-to-point and ring applications. These DWDM systems with single-channel interfaces are primarily intended to be used in metropolitan area networks for a variety of clients, services, and protocols.

The specification method in this Recommendation uses a "black link" approach, which means that optical interface parameters for only (single-channel) optical tributary signals are specified. Additional specifications are provided for the black link parameters such as maximum attenuation, chromatic dispersion, ripple and polarization mode dispersion. This approach enables transverse compatibility at the single-channel point using a direct wavelength-multiplexing configuration. However, it does not enable transverse compatibility at the multichannel points. In this approach, the OM and OD are treated as a single set of optical devices and OADMs can be included.

This Recommendation only considers DWDM applications where the black link does not contain optical amplifiers.

5.2 Reference points

5.2.1 Unidirectional applications

Figure 5-1 shows a set of reference points, for the linear "black link" approach, for single-channel connection (S_S and R_S) between transmitters (Tx) and receivers (Rx). Here, the DWDM network elements include an OM and an OD, which are used as a pair with the opposing element, and may also include one or more OADMs.

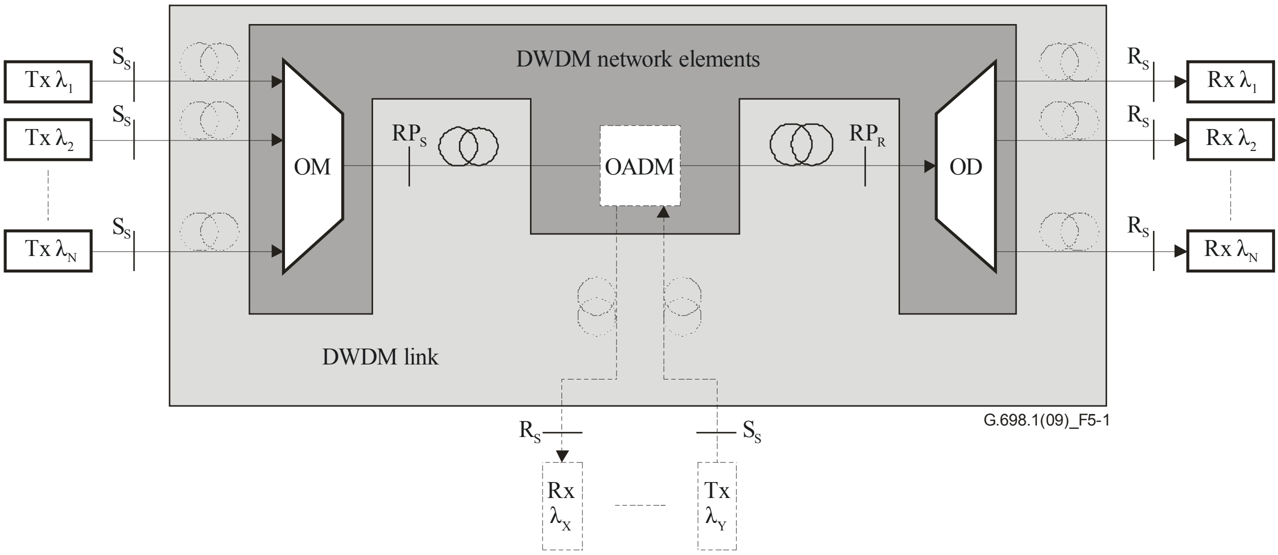

Figure 5-1 – Linear "black link" approach

As indicated in Figure 5-1, in cases where the transmitter or receiver is some distance from the OM, OD or OADM, the fibre between point S_S or R_S and the DWDM network element is considered to be part of the black link.

Figure 5-2 shows a corresponding set of reference points for the ring "black link" approach, for single-channel connection (S_S and R_S) between transmitters (Tx) and receivers (Rx). Here, the DWDM network elements include two or more OADMs connected in a ring.

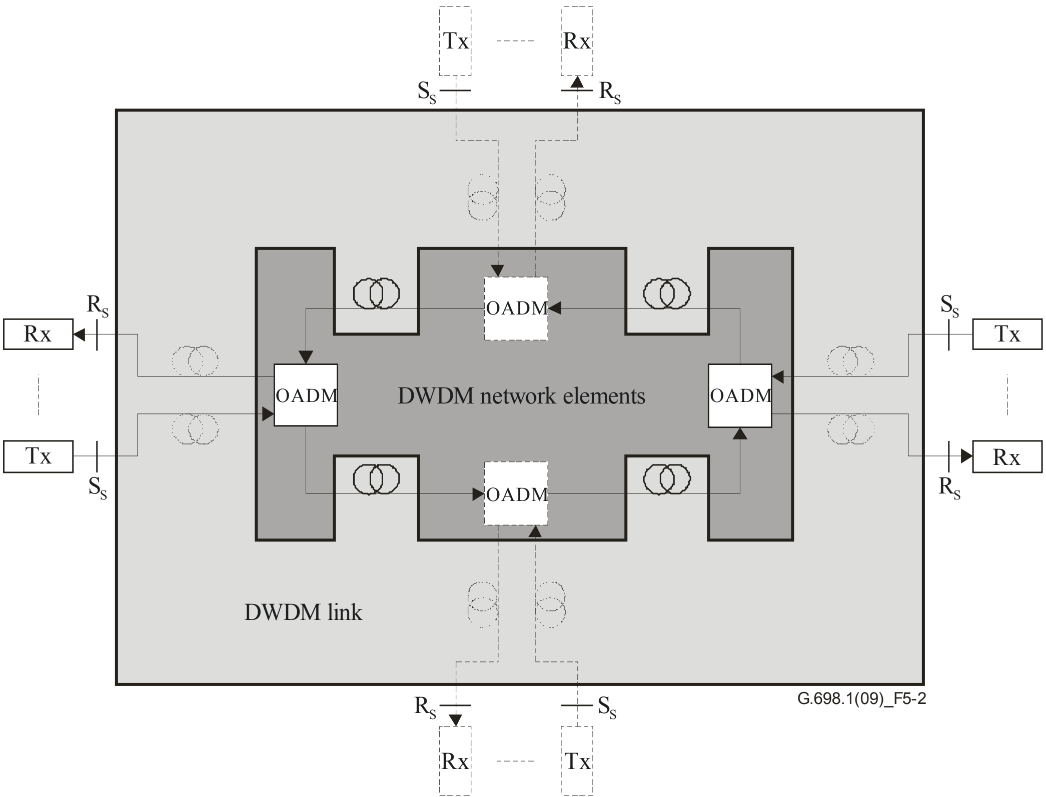

Figure 5-2 – Ring "black link" approach

These reference models do not include any optical amplifiers in the DWDM system. The reference points in Figures 5-1 and 5-2 are defined as follows:

– S_S is a single-channel reference point at the DWDM network element tributary input;

– R_S is a single-channel reference point at the DWDM network element tributary output;

– RP_S is a link reference point at the DWDM network element aggregate output;

– RP_R is a link reference point at the DWDM network element aggregate input.

Here, single-channel reference points S_S and R_S are applied to systems for the (linear or ring) "black link" approach where every path from S_S to its corresponding R_S must comply with the parameter values of the application code.

Note that RP_S and RP_R are only defined to provide information for the fibre link and not to provide signal characteristics at these points.

5.2.2 Bidirectional applications

While this Recommendation does not currently contain any bidirectional applications, it is expected that they will be added in a future revision. Figure 5-3 shows a set of reference points, for the single-fibre bidirectional linear "black link" approach, for single-channel connection (S_S and R_S) between transmitters (Tx) and receivers (Rx). Here, the DWDM network elements include an OM/OD, which is used as a pair with the opposing element and may also include one or more OADMs.

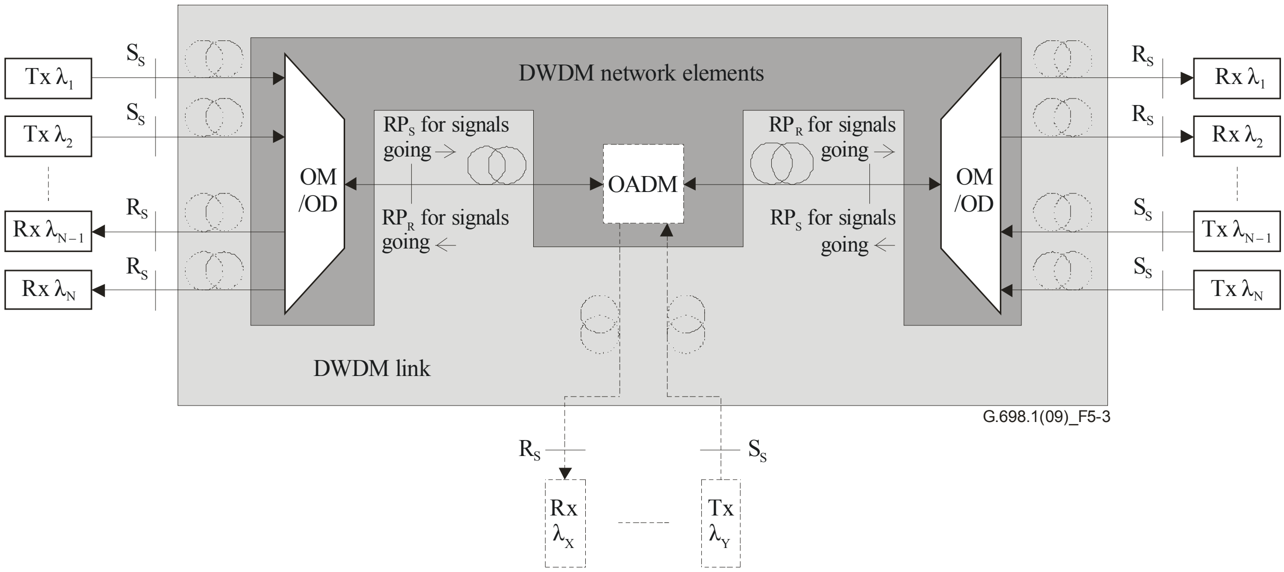

Figure 5-3 – Linear "black link" approach for bidirectional applications

Figure 5-4 shows a corresponding set of reference points for the single-fibre bidirectional ring "black link" approach, for a single-channel connection (S_S and R_S) between transmitters (Tx) and receivers (Rx). Here, the DWDM network elements include two or more OADMs connected in a ring.

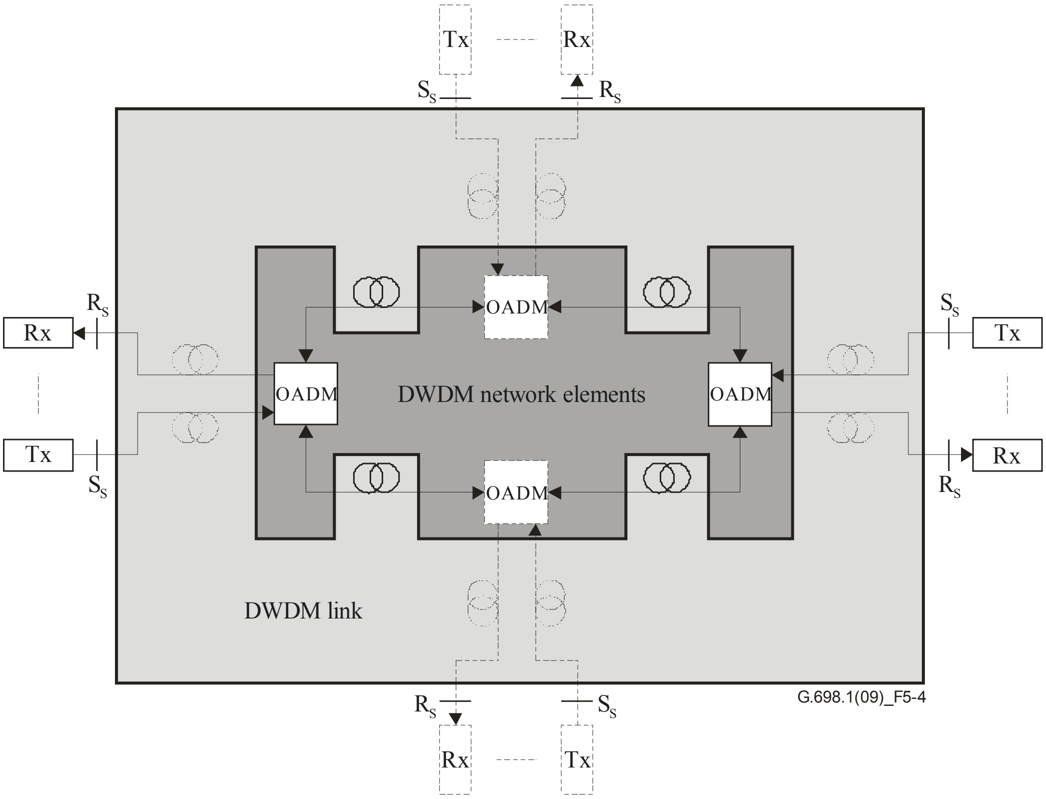

Figure 5-4 – Ring "black link" approach for bidirectional applications

The reference points in Figures 5-3 and 5-4 are as defined in clause 5.2.1.

5.3 Nomenclature

The application code identifies the network, implementation, and architectural characteristics of an application.

The application code notation is constructed as follows:

DScW-ytz(v)

where:

D is the indicator of DWDM applications.

S indicates options of maximum spectral excursion such as:

– **N** indicating narrow spectral excursion;

– **W** indicating wide spectral excursion.

c is the channel spacing in GHz.

W is a letter indicating the span distance such as:

– **S** indicating short-haul;

– **L** indicating long-haul.

y indicates the highest class of optical tributary signal supported:

– 1 indicating NRZ 2.5G;

– 2 indicating NRZ 10G.

t is a placeholder letter indicating the configuration supported by the application code. In the current version of this Recommendation, the only value used is:

– **D** indicating that the black link does not contain any optical amplifiers.

z indicates the fibre types, as follows:

– 2 indicating ITU-T G.652 fibre;

– 3 indicating ITU-T G.653 fibre;

– 5 indicating ITU-T G.655 fibre.

v indicates the operating wavelength range in terms of spectral bands (see [b-ITU-T G-Sup.39]):

v	Descriptor	Nominal wavelength range (nm)
S	Short wavelength	1460 to 1530
C	Conventional	1530 to 1565
L	Long wavelength	1565 to 1625

If more than one spectral band is used, then v becomes the band letters separated by "+" e.g., for an application requiring the use of both of the C and L bands, v would be "C+L".

NOTE – The nominal wavelength ranges given here are for classification and not specification. The actual minimum and maximum wavelength for each application should be calculated from the maximum and minimum channel frequencies for that application.

A bidirectional system is indicated by the addition of the letter **B** at the front of the application code. For DWDM application codes this will be:

B-DScW-ytz(v)

For some application codes, a suffix is added to the end of the code. The only suffix currently defined is:

– **F**, to indicate that this application requires FEC bytes as specified in [ITU-T G.709] to be transmitted.

5.4 Single-channel interfaces at the reference points S_S and R_S

The single-channel interfaces described in Tables 8-1 to 8-5 are intended to enable transverse compatibility at the single-channel interfaces at ingress/egress points of the DWDM link (OM, fibre, and OD) as shown in Figures 5-1 to 5-4.

Further requirements related to transverse compatibility can be found in clause 6.

Table 5-1 summarizes the single-channel application codes, which are structured according to the nomenclature in clause 5.3.

Table 5-1 – Classification of applications

Application	Short-haul (S)	Long-haul (L)
Type of fibre	G.652, G.653, G.655	G.652, G.653, G.655
Optical tributary signal class NRZ 2.5G	DN100S-1D2(C), DW100S-1D2(C), DN100S-1D3(L), DW100S-1D3(L), DN100S-1D5(C), DW100S-1D5(C)	DN100L-1D2(C), DW100L-1D2(C), DN100L-1D3(L), DW100L-1D3(L), DN100L-1D5(C), DW100L-1D5(C)

Table 5-1 – Classification of applications

Application	Short-haul (S)	Long-haul (L)
OTU1 with FEC enabled	DN100S-1D2(C)F, DW100S-1D2(C)F, DN100S-1D3(L)F, DW100S-1D3(L)F, DN100S-1D5(C)F, DW100S-1D5(C)F	DN100L-1D2(C)F, DW100L-1D2(C)F, DN100L-1D3(L)F, DW100L-1D3(L)F, DN100L-1D5(C)F, DW100L-1D5(C)F
Optical tributary signal class NRZ 10G	DN100S-2D2(C), DW100S-2D2(C), DN100S-2D3(L), DW100S-2D3(L), DN100S-2D5(C), DW100S-2D5(C) DN50S-2D2(C), DN50S-2D3(L), DN50S-2D5(C)	DN100L-2D2(C), DW100L-2D2(C), DN100L-2D3(L), DW100L-2D3(L), DN100L-2D5(C), DW100L-2D5(C) DN50L-2D2(C), DN50L-2D3(L), DN50L-2D5(C)
OTU2 with FEC enabled	DN100S-2D2(C)F, DW100S-2D2(C)F, DN100S-2D3(L)F, DW100S-2D3(L)F, DN100S-2D5(C)F, DW100S-2D5(C)F DN50S-2D2(C)F, DN50S-2D3(L)F, DN50S-2D5(C)F	DN100L-2D2(C)F, DW100L-2D2(C)F, DN100L-2D3(L)F, DW100L-2D3(L)F, DN100L-2D5(C)F, DW100L-2D5(C)F DN50L-2D2(C)F, DN50L-2D3(L)F, DN50L-2D5(C)F

The non-amplified multichannel systems with single-channel interfaces in this Recommendation are specified in Tables 8-1 to 8-5.

6 Transverse compatibility

This Recommendation specifies parameters in order to enable transverse (i.e., multivendor) compatibility at single-channel reference points S_S and R_S of the "black link" approach DWDM NEs.

The single-channel reference points S_S and R_S are intended to make multiple tributary interfaces of DWDM NEs transversely compatible. In this case, multiple tributary signal transmitters (Tx λ_i) and receivers (Rx λ_i) may be from different vendors. Note that DWDM NEs (OM and OD) for the "black link" approach are from a single vendor, and considered as a single set of optical devices.

Transverse (multivendor) compatibility is enabled for all single-channel reference points S_S and R_S of "black link" approach DWDM NEs having exactly the same application code.

Coexistence of tributary interfaces with different application codes over the same black link is a matter of joint engineering. Care must be taken, particularly with respect to critical parameters that must be consistent, e.g., S_S output power and R_S input power, S_S bit-rate/line coding and R_S bit-rate/line coding, etc.

For the element of the application code, referring to the maximum spectral excursion (indicator **S** in the application code; see clause 5.3), a mismatch between the indicator of the transmitter and that of the link will cause incompatibility when the transmitter has a code containing W (wide spectral excursion) and the link contains N (narrow spectral excursion). All other combinations are transversely compatible.

7 Parameter definitions

The parameters in Table 7-1 are defined at the interface points, and the definitions are provided in the clauses below.

Table 7-1 – Physical layer parameters for DWDM applications using the "black link" approach

Parameter	Units	Defined in
General information		
Minimum channel spacing	GHz	7.1.1
Bit-rate/line coding of optical tributary signals	–	7.1.2
Maximum bit error ratio	–	7.1.3
Fibre type	–	7.1.4
Interface at point S_S		
Maximum mean channel output power	dBm	7.2.1
Minimum mean channel output power	dBm	7.2.1
Minimum central frequency	THz	7.2.2
Maximum central frequency	THz	7.2.2
Maximum spectral excursion	GHz	7.2.3
Minimum side mode suppression ratio	dB	7.2.4
Minimum channel extinction ratio	dB	7.2.5
Eye mask	–	7.2.6
Optical path from point S_S to R_S		
Maximum channel insertion loss	dB	7.3.1
Minimum channel insertion loss	dB	7.3.1
Maximum ripple	dB	7.3.2
Maximum chromatic dispersion	ps/nm	7.3.3
Minimum optical return loss at S_S	dB	7.3.4
Maximum discrete reflectance between S_S and R_S	dB	7.3.5
Maximum differential group delay	ps	7.3.6
Maximum inter-channel crosstalk at R_S	dB	7.3.7
Maximum interferometric crosstalk at R_s	dB	7.3.8
Interface at point R_S		
Maximum mean input power	dBm	7.4.1
Receiver sensitivity	dBm	7.4.2
Maximum optical path penalty	dB	7.4.3
Maximum reflectance of receiver	dB	7.4.4

7.1 General information

7.1.1 Minimum channel spacing

The minimum nominal difference in frequency between two adjacent channels. All possible tolerances of actual frequencies are considered in clause 7.2.3.

7.1.2 Bit-rate/line coding of optical tributary signals

Optical tributary signal class NRZ 2.5G applies to continuous digital signals with non-return to zero line coding, from nominally 622 Mbit/s to nominally 2.67 Gbit/s. Optical tributary signal class NRZ 10G applies to continuous digital signals with non-return to zero line coding, from nominally 2.4 Gbit/s to nominally 10.71 Gbit/s.

7.1.3 Maximum bit error ratio

The parameters are specified relative to an optical section design objective of a bit error ratio (BER) not worse than the value specified by the application code. This value applies to each optical channel under the extreme case of optical path attenuation and dispersion conditions in each application. In the case of application codes requiring FEC bytes to be transmitted (i.e., having a code with a suffix of F), the BER is required to be met only after the correction (if used) has been applied. For all other application codes, the BER is required to be met without the use of FEC.

7.1.4 Fibre type

Single-mode optical fibre types are chosen from those defined in [ITU-T G.652], [ITU-T G.653] and [ITU-T G.655].

7.2 Interface at point S_S

7.2.1 Maximum and minimum mean channel output power

The mean launched power of each optical channel at reference point S_S is the average power of a pseudo-random data sequence coupled into the DWDM link. It is given as a range (maximum and minimum) to allow for some cost optimization and to cover allowances for operation under the standard operating conditions, connector degradations, measurement tolerances, and aging effects.

7.2.2 Minimum and maximum central frequency

The central frequency is the nominal single-channel frequency on which the digital coded information of the particular optical channel is modulated by use of the NRZ line code.

The central frequencies of all channels within an application lie on the frequency grid for the minimum channel spacing of the application given in [ITU-T G.694.1].

While the specific central frequencies used within each application are not specified in this Recommendation, the nominal central frequencies of all channels within an application should be greater than or equal to the minimum central frequency and less than or equal to the maximum central frequency.

Note that the value of "c" (speed of light in vacuum) that should be used for converting between frequency and wavelength is 2.99792458×10^8 m/s.

7.2.3 Maximum spectral excursion

This is the maximum acceptable difference between the nominal central frequency of the channel and the –15 dB points of the transmitter spectrum furthest from the nominal central frequency measured at point S_S. This is illustrated in Figure 7-1.

NOTE – The measurement of the –15 dB points of the transmitter spectrum should be performed with a nominal resolution bandwidth of 0.01 nm.

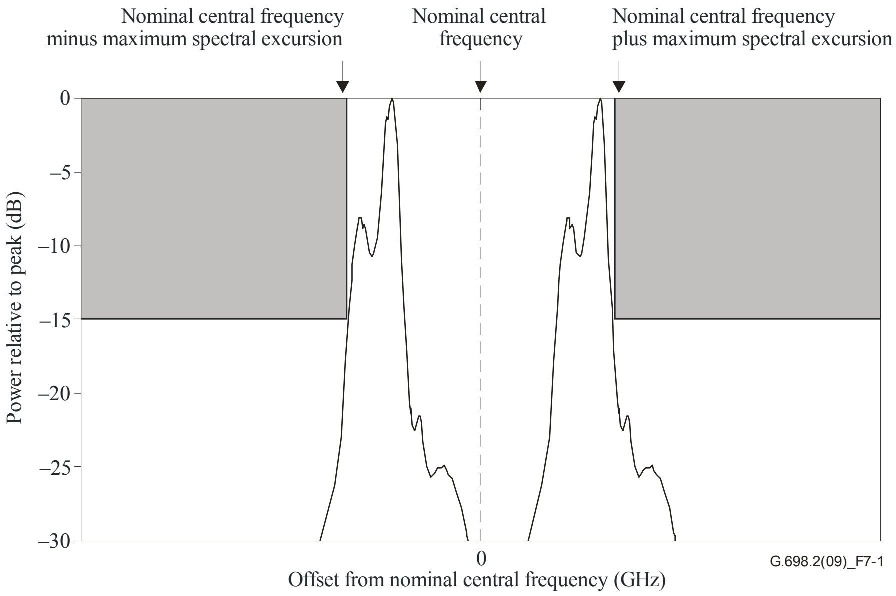

Figure 7-1 – Illustration of maximum spectral excursion

This parameter also defines the range of frequencies over which the channel insertion loss and ripple specifications must be met.

7.2.4 Minimum side mode suppression ratio

The minimum side mode suppression ratio is the minimum value of the ratio of the largest peak of the total transmitter spectrum to the second largest peak. The spectral resolution of the measurement shall be better than the maximum spectral width of the peak, as defined in [ITU-T G.691]. The second largest peak may be next to the main peak, or far removed from it.

NOTE – Within this definition, spectral peaks that are separated from the largest peak by the clock frequency are not considered to be side modes.

7.2.5 Minimum channel extinction ratio

The extinction ratio (EX) is defined as:

$$EX = 10\log_{10}(A/B)$$

In the above definition of EX, A is the average optical power level at the centre of a logical "1" and B is the average optical power level at the centre of a logical "0". The convention adopted for optical logic levels is:

– emission of light for a logical "1";
– no emission for a logical "0".

The minimum channel extinction ratio is not required to be met in the presence of a fourth-order Bessel-Thomson filter.

7.2.6 Eye mask

The definition and limits for this parameter are found in [ITU-T G.959.1].

7.3 Optical path parameters (single span) from S_S to R_S

7.3.1 Minimum and maximum channel insertion loss

Channel insertion loss is defined in [ITU-T G.671]. For any optical channel, it is the minimum (or maximum) reduction in optical power between the input and output ports of the black link for that channel in the frequency range of the central frequency of the channel ± the maximum spectral excursion.

Insertion loss specifications are assumed to be worst-case values including losses due to the OM/OD pair, splices, connectors, optical attenuators (if used) or other passive optical devices, and any additional cable margin to cover allowances for:

1) future modifications to the cable configuration (additional splices, increased cable lengths, etc.);
2) fibre cable performance variations due to environmental factors; and
3) degradation of any connectors, optical attenuators or other passive optical devices between points S_S and R_S, if used.

7.3.2 Maximum ripple

The ripple (of a DWDM device) is defined in [ITU-T G.671]. In this Recommendation, it is applied to the entire black link from reference point S_S to the corresponding R_S. For any optical channel, it is the peak-to-peak difference in insertion loss between the input and output ports of the black link for that channel in the frequency range of the central frequency of the channel ± the maximum spectral excursion. This is illustrated in Figure 7-2.

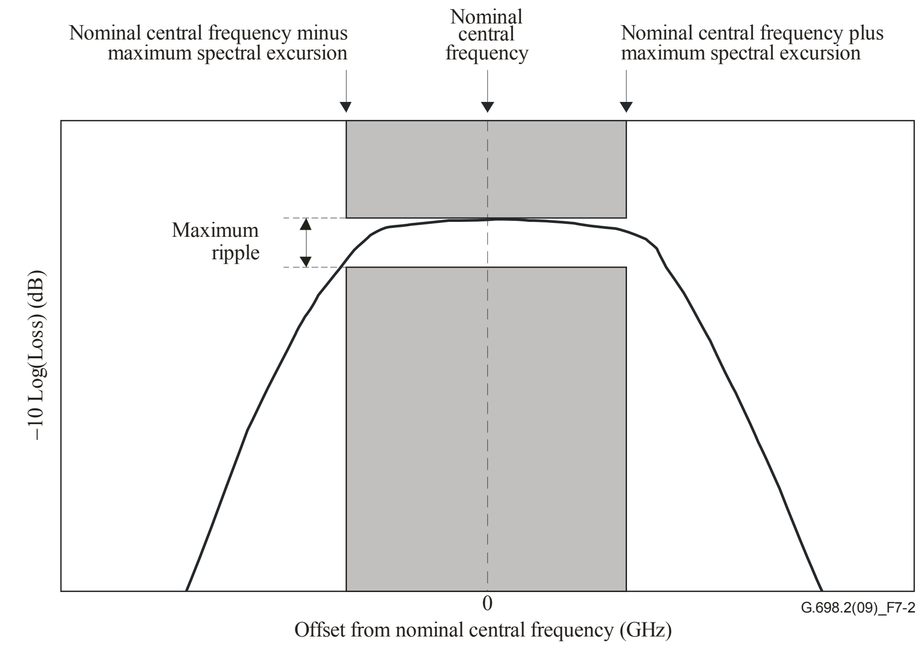

Figure 7-2 – Illustration of maximum ripple

7.3.3 Maximum chromatic dispersion

This parameter defines the maximum value of the optical path chromatic dispersion that the system shall be able to tolerate. This is considered a worst-case dispersion value. The worst-case approach on this parameter is intended to give some margins on a sensitive parameter, as well as making it possible to stretch the transmission distances for low-loss fibre links.

The values of maximum chromatic dispersion, contained in Tables 8-1 to 8-5, were derived from an estimate for the maximum link length supported by each application code calculated from the maximum channel insertion loss (with an allowance for the loss of an OM/OD pair subtracted from it) divided by 0.21 dB/km. Where the dispersion values obtained by this method were considered to be higher than is feasible for current cost-effective optical transmitters, the dispersion values were reduced in accordance with current technology capability and so these applications may be dispersion-limited whereas the others are loss-limited.

The allowed optical path penalty considers all deterministic effects due to chromatic dispersion as well as the penalty due to the maximum differential group delay.

7.3.4 Minimum optical return loss at S_S

Reflections are caused by refractive index discontinuities along the optical path. If not controlled, they can degrade system performance through their disturbing effect on the operation of the optical source, or through multiple reflections which lead to interferometric noise at the receiver. Reflections from the optical path are controlled by specifying the:

– minimum optical return loss of the cable plant at the source reference point (S_S), including any connectors; and

– maximum discrete reflectance between source reference point (S_S) and receive reference point (R_S).

Reflectance denotes the reflection from any single discrete reflection point, whereas the optical return loss is the ratio of the incident optical power to the total returned optical power from the entire fibre including both discrete reflections and distributed backscattering such as Rayleigh scattering.

Measurement methods for reflections are described in Appendix I of [ITU-T G.957]. For the purpose of reflectance and return loss measurements, points S_S and R_S are assumed to coincide with the endface of each connector plug. It is recognized that this does not include the actual reflection performance of the respective connectors in the operational system. These reflections are assumed to have the nominal value of reflection for the specific type of connector used.

7.3.5 Maximum discrete reflectance between S_S and R_S

Optical reflectance is defined to be the ratio of the reflected optical power present at a point, to the optical power incident to that point. Control of reflections is discussed extensively in [ITU-T G.957]. The maximum number of connectors, or other discrete reflection points which may be included in the optical path (e.g., for distribution frames, OADMs or other WDM components), must be such as to allow the specified overall optical return loss to be achieved. If this cannot be done using connectors meeting the maximum discrete reflections cited in the tables of clause 8, then connectors having better reflection performance must be employed. Alternatively, the number of connectors must be reduced. It also may be necessary to limit the number of connectors or to use connectors having improved reflectance performance in order to avoid unacceptable impairments due to multiple reflections.

In the tables of clause 8, the value of maximum discrete reflectance between source reference points and receive reference points is intended to minimize the effects of multiple reflections (e.g., interferometric noise). The value for maximum receiver reflectance is chosen to ensure acceptable penalties due to multiple reflections for all likely system configurations involving multiple connectors, etc. However, the values of maximum discrete reflectance between S_S and R_S given in Tables 8-1 to 8-5 may not be adequate to ensure compliance with the minimum optical return loss at S_S if there are more than a few OADMs in a link.

Systems employing fewer or higher performance connectors produce fewer multiple reflections and consequently are able to tolerate receivers exhibiting higher reflectance.

7.3.6 Maximum differential group delay

Differential group delay (DGD) is the time difference between the fractions of a pulse that are transmitted in the two principal states of polarization of an optical signal. For distances greater than several kilometres, and assuming random (strong) polarization mode coupling, DGD in a fibre can be statistically modelled as having a Maxwellian distribution.

In this Recommendation, the maximum differential group delay is defined to be the value of DGD that the system must tolerate with a maximum sensitivity degradation of 1 dB.

Due to the statistical nature of polarization mode dispersion (PMD), the relationship between maximum DGD and mean DGD can only be defined probabilistically. The probability of the instantaneous DGD exceeding any given value can be inferred from its Maxwellian statistics. Therefore, if we know the maximum DGD that the system can tolerate, we can derive the equivalent mean DGD by dividing by the ratio of maximum to mean that corresponds to an acceptable probability. Some example ratios are given in Table 7-2.

Table 7-2 – DGD means and probabilities

Ratio of maximum to mean	Probability of exceeding maximum
3.0	4.2×10^{-5}
3.5	7.7×10^{-7}
4.0	7.4×10^{-9}

7.3.7 Maximum inter-channel crosstalk

This parameter places a requirement on the isolation of a link conforming to the "black link" approach such that under the worst-case operating conditions, the inter-channel crosstalk at any reference point R_S is less than the maximum inter-channel crosstalk value.

Inter-channel crosstalk is defined as the ratio of total power in all of the disturbing channels to that in the wanted channel, where the wanted and disturbing channels are at different wavelengths.

Specifically, the isolation of the link shall be greater than the amount required to ensure that when any channel is operating at the minimum mean output power at point S_S and all of the others are at the maximum mean output power, then the inter-channel crosstalk at the corresponding point R_S is less than the maximum inter-channel crosstalk value.

7.3.8 Maximum interferometric crosstalk

This parameter places a requirement on the isolation of a link conforming to the "black link" approach such that under the worst-case operating conditions, the interferometric crosstalk at any reference point R_S is less than the maximum interferometric crosstalk value.

Interferometric crosstalk is defined as the ratio of the disturbing power to the wanted power within a single channel, where the disturbing power is the power (not including ASE) within the optical channel that would remain if the wanted signal were removed from the link while leaving all of the other link conditions the same.

Specifically, the isolation of the link shall be greater than the amount required to ensure that when any channel is operating at the minimum mean output power at point S_S and all of the others are at the maximum mean output power, then the interferometric crosstalk at the corresponding point R_S is less than the maximum interferometric crosstalk value.

7.4 Interface at point R_S

7.4.1 Maximum mean input power

The maximum acceptable value of the average received power at point R_S to achieve the specified maximum BER of the application code.

7.4.2 Receiver sensitivity

Receiver sensitivity is defined as the minimum value of average received power at point R_S to achieve a 10^{-12} BER. This must be met with a transmitter with worst-case values of transmitter eye mask, extinction ratio, optical return loss at point S_S, receiver connector degradations and measurement tolerances. The receiver sensitivity does not have to be met in the presence of dispersion, reflections from the optical path or optical crosstalk; these effects are specified separately in the allocation of maximum optical path penalty.

NOTE – The receiver sensitivity does not have to be met in the presence of transmitter jitter in excess of the appropriate jitter generation limit (e.g., [b-ITU-T G.8251] for OTN optical tributary signals).

Aging effects are not specified separately since they are typically a matter between a network operator and an equipment manufacturer.

7.4.3 Maximum optical path penalty

The path penalty is the apparent reduction of receiver sensitivity due to distortion of the signal waveform during its transmission over the path. It is manifested as a shift of the system's BER curves towards higher input power levels. This corresponds to a positive path penalty. Negative path penalties may exist under some circumstances, but should be small. (A negative path penalty indicates that a less than perfect transmitter eye has been partially improved by the path-dependent distortions.) Ideally, the BER curves should be translated only, but shape variations are not uncommon, and may indicate the emergence of BER floors. Since the path penalty is a change in the receiver's sensitivity, it is measured at a BER level of 10^{-12}.

For the applications defined in this Recommendation, the path penalties are limited to a maximum of 1.5 dB for NRZ 2.5G short-haul systems and 2.5 dB for all others. These limits are higher than in other Recommendations due to the additional penalty caused by optical crosstalk.

In the future, systems employing dispersion accommodation techniques based on pre-distortion of the signal at the transmitter may be introduced. In this case, the path penalty, in the above sense, can only be defined between points with undistorted signals. These points, however, do not coincide with the main path interfaces, and may thus not even be accessible. The definition of path penalty for this case is for further study.

The average value of the random dispersion penalties due to PMD is included in the allowed path penalty. In this respect, the transmitter/receiver combination is required to tolerate an actual DGD of 0.3-bit period with a maximum sensitivity degradation of 1 dB (with 50% of optical power in each principal state of polarization). For a well-designed receiver, this corresponds to a penalty of 0.1-0.2 dB for a DGD of 0.1-bit period. The actual DGD that may be encountered in operation is a randomly varying fibre/cable property, and cannot be specified in this Recommendation. This subject is further discussed in Appendix I of [ITU-T G.691].

Note that a signal-to-noise ratio reduction due to optical amplification (should this be introduced in a future revision of this Recommendation) is not considered a path penalty.

For applications using the "black link" approach, path penalty includes crosstalk penalty.

7.4.4 Maximum reflectance of receiver

Reflections from the receiver back into the DWDM link are specified by the maximum permissible reflectance of the receiver measured at reference point R_S. Optical reflectance is defined in [ITU-T G.671].

8 Parameter values

The physical layer parameters and values are given in Tables 8-1 to 8-5.

Table 8-1 – Physical layer parameters and values for class NRZ 2.5G, 100-GHz-spaced short-haul applications

Parameter	Units	DN100S-1D2(C) DN100S-1D3(L) DN100S-1D5(C)	DW100S-1D2(C) DW100S-1D3(L) DW100S-1D5(C)	DN100S-1D2(C)F DN100S-1D3(L)F DN100S-1D5(C)F	DW100S-1D2(C)F DW100S-1D3(L)F DW100S-1D5(C)F
General information					
Minimum channel spacing	GHz	100		100	
Bit-rate/line coding of optical tributary signals	–	NRZ 2.5G		NRZ OTU1 FEC enabled	
Maximum bit error ratio	–	10^{-12}		10^{-12} (Note)	
Fibre type	–	G.652, G.653, G.655		G.652, G.653, G.655	
Interface at point S_S					
Maximum mean channel output power	dBm	+4		+4	
Minimum mean channel output power	dBm	0		0	
Minimum central frequency	THz	191.5 for (C) 186.0 for (L)		191.5 for (C) 186.0 for (L)	
Maximum central frequency	THz	196.2 for (C) 191.5 for (L)		196.2 for (C) 191.5 for (L)	
Maximum spectral excursion	GHz	±12.5	±20	±12.5	±20
Minimum side mode suppression ratio	dB	30		30	
Minimum channel extinction ratio	dB	8.2		8.2	
Eye mask	–	NRZ 2.5G per ITU-T G.959.1		NRZ 2.5G per ITU-T G.959.1	
Optical path from point S_S to R_S					
Maximum channel insertion loss	dB	16.5		19.5	
Minimum channel insertion loss	dB	4		4	
Maximum ripple	dB	2		2	
Maximum chromatic dispersion	ps/nm	950		1200	
Minimum optical return loss at S_S	dB	24		24	
Maximum discrete reflectance between S_S and R_S	dB	–27		–27	
Maximum differential group delay	ps	120		120	
Maximum inter-channel crosstalk	dB	–15		–15	
Maximum interferometric crosstalk	dB	–45		–45	
Interface at point R_S					
Maximum mean channel input power	dBm	0		0	
Minimum receiver sensitivity	dBm	–18		–21	
Maximum optical path penalty	dB	1.5		1.5	
Maximum reflectance of receiver	dB	–27		–27	
NOTE – The BER for these application codes is required to be met only after the error correction (if used) has been applied. The BER at the input of the FEC decoder can, therefore, be significantly higher than 10^{-12}.					

Table 8-2 – Physical layer parameters and values for class NRZ 2.5G, 100-GHz-spaced long-haul applications

Parameter	Units	DN100L-1D2(C) DN100L-1D3(L) DN100L-1D5(C)	DW100L-1D2(C) DW100L-1D3(L) DW100L-1D5(C)	DN100L-1D2(C)F DN100L-1D3(L)F DN100L-1D5(C)F	DW100L-1D2(C)F DW100L-1D3(L)F DW100L-1D5(C)F
General information					
Minimum channel spacing	GHz	100		100	
Bit-rate/line coding of optical tributary signals	–	NRZ 2.5G		NRZ OTU1 FEC enabled	
Maximum bit error ratio	–	10^{-12}		10^{-12} (Note 1)	
Fibre type	–	G.652, G.653, G.655		G.652, G.653, G.655	
Interface at point S_S					
Maximum mean channel output power	dBm	+4		+4	
Minimum mean channel output power	dBm	0		0	
Minimum central frequency	THz	191.5 for (C) 186.0 for (L)		191.5 for (C) 186.0 for (L)	
Maximum central frequency	THz	196.2 for (C) 191.5 for (L)		196.2 for (C) 191.5 for (L)	
Maximum spectral excursion	GHz	±12.5	±20	±12.5	±20
Minimum side mode suppression ratio	dB	30		30	
Minimum channel extinction ratio	dB	8.2		8.2	
Eye mask	–	NRZ 2.5G per ITU-T G.959.1		NRZ 2.5G per ITU-T G.959.1	
Optical path from point S_S to R_S					
Maximum channel insertion loss	dB	25.5		28.5	
Minimum channel insertion loss	dB	13		13	
Maximum ripple	dB	2		2	
Maximum chromatic dispersion	ps/nm	1400 (Note 2)		1600	
Minimum optical return loss at S_S	dB	24		24	
Maximum discrete reflectance between S_S and R_S	dB	–27		–27	
Maximum differential group delay	ps	120		120	
Maximum inter-channel crosstalk	dB	–16		–16	
Maximum interferometric crosstalk	dB	–45		–45	

Table 8-2 – Physical layer parameters and values for class NRZ 2.5G, 100-GHz-spaced long-haul applications

Parameter	Units	DN100L-1D2(C) DN100L-1D3(L) DN100L-1D5(C)	DW100L-1D2(C) DW100L-1D3(L) DW100L-1D5(C)	DN100L-1D2(C)F DN100L-1D3(L)F DN100L-1D5(C)F	DW100L-1D2(C)F DW100L-1D3(L)F DW100L-1D5(C)F
Interface at point R_S					
Maximum mean channel input power	dBm	–9		–9	
Minimum receiver sensitivity	dBm	–28		–31	
Maximum optical path penalty	dB	2.5		2.5	
Maximum reflectance of receiver	dB	–27		–27	
NOTE 1 – The BER for these application codes is required to be met only after the error correction (if used) has been applied. The BER at the input of the FEC decoder can, therefore, be significantly higher than 10^{-12}. NOTE 2 – In cases where the maximum bit rate is restricted to 2.488 Gbit/s (STM-16), a maximum chromatic dispersion of 1600 ps/nm applies.					

Table 8-3 – Physical layer parameters and values for class NRZ 10G, 100-GHz-spaced short-haul applications

Parameter	Units	DN100S-2D2(C) DN100S-2D3(L) DN100S-2D5(C)	DW100S-2D2(C) DW100S-2D3(L) DW100S-2D5(C)	DN100S-2D2(C)F DN100S-2D3(L)F DN100S-2D5(C)F	DW100S-2D2(C)F DW100S-2D3(L)F DW100S-2D5(C)F
General information					
Minimum channel spacing	GHz	100		100	
Bit-rate/line coding of optical tributary signals	–	NRZ 10G		NRZ OTU2 FEC enabled	
Maximum bit error ratio	–	10^{-12}		10^{-12} (Note)	
Fibre type	–	G.652, G.653, G.655		G.652, G.653, G.655	
Interface at point S_S					
Maximum mean channel output power	dBm	+3		+3	
Minimum mean channel output power	dBm	–1		–1	
Minimum central frequency	THz	191.5 for (C) 186.0 for (L)		191.5 for (C) 186.0 for (L)	
Maximum central frequency	THz	196.2 for (C) 191.5 for (L)		196.2 for (C) 191.5 for (L)	
Maximum spectral excursion	GHz	±12.5	±20	±12.5	±20

Table 8-3 – Physical layer parameters and values for class NRZ 10G, 100-GHz-spaced short-haul applications

Parameter	Units	DN100S-2D2(C) DN100S-2D3(L) DN100S-2D5(C)	DW100S-2D2(C) DW100S-2D3(L) DW100S-2D5(C)	DN100S-2D2(C)F DN100S-2D3(L)F DN100S-2D5(C)F	DW100S-2D2(C)F DW100S-2D3(L)F DW100S-2D5(C)F
Minimum side mode suppression ratio	dB	30		30	
Minimum channel extinction ratio	dB	8.2		8.2	
Eye mask	–	NRZ 10G 1550 nm region per ITU-T G.959.1		NRZ 10G 1550 nm region per ITU-T G.959.1	
Optical path from point S_S to R_S					
Maximum channel insertion loss	dB	18.5		21.5	
Minimum channel insertion loss	dB	10		10	
Maximum ripple	dB	2		2	
Maximum chromatic dispersion	ps/nm	1100		1400	
Minimum optical return loss at S_S	dB	24		24	
Maximum discrete reflectance between S_S and R_S	dB	–27		–27	
Maximum differential group delay	ps	30		30	
Maximum inter-channel crosstalk	dB	–16		–16	
Maximum interferometric crosstalk	dB	–45		–45	
Interface at point R_S					
Maximum mean channel input power	dBm	–7		–7	
Minimum receiver sensitivity	dBm	–22		–25	
Maximum optical path penalty	dB	2.5		2.5	
Maximum reflectance of receiver	dB	–27		–27	
NOTE – The BER for these application codes is required to be met only after the error correction (if used) has been applied. The BER at the input of the FEC decoder can, therefore, be significantly higher than 10^{-12}.					

Table 8-4 – Physical layer parameters and values for class NRZ 10G, 100-GHz-spaced long-haul applications

Parameter	Units	DN100L-2D2(C) DN100L-2D3(L) DN100L-2D5(C)	DW100L-2D2(C) DW100L-2D3(L) DW100L-2D5(C)	DN100L-2D2(C)F DN100L-2D3(L)F DN100L-2D5(C)F	DW100L-2D2(C)F DW100L-2D3(L)F DW100L-2D5(C)F
General information					
Minimum channel spacing	GHz	100		100	
Bit-rate/line coding of optical tributary signals	–	NRZ 10G		NRZ OTU2 FEC enabled	
Maximum bit error ratio	–	10^{-12}		10^{-12} (Note)	
Fibre type	–	G.652, G.653, G.655		G.652, G.653, G.655	
Interface at point S_S					
Maximum mean channel output power	dBm	+6		+6	
Minimum mean channel output power	dBm	+3		+3	
Minimum central frequency	THz	191.5 for (C) 186.0 for (L)		191.5 for (C) 186.0 for (L)	
Maximum central frequency	THz	196.2 for (C) 191.5 for (L)		196.2 for (C) 191.5 for (L)	
Maximum spectral excursion	GHz	±12.5	±20	±12.5	±20
Minimum side mode suppression ratio	dB	30		30	
Minimum channel extinction ratio	dB	9		9	
Eye mask	–	NRZ 10G 1550 nm region per ITU-T G.959.1		NRZ 10G 1550 nm region per ITU-T G.959.1	
Optical path from point S_S to R_S					
Maximum channel insertion loss	dB	24.5		27.5	
Minimum channel insertion loss	dB	13		13	
Maximum ripple	dB	2		2	
Maximum chromatic dispersion	ps/nm	1600		1700	
Minimum optical return loss at S_S	dB	24		24	
Maximum discrete reflectance between S_S and R_S	dB	–27		–27	
Maximum differential group delay	ps	30		30	
Maximum inter-channel crosstalk	dB	–16		–16	
Maximum interferometric crosstalk	dB	–45		–45	

Table 8-4 – Physical layer parameters and values for class NRZ 10G, 100-GHz-spaced long-haul applications

Parameter	Units	DN100L-2D2(C) DN100L-2D3(L) DN100L-2D5(C)	DW100L-2D2(C) DW100L-2D3(L) DW100L-2D5(C)	DN100L-2D2(C)F DN100L-2D3(L)F DN100L-2D5(C)F	DW100L-2D2(C)F DW100L-2D3(L)F DW100L-2D5(C)F
Interface at point R_S					
Maximum mean channel input power	dBm	–7		–7	
Minimum receiver sensitivity	dBm	–24		–27	
Maximum optical path penalty	dB	2.5		2.5	
Maximum reflectance of receiver	dB	–27		–27	
NOTE – The BER for these application codes is required to be met only after the error correction (if used) has been applied. The BER at the input of the FEC decoder can, therefore, be significantly higher than 10^{-12}.					

Table 8-5 – Physical layer parameters and values for class NRZ 10G, 50-GHz-spaced applications

Parameter	Units	DN50S-2D2(C) DN50S-2D3(L) DN50S-2D5(C)	DN50L-2D2(C) DN50L-2D3(L) DN50L-2D5(C)	DN50S-2D2(C)F DN50S-2D3(L)F DN50S-2D5(C)F	DN50L-2D2(C)F DN50L-2D3(L)F DN50L-2D5(C)F
General information					
Minimum channel spacing	GHz	50		50	
Bit-rate/line coding of optical tributary signals	–	NRZ 10G		NRZ OTU2 FEC enabled	
Maximum bit-error ratio	–	10^{-12}		10^{-12} (Note 1)	
Fibre type	–	G.652, G.653, G.655		G.652, G.653, G.655	
Interface at point S_S					
Maximum mean channel output power	dBm	+3	+6	+3	+6
Minimum mean channel output power	dBm	–1	+3	–1	+3
Minimum central frequency	THz	191.5 for (C) 186.0 for (L)		191.5 for (C) 186.0 for (L)	
Maximum central frequency	THz	196.2 for (C) 191.5 for (L)		196.2 for (C) 191.5 for (L)	
Maximum spectral excursion	GHz	±12.5 (±11 Note 2)		±12.5 (±11 Note 2)	
Minimum side mode suppression ratio	dB	30		30	
Minimum channel extinction ratio	dB	8.2	9	8.2	9

Table 8-5 – Physical layer parameters and values for class NRZ 10G, 50-GHz-spaced applications

Parameter	Units	DN50S-2D2(C) DN50S-2D3(L) DN50S-2D5(C)	DN50L-2D2(C) DN50L-2D3(L) DN50L-2D5(C)	DN50S-2D2(C)F DN50S-2D3(L)F DN50S-2D5(C)F	DN50L-2D2(C)F DN50L-2D3(L)F DN50L-2D5(C)F
Eye mask	–	NRZ 10G 1550 nm region per ITU-T G.959.1		NRZ 10G 1550 nm region per ITU-T G.959.1	
Optical path from point S_S to R_S					
Maximum channel insertion loss	dB	18.5	24.5	21.5	27.5
Minimum channel insertion loss	dB	10	13	10	13
Maximum ripple	dB	2		2	
Maximum chromatic dispersion	ps/nm	1100	1600	1400	1700
Minimum optical return loss at S_S	dB	24		24	
Maximum discrete reflectance between S_S and R_S	dB	–27		–27	
Maximum differential group delay	ps	30		30	
Maximum inter-channel crosstalk	dB	–16		–16	
Maximum interferometric crosstalk	dB	–45		–45	
Interface at point R_S					
Maximum mean channel input power	dBm	–7		–7	
Minimum receiver sensitivity	dBm	–22	–24	–25	–27
Maximum optical path penalty	dB	2.5		2.5	
Maximum reflectance of receiver	dB	–27		–27	

NOTE 1 – The BER for these application codes is required to be met only after the error correction (if used) has been applied. The BER at the input of the FEC decoder can, therefore, be significantly higher than 10^{-12}.

NOTE 2 – In order to use a common transmitter for this application and also for the 50 GHz channel spacing 10 Gbit/s application codes in [ITU-T G.698.2], the maximum spectral excursion of the transmitter may need to be reduced to ±11 GHz. In this case, the width for the ripple specification of the black link can be reduced to ±11 GHz.

9 Optical safety considerations

See [ITU-T G.664], [IEC 60825-1] and [IEC 60825-2] for optical safety considerations.

Appendix I

Number of OADMs supported in a link

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

I.1 Introduction

The maximum number of OADMs which can be supported in a link and the maximum length of the link are constrained by the parameters which characterize the optical path between S_S and R_S (see Tables 8-1 to 8-5).

In this appendix, some indications are given on the way to evaluate the maximum number of OADMs which can be supported in a link and the maximum length of the link itself.

I.2 Maximum channel insertion loss

The value of the "Maximum channel insertion loss", indicated in Tables 8-1 to 8-5, includes the attenuation of the OM/OD equipment, of the OADMs and of the optical fibre plant.

The maximum number of OADMs can be calculated as follows:

$$\text{Number of OADMs} \leq \frac{\text{Max. channel insertion loss} - \text{OM loss} - \text{Total fibre loss} - \text{OD loss}}{\text{OADM insertion loss}}$$

NOTE – The attenuation of an OADM strongly depends on its type (fixed, reconfigurable, etc.).

If the required number of OADMs is known, this constraint can be re-arranged to establish the maximum fibre length:

$$\text{Maximum fibre length} \leq \frac{\text{Max. channel insertion loss} - \text{OM loss} - \text{Total OADM loss} - \text{OD loss}}{\text{Fibre loss per unit length (including splices, etc.)}}$$

I.3 Maximum ripple

The maximum ripple can also put some limitations to the number of cascaded OADMs in a DWDM system.

The impact of the ripple depends on which channels are added or dropped in the cascaded locations. If it were the same channel at each site (which could be a practical case), the device ripple would tend to impact the same adjacent channel at each OADM site. If it is desired to maintain complete flexibility for adding and dropping any channel or group of channels at each OADM (for instance with reconfigurable OADMs), then the number of OADMs is constrained so that:

$$\text{Number of OADMs} \leq \frac{\text{Maximum ripple} - \text{OM ripple} - \text{OD ripple}}{\text{OADM ripple}}$$

The value of OADM ripple here is the ripple seen by any channel that is passed straight through the OADM.

There are, however, some ways to make this constraint less onerous. If the DWDM system is designed in a banded structure (one example might be four channels used and two gaps, four channels used and two gaps, etc.), it is possible to drop a group of four channels at a time. Then, the OADM filters would have the two unused channels in which the roll-off and the ripple in the nearest used adjacent channel to the dropped group could be very small thereby increasing the number of OADMs that can be cascaded before being constrained by ripple.

I.4 Maximum chromatic dispersion

As described in clause 7.3.3, the maximum chromatic dispersion values for each application have been calculated from the maximum channel insertion loss (with an allowance for the loss of an OM/OD pair subtracted from it) divided by 0.21 dB/km. Where the dispersion values obtained by this method were considered to be higher than is feasible for current cost-effective optical transmitters, the dispersion values were reduced in accordance with current technology capability. Consequently, if the ratio of the chromatic dispersion to the insertion loss of any OADM inserted into the link is less than or equal to that of the fibre it replaces (about 68 ps/nm/dB worst case), this parameter does not constrain the total number of OADMs in any one link. If, however, the above ratio is higher than that of the fibre it replaces, then the number of OADMs could place a constraint on the maximum link length for some application codes (particularly for low-loss OM/OD pairs).

In all cases (including no OADMs), the link length is constrained to:

$$\text{Maximum fibre length} \leq \frac{\text{Max. chromatic dispersion} - \text{Total OM, OADM and OD dispersion}}{\text{Fibre dispersion per unit length}}$$

I.5 Reflections

As described in clause 7.3.5, the maximum number of connectors or other discrete reflection points which may be included in the optical path (which includes any OADMs and associated connectors), must be such as to allow the specified overall optical return loss to be achieved. Because any reflections from OADMs and any associated connectors will be separated by an unknown distance and loss, no guidelines are given here as to what constraint this imposes on the number of OADMs in a link.

The values of maximum discrete reflectance between S_S and R_S given in Tables 8-1 to 8-5 may not be adequate to ensure compliance with the minimum optical return loss at S_S if there are more than a few OADMs in a link.

If the specified "Minimum optical return loss at S_S" or "Maximum discrete reflectance between S_S and R_S" are not achieved, then components having better reflection performance must be employed and/or the number of discrete reflectance points must be reduced. Information on the measurement of reflections can be found in [b-IEC 61300-3-6].

I.6 Maximum differential group delay

The maximum differential group delay (DGD) indicated in Tables 8-1 to 8-5 is the maximum differential group delay for the whole link between points S_S and R_S.

The equation below can be used to calculate the maximum DGD of a link (containing multiple OADMs and fibre sections) with a defined probability of being exceeded.

$$DGD\max_{link} = \left[DGM\max_F^2 + S^2 \sum_i PMD_{Oi}^2 \right]^{1/2}$$

where:

- $DGD\max_{link}$: is the maximum link DGD (ps)
- $DGD\max_F$: is the maximum concatenated optical fibre cable DGD (ps)
- S: is Maxwell adjustment factor (see Table 7-2 ratio of maximum to mean)
- PMD_{Oi}: is PMD value of the i-th OADM (ps).

This equation assumes that the statistics of the instantaneous DGD are approximated by a Maxwell distribution, with the probability of the instantaneous DGD exceeding $DGD\max_{link}$ being controlled by the value of the Maxwell adjustment factor (ratio of maximum to mean) taken from Table 7-2.

Further details can be found in [b-ITU-T G.650.2] and [b-ITU-T G.696.1]. The value of $DGD\max_F$ (the maximum DGD due to the fibre part) can either be measured or, alternatively, an upper limit can be calculated for a given fibre length using the PMD_Q coefficient in the corresponding fibre Recommendation.

I.7 Maximum interferometric crosstalk

Interferometric crosstalk can occur when a channel is used more than once in a particular link. If the signal from a dropped channel is not completely extinguished by the OADM where it is dropped, then it can interfere with the signal for the same channel when it is subsequently added. However, if this process occurs twice (the channel is dropped, added, dropped and added again), the signal from the first source will be extinguished by both of the OADMs where the channel is dropped and the interferometric crosstalk will be dominated by the performance of the last OADM that dropped and added that channel. This parameter, therefore, does not constrain the number of OADMs in a link.

Bibliography

[b-ITU-T G-Sup.39] ITU-T G-series Recommendations – Supplement 39 (2006), *Optical system design and engineering considerations*.

[b-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*.

[b-ITU-T G.696.1] Recommendation ITU-T G.696.1 (2005), *Longitudinally compatible intra-domain DWDM applications.*

[b-ITU-T G.8251] Recommendation ITU-T G.8251 (2001), *The control of jitter and wander within the optical transport network (OTN)*.

[b-IEC 61300-3-6] IEC 61300-3-6 (2008), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-6: Examinations and measurements – Return loss*.

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	General tariff principles
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	**Transmission systems and media, digital systems and networks**
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	Construction, installation and protection of cables and other elements of outside plant
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Terminals and subjective and objective assessment methods
Series Q	Switching and signalling
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	Global information infrastructure, Internet protocol aspects and next-generation networks
Series Z	Languages and general software aspects for telecommunication systems

Printed in Switzerland
Geneva, 2010