I n t e r n a t i o n a l   T e l e c o m m u n i c a t i o n   U n i o n

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.698.2

(11/2018)

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

Transmission media and optical systems characteristics – Characteristics of optical systems

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Amplified multichannel dense wavelength division multiplexing applications with single channel optical interfaces

Recommendation ITU-T G.698.2

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International Telecommunication Union

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Recommendation ITU-T G.698.2

Amplified multichannel dense wavelength division multiplexing applications with single channel optical interfaces

Summary

Recommendation ITU-T G.698.2 provides optical parameter values for physical layer interfaces of dense wavelength division multiplexing (DWDM) systems primarily intended for metro applications which include optical amplifiers. 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 does not specify the details of the optical link, e.g., the maximum fibre length, explicitly. This version of this Recommendation includes unidirectional DWDM applications at 100 Gbit/s with 100 GHz and 50 GHz channel frequency spacing.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.698.2	2007-07-29	15	11.1002/1000/9183
2.0	ITU-T G.698.2	2009-11-13	15	11.1002/1000/10396
3.0	ITU-T G.698.2	2018-11-29	15	11.1002/1000/13740

Keywords

100G, 10G, 2.5G, application codes, black link, DWDM, metro, multi-vendor, OADM, optical.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

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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.

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As of the date of approval of this Recommendation, ITU had 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/.

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Recommendation ITU-T G.698.2

Amplified multichannel dense wavelength division multiplexing 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 which include optical amplifiers.

This Recommendation defines and provides values for single-channel optical interface parameters of physical point-to-point and ring DWDM applications on single-mode optical fibres through the use of the "black link" approach. The black links covered by this Recommendation may contain optical amplifiers.

The use of these single channel optical interfaces for DWDM systems enables the elimination of transponders which would otherwise be needed in multivendor DWDM optical transmission networks. Further details can be found in Appendix II.

This Recommendation describes single channel interfaces to 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 100 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 (2016), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.653] Recommendation ITU-T G.653 (2010), *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 (2009), *Optical safety procedures and requirements for optical transport systems*.

[ITU-T G.671] Recommendation ITU-T G.671 (2012), *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 (2012), *Spectral grids for WDM applications: DWDM frequency grid*.

[ITU-T G.709] Recommendation ITU-T G.709/Y.1331 (2016), *Interfaces for the Optical Transport Network (OTN)*.

[ITU-T G.709.2] Recommendation ITU-T G.709.2/Y.1331.2 (2018), *OTU4 long-reach interface*.

[ITU-T G.709.3] Recommendation ITU-T G.709.3/Y.1331.3 (2018), *Flexible OTN long-reach interfaces.*

[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 (2018), *Optical transport network physical layer interfaces*.

[IEC 60825-1] IEC 60825-1:2014, *Safety of laser products – Part 1: Equipment classification and requirements*.

[IEC 60825-2] IEC 60825-2:2010, *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 in [ITU-T G.671]:

– Dense Wavelength Division Multiplexing (DWDM);

– Channel insertion loss;

– Reflectance;

– Ripple;

– Channel spacing;

– Differential group delay;

– Reflectance.

This Recommendation uses the following term defined in [ITU-T G.691]:

– (Optical) transponder.

This Recommendation uses the following term defined in [ITU-T G.694.1]:

– Frequency grid.

This Recommendation uses the following term defined in [ITU-T G.709]:

– Completely standardized OTUk (OTUk).

This Recommendation uses the following terms defined in [ITU-T G.709.2]:

– OTL4.4-SC;

– OTU4-SC.

This Recommendation uses the following term defined in [ITU-T G.709.3]:

– FOIC1.4-SC.

This Recommendation uses the following terms defined in [ITU-T G.957]:

– Joint engineering;

– Transverse compatibility.

This Recommendation uses the following terms defined in [ITU-T G.959.1]:

– Optical tributary signal;

– Optical tributary signal class NRZ 2.5G;

– Optical tributary signal class NRZ 10G.

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 optical tributary signal class DP-DQPSK 100G: A class of continuous digital signals with non-return to zero differential quadrature phase shift keying modulation applied separately to two orthogonal polarizations of a carrier, operating at a total bit rate from nominally 103.1 Gbit/s to nominally 112.74 Gbit/s. Optical tributary signal class DP-DQPSK 100G includes a signal with FOIC1.4-SC bit rate according to [ITU-T G.709.3] and OTL4.4-SC bit rate according to [ITU-T G.709.2].

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

APD	Avalanche Photodiode
ASE	Amplified Spontaneous Emission
BER	Bit Error Ratio
DGD	Differential Group Delay
DP-DQPSK	Dual Polarization – Differential Quadrature Phase Shift Keying
EX	Extinction ratio
FEC	Forward Error Correction
FIR	Finite Impulse Response
FOIC1.4-SC	FlexO Interface of order C1 with 4 lanes
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
OTL4.4-SC	Group of 4 Optical Transport Lanes that carry one OTU4-SC
OTU4-SC	Completely standardized 100G Optical Transport Unit for long-reach applications with Staircase FEC
OTUk	Completely standardized optical channel transport unit – k
PDL	Polarization Dependent Loss
PIN	P type-intrinsic-n type

PMD	Polarization Mode Dispersion
R_S	Single-channel reference point at the DWDM network element tributary output
SOP	State of Polarization
S_S	Single-channel reference point at the DWDM network element tributary input
VOA	Variable Optical Attenuator
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.

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 residual 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.

This Recommendation considers DWDM applications where the black link may 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 optical multiplexer (OM) and an optical demultiplexer (OD) (which are used as a pair with the opposing element), one or more optical amplifiers and may also include one or more optical add-drop multiplexers (OADMs).

The arrangement of elements within the black link shown in Figures 5-1 to 5-4 is not intended to place constraints on the construction of the black link, but simply to define the location of the single channel interfaces.

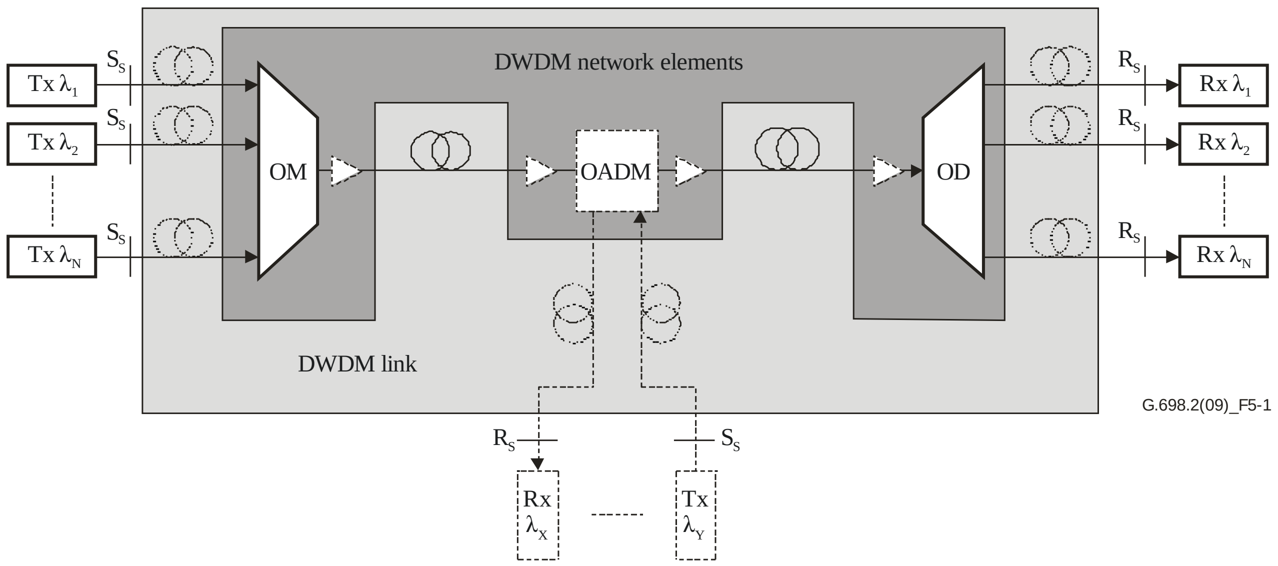

Figure 5-1 – Linear "black link" approach

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 one or more amplifiers and two or more OADMs connected in a ring.

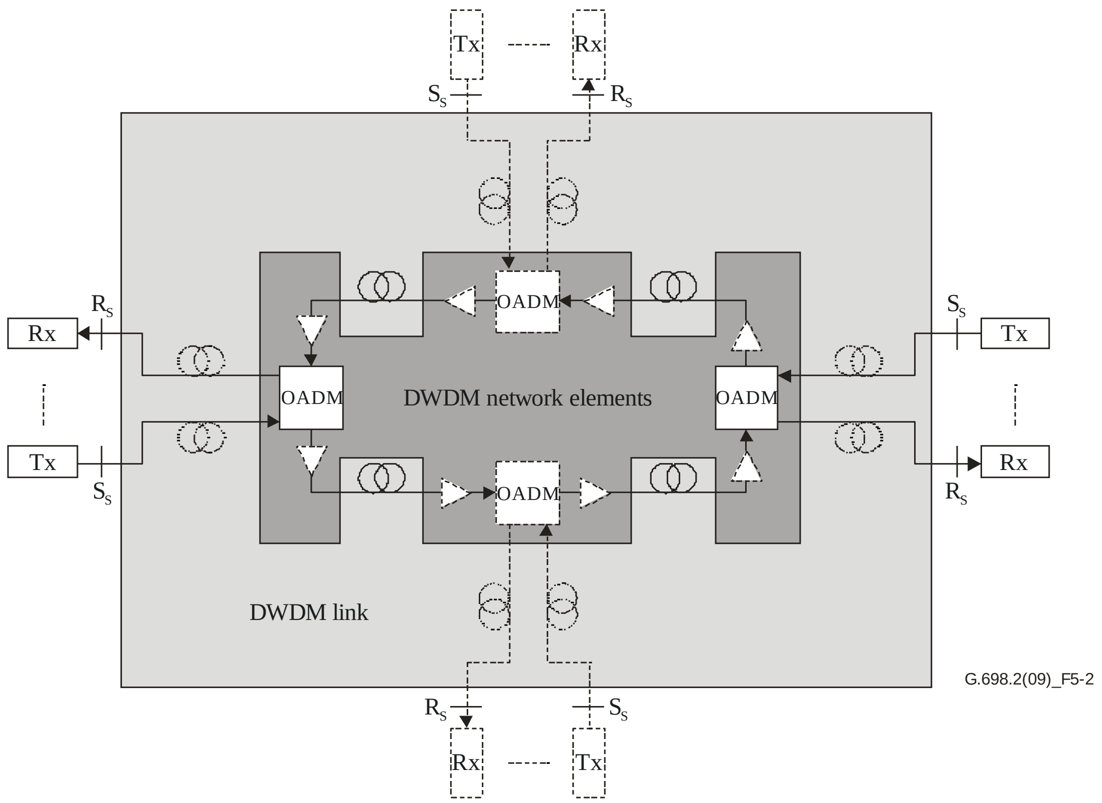

Figure 5-2 – Ring "black link" approach

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.

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.

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), one or more optical amplifiers and may also include one or more OADMs.

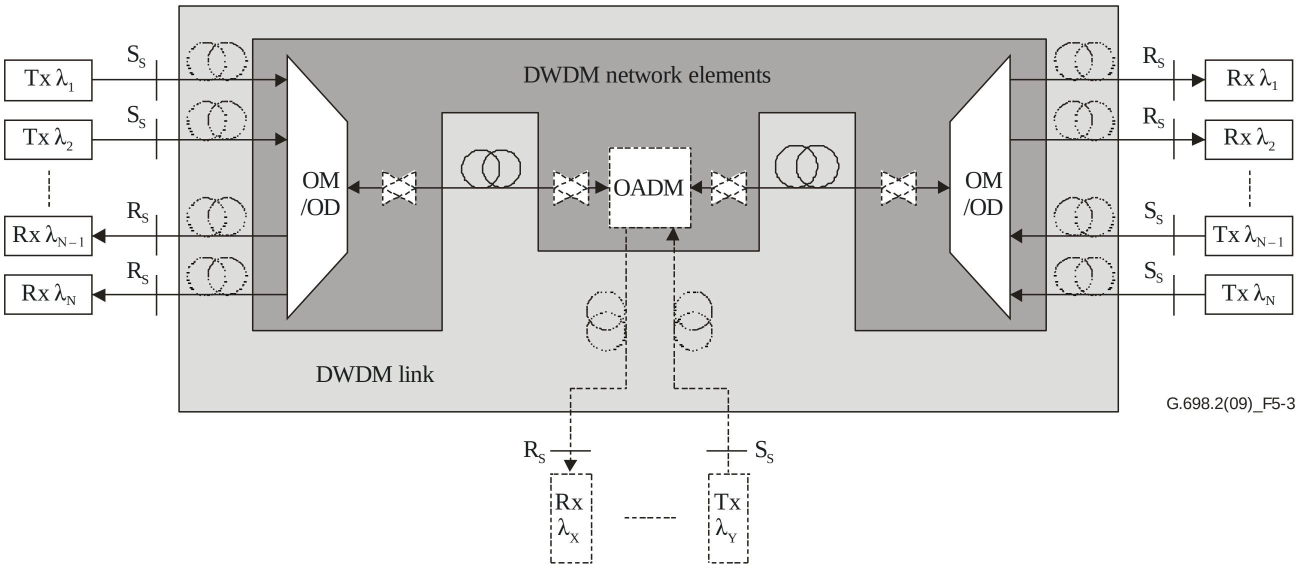

Figure 5-3 – Linear "black link" approach for bidirectional applications

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

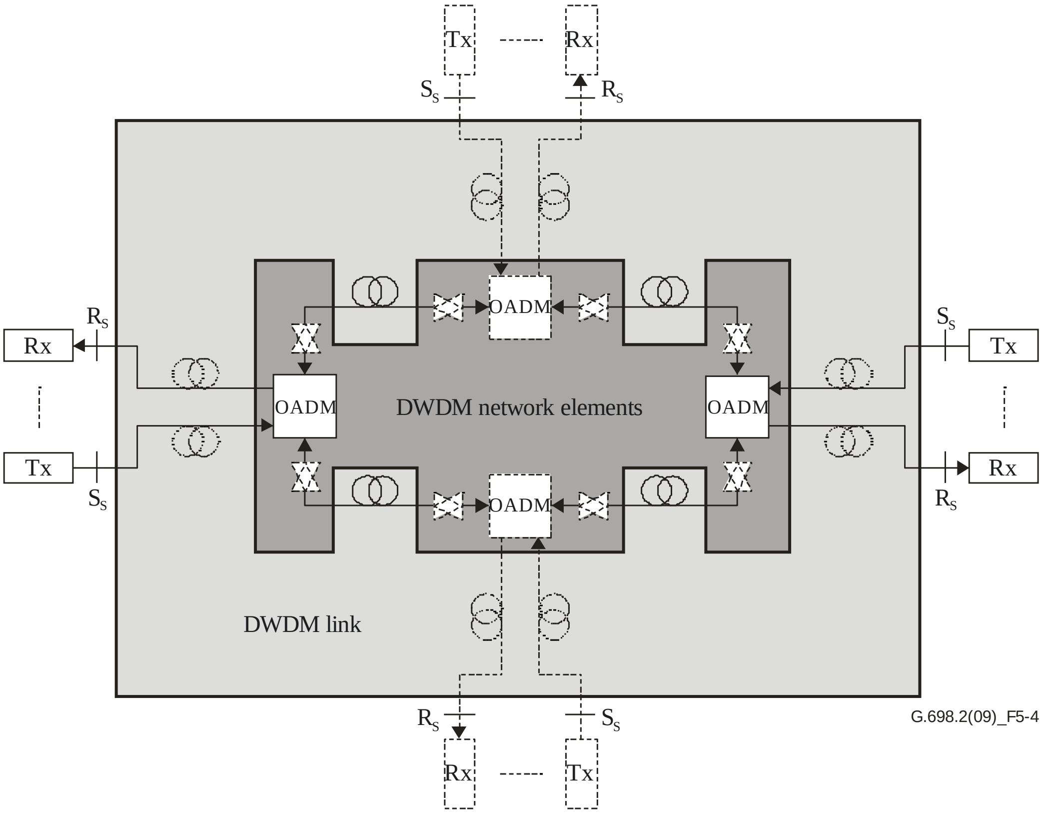

Figure 5-4 – Ring "black link" approach for bidirectional applications

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

5.3 Nomenclature

The application code 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 indicates the black link dispersion compensation regime as follows:

– **C** indicating that the chromatic dispersion values are appropriate to a black link that is dispersion compensated.

– **U** indicating that the chromatic dispersion values are appropriate to a black link that is dispersion uncompensated.

NOTE 1 – This letter is used to indicate the dispersion tolerance of the transmitters and receivers and not to constrain the construction of the black link. While application codes that include "C" have transmitters and receivers that have dispersion tolerance appropriate to DWDM links including dispersion compensation, they may be used with black links that do not contain dispersion compensators provided that the application code parameters are met. Likewise, while application codes that include "U" have transmitters and receivers that have dispersion tolerance appropriate to DWDM links without dispersion compensation, they may be used with black links that contain dispersion compensators provided that the application code parameters are met.

y indicates the highest class of optical tributary signal supported:

– **1** indicating NRZ 2.5G.

– **2** indicating NRZ 10G.

– **8** indicating DP-DQPSK 100G.

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

– **A** indicating that the black link may contain 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 2 – 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] or for DP-DQPSK 100G in [ITU-T G.709.2] or [ITU-T G.709.3] to be transmitted.

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

The single-channel interfaces described in this Recommendation are intended to enable transverse compatibility at the single-channel interfaces at either end of the DWDM black link 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

	Dispersion compensated	Dispersion uncompensated
Optical tributary signal class NRZ 2.5G	DN100C-1A2(C) DW100C-1A2(C) DN100C-1A3(L) DW100C-1A3(L) DN100C-1A5(C) DW100C-1A5(C)	DN100U-1A2(C) DN100U-1A3(L) DN100U-1A5(C)
OTU1 with FEC enabled	DW100C-1A2(C)F DW100C-1A3(L)F DW100C-1A5(C)F	
Optical tributary signal class NRZ 10G	DN100C-2A2(C) DW100C-2A2(C) DN100C-2A3(L) DW100C-2A3(L) DN100C-2A5(C) DW100C-2A5(C) DN50C-2A2(C) DN50C-2A3(L) DN50C-2A5(C)	
OTU2 with FEC enabled	DN100C-2A2(C)F DW100C-2A2(C)F DN100C-2A3(L)F DW100C-2A3(L)F DN100C-2A5(C)F DW100C-2A5(C)F DN50C-2A2(C)F DN50C-2A3(L)F DN50C-2A5(C)F	DN100U-2A2(C)F DN100U-2A3(L)F DN100U-2A5(C)F DN50U-2A2(C)F DN50U-2A3(L)F DN50U-2A5(C)F
OTL4.4-SC or FOIC1.4-SC		DN50U-8A2(C)F DN50U-8A3(L)F DN50U-8A5(C)F DN100U-8A2(C)F DN100U-8A3(L)F DN100U-8A5(C)F DW50U-8A2(C)F DW50U-8A3(L)F DW50U-8A5(C)F DW100U-8A2(C)F DW100U-8A3(L)F DW100U-8A5(C)F

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

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.

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 – Parameters for DWDM applications using the "black link" approach with amplifiers

Parameter	Units	For Tables 8-1 to 8-6, defined in	For Tables 8-7 and 8-8, defined in
General information			
Minimum channel spacing	GHz	7.1.1	7.1.1
Bit rate/line coding of optical tributary signals	–	7.1.2	7.1.2
Maximum bit error ratio	–	7.1.3	7.1.3
Fibre type	–	7.1.4	7.1.4
Interface at point S_S			
Maximum mean channel output power	dBm	7.2.1	7.2.1
Minimum mean channel output power	dBm	7.2.1	7.2.1
Minimum central frequency	THz	7.2.2	7.2.2
Maximum central frequency	THz	7.2.2	7.2.2
Maximum spectral excursion	GHz	7.2.3	7.2.3
Minimum side mode suppression ratio	dB	7.2.4	7.2.4
Minimum channel extinction ratio	dB	7.2.5	NA
Eye mask	–	7.2.6	NA
Maximum transmitter (residual) dispersion OSNR penalty	dB	7.2.7	NA
Maximum laser linewidth	kHz	NA	7.2.8

Table 7-1 – Parameters for DWDM applications using the "black link" approach with amplifiers

Parameter	Units	For Tables 8-1 to 8-6, defined in	For Tables 8-7 and 8-8, defined in
Maximum offset between the carrier and the nominal central frequency	GHz	NA	7.2.9
Maximum power difference between polarizations	dB	NA	7.2.10
Maximum skew between the two polarizations	ps	NA	7.2.11
Maximum error vector magnitude	%	NA	7.2.12
Maximum I-Q offset	dB	NA	7.2.13
Optical path from point S_S to R_S			
Maximum ripple	dB	7.3.1	7.3.1
Maximum (residual) chromatic dispersion	ps/nm	7.3.2	7.3.2
Minimum (residual) chromatic dispersion	ps/nm	7.3.2	7.3.2
Minimum optical return loss at S_S	dB	7.3.3	7.3.3
Maximum discrete reflectance between S_S and R_S	dB	7.3.4	7.3.4
Maximum differential group delay	ps	7.3.5	7.3.5
Maximum polarization dependent loss	dB	7.3.6	7.3.6
Maximum polarization rotation speed	krad/s	NA	7.3.7
Maximum inter-channel crosstalk at R_S	dB	7.3.8	7.3.8
Maximum interferometric crosstalk at R_S	dB	7.3.9	7.3.9
Maximum optical path OSNR penalty	dB	7.3.10	7.3.10
Interface at point R_S			
Maximum mean input power	dBm	7.4.1	7.4.1
Minimum mean input power	dBm	7.4.1	7.4.1
Minimum OSNR	dB (0.1 nm)	7.4.2	NA
Minimum OSNR(193.6)	dB (0.1 nm)	NA	7.4.2
Receiver OSNR tolerance	dB (0.1 nm)	7.4.3	NA
Receiver OSNR tolerance(193.6)	dB (0.1 nm)	NA	7.4.3
Maximum reflectance of receiver	dB	7.4.4	7.4.4

7.1 General information

7.1.1 Minimum channel spacing

This is 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.

Optical tributary signal class DP-DQPSK 100G applies to continuous digital signals with non-return to zero differential quadrature phase shift keying modulation applied separately to two orthogonal polarizations of a carrier, operating at a total bit rate from nominally 103.1 Gbit/s to nominally 112.74 Gbit/s.

Optical tributary signal class DP-DQPSK 100G uses two orthogonal polarizations, each carrying a DQPSK signal.

Each DQPSK signal is generated from two of the four client lanes by taking one bit from each lane and then encoding them as a change in phase angle between successive symbols. Hence the phase change between two successive symbols encodes two bits of data according to the mapping shown in Table 7-2.

Table 7-2 – Bit mapping for the phase change of one polarization of the DP-DQPSK 100G signal

Lane bit values AB	Phase change between successive symbols (Radians)
00	0
10	$\pi/2$, $-3\pi/2$
11	π, $-\pi$
01	$3\pi/2$, $-\pi/2$

Bit A comes from any of the four lanes and bit B comes from any other lane. The lanes providing bits A and B cannot change while the link is in service. The other two lanes are used to generate the DQPSK signal on the other polarization in a similar manner.

For an application that does not have a suffix of **F**, the parameter values are the same for any bit rate within the range of the applicable optical tributary signal class. When an optical system uses one of these codes, therefore, it is necessary to specify both the application code and also the exact bit rate of the system. In other words, there is no requirement for equipment compliant with one of these codes to operate over the complete range of bit rates specified for its optical tributary signal class.

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 ageing effects.

Note that it is not required for any implementation to provide a mean channel output power that is as high as the maximum mean channel output power or as low as the minimum mean channel output power. Furthermore, the actual mean channel output power of a particular interface device must not exceed the limits defined for the maximum and minimum mean channel output power but can be somewhere between those limits.

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 the 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 a 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 for NRZ type signals or the –2.5 dB points of the transmitter spectrum furthest from the nominal central frequency measured at point S_S for DP-DQPSK type signals. This is illustrated in Figure 7-1 for NRZ-type signals and in Figure 7-2 for DP-DQPSK type signals.

NOTE – The measurement of the –15 dB points of the transmitter spectrum for the NRZ-type signals and -2.5 dB points for the DP-DQPSK type signals should be performed with a nominal resolution bandwidth of 0.01 nm.

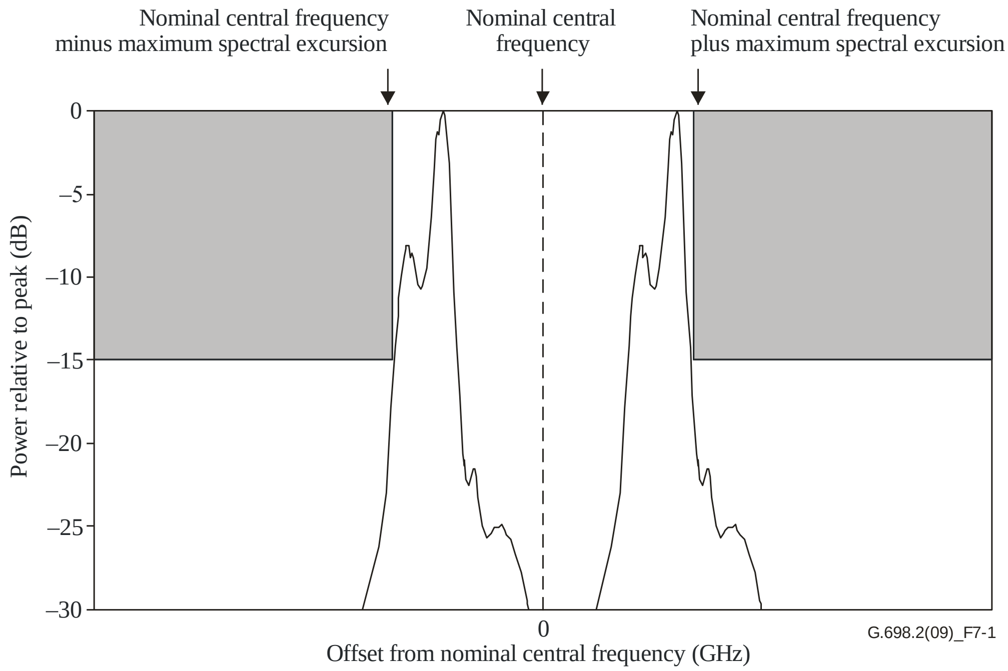

Figure 7-1 – Illustration of maximum spectral excursion for NRZ-type signals

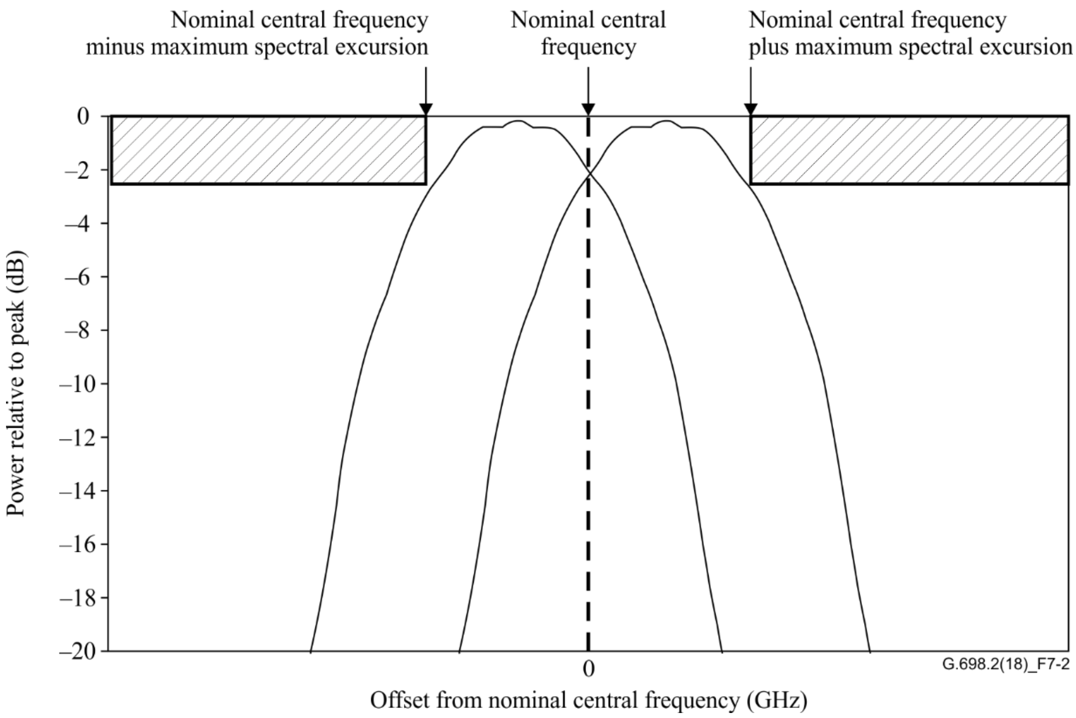

Figure 7-2 – Illustration of maximum spectral excursion for DP-DQPSK type signals

This parameter also defines the range of frequencies over which the 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].

7.2.7 Maximum transmitter (residual) dispersion OSNR penalty

The transmitter (residual) dispersion OSNR penalty is defined as:

Lowest OSNR at S_S with worst case (residual) dispersion – Lowest OSNR at S_S with no dispersion

Where:

– Lowest OSNR at S_S with no dispersion is the lowest OSNR that meets the maximum BER of the application from a reference receiver as defined in clause B.3 of [ITU-T G.959.1] at point S_S.

– Lowest OSNR at S_S with worst case (residual) dispersion is the lowest OSNR that meets the maximum BER of the application from a reference receiver as defined in clause B.3 of [ITU-T G.959.1] at point S_S with the chromatic dispersion (within the range specified for the application code) applied which gives the highest OSNR penalty.

NOTE – The measurement of the transmitter (residual) dispersion OSNR penalty therefore requires filtered ASE noise to be added to the signal at point S_S. This subject is further discussed in Appendix I.

This penalty is not part of the system budget directly (since it is included as part of the optical path OSNR penalty defined in clause 7.3.9) but rather provides an upper bound on the OSNR penalty due to dispersion alone, thereby ensuring that some of the optical path OSNR penalty is available to cover the other impairments listed.

7.2.8 Maximum laser linewidth

The laser linewidth is defined as: The level of the white noise component of the power spectrum density of the instantaneous laser frequency multiplied by π.

7.2.9 Maximum offset between the carrier and the nominal central frequency

The offset between the carrier and the nominal central frequency is defined as:

Difference between the centroid of the power spectrum of the optical signal and the nominal central frequency of the channel.

7.2.10 Maximum power difference between polarizations

The power difference between polarizations is defined as:

Difference ΔPpol of the optical power levels P_X and P_Y at the reference point S_S, i.e.:

$$\Delta Ppol = abs\ (10 \bullet \log_{10} (P_X / P_Y)),$$

where by P_X and P_Y are the powers of the two nominally orthogonal polarizations carrying the two data streams.

7.2.11 Maximum skew between the two polarizations

The skew between the two polarizations is defined as:

The time delay between the symbol sequences on each polarization at reference point S_S when the same sequence is applied to both polarizations.

7.2.12 Maximum error vector magnitude

The error vector magnitude is defined as follows:

N pairs of in-phase (I) and quadrature (Q) samples are acquired for each of the two polarizations after filtering with a 4th order Bessel-Thomson low-pass filter with a –3 dB bandwidth of 0.7 times the symbol rate. The following calculations are done for each of the polarizations separately.

Split the sample pairs into blocks of size B (where B equals 1000 for DP-DQPSK 100G) and for each block:

The carrier frequency offset f_{offs} is estimated for each individual block of pairs of raw in-phase (I) and quadrature (Q) samples by first calculating the phase error of each sample pair:

$$\varphi_{\text{raw}}(b) = \frac{\pi}{4} - \text{mod}\left(\text{atan2}\left(Q_{\text{raw}}(b), I_{\text{raw}}(b)\right), \frac{\pi}{2}\right)$$

where:

$$\mathrm{mod}(a, m) = a - m \cdot \mathrm{floor}\left(\frac{a}{m}\right)$$

and floor(x) rounds x to the nearest integer less than or equal to that element and:

$$\mathrm{atan2}(y, x) = \begin{cases} \arctan(y/x) & :x>0 \\ \arctan(y/x)+\pi & :y\geq 0,\ x<0 \\ \arctan(y/x) - \pi & :y<0,\ x<0 \\ +\pi/2 & :y>0,\ x=0 \\ -\pi/2 & :y<0,\ x=0 \\ \text{undefined} & :y=0,\ x=0 \end{cases}$$

Calculate the phase offset for each sample:

$$\varphi_{\mathrm{offset}}(b) = \varphi_{\mathrm{raw}}(b) - \sum_{k=0}^{B-1} \pi/2 \ \mathrm{round}\left(\frac{\varphi_{\mathrm{raw}}(k+1) - \varphi_{\mathrm{raw}}(k)}{\pi/2}\right)$$

Finally calculate the frequency offset by calculating the slope of the phase offset:

$$f_{\mathrm{offs}} = -\frac{B\sum_{k=0}^{B-1} k\varphi_{\mathrm{offset}}(k) - (\sum_{k=0}^{B-1} k) \times (\sum_{k=0}^{B-1} \varphi_{\mathrm{offset}}(k))}{2\pi T\ [B\sum_{k=0}^{B-1} k^2 - (\sum_{k=0}^{B-1} k)^2]}$$

The samples in this block are then rotated using a linear increasing phase:

$$I(b) = I_{raw}(b) \cdot \cos\left(b \cdot 2\pi \cdot \frac{f_{offs}}{f_{symbol}}\right) - \mathrm{Q}_{raw}(b) \cdot \sin(b \cdot 2\pi \cdot \frac{f_{offs}}{f_{symbol}})$$

$$\mathrm{Q}(b) = I_{raw}(b) \cdot \sin\left(b \cdot 2\pi \cdot \frac{f_{offs}}{f_{symbol}}\right) + \mathrm{Q}_{raw}(b) \cdot \cos(b \cdot 2\pi \cdot \frac{f_{offs}}{f_{symbol}})$$

where f_{symbol} is the symbol rate of the samples and b is the symbol number within the block starting at 0.

For B pairs of in-phase (I) and quadrature (Q) samples, calculate the DC offsets for the I and Q samples:

$$\mathrm{I}_{mean} = \sum_{b=0}^{B-1} \mathrm{I(b)/B}$$

$$\mathrm{Q}_{mean} = \sum_{b=0}^{B-1} \mathrm{Q(b)/B}$$

The values for $\mathrm{I_{mean}}$ and $\mathrm{Q_{mean}}$ are then corrected for any imbalance in the symbol occurrence within each block.

Subtract the DC offsets from the B sample pairs to obtain the DC-free sample pairs:

$$\mathrm{I}_{AC}(b) = \mathrm{I(b)} - I_{mean}$$

$$\mathrm{Q}_{AC}(b) = \mathrm{Q(b)} - \mathrm{Q}_{mean}$$

Find the signal power of the I and Q samples:

$$P_{Signal} = \sum_{b=0}^{B-1} (I_{AC}^2(b) + Q_{AC}^2(b)) \Big/ B$$

Divide the DC-free sample pairs by the square root of half the signal power to obtain the normalized sample pairs:

$$I_{norm}(b) = I_{AC}(b)/\sqrt{P_{signal}/2}$$

$$Q_{norm}(b) = Q_{AC}(b)/\sqrt{P_{signal}/2}$$

Calculate the phase error:

$$\varphi_{err} = \frac{\pi}{4} - \frac{1}{B}\sum_{b=0}^{B-1} \mathrm{mod}\left(\mathrm{atan2}(Q_{norm}(b), I_{norm}(b)), \frac{\pi}{2}\right)$$

rotate the data:

$$I_{\varphi}(b) = \cos(\varphi_{err})\, I_{norm}(b) - \sin(\varphi_{err})\, Q_{norm}(b)$$

$$Q_{\varphi}(b) = \sin(\varphi_{err})\, I_{norm}(b) + \cos(\varphi_{err})\, Q_{norm}(b)$$

Create an integer value between 0 and 3 to define which of the four constellation points each sample belongs to:

$$D(b) = \mathrm{mod}\left(\mathrm{round}\left(\frac{\mathrm{atan2}\left(Q_{\varphi}(b), I_{\varphi}(b)\right)}{\pi/2} - \frac{1}{2}\right), 4\right)$$

Calculate the average values I_k and Q_k for each of the four constellation points:

$$\hat{I}_k = \sum_{b=0}^{B-1} \left(I_{\varphi}(b) \cdot \delta(D(b) - k)\right) \Big/ \sum_{b=0}^{B-1} \delta(D(b) - k)\,, \quad k = [0, 1, 2, 3]$$

$$\hat{Q}_k = \sum_{b=0}^{B-1} \left(Q_{\varphi}(b) \cdot \delta(D(b) - k)\right) \Big/ \sum_{b=0}^{B-1} \delta(D(b) - k)\,, \quad k = [0, 1, 2, 3]$$

where:

$$\delta(x) = \begin{cases} 1 & : x = 0 \\ 0 & : x \neq 0 \end{cases}$$

Calculate the remaining phase error:

$$\delta_{err} = \frac{1}{2}\arccos\left(\frac{\hat{Q}_3 + \hat{Q}_0 - \hat{Q}_1 - \hat{Q}_2}{\cdot\sqrt{\left(\hat{I}_3 + \hat{I}_0 - \hat{I}_1 - \hat{I}_2\right)^2 + \left(\hat{Q}_3 + \hat{Q}_0 - \hat{Q}_1 - \hat{Q}_2\right)^2}}\right) - \frac{1}{2}\arccos\left(\frac{\hat{I}_0 + \hat{I}_1 - \hat{I}_2 - \hat{I}_3}{\sqrt{\left(\hat{I}_0 + \hat{I}_1 - \hat{I}_2 - \hat{I}_3\right)^2 + \left(\hat{Q}_0 + \hat{Q}_1 - \hat{Q}_2 - \hat{Q}_3\right)^2}}\right)$$

White Gaussian noise is added to the resulting $I_{\varphi}(b)$ and $Q_{\varphi}(b)$ of the previous step. The amplitude of the noise for each quadrature is calculated from the following equation:

$$A_{RMS} = \sqrt{\frac{1.466 \cdot f_{symbol}}{10^{\frac{OSNR(193.6)}{10}} \cdot 12.5}}$$

Where f_{symbol} is the symbol rate in GHz and OSNR(193.6) is the Minimum OSNR at reference point R_s referenced to 193.6 THz, specified in the applicable parameter value tables.

NOTE – The value of 193.6 THz was chosen so that the optical measurement bandwidth of 0.1 nm corresponds to 12.5 GHz, which is a value commonly used in the industry.

The data is then equalized using a real valued 7-tap T-spaced finite impulse response (FIR) filter. The sum of all filter tap coefficients is equal to one, and the largest coefficient can be for any of the 7 taps. The individual filter taps are found by minimizing the EVM_{RMS} value, which is calculated as described below.

Remove the remaining phase error:

$$I_{\delta}(b) = \cos(\delta_{err})\, I_{\varphi}(b) - \sin(\delta_{err})\, Q_{\varphi}(b)$$

$$Q_{\delta}(b) = \sin(\delta_{err})\, I_{\varphi}(b) + \cos(\delta_{err})\, Q_{\varphi}(b)$$

Calculate the error vector magnitude for each sample pair in each of the polarizations:

$$EVM(b) = \sqrt{[(|I_{\delta}(b)| - 1)^2 + (|Q_{\delta}(b)| - 1)^2]/2}$$

Using all the N samples from the x polarization calculate $EVM_{RMS,x}$ as:

$$EVM_{RMS,x} = \sqrt{\frac{1}{N}\sum_{n=0}^{N-1} EVM(n)^2}$$

Using all the N samples from the y polarization and calculate $EVM_{RMS,y}$ as:

$$EVM_{RMS,y} = \sqrt{\frac{1}{N}\sum_{n=0}^{N-1} EVM(n)^2}$$

Then calculate EVM_{RMS} from:

$$EVM_{RMS} = \sqrt{0.5\left(EVM_{RMS,x}^2 + EVM_{RMS,y}^2\right)}\ x\ 100\%$$

7.2.13 Maximum I-Q offset

The I-Q offset of a modulated signal relates to the average signal amplitudes in the I- and Q-phases of that signal. The relative excess (unmodulated) power, P_{excess}, is a measure of this impairment and is obtained from the parameters I_{mean} and Q_{mean} and P_{Signal}, which are intermediate results during the calculation of the error vector magnitude (see clause 7.2.12):

$$P_{excess} = \frac{I_{mean}^2 + Q_{mean}^2}{P_{Signal}}$$

$$IQ_{offset} = 10\log_{10}(P_{excess})$$

7.3 Optical path parameters from S_S to R_S

7.3.1 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 7-3.

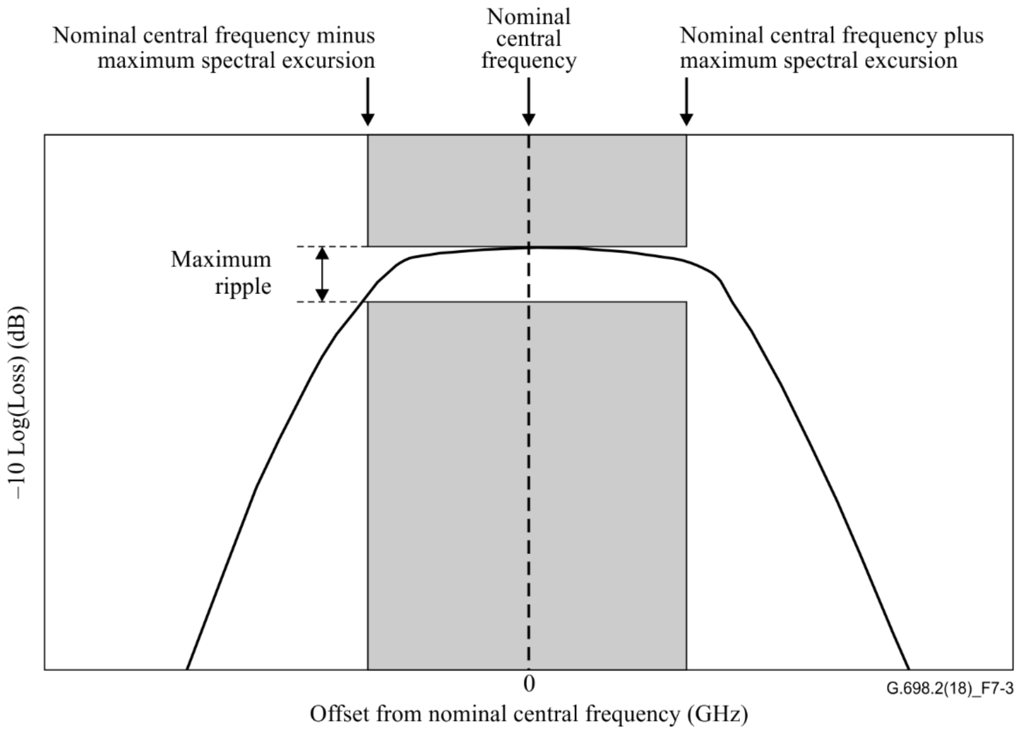

Figure 7-3 – Illustration of maximum ripple

7.3.2 Maximum and minimum (residual) chromatic dispersion

These parameters define the maximum and minimum value of the optical path end-to-end chromatic dispersion that the system shall be able to tolerate. These are the worst-case dispersion values of the optical path from point S_S to the corresponding receive reference point R_S. In the case that the black link contains dispersion compensation between these two points, its effect is included.

These parameters contain the word "residual" in brackets because, in the case of links which include dispersion compensators, these are the maximum and minimum residual chromatic dispersion, and in the case of links that do not include any dispersion compensators, these parameters are simply the maximum and minimum chromatic dispersion.

7.3.3 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 connectors used.

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

7.3.5 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, for NRZ application codes, the maximum differential group delay is defined to be the value of DGD that the system must tolerate with a maximum OSNR penalty of 2 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 7-3.

Table 7-3 – 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}

7.3.6 Maximum polarization dependent loss

The polarization dependent loss (PDL) is the difference (in dB) between the maximum and minimum values of the channel insertion loss (or gain) of the black link from point S_S to R_S due to a variation of the state of polarization (SOP) over all SOPs.

7.3.7 Maximum polarization rotation speed

The polarization rotation speed is the rate of rotation in Stokes space of the two polarizations of the optical signal at point R_S measured in krad/s.

7.3.8 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.

7.3.9 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.

7.3.10 Maximum optical path OSNR penalty

The optical path OSNR penalty is defined as:

$$\text{Lowest OSNR at } R_S - \text{Lowest OSNR at } S_S$$

where:

– Lowest OSNR at S_S is the lowest OSNR that meets the maximum BER of the application from a reference receiver as defined in clause B.3 of [ITU-T G.959.1] for NRZ signal classes and in Annex A for DP-DQPSK 100G, at point S_S i.e., *before* transmission through the black link.

– Lowest OSNR at R_S is the lowest OSNR that meets the maximum BER of the application from a reference receiver as defined in clause B.3 of [ITU-T G.959.1] for NRZ signal classes and in Annex A for DP-DQPSK 100G, at point R_S i.e., *after* transmission through the black link.

NOTE – The measurement of the optical path OSNR penalty therefore requires filtered ASE noise to be added to the signal at points S_S and R_S. This subject is further discussed in Appendix I.

The effects that contribute to the optical path OSNR penalty include:

– transmitter (residual) dispersion penalty for NRZ signal classes;
– non-linear effects within the black link;
– inter-channel crosstalk;
– interferometric crosstalk;
– reflections from the optical path;
– polarization dependent loss.

The average value of the random dispersion penalties due to PMD is included in the allowed path OSNR penalty. 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].

For NRZ signal classes, the transmitter/receiver combination is required to tolerate an actual DGD of 0.3-bit period with a maximum optical path OSNR penalty of 2 dB (with 50% of optical power in each principal state of polarization). For a well-designed receiver, this corresponds to an OSNR penalty of 0.2 – 0.4 dB for a DGD of 0.1-bit period.

7.4 Interface at point R_S

7.4.1 Maximum and minimum mean input power

The maximum and minimum values of the average received power at point R_S.

For any optical power level at point R_S that is between these two values and while all of the other parameters are within their limiting values, the receiver is required to achieve the specified maximum BER of the application code.

This means that the receiver must meet the specified maximum BER for a transmitter with worst-case values of:

– transmitter eye mask for NRZ signal classes or EVM_{RMS} for DP-DQPSK signal classes;
– extinction ratio for NRZ signal classes or IQ offset for DP-DQPSK signal classes;
– optical return loss at point S_S,

and a link with worst-case values of:

– (residual) dispersion;
– OSNR;
– optical path OSNR penalty.

Ageing effects are not specified separately. Worst-case, end-of-life values are specified.

This parameter (together with the maximum and minimum mean channel output power) also places a requirement on the maximum and minimum channel insertion loss (or gain) of the black link.

The requirement is that while the mean channel output power at point S_S is within the specified limits, the channel insertion loss (or gain) of the black link for that channel must be such that the power level at point R_S is within the maximum and minimum mean input power limits.

Channel insertion loss is defined in [ITU-T G.671]. For any optical channel, it is the minimum (or maximum) reduction or gain 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 amplifiers and optical attenuators (if used) or other optical devices, and any additional margin to cover allowances for:

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

7.4.2 Minimum optical signal-to-noise ratio (OSNR) and OSNR(193.6)

The minimum optical signal-to-noise ratio (OSNR) is the minimum value of the ratio of the signal power in the wanted channel to the highest noise power density (referred to 0.1 nm) in the range of the central frequency plus and minus the maximum spectral excursion. For the purposes of this definition, the noise is defined to be that which would be present if the signal in the wanted channel were removed from the black link while keeping all other black link conditions the same (e.g., the gain and noise figure of all amplifiers).

This parameter places a requirement on the characteristics of the black link that the OSNR at any reference point R_S must be greater than the minimum OSNR.

For 100 Gbit/s applications, specified in Tables 8-7 and 8-8, the minimum optical signal-to-noise ratio OSNR(f) is specified as a function of channel frequency f and referred to its value at 193.6 THz, OSNR(193.6), according to the following relationship:

$$OSNR(f) = OSNR(193.6) - 20\log_{10}(f\ /\ 193.6) \qquad \text{(dB)}$$

where:

f: is the channel central frequency in THz.

$OSNR(f)$: is the minimum optical signal-to-noise ratio of the channel with channel central frequency f in dB (0.1 nm).

$OSNR(193.6)$: is the minimum optical signal-to-noise ratio referred to 193.6 THz in dB (0.1 nm).

7.4.3 Receiver OSNR tolerance and OSNR tolerance(193.6)

The receiver OSNR tolerance is defined as the minimum value of OSNR at point R_S that can be tolerated while maintaining the maximum BER of the application. This must be met for all powers between the maximum and minimum mean input power with a transmitter with worst-case values of:

– transmitter eye mask for NRZ signal classes or EVM_{RMS} for DP-DQPSK signal classes;
– extinction ratio for NRZ signal classes or IQ offset for DP-DQPSK signal classes;
– optical return loss at point S_S,
– receiver connector degradations;
– measurement tolerances.

The receiver OSNR tolerance does not have to be met in the presence of chromatic dispersion, non-linear effects, reflections from the optical path, PMD, PDL or optical crosstalk; these effects are specified separately in the allocation of maximum optical path OSNR penalty.

For 100 Gbit/s applications, specified in Tables 8-7 and 8-8, the receiver optical signal-to-noise ratio tolerance is specified as a function of channel frequency f and referred to its value at 193.6 THz, receiver OSNR tolerance(193.6), according to the following relationship:

$$OSNR\_tolerance(f) = OSNR\_tolerance(193.6) - 20\log_{10}(f\ /\ 193.6) \quad \text{(dB)}$$

where:

f is the channel central frequency in THz.

OSNR_tolerance(*f*) is the receiver optical signal-to-noise ratio tolerance of the channel with channel central frequency *f* in dB (0.1 nm).

OSNR_tolerance(193.6) is the receiver optical signal-to-noise ratio tolerance referred to 193.6 THz in dB (0.1 nm).

NOTE 1 – The receiver OSNR tolerance is equal to the minimum OSNR at point R_S minus the maximum optical path OSNR penalty.

NOTE 2 – The receiver OSNR tolerance 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).

Ageing effects are not specified separately. Worst-case, end-of-life values are specified.

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 8-8.

Table 8-1 – Physical layer parameters and values for class NRZ 2.5G without FEC, 100-GHz-spaced applications

Parameter	Units	DN100C-1A2(C) DN100C-1A3(L) DN100C-1A5(C)	DW100C-1A2(C) DW100C-1A3(L) DW100C-1A5(C)	DN100U-1A2(C) DN100U-1A3(L) DN100U-1A5(C)
General information				
Minimum channel spacing	GHz	100		100
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G		NRZ 2.5G
Maximum bit error ratio	–	10^{-12}		10^{-12}
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
Minimum side mode suppression ratio	dB	30		30
Minimum channel extinction ratio	dB	8.2		8.2

Table 8-1 – Physical layer parameters and values for class NRZ 2.5G without FEC, 100-GHz-spaced applications

Parameter	Units	DN100C-1A2(C) DN100C-1A3(L) DN100C-1A5(C)	DW100C-1A2(C) DW100C-1A3(L) DW100C-1A5(C)	DN100U-1A2(C) DN100U-1A3(L) DN100U-1A5(C)
Eye mask	–	NRZ 2.5G per G.959.1		NRZ 2.5G per G.959.1
Maximum transmitter (residual) dispersion OSNR penalty	dB	2		2
Optical path from point S_S to R_S				
Maximum ripple	dB	2		2
Maximum (residual) chromatic dispersion	ps/nm	+2200		+9600
Minimum (residual) chromatic dispersion	ps/nm	–600		0
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 polarization dependent loss	dB	ffs		ffs
Maximum inter-channel crosstalk	dB	–16		–16
Maximum interferometric crosstalk	dB	–40		–40
Maximum optical path OSNR penalty	dB	5		5
Interface at point R_S				
Maximum mean input power	dBm	–9		–9
Minimum mean input power	dBm	–24		–24
Minimum OSNR	dB (0.1 nm)	21	23	21
Receiver OSNR tolerance	dB (0.1 nm)	16	18	16
Maximum reflectance of receiver	dB	–27		–27

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

Parameter	Units	DW100C-1A2(C)F DW100C-1A3(L)F DW100C-1A5(C)F
General information		
Minimum channel spacing	GHz	100

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

Parameter	Units	DW100C-1A2(C)F DW100C-1A3(L)F DW100C-1A5(C)F
Bit rate/line coding of optical tributary signals	–	NRZ OTU1 FEC enabled
Maximum bit error ratio	–	10^{-12} (Note)
Fibre type	–	G.652, G.653, G.655
Interface at point S_S		
Maximum mean channel output power	dBm	+6
Minimum mean channel output power	dBm	–3
Minimum central frequency	THz	191.5 for (C) 186.0 for (L)
Maximum central frequency	THz	196.2 for (C) 191.5 for (L)
Maximum spectral excursion	GHz	±20
Minimum side mode suppression ratio	dB	30
Minimum channel extinction ratio	dB	8.2
Eye mask	–	NRZ 2.5G per G.959.1
Maximum transmitter (residual) dispersion OSNR penalty	dB	2
Optical path from point S_S to R_S		
Maximum ripple	dB	2
Maximum (residual) chromatic dispersion	ps/nm	+2200
Minimum (residual) chromatic dispersion	ps/nm	–600
Minimum optical return loss at S_S	dB	24
Maximum discrete reflectance between S_S and R_S	dB	–27
Maximum differential group delay	ps	120
Maximum polarization dependent loss	dB	ffs
Maximum inter-channel crosstalk	dB	–16
Maximum interferometric crosstalk	dB	–40
Maximum optical path OSNR penalty	dB	5
Interface at point R_S		
Maximum mean input power	dBm	–9
Minimum mean input power	dBm	–26
Minimum OSNR	dB (0.1 nm)	15
Receiver OSNR tolerance	dB (0.1 nm)	10
Maximum reflectance of receiver	dB	–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 8-3 – Physical layer parameters and values for class NRZ 10G without FEC, 100-GHz-spaced applications

Parameter	Units	DN100C-2A2(C) DN100C-2A3(L) DN100C-2A5(C)	DW100C-2A2(C) DW100C-2A3(L) DW100C-2A5(C)
General information			
Minimum channel spacing	GHz	100	
Bit rate/line coding of optical tributary signals	–	NRZ 10G	
Maximum bit error ratio	–	10^{-12}	
Fibre type	–	G.652, G.653, G.655	
Interface at point S_S			
Maximum mean channel output power	dBm	+6	
Minimum mean channel output power	dBm	–3	
Minimum central frequency	THz	191.5 for (C) 186.0 for (L)	
Maximum central frequency	THz	196.2 for (C) 191.5 for (L)	
Maximum spectral excursion	GHz	±12.5	±20
Minimum side mode suppression ratio	dB	30	
Minimum channel extinction ratio	dB	8.2	
Eye mask	–	NRZ 10G 1550 nm region per G.959.1	
Maximum transmitter (residual) dispersion OSNR penalty	dB	2	
Optical path from point S_S to R_S			
Maximum ripple	dB	2	
Maximum (residual) chromatic dispersion	ps/nm	+800	
Minimum (residual) chromatic dispersion	ps/nm	–300	
Minimum optical return loss at S_S	dB	24	
Maximum discrete reflectance between S_S and R_S	dB	–27	
Maximum differential group delay	ps	30	
Maximum polarization dependent loss	dB	ffs	
Maximum inter-channel crosstalk	dB	–16	
Maximum interferometric crosstalk	dB	–40	
Maximum optical path OSNR penalty	dB	5	
Interface at point R_S			
Maximum mean input power	dBm	0	–8
Minimum mean input power	dBm	–11	–17
Minimum OSNR	dB (0.1 nm)	27	
Receiver OSNR tolerance	dB (0.1 nm)	22	
Maximum reflectance of receiver	dB	–27	

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

Parameter	Units	DN100C-2A2(C)F DN100C-2A3(L)F DN100C-2A5(C)F	DW100C-2A2(C)F DW100C-2A3(L)F DW100C-2A5(C)F	DN100U-2A2(C)F DN100U-2A3(L)F DN100U-2A5(C)F
General information				
Minimum channel spacing	GHz	100		100
Bit rate/line coding of optical tributary signals	–	NRZ OTU2 FEC enabled		NRZ OTU2 FEC enabled
Maximum bit error ratio	–	10^{-12} (Note)		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
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 G.959.1		NRZ 10G amplified per G.959.1
Maximum transmitter (residual) dispersion OSNR penalty	dB	2		2
Optical path from point S_S to R_S				
Maximum ripple	dB	2		2
Maximum (residual) chromatic dispersion	ps/nm	+800		+3200
Minimum (residual) chromatic dispersion	ps/nm	–300		0
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 polarization dependent loss	dB	ffs		ffs
Maximum inter-channel crosstalk	dB	–16		–16
Maximum interferometric crosstalk	dB	–40		–40
Maximum optical path OSNR penalty	dB	5		5
Interface at point R_S				
Maximum mean input power	dBm	0	–8	0
Minimum mean input power	dBm	–14	–20	–14
Minimum OSNR	dB (0.1 nm)	21		21
Receiver OSNR tolerance	dB (0.1 nm)	16		16
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 without FEC, 50-GHz-spaced applications

Parameter	Units	DN50C-2A2(C) DN50C-2A3(L) DN50C-2A5(C)	
General information			
Minimum channel spacing	GHz	50	
Bit rate/line coding of optical tributary signals	–	NRZ 10G	
Maximum bit error ratio	–	10^{-12}	
Fibre type	–	G.652, G.653, G.655	
Interface at point S_S			
Maximum mean channel output power	dBm	+6	
Minimum mean channel output power	dBm	–3	
Minimum central frequency	THz	191.5 for (C) 186.0 for (L)	
Maximum central frequency	THz	196.2 for (C) 191.5 for (L)	
Maximum spectral excursion	GHz	±11 (±12.5 Note 1)	
Minimum side mode suppression ratio	dB	30	
Minimum channel extinction ratio	dB	8.2	
Eye mask	–	NRZ 10G 1550 nm region per G.959.1	
Maximum transmitter (residual) dispersion OSNR penalty	dB	2	
Optical path from point S_S to R_S			
Maximum ripple	dB	2	
Maximum (residual) chromatic dispersion	ps/nm	+800	
Minimum (residual) chromatic dispersion	ps/nm	–300	
Minimum optical return loss at S_S	dB	24	
Maximum discrete reflectance between S_S and R_S	dB	–27	
Maximum differential group delay	ps	30	
Maximum polarization dependent loss	dB	ffs	
Maximum inter-channel crosstalk	dB	–16	
Maximum interferometric crosstalk	dB	–40	
Maximum optical path OSNR penalty	dB	5	
Interface at point R_S			
Maximum mean input power	dBm	0 (Note 2)	–8 (Note 3)
Minimum mean input power	dBm	–11 (Note 2)	–17 (Note 3)
Minimum OSNR	dB (0.1 nm)	27	
Receiver OSNR tolerance	dB (0.1 nm)	22	
Maximum reflectance of receiver	dB	–27	

NOTE 1 – If the ripple specification of the black link is met over a width of at least ±12.5 GHz, then the transmitter can have a maximum spectral excursion of ±12.5 GHz.

NOTE 2 – These power levels are appropriate for P type-intrinsic-n type (PIN) receivers. As an alternative, the power levels appropriate for avalanche photodiode (APD) receivers can be used.

NOTE 3 – These power levels are appropriate for APD receivers. As an alternative, the power levels appropriate for PIN receivers can be used.

Table 8-6 – Physical layer parameters and values for class NRZ 10G with FEC, 50-GHz-spaced applications

Parameter	Units	DN50C-2A2(C)F DN50C-2A3(L)F DN50C-2A5(C)F	DN50U-2A2(C)F DN50U-2A3(L)F DN50U-2A5(C)F
General information			
Minimum channel spacing	GHz	50	50
Bit rate/line coding of optical tributary signals	–	NRZ OTU2 FEC enabled	NRZ OTU2 FEC enabled
Maximum bit error ratio	–	10^{-12} (Note 1)	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	+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	±11 (±12.5 Note 2)	±11 (±12.5 Note 2)
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 G.959.1	NRZ 10G amplified per G.959.1
Maximum transmitter (residual) dispersion OSNR penalty	dB	2	2
Optical path from point S_S to R_S			
Maximum ripple	dB	2	2
Maximum (residual) chromatic dispersion	ps/nm	+800	+3200
Minimum (residual) chromatic dispersion	ps/nm	–300	0
Minimum optical return loss at SS	dB	24	24
Maximum discrete reflectance between SS and RS	dB	–27	–27
Maximum differential group delay	ps	30	30
Maximum polarization dependent loss	dB	ffs	ffs
Maximum inter-channel crosstalk	dB	–16	–16
Maximum interferometric crosstalk	dB	–40	–40
Maximum optical path OSNR penalty	dB	5	5

Table 8-6 – Physical layer parameters and values for class NRZ 10G with FEC, 50-GHz-spaced applications

Parameter	Units	DN50C-2A2(C)F DN50C-2A3(L)F DN50C-2A5(C)F		DN50U-2A2(C)F DN50U-2A3(L)F DN50U-2A5(C)F	
Interface at point R_S					
Maximum mean input power	dBm	0 (Note 3)	–8 (Note 4)	0 (Note 3)	–8 (Note 4)
Minimum mean input power	dBm	–14 (Note 3)	–20 (Note 4)	–14 (Note 3)	–20 (Note 4)
Minimum OSNR	dB (0.1 nm)	21		21	
Receiver OSNR tolerance	dB (0.1 nm)	16		16	
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 – If the ripple specification of the black link is met over a width of at least ±12.5 GHz, then the transmitter can have a maximum spectral excursion of ±12.5 GHz.

NOTE 3 – These power levels are appropriate for PIN receivers. As an alternative, the power levels appropriate for APD receivers can be used.

NOTE 4 – These power levels are appropriate for APD receivers. As an alternative, the power levels appropriate for PIN receivers can be used.

Table 8-7 – Physical layer parameters and values for class DP-DQPSK 100G, narrow spectral excursion applications

Parameter	Units	DN50U-8A2(C)F DN50U-8A3(L)F DN50U-8A5(C)F	DN100U-8A2(C)F DN100U-8A3(L)F DN100U-8A5(C)F
General information			
Minimum channel spacing	GHz	50	100
Bit rate/line coding of optical tributary signals	–	OTL4.4-SC or FOIC1.4-SC	
Maximum bit error ratio	–	10^{-12} (Note 1)	
Fibre type	–	G.652, G.653, G.655	
Interface at point S_S			
Maximum mean channel output power	dBm	0	
Minimum mean channel output power	dBm	–5	
Minimum central frequency	THz	191.5 for (C) 186.0 for (L)	
Maximum central frequency	THz	196.2 for (C) 191.5 for (L)	
Maximum spectral excursion	GHz	±15	
Minimum side mode suppression ratio	dB	30	
Maximum laser linewidth	kHz	500	
Maximum offset between the carrier and the nominal central frequency	GHz	1.8	
Maximum power difference between polarizations	dB	1.5	
Maximum skew between the two polarizations	ps	5	
Maximum error vector magnitude	%	26	
Maximum I-Q offset	dB	–25	
Optical path from point S_S to R_S			
Maximum ripple	dB	2.5	
Maximum (residual) chromatic dispersion	ps/nm	10 000	
Minimum (residual) chromatic dispersion	ps/nm	–820	
Minimum optical return loss at S_S	dB	24	
Maximum discrete reflectance between S_S and R_S	dB	–27	
Maximum differential group delay	ps	50	
Maximum polarization dependent loss	dB	2	
Maximum polarization rotation speed	krad/s	50	
Maximum inter-channel crosstalk	dB	–16	
Maximum interferometric crosstalk	dB	–25	
Maximum optical path OSNR penalty	dB	5	

Table 8-7 – Physical layer parameters and values for class DP-DQPSK 100G, narrow spectral excursion applications

Parameter	Units	DN50U-8A2(C)F DN50U-8A3(L)F DN50U-8A5(C)F	DN100U-8A2(C)F DN100U-8A3(L)F DN100U-8A5(C)F
Interface at point R_S			
Maximum mean input power	dBm	0	
Minimum mean input power	dBm	–18	
Minimum OSNR(193.6) (Note 2)	dB (0.1 nm)	21	
Receiver OSNR tolerance(193.6) (Note 3)	dB (0.1 nm)	16	
Maximum reflectance of receiver	dB	–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 – The value for minimum OSNR(193.6) is specified at a channel frequency of 193.6 THz. For OSNR values at other channel frequencies, the formula shown in clause 7.4.2 should be applied.

NOTE 3 – The value for receiver OSNR tolerance(193.6) is specified at a channel frequency of 193.6 THz. For OSNR tolerance values at other channel frequencies, the formula shown in clause 7.4.3 should be applied.

Table 8-8 – Physical layer parameters and values for class DP-DQPSK 100G, wide spectral excursion applications

Parameter	Units	DW50U-8A2(C)F DW50U-8A3(L)F DW50U-8A5(C)F	DW100U-8A2(C)F DW100U-8A3(L)F DW100U-8A5(C)F
General information			
Minimum channel spacing	GHz	50	100
Bit rate/line coding of optical tributary signals	–	OTL4.4-SC or FOIC1.4-SC	
Maximum bit error ratio	–	10^{-12} (Note 1)	
Fibre type	–	G.652, G.653, G.655	
Interface at point S_S			
Maximum mean channel output power	dBm	–3	
Minimum mean channel output power	dBm	–8	
Minimum central frequency	THz	191.5 for (C) 186.0 for (L)	
Maximum central frequency	THz	196.2 for (C) 191.5 for (L)	
Maximum spectral excursion	GHz	±15	

Table 8-8 – Physical layer parameters and values for class DP-DQPSK 100G, wide spectral excursion applications

Parameter	Units	DW50U-8A2(C)F DW50U-8A3(L)F DW50U-8A5(C)F	DW100U-8A2(C)F DW100U-8A3(L)F DW100U-8A5(C)F
Minimum side mode suppression ratio	dB	30	
Maximum laser linewidth	kHz	500	
Maximum offset between the carrier and the nominal central frequency	GHz	1.8	
Maximum power difference between polarizations	dB	1.5	
Maximum skew between the two polarizations	ps	10	
Maximum error vector magnitude	%	23	
Maximum I-Q offset	dB	–25	
Optical path from point S_S to R_S			
Maximum ripple	dB	2.5	
Maximum (residual) chromatic dispersion	ps/nm	2 400	
Minimum (residual) chromatic dispersion	ps/nm	–200	
Minimum optical return loss at S_S	dB	24	
Maximum discrete reflectance between S_S and R_S	dB	–27	
Maximum differential group delay	ps	20	
Maximum polarization dependent loss	dB	1.5	
Maximum polarization rotation speed	krad/s	50	
Maximum inter-channel crosstalk	dB	–16	
Maximum interferometric crosstalk	dB	–25	
Maximum optical path OSNR penalty	dB	5	
Interface at point R_S			
Maximum mean input power	dBm	0	
Minimum mean input power	dBm	–18	
Minimum OSNR(193.6) (Note 2)	dB (0.1 nm)	24	
Receiver OSNR tolerance(193.6) (Note 3)	dB (0.1 nm)	19	
Maximum reflectance of receiver	dB	–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}.

NOTE 2 – The value for minimum OSNR(193.6) is specified at a channel frequency of 193.6 THz. For OSNR values at other channel frequencies, the formula shown in clause 7.4.2 should be applied.

NOTE 3 – The value for receiver OSNR tolerance(193.6) is specified at a channel frequency of 193.6 THz. For OSNR tolerance values at other channel frequencies, the formula shown in clause 7.4.3 should be applied.

9 Optical safety considerations

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

Annex A

Reference receiver characteristics for DP-DQPSK 100G

(This annex forms an integral part of this Recommendation.)

The reference receiver includes the following steps as defined in the EVM calculation in clause 7.2.12, except the first item:

– compensate for chromatic dispersion and differential group delay;
– demultiplex the two polarizations;
– remove the frequency offset between carrier laser and local oscillator;
– recover the carrier phase;
– retime and resample to one sample per symbol;
– compensate for IQ-offset;
– apply a 7-tap T-spaced FIR filter with the tap coefficients optimized for BER.

Appendix I

Measurement of transmitter (residual) dispersion OSNR penalty and optical path OSNR penalty

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

Since the applications in this Recommendation use the "black link" approach, single-channel reference points (S_S and R_S) can be used to access the individual signals for measuring OSNR penalty. Three measurements for OSNR penalty are performed as illustrated in Figures I.1 to I.3.

For measurement 1, the lowest OSNR to achieve the reference BER at S_S with no dispersion is established by varying the amount of ASE noise added to the signal using a set-up similar to that shown in Figure I.1.

For measurement 2, the lowest OSNR to achieve the reference BER at S_S with worst case (residual) dispersion is established using a set-up similar to that shown in Figure I.2.

For measurement 3, the lowest OSNR to achieve the reference BER at R_S *after* transmission through the black link is established using a set-up similar to that shown in Figure I.3.

In the case of transmitter (residual) dispersion OSNR penalty, measurements 1 and 2 are performed as above and then:

Maximum transmitter (residual) dispersion OSNR penalty = OSNR of measurement 2 – OSNR of measurement 1.

In the case of optical path OSNR penalty, measurements 1 and 3 are performed as above and then:

Maximum optical path OSNR penalty = OSNR of measurement 3 – OSNR of measurement 1.

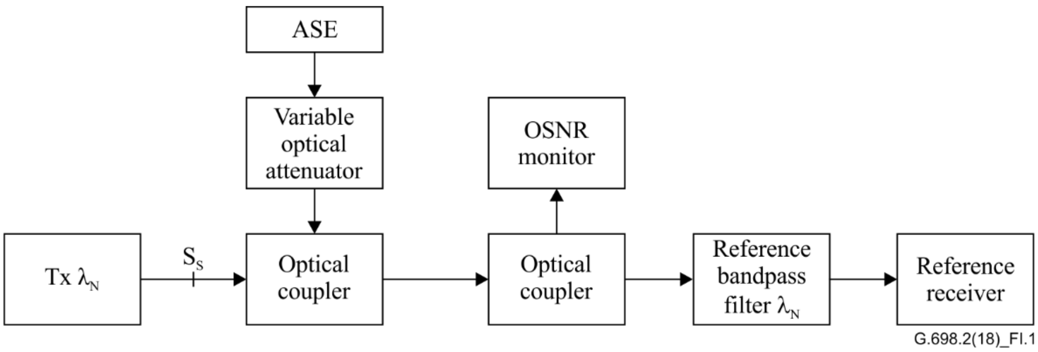

Figure I.1 – Configuration for measurement 1 (at S_S)

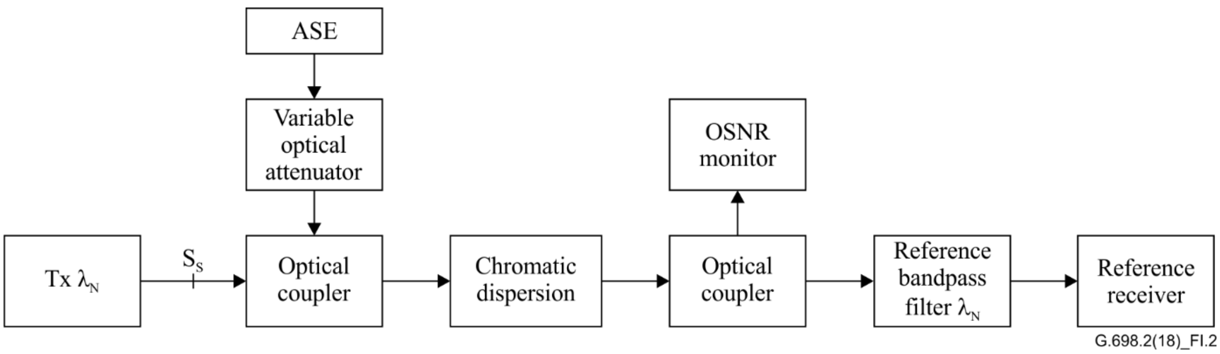

Figure I.2 – Configuration for measurement 2 (at S_S)

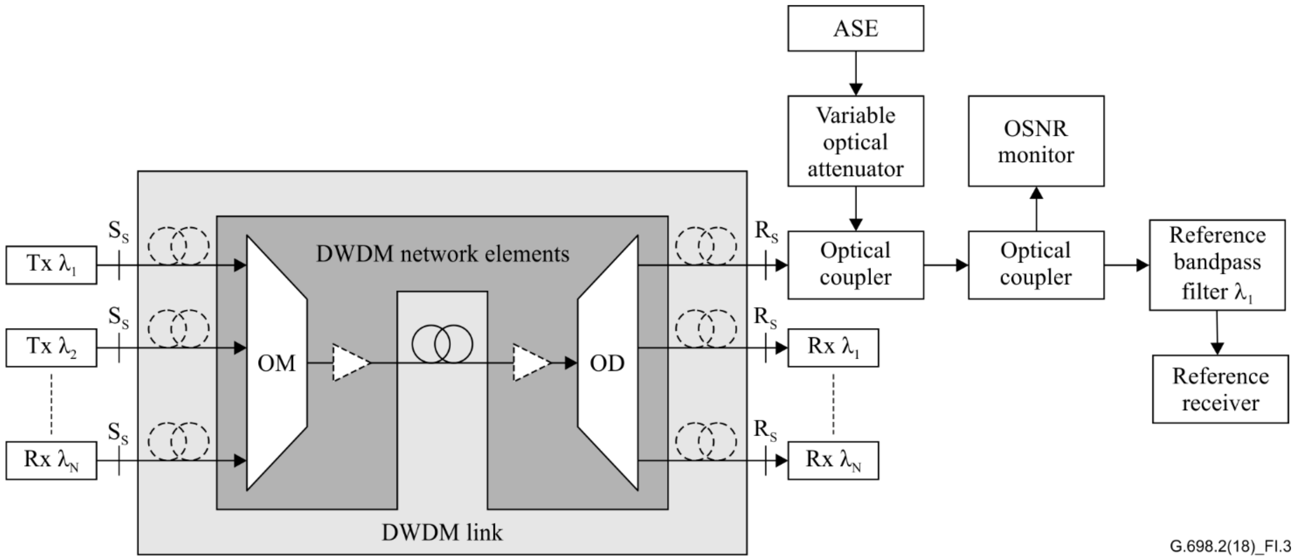

Figure I.3 – Configuration for measurement 3 (at R_S)

It should be noted that:

– The reference bandpass filter is defined in clause B.2 of [ITU-T G.959.1].

– The reference receiver is defined in clause B.3 of [ITU-T G.959.1].

– The means used to introduce the chromatic dispersion in measurement 2 should not result in non-linear effects. Any optical amplifiers used to offset the loss of this dispersive element should be inserted before the OSNR monitoring point.

– The amount of ASE noise that is added to the signal at S_S or R_S (and therefore the OSNR) is controlled by adjusting the variable optical attenuator (VOA). The OSNR monitoring point should be after the last optical amplifier, e.g., before the reference bandpass filter.

– When significant noise shaping is present before the monitoring point, e.g., at point R_S due to OD filtering or OADMs in the black link, care must be taken to use an OSNR monitoring technique that gives an accurate reading. More information on this issue can be found in Appendix III of [b-ITU-T G.697].

– An optical amplifier or optical attenuator may be used when the input power of the reference receiver is not appropriate, however, any added optical amplifiers must be placed before the OSNR monitoring point.

Appendix II

Transponder elimination via single channel DWDM interfaces

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

The transport network of most operators is based on the use of equipment from a variety of different vendors.

Previously, for those parts of the network involving DWDM optical transmission, this has been achieved via the use of optical transponders as shown in Figure II.1. The optical interfaces labelled "single channel non-DWDM interfaces from other vendor(s)" and "Single channel non-DWDM interfaces to/from other vendor(s)" can then be any short-reach standardized optical interface that both vendors support, such as those found in [ITU-T G.957] [ITU-T G.691], [ITU-T G.693], [ITU-T G.959.1], etc. This arrangement allows the direct connection of a wide variety of equipment to the DWDM line system, for example:

– a digital cross-connect with multiple optical interfaces, supplied by a different vendor from the line system;

– multiple optical client devices, each from a different vendor, supplying one channel each;

– a combination of the above.

Through the use of the single channel DWDM interfaces found in this Recommendation, however, this interconnection can also be achieved while removing the need for one short reach transmitter and receiver pair per channel (eliminating the transponders) with obvious associated cost savings.

This is shown in Figure II.2.

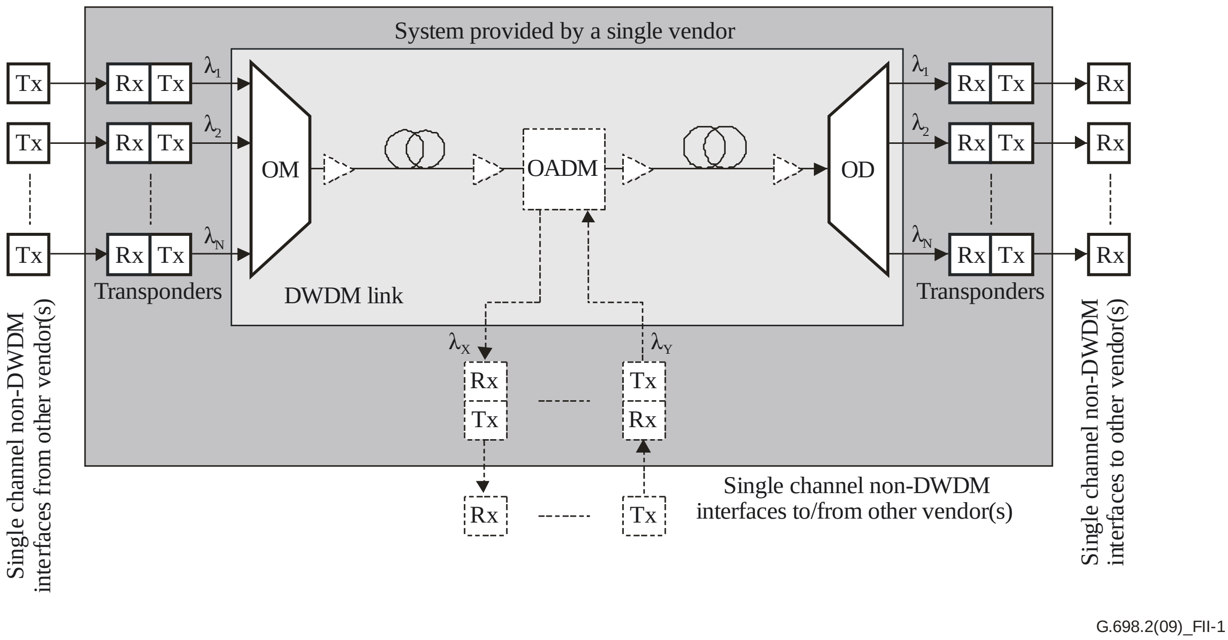

Figure II.1 – Multivendor DWDM line system with transponders

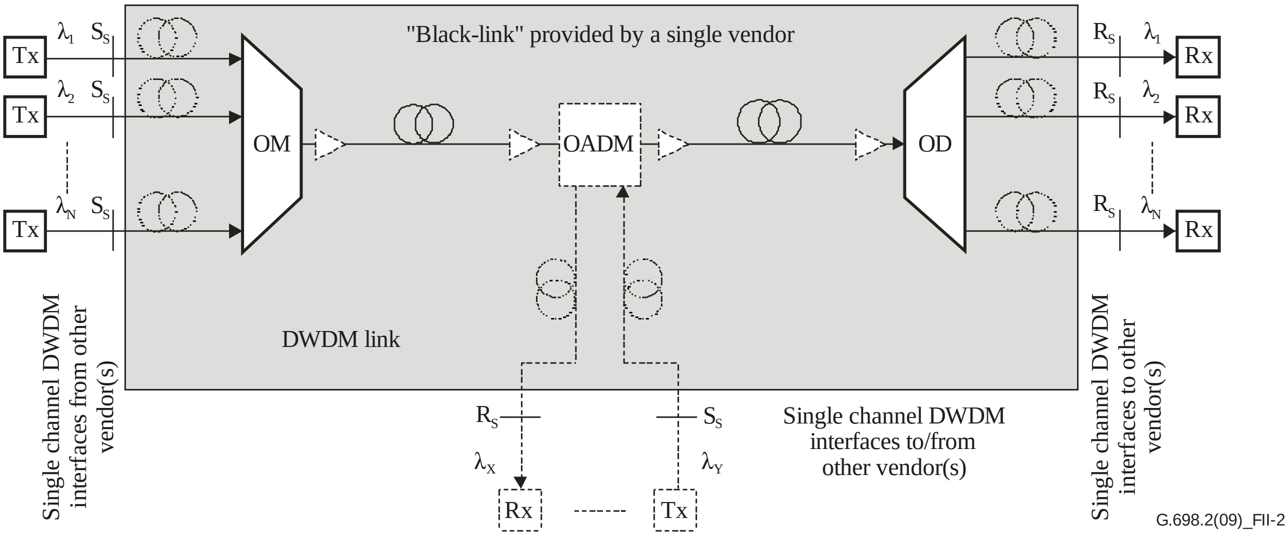

Figure II.2 – Multivendor DWDM line system with transponders removed

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Printed in Switzerland
Geneva, 2019