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DIGITAL SYSTEMS AND NETWORKS

Transmission media characteristics – Characteristics of
optical components and subsystems

**Multichannel DWDM applications with
single-channel optical interfaces**

ITU-T Recommendation G.698.1

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ITU-T Recommendation G.698.1

Multichannel DWDM applications with single-channel optical interfaces

Summary

This Recommendation 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 version of the Recommendation includes unidirectional DWDM applications at 2.5 and 10 Gbit/s with 100 GHz channel frequency spacing.

Source

ITU-T Recommendation G.698.1 was approved on 29 June 2005 by ITU-T Study Group 15 (2005-2008) under the ITU-T Recommendation A.8 procedure.

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.

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ITU-T Recommendation 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 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.

While applications containing amplifiers are not currently defined in this Recommendation, it is intended that they be introduced in a future revision.

This Recommendation describes DWDM systems that include the following features:

- Channel frequency spacing: 100 GHz and above (defined in ITU-T Rec. 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.

2.1 Normative references

- ITU-T Recommendation G.652 (2005), *Characteristics of a single-mode optical fibre and cable*.
- ITU-T Recommendation G.653 (2003), *Characteristics of a dispersion-shifted single-mode optical fibre and cable*.
- ITU-T Recommendation G.655 (2003), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable*.
- ITU-T Recommendation G.664 (2003), *Optical safety procedures and requirements for optical transport systems*.
- ITU-T Recommendation G.671 (2005), *Transmission characteristics of optical components and subsystems*.
- ITU-T Recommendation G.691 (2003), *Optical interfaces for single-channel STM-64 and other SDH systems with optical amplifiers*.
- ITU-T Recommendation G.692 (1998), *Optical interfaces for multichannel systems with optical amplifiers*.
- ITU-T Recommendation G.694.1 (2002), *Spectral grids for WDM Applications: DWDM frequency grid*.

- ITU-T Recommendation G.709/Y.1331 (2003), *Interfaces for the Optical Transport Network (OTN)*.
- ITU-T Recommendation G.957 (1999), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.
- ITU-T Recommendation G.959.1 (2003), *Optical transport network physical layer interfaces*.
- IEC 60825-1 (2001), *Safety of laser products – Part 1: Equipment classification, requirements and user's guide*.
- IEC 60825-2 (2005), *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*.

2.2 Informative references

- ITU-T G-series Recommendations – Supplement 39 (2003), *Optical system design and engineering considerations*.
- ITU-T Recommendation G.8251 (2001), *The control of jitter and wander within the optical transport network (OTN)*.

3 Terms and definitions

This Recommendation uses the following terms defined in ITU-T Rec. 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 Rec. G.694.1:

- Frequency grid.

This Recommendation uses the following term defined in ITU-T Rec. G.709/Y.1331:

- Completely standardized OTUk (OTUk).

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

- Joint engineering;
- Receiver sensitivity;
- Transverse compatibility.

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

- Optical tributary signal;
- Optical tributary signal class NRZ 2.5G;
- Optical tributary signal class NRZ 10G.

4 Abbreviations

This Recommendation uses the following abbreviations:

BER	Bit Error Ratio
DGD	Differential Group Delay
EX	Extinction Ratio
FEC	Forward Error Correction
ffs	For further study
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
OTU _k	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 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.

This Recommendation currently 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 "black-link" approach, for single-channel connection (S_S and R_S) between transmitters (Tx) and receivers (Rx). Here the DWDM network element includes an OM or an OD, which is used as a pair with the opposing element.

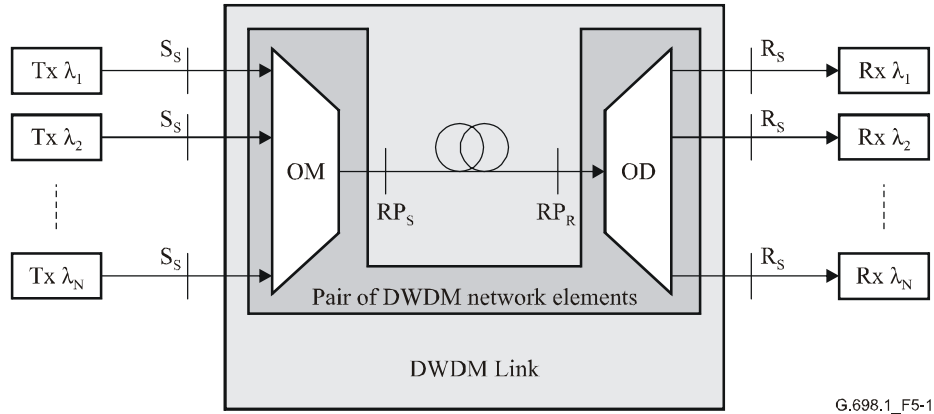


Figure 5-1/G.698.1 – "Black-link" approach

This reference model does not include any optical amplifiers in the DWDM system. The reference points in Figure 5-1 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.

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 5-2 shows a set of reference points, for the single-fibre bidirectional "black-link" approach, for single-channel connection (S_S and R_S) between transmitters (Tx) and receivers (Rx). Here the DWDM network element includes an OM/OD, which is used as a pair with the opposing element.

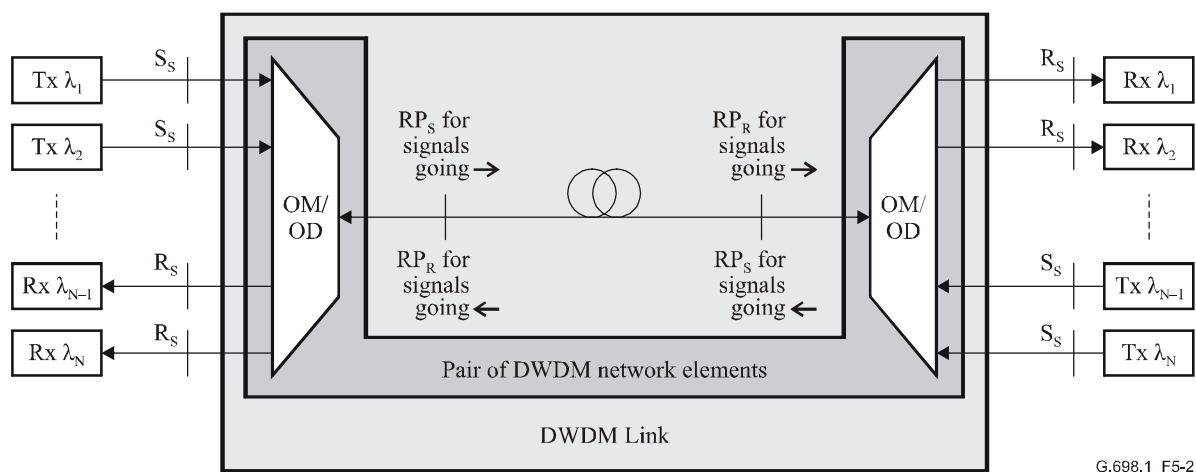


Figure 5-2/G.698.1 – "Black Link" Approach for bidirectional applications

The reference points in Figure 5-2 are as defined in 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:

$$DScWx-ytz(v)$$

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.

x is the maximum number of spans allowed within the application code.

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 G.652 fibre;
- 3 indicating G.653 fibre;
- 5 indicating G.655 fibre.

v indicates the operating wavelength range in terms of spectral bands (see ITU-T G-series Recommendations – Supplement 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_x-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 Rec. G.709/Y.1331 to be transmitted.

5.4 Single-channel interfaces at the reference points **S_s** and **R_s**

The single-channel interfaces described in 5.4.1 are intended to enable transverse compatibility at the single-channel interfaces at either end of the DWDM link (OM, fibre, and OD) as shown in Figures 5-1 and 5-2.

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 5.3.

Table 5-1/G.698.1 – 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	DN100S1-1D2(C), DW100S1-1D2(C), DN100S1-1D3(L), DW100S1-1D3(L), DN100S1-1D5(C), DW100S1-1D5(C)	DN100L1-1D2(C), DW100L1-1D2(C), DN100L1-1D3(L), DW100L1-1D3(L), DN100L1-1D5(C), DW100L1-1D5(C)

Table 5-1/G.698.1 – 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
OTU1 with FEC enabled	DN100S1-1D2(C)F, DW100S1-1D2(C)F, DN100S1-1D3(L)F, DW100S1-1D3(L)F, DN100S1-1D5(C)F, DW100S1-1D5(C)F	DN100L1-1D2(C)F, DW100L1-1D2(C)F, DN100L1-1D3(L)F, DW100L1-1D3(L)F, DN100L1-1D5(C)F, DW100L1-1D5(C)F
Optical tributary signal class NRZ 10G	DN100S1-2D2(C), DW100S1-2D2(C), DN100S1-2D3(L), DW100S1-2D3(L), DN100S1-2D5(C), DW100S1-2D5(C)	DN100L1-2D2(C), DW100L1-2D2(C), DN100L1-2D3(L), DW100L1-2D3(L), DN100L1-2D5(C), DW100L1-2D5(C)
OTU2 with FEC enabled	DN100S1-2D2(C)F, DW100S1-2D2(C)F, DN100S1-2D3(L)F, DW100S1-2D3(L)F, DN100S1-2D5(C)F, DW100S1-2D5(C)F	DN100L1-2D2(C)F, DW100L1-2D2(C)F, DN100L1-2D3(L)F, DW100L1-2D3(L)F, DN100L1-2D5(C)F, DW100L1-2D5(C)F

5.4.1 Non-amplified multichannel systems with single-channel interfaces

The non-amplified multichannel systems with single-channel interfaces in this Recommendation are specified in Tables 8-1 to 8-4.

5.4.2 Amplified multichannel systems with single-channel interfaces

Amplified multichannel systems with single-channel interfaces are not currently defined in this Recommendation.

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 ($T_x \lambda_i$) and receivers ($R_x \lambda_i$) 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.

Co-existence 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 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/G.698.1 – Physical layer parameters and values 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 optical crosstalk at R _s	dB	7.3.7
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 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 Recs G.652, G.653, and 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 Rec. 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.

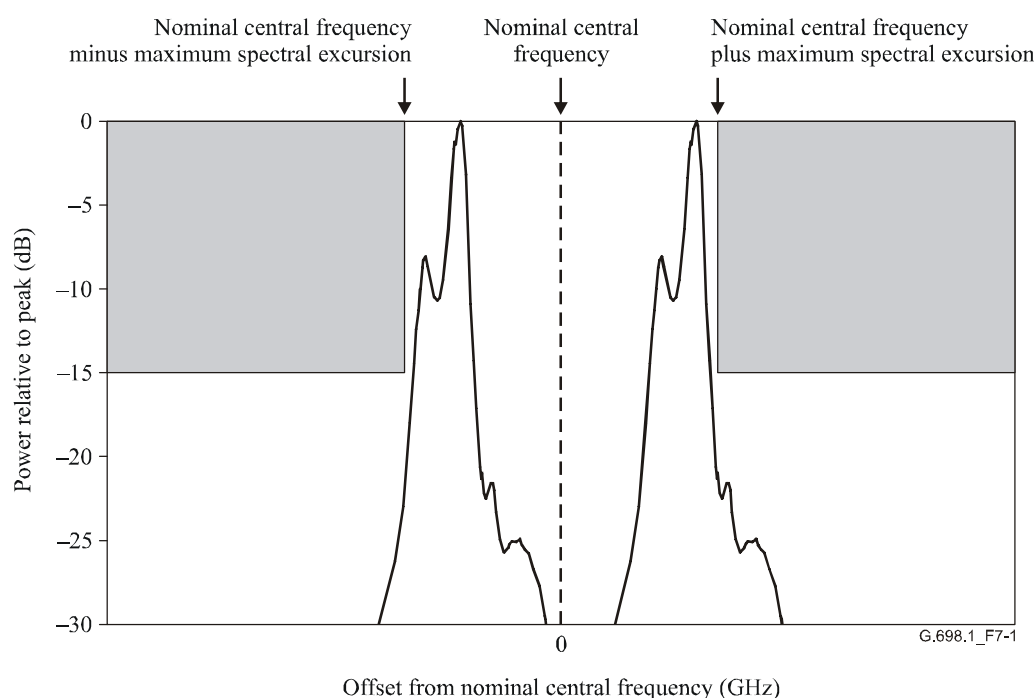


Figure 7-1/G.698.1 – Illustration of maximum spectral excursion

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 Rec. 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".

7.2.6 Eye mask

The definition and limits for this parameter are found in ITU-T Rec. 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 Rec. 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 \pm 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 Rec. 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 \pm the maximum spectral excursion. This is illustrated in Figure 7-2.

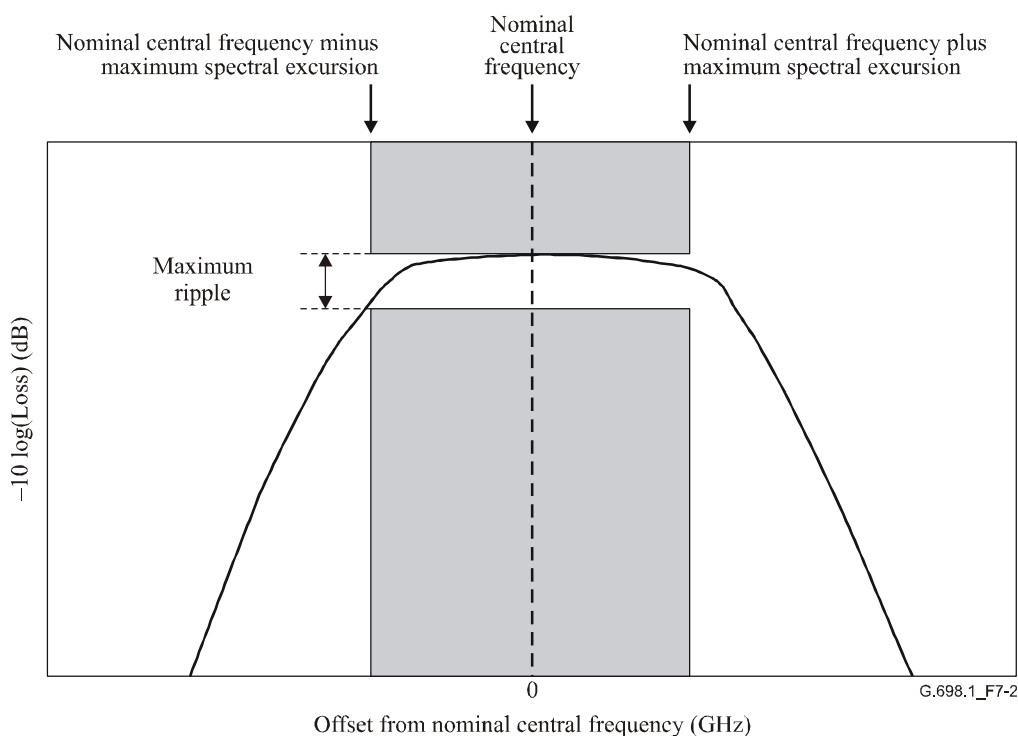


Figure 7-2/G.698.1 – Illustration of maximum ripple

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 8-4, 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/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.

7.3.5 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 Rec. 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.

7.3.6 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/G.698.1 – 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 optical 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 optical crosstalk at any reference point R_S is less than the maximum optical crosstalk value.

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 optical crosstalk at the corresponding point R_S is less than the maximum optical 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., 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/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 Rec. G.671.

8 Parameter values

The physical layer parameters and values are given in Tables 8-1 to 8-4.

**Table 8-1/G.698.1 – Physical layer parameters and values for class NRZ 2.5G,
100-GHz-spaced short-haul applications**

Parameter	Units	DN100S1-1D2(C) DN100S1-1D3(L) DN100S1-1D5(C)	DW100S1-1D2(C) DW100S1-1D3(L) DW100S1-1D5(C)	DN100S1-1D2(C)F DN100S1-1D3(L)F DN100S1-1D5(C)F	DW100S1-1D2(C)F DW100S1-1D3(L)F DW100S1-1D5(C)F
General information					
Minimum channel spacing	GHz	100		100	
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G		NRZ OTU1	
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 G.959.1		NRZ 2.5G per 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 optical crosstalk	dB	–15		–15	
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/G.698.1 – Physical layer parameters and values for class NRZ 2.5G,
100-GHz-spaced long-haul applications**

Parameter	Units	DN100L1-1D2(C) DN100L1-1D3(L) DN100L1-1D5(C)	DW100L1-1D2(C) DW100L1-1D3(L) DW100L1-1D5(C)	DN100L1-1D2(C)F DN100L1-1D3(L)F DN100L1-1D5(C)F	DW100L1-1D2(C)F DW100L1-1D3(L)F DW100L1-1D5(C)F
General information					
Minimum channel spacing	GHz	100		100	
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G		NRZ OTU1	
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 G.959.1		NRZ 2.5G per 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 optical crosstalk	dB	–16		–16	
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/G.698.1 – Physical layer parameters and values for class NRZ 10G,
100-GHz-spaced short-haul applications**

Parameter	Units	DN100S1-2D2(C) DN100S1-2D3(L) DN100S1-2D5(C)	DW100S1-2D2(C) DW100S1-2D3(L) DW100S1-2D5(C)	DN100S1-2D2(C)F DN100S1-2D3(L)F DN100S1-2D5(C)F	DW100S1-2D2(C)F DW100S1-2D3(L)F DW100S1-2D5(C)F
General information					
Minimum channel spacing	GHz	100		100	
Bit rate/line coding of optical tributary signals	–	NRZ 10G		NRZ OTU2	
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	
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 1550 nm region per 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 optical crosstalk	dB	–16		–16	
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/G.698.1 – Physical layer parameters and values for class NRZ 10G,
100-GHz-spaced long-haul applications**

Parameter	Units	DN100L1-2D2(C) DN100L1-2D3(L) DN100L1-2D5(C)	DW100L1-2D2(C) DW100L1-2D3(L) DW100L1-2D5(C)	DN100L1-2D2(C)F DN100L1-2D3(L)F DN100L1-2D5(C)F	DW100L1-2D2(C)F DW100L1-2D3(L)F DW100L1-2D5(C)F
General information					
Minimum channel spacing	GHz	100		100	
Bit rate/line coding of optical tributary signals	–	NRZ 10G		NRZ OTU2	
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 G.959.1		NRZ 10G 1550 nm region per 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 optical crosstalk	dB	–16		–16	
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} .					

9 Optical safety considerations

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

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